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Volume 4

Department of Energy

FY 2018 Congressional Budget Request

Science

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May 2017 Office of Chief Financial Officer Volume 4

FY 2018 Congressional Budget

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FUNDING BY APPROPRIATION

	FY 2016 Enacted	FY 2017 Annualized CR*	FY 2018 Request	FY 2018 vs FY 2016 $	FY 2018 vs FY 2016 %
	($K)				
Department of Energy Budget by Appropriation					
Energy and Water Development, and Related Agencies					
Energy Programs					
Energy Efficiency and Renewable Energy	2,069,194	2,069,059	636,149	-1,433,045	-69.3%
Electricity Delivery and Energy Reliability	206,000	205,608	120,000	-86,000	-41.7%
Nuclear Energy	986,161	984,286	703,000	-283,161	-28.7%
Fossil Energy Programs					
Fossil Energy Research and Development	632,000	630,799	280,000	-352,000	-55.7%
Naval Petroleum and Oil Shale Reserves	17,500	17,467	4,900	-12,600	-72.0%
Strategic Petroleum Reserve	212,000	211,597	180,000	-32,000	-15.1%
Strategic Petroleum Account	0	0	8,400	+8,400	N/A
Northeast Home Heating Oil Reserve	7,600	7,586	6,500	-1,100	-14.5%
Total, Fossil Energy Programs	**869,100**	**867,449**	**479,800**	**-389,300**	**-44.8%**
Uranium Enrichment Decontamination and Decommissioning (UED&D) Fund	673,749	767,014	752,749	+79,000	+11.7%
Energy Information Administration	122,000	121,768	118,000	-4,000	-3.3%
Non-Defense Environmental Cleanup	255,000	254,515	218,400	-36,600	-14.4%
Science	5,347,000	5,336,835	4,472,516	-874,484	-16.4%
Advanced Research Projects Agency - Energy	291,000	290,446	20,000	-271,000	-93.1%
Nuclear Waste Disposal	0	0	90,000	+90,000	N/A
Departmental Administration	130,971	130,722	145,652	+14,681	+11.2%
Office of the Inspector General	46,424	46,336	49,000	+2,576	+5.5%
Title 17 - Innovative Technology Loan Guarantee Program	17,000	14,920	0	-17,000	-100.0%
Advanced Technology Vehicles Manufacturing Loan Program	6,000	5,989	0	-6,000	-100.0%
Total, Energy Programs	**11,019,599**	**11,094,947**	**7,805,266**	**-3,214,333**	**-29.2%**
Atomic Energy Defense Activities					
National Nuclear Security Administration					
Weapons Activities	8,846,948	8,830,130	10,239,344	+1,392,396	+15.7%
Defense Nuclear Nonproliferation	1,940,302	1,936,614	1,793,310	-146,992	-7.6%
Naval Reactors	1,375,496	1,372,881	1,479,751	+104,255	+7.6%
Federal Salaries and Expenses	363,766	363,937	418,595	+54,829	+15.1%
Total, National Nuclear Security Administration	**12,526,512**	**12,503,562**	**13,931,000**	**+1,404,488**	**+11.2%**
Environmental and Other Defense Activities					
Defense Environmental Cleanup	5,289,742	5,279,686	5,537,186	+247,444	+4.7%
Other Defense Activities	776,425	774,949	815,512	+39,087	+5.0%
Defense Nuclear Waste Disposal	0	0	30,000	+30,000	N/A
Total, Environmental and Other Defense Activities	**6,066,167**	**6,054,635**	**6,382,698**	**+316,531**	**+5.2%**
Total, Atomic Energy Defense Activities	**18,592,679**	**18,558,197**	**20,313,698**	**+1,721,019**	**+9.3%**
Power Marketing Administrations					
Southeastern Power Administration	0	0	0	0	N/A
Southwestern Power Administration	11,400	11,378	11,400	0	N/A
Western Area Power Administration	93,372	93,194	93,372	0	N/A
Falcon and Amistad Operating and Maintenance Fund	228	228	228	0	N/A
Colorado River Basins Power Marketing Fund	-23,000	-23,000	-23,000	0	N/A
Total, Power Marketing Administrations	**82,000**	**81,800**	**82,000**	**0**	**N/A**
Federal Energy Regulatory Commission (FERC)	0	0	0	0	N/A
Subtotal, Energy and Water Development and Related Agencies	**29,694,278**	**29,734,944**	**28,200,964**	**-1,493,314**	**-5.0%**
Excess Fees and Recoveries, FERC	-23,587	-15,882	-9,000	+14,587	+61.8%
Title XVII Loan Guarantee Program Section 1703 Negative Credit Subsidy Receipt	-68,000	-67,871	-35,000	+33,000	+48.5%
Sale of Northeast Gas Reserve	0	0	-69,000	-69,000	N/A
Use of Advanced Research Projects Agency - Energy Balances	0	0	-46,367	-46,367	N/A
Total, Funding by Appropriation	**29,602,691**	**29,651,191**	**28,041,597**	**-1,561,094**	**-5.3%**

*The Consolidated Appropriations Act was not available when the Department of Energy developed the FY 2018 Congressional Budget. Therefore, the FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year.

Science

Science

Science
Proposed Appropriation Language

For Department of Energy expenses including the purchase, construction, and acquisition of plant and capital equipment, and other expenses necessary for science activities in carrying out the purposes of the Department of Energy Organization Act (42 U.S.C. 7101 et seq.), including the acquisition or condemnation of any real property or facility or for plant or facility acquisition, construction, or expansion, and purchase of not more than 16 passenger motor vehicles for replacement only, including one ambulance and one bus, $4,472,516,000, to remain available until expended: Provided, That of such amount, $168,516,000, shall be available until September 30, 2019, for program direction.

Note.—A full-year 2017 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Further Continuing Appropriations Act, 2017 (P.L. 114–254). The amounts included for 2017 reflect the annualized level provided by the continuing resolution.

Explanation of Change

Proposed appropriation language updates reflect the funding and replacement of passenger motor vehicle levels requested in FY 2018.

Public Law Authorizations

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

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

Workforce Development for Teachers and Scientists:
- Public Law 101-510, "DOE Science Education Enhancement Act of 1991"
- Public Law 103-382, "The Albert Einstein Distinguished Educator Fellowship Act of 1994"

Science
($K)

FY 2016 Enacted[a]	FY 2017 Annualized CR[b]	FY 2018 Request
5,347,000	5,336,835	4,472,516

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 2016 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 2018 Budget Request

The FY 2018 Budget Request for SC is $4,473 billion, a decrease of $874 million, or 16.2 percent, relative to the FY 2016 Enacted level, to implement the Administration's objectives for achieving overall reductions in civilian, discretionary spending. The FY 2018 Request supports a balanced research portfolio of basic scientific research probing some of the most fundamental questions in areas such as: high energy, nuclear, and plasma physics; materials and chemistry; biological and environmental systems; applied mathematics; next generation high-performance computing and simulation capabilities; and basic research for advancement in new energy technologies. The Request supports about 19,000 investigators at over 300 U.S. institutions and the Department of Energy (DOE) laboratories. In FY 2018, SC's suite of scientific user facilities will continue to provide unmatched tools and capabilities for over 27,000 researchers 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.

[a] ~~The FY 2016 Enacted level includes~~ SBIR and STTR and reflects updates through the end of the fiscal year.
[b] FY 2017 amounts shown reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above, below that level, a dash (-) is shown.

Highlights of the FY 2018 Budget 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 Budget Request of $722 million, is an increase of $101 million, or 16.3 percent, relative to the FY 2016 Enacted level. The increase supports activities to accelerate the Department's Exascale Computing Initiative (ECI) and intends to accelerate delivery of at least one exascale-capable system in 2021 —reasserting U.S. leadership in this critical area. These activities includes research and development to accelerate application and software stack development, vendor R&D partnerships, and site preparations. ASCR will also continue to focus research efforts on the linked challenges of exascale computing and data-intensive science, on computational partnerships under the Scientific Discovery through Advanced Computing (SciDAC) program, and on quantum information and machine learning to ensure continued U.S. leadership in computational science building toward exascale. Within the Office of Science Exascale Project (SC-ECP), the ASCR portion includes only the research activities required for the delivery of exascale-capable systems. Funding for the Leadership Computing Facilities is significantly increased to initiate site preparations and vendor partnerships that will allow them to deploy an exascale-capable system as rapidly as possible. The four areas of focus of SC-ECP are hardware technology R&D, system software technology R&D, application development, and system engineering for exascale systems. The FY 2018 Request supports the upgrade of the Oak Ridge Leadership Computing Facilities to 200 petaflops (pf) and early science operations of this powerful new capability. The Argonne Leadership Computing Facility will operate Mira (at 10pf) and Theta (at 8.5pf) for existing users, while turning focus to site preparations for deployment of exascale system of novel architecture. The National Energy Research Scientific Computing Center (NERSC) operates the NERSC-8 supercomputer and prepares for the delivery of NERSC-9 in 2020, and additional funds are requested to upgrade the Energy Sciences Network 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 Budget Request of $1,554.5 million is a decrease of $294.5 million, or 15.9 percent from the FY 2016 Enacted level. The FY 2018 Request focuses resources toward early-stage fundamental research, on the operation and maintenance of a complementary suite of scientific user facilities, and in the highest priority facility upgrades. No funding is requested for the two BES-supported Energy Innovation Hubs, *Batteries and Energy Storage* and *Fuels from Sunlight*, or for the DOE Experimental Program to Stimulate Competitive Research. In the remaining core research activities, BES will place emphasis on basic science areas with the potential to transform the understanding and control of matter and energy including emphasis on emerging high priorities in quantum materials and chemistry, catalysis science, synthesis, instrumentation science, and materials and chemical research related to interdependent energy-water issues. The funding decrease will require BES to curtail the operation and maintenance of BES suite of facilities. The Stanford Synchrotron Radiation Lightsource will operate through the first quarter of the fiscal year, then will transition to a warm standby status. The Request contains no funding for two of the five nanoscience centers: the Center for Functional Nanomaterials at Brookhaven National Laboratory and the Center for Integrated Nanotechnologies at Sandia and Los Alamos National Laboratories. The remaining BES facilities will operate at 6–10% below the FY 2016 Enacted level. BES decreases funding for related accelerator and detector research. The Request will continue to support construction of the Linac Coherent Light Source-II, and will convert the Advanced Photon Source Upgrade project from a Major Item of Equipment to a line-item construction project and will provide support per the project plan.

- *Biological and Environmental Research (BER)* supports fundamental research and scientific user facilities to achieve a predictive understanding of complex biological, earth, and environmental systems for energy and infrastructure resilience and sustainability. The BER Budget Request of $349 million is a decrease of $260 million, or 42.7 percent, below the FY 2016 Enacted level. The FY 2018 Request implements Administration decisions to shift focus to more fundamental research, and to prioritize research focused on biological and earth and environmental systems. In the Earth and Environmental Systems Sciences subprogram (formerly named "Climate and Environmental Sciences"), the Request focuses on continuing to support development of the DOE high-resolution earth system model and for model diagnostics and intercomparisons, as well as ARM observations at two fixed sites. Targeted reductions occur in lower priority activities, including integrated assessments, climate feedbacks, anthropogenic aerosols and black carbon, and field activities in the tropics and northern peatlands focused on functional responses to climate variability and atmospheric stressors. The Biological Systems Science subprogram implements priority-shifts to the core research areas of Genomic Sciences, including biodesign and microbiome, and support for the recompeted Bioenergy Research

Centers. Mesoscale activities supported include new efforts to utilize quantum materials for advanced bioimaging capabilities. The Request supports reduced operations of BER's three scientific user facilities: the DOE Joint Genome Institute (JGI), the Environmental Molecular Sciences Laboratory (EMSL), and ARM.

- *Fusion Energy Sciences (FES)* supports research to expand the fundamental understanding of matter at very high temperatures and densities and to build the scientific foundation for fusion energy. The FES FY 2018 Request of $309.9 million is a decrease of $128 million, or 29.2 percent, below the FY 2016 Enacted level. The FES Budget Request will support design activities and existing hardware fabrication contracts for the U.S. Contributions to ITER Project along with foundational research in burning plasma science. The Request provides increased support for the DIII-D program, including operations funding that will support 18 weeks of run time, and research in priority areas identified by the 2015 community workshop. NSTX-U operations funding will support continued facility repair and recovery actions to obtain reliable research operation, while NSTX research will address priorities identified by the 2015 community workshops. FES will increase funding for massively parallel scientific computing through the SciDAC partnership with ASCR to accelerate development of a whole-device modeling capability. The FY 2018 Request will also continue support for leveraged research opportunities by U.S. scientists on international superconducting tokamak and stellarator facilities with unique capabilities. FES will also provide support to emphasize opportunities for core discovery plasma science on intermediate-scale facilities.

- *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 HEP FY 2018 Request of $672.7 million is a decrease of $122.3 million, or 15.4 percent below the FY 2016 Enacted level. The Request will focus support on the highest priority elements identified in the 2014 High Energy Physics Advisory Panel (HEPAP) Particle Physics Project Prioritization Panel (P5) Report. The Request will enhance support for the Long-Baseline Neutrino Facility and Deep Underground Neutrino Experiment (LBNF/DUNE) early far-site construction, including site preparation and cavern excavation, and design efforts for the facility and detector. The Request will also provide funding for the start of Major Item of Equipment (MIE) funding for the High-Luminosity Large Hadron Collider (HL-LHC) Accelerator Upgrade Project (AUP) and supports the design efforts for the HL-LHC A Toroidal LHC Apparatus (ATLAS) and Compact Muon Solenoid (CMS) Detector Upgrade Projects. It will provide support for the Large Synoptic Survey Telescope camera (LSSTcam), Muon to Electron Conversion Experiment (Mu2e), and Large Underground Xenon (LUX)-ZonEd Proportional scintillation in LIquid Nobles gases (Zeplin) (LZ) projects consistent with the planned fabrication funding profiles. The Request will provide funding for one new MIE, the Facility for Advanced Accelerator Experimental Tests II (FACET-II), for the design and fabrication of the Super Cryogenic Dark Matter Search at Sudbury Neutrino Observatory Laboratory (SuperCDMS-SNOLAB) project, and for research and conceptual design of the Proton Improvement Plan II (PIP-II) construction project. HEP will rebaseline the Dark Energy Spectroscopic Instrument (DESI) project, which received CD-3 approval for start of fabrication so that it can be completed on a delayed timescale. The Request also will place a higher priority on supporting the research programs that are critical to executing the P5 Report recommendations. The Request also reduces funding for the Fermilab Accelerator Complex to operate and support the neutrino and muon experiments.

- *Nuclear Physics (NP)* supports experimental and theoretical research to discover, explore, and understand all forms of nuclear matter. The FY 2018 Budget Request of $502.7 million is a decrease of $114.4 million, or 18.5 percent, below the FY 2016 Enacted level. The FY 2018 Budget Request will continue support for the highest priority research and scientific user facilities to maintain U.S. leadership in some areas of nuclear science following an overall reduction in program scope in response to the funding decrease. Funding was completed for the 12 GeV Upgrade at the Continuous Electron Beam Accelerator Facility (CEBAF) in FY 2016, allowing NP to initiate the associated science program in FY 2018 to search for exotic particles and new physics. The FY 2018 Request will provide for modified operations of the Relativistic Heavy Ion Collider (RHIC) to confirm the origin of intriguing new phenomena observed in quark gluon plasma formation, and for 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) at a level below the performance baseline profile; FRIB will provide world-leading capabilities for nuclear structure and astrophysics. The Request will also continue to support the Gamma-Ray Energy Tracking Array (GRETA) detector, which will exploit the world-leading science capabilities of FRIB, and the Stable Isotope Production Facility (SIPF) within available resources. The Request supports core research at universities and DOE national laboratories and the development of cutting-edge approaches for producing isotopes critical to the Nation.

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 (SBIR) and Small Business Technology Transfer Research (STTR) programs. Co-funding of research activities and facilities at the DOE laboratories and partnership/collaboration encouraging funding mechanisms facilitate research integration within the basic and applied research communities. SC's R&D coordination also occurs at the interagency level. Specific collaborative activities are highlighted in the "Basic and Applied R&D Coordination" sections of each individual SC program budget justification narrative.

High-Risk, High-Reward Research[a]

SC incorporates high-risk, high-reward, basic research elements in all of its research portfolios; each SC research program considers a significant proportion of its supported research as high-risk, high-reward. Because advancing the frontiers of science also depends on the continued availability of state-of-the-art scientific facilities, SC constructs and operates national scientific facilities and instruments that comprise the world's most sophisticated suite of research capabilities. SC's basic research is integrated within program portfolios, projects, and individual awards; as such, it is not possible to quantitatively separate the funding contributions of particular experiments or theoretical studies that are high-risk, high-reward from other mission-driven research in a manner that is credible and auditable. SC incorporates high-risk, high-reward basic research elements in its research portfolios to drive innovation and challenge current thinking, using a variety of mechanisms to develop topics: Federal advisory committees, triennial Committees of Visitors, program and topical workshops, interagency working groups, National Academies' studies, and special SC program solicitations. Many of these topics are captured in formal reports, e.g., *Building for Discovery: Strategic Plan for U.S. Particle Physics in the Global* Context, by the High Energy Physics Advisory Panel (HEPAP-P5) (2014)[b]; *Neuromorphic Computing—From Materials to Systems Architecture Roundtable*, BES and ASCR workshop report (2015)[c]; *Report of the BESAC Subcommittee on Future X-ray Light Sources,* by the Basic Energy Sciences Advisory Committee (BESAC) (2013) [d]; *Challenges at the Frontiers of Matter and Energy: Transformative Opportunities for Discovery Science*, by BESAC (2015)[e]; *Basic Research Needs Workshop on Quantum Materials for Energy Relevant Technology,* BES workshop report (2016)[f]; *Molecular Science Challenges*, BER workshop report (2014)[g]; *Building Virtual Ecosystems: Computational Challenges for Mechanistic Modeling of Terrestrial Environments*, BER workshop report (2014)[h]; *Isotope Research and Production Opportunities and Priorities*, by the Nuclear Science Advisory Committee (NSAC) (2015)[i]; and *Nuclear Physics Long Range Plan*, by the NSAC (2015) [j].

Scientific Workforce

SC and its predecessors have fostered the training of a skilled scientific workforce for more than 50 years. In addition to the undergraduate and graduate research opportunities provided through SC's Office of Workforce Development for Teachers and Scientists (WDTS), the six SC research program offices train undergraduates, graduate students, and postdoctoral researchers through sponsored research awards at universities and the DOE national laboratories. The research program offices also support targeted, undergraduate and graduate-level experimental training in areas associated with scientific user facilities and not readily available in university academic departments, such as particle and accelerator physics, neutron and x-ray scattering, nuclear chemistry, and nuclear physics. 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 (NSTC's) Committee on Science, Technology, Engineering, and Mathematics

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[a] In compliance with the reporting requirements in the America COMPETES Act of 2007 (P.L. 110-69, section 1008)
[b] http://science.energy.gov/~/media/hep/hepap/pdf/May%202014/FINAL_P5_Report_Interactive_060214.pdf
[c] https://science.energy.gov/~/media/bes/pdf/reports/2016/NCFMtSA_rpt.pdf
[d] http://science.energy.gov/~/media/bes/besac/pdf/Reports/Future_Light_Sources_report_BESAC_approved_72513.pdf
[e] http://science.energy.gov/~/media/bes/besac/pdf/Reports/CFME_rpt_print.pdf
[f] https://science.energy.gov/~/media/bes/pdf/reports/2016/BRNQM_rpt_Final_12-09-2016.pdf
[g] http://genomicscience.energy.gov/biosystemsdesign/index.shtml
[h] http://science.energy.gov/~/media/ber/pdf/workshop%20reports/VirtualEcosystems.pdf
[i] http://science.energy.gov/~/media/np/nsac/pdf/docs/2015/2015_NSACI_Report_to_NSAC_Final.pdf
[j] Working title, to be released in Fall 2015, link TBD

Education (CoSTEM). SC also participates in the American Association for the Advancement of Science's (AAAS) Science & Technology Policy Fellowships program and the Presidential Management Fellows (PMF) Program to bring highly qualified scientists and professionals to DOE headquarters for a maximum term of two years.

Cybersecurity

DOE is engaged in two categories of cyber-related activities: protecting the DOE enterprise from a range of cyber threats that can adversely impact mission capabilities and improving cybersecurity in the electric power subsector and the oil and natural gas subsector. The cybersecurity crosscut supports central coordination of the strategic and operational aspects of cybersecurity and facilitates cooperative efforts such as the Joint Cybersecurity Coordination Center (JC3) for incident response and the implementation of Department-wide Identity, Credentials, and Access Management (ICAM).

FY 2016 Enacted Level

In the tables throughout this Budget Request, FY 2016 funding is reflected at the Enacted level at the congressional control points. Below the congressional control points, funding reflects the execution of the budget, including reallocations at the subprogram level.

Science
Funding by Congressional Control ($K)

	FY 2016 Enacted[a]	FY 2017 Annualized CR[b]	FY 2018 Request	FY 2018 vs FY 2016
Advanced Scientific Computing Research				
Research	621,000	619,819	525,430	-95,570
17-SC-20 Office of Science Exascale Computing Project (SC-ECP)	......	......	196,580	+196,580
Total, Advanced Scientific Computing Research	**621,000**	**619,819**	**722,010**	**+101,010**
Basic Energy Sciences				
Research	1,648,700	1,645,566	1,352,400	-296,300
Construction				
13-SC-10 Linac Coherent Light Source-II, SLAC	200,300	199,919	182,100	-18,200
18-SC-10 APS Upgrade, ANL	......	......	20,000	+20,000
Total, Construction	**200,300**	**199,919**	**202,100**	**+1,800**
Total, Basic Energy Sciences	**1,849,000**	**1,845,485**	**1,554,500**	**-294,500**
Biological and Environmental Research	**609,000**	**607,842**	**348,950**	**-260,050**
Fusion Energy Sciences				
Research	323,000	322,386	246,940	-76,060
Construction				
14-SC-60 ITER	115,000	114,781	63,000	-52,000
Total, Fusion Energy Sciences	**438,000**	**437,167**	**309,940**	**-128,060**

[a] The FY 2016 Enacted level includes SBIR and STTR and reflects updates through the end of the fiscal year.
[b] FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above, below that level, a dash (-) is shown.

	FY 2016 Enacted[a]	FY 2017 Annualized CR[b]	FY 2018 Request	FY 2018 vs FY 2016
High Energy Physics				
Research	728,900	727,514	573,400	-155,500
Construction				
11-SC-40 Long Baseline Neutrino Facility/Deep Underground Neutrino Facility, FNAL	26,000	25,951	54,900	+28,900
11-SC-41 Muon to Electron Conversion Experiment, FNAL	40,100	40,024	44,400	+4,300
Total, Construction	**66,100**	**65,975**	**99,300**	**+33,200**
Total, High Energy Physics	**795,000**	**793,489**	**672,700**	**-122,300**
Nuclear Physics				
Operation and Maintenance	509,600	508,631	422,700	-86,900
Construction				
14-SC-50 Facility for Rare Isotope Beams, Michigan State University	100,000	99,810	80,000	-20,000
06-SC-01 12 GeV CEBAF Upgrade, TJNAF	7,500	7,486	......	-7,500
Total, Construction	**107,500**	**107,296**	**80,000**	**-27,500**
Total, Nuclear Physics	**617,100**	**615,927**	**502,700**	**-114,400**
Workforce Development for Teachers and Scientists	**19,500**	**19,463**	**14,000**	**-5,500**
Science Laboratories Infrastructure				
Infrastructure Support				
Payment in Lieu of Taxes	1,713	1,710	1,713	......
Oak Ridge Landlord	6,177	6,165	6,082	-95
Facilities and Infrastructure	24,800	24,753	5,105	-19,695
Oak Ridge Nuclear Operations	12,000	11,977	10,000	-2,000
Total, Infrastructure Support	44,690	44,605	22,900	-21,790
Construction				
18-SC-71 Energy Science Capability at PNNL	......	......	1,000	+1,000
17-SC-71 Integrated Engineering Research Center, FNAL	......	......	1,500	+1,500
17-SC-73 Core Facility Revitalization at BNL	......	......	1,500	+1,500

	FY 2016 Enacted[a]	FY 2017 Annualized CR[b]	FY 2018 Request	FY 2018 vs FY 2016
15-SC-76 Materials Design Laboratory at ANL	23,910	23,865	24,500	+590
15-SC-77 Photon Science Laboratory Building at SLAC	25,000	24,952	......	-25,000
15-SC-78 Integrative Genomics Building at LBNL	20,000	19,962	24,800	+4,800
Total, Construction	**68,910**	**68,779**	**53,300**	**-15,610**
Total, Science Laboratories Infrastructure	**113,600**	**113,384**	**76,200**	**-37,400**
Safeguards and Security	**103,000**	**102,805**	**103,000**	......
Program Direction	**185,000**	**184,648**	**168,516**	**-16,484**
Subtotal, Science	**5,350,200**	**5,340,029**	**4,472,516**	**-877,684**
Rescission of prior year balances	**-3,200**	**-3,194**	......	**+3,200**
Total, Science	**5,347,000**	**5,336,835**	**4,472,516**	**-874,484**
Federal FTEs	**918**	**881**	**785**	**-133**

SBIR/STTR:

- FY 2016 Enacted: SBIR: $125,554,000 and STTR: $18,833,000 (SC only).
- FY 2018 Request: SBIR: $129,490,000 and STTR: $113,525,000 (SC only).

Advanced Scientific Computing Research

Overview

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

For over half a century, the U.S. maintained world-leading computing capabilities through sustained investments in research and the development and deployment of new computing systems. The benefits of U.S. computational leadership have been enormous – huge gains in workforce productivity, an acceleration of 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 that are too large, too complex, too dangerous, too small or too fleeting to explore experimentally. As the Council on Competitiveness noted and documented in a series of case studies, "A country that wishes to out-compete in any market must also be able to out-compute its rivals."[a]

The U.S. is now entering an era where advances in computing capabilities are becoming increasingly costly and risky, while at the same time, U.S. dominance in computing is under threat from significant new investments in Asia and Europe. We cannot afford to fall behind in an area that impacts every sector of our economy and every field of science and engineering. Therefore, this Budget Request increases our investments in the Exascale Computing Initiative (ECI) to accelerate the project and intends to accelerate delivery of at least one exascale-capable system in 2021.

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

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

- Deploy and apply new HPC technologies broadly for economic competitiveness and scientific discovery.
- Foster public-private partnerships, relying on the respective strengths of government, industry, and academia to maximize the benefits of HPC.
- Draw upon the strengths of and seek cooperation among all executive departments and agencies with significant expertise or equities in HPC while also broadly collaborating with industry and academia.
- Develop a comprehensive technical and scientific approach to rapidly transition research on hardware, system software, development tools, and applications into production.

Within the context of this coordinated Federal strategy, the DOE Office of Science (SC) and the DOE National Nuclear Security Administration (NNSA) are overseeing an ECI. The ECI, which began in FY 2016, is a partnership between SC and

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

NNSA to perform the research and development (R&D) necessary to overcome key exascale challenges in parallelism, energy efficiency, and reliability, leading to intended deployment of exascale systems in 2021. The ECI's goal for an exascale-capable system is a fifty-fold increase in sustained performance over today's computing capabilities, with applications that address next-generation science, engineering, and data problems. The ECI focuses on delivering advanced simulation through an exascale-capable computing program, with an emphasis on sustained performance on science and national security mission applications and increased convergence between exascale and large-data analytic computing.

The SC FY 2018 Budget Request funds two components of the ECI: planning, site preparations, and non-recurring engineering at the Leadership Computing Facilities (LCF) to prepare for intended deployment of at least one exascale system in 2021, and the ASCR-supported Office of Science Exascale Computing Project (SC-ECP), proposed in the FY 2017 Request and again in this FY 2018 Request, which includes only the R&D activities required to develop exascale-capable computers.

The scope of the SC-ECP has three focus areas:

- *Hardware Technology:* The Hardware Technology focus area supports vendor-based R&D activities required to deploy at least two exascale systems with diverse architectural features. Within this focus area, a node design effort targets component technologies needed to build exascale nodes, including the required software, while a system design effort performs the engineering and R&D activities required to build a full exascale computer and the required systems software;
- *System Software Technology:* The System 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
- *Application Development:* The Application Development focus area includes: working with scientific application areas to address the challenges of extreme parallelism, reliability and resiliency, deep hierarchies of hardware processors and memory, scaling to larger systems, and data-intensive science.

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

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

Highlights of the FY 2018 Budget Request

The FY 2018 Budget Request for ASCR increases our investments in the ECI with the intention to accelerate the project and deliver at least one exascale-capable system in 2021. To ensure continued progress during and after the exascale project, this Request also maintains support for ASCR's fundamental research in Applied Mathematics, Computer Science, and Computational Partnerships. Funding for the ASCR facilities supports continued operations of the upgraded Oak Ridge Leadership Computing Facility (OLCF), the Argonne Leadership Computing Facility (ALCF), the National Energy Research Scientific Computing Center (NERSC), and the Energy Sciences Network (ESnet). Funding also supports initiation of an upgrade of the ESnet and site preparations at the LCFs in support of an intended 2021 delivery of at least one exascale computing system.

<u>Mathematical, Computational, and Computer Sciences Research</u>

Recognizing that Moore's Law (microchip feature sizes reduces by a factor of two approximately every two years) is nearing an end due to limits imposed by fundamental physics, ASCR began new activities in FY 2017 to explore future computing, such as quantum information, that are not based on silicon microelectronics. In FY 2018, ASCR will continue the research and computational partnerships with the Basic Energy Sciences (BES), Biological and Environmental Research (BER) and High Energy Physics (HEP) programs aimed at understanding the challenges that quantum information and neuromorphic technologies pose to DOE mission applications and to identify the hardware, software, and algorithms that will need to be developed for DOE mission applications to harness these emerging technologies.

Activities in Applied Mathematics and Computer Science provide the foundation for increasing the capability of the national HPC ecosystem. In FY 2018, these activities will continue to develop the methods, software, and tools to ensure DOE applications can fully exploit the most advanced computing systems available today and use HPC systems for data-intensive and computational science at the exascale and beyond.

Software, tools, and methods developed by these core research efforts are used by the Scientific Discovery through Advanced Computing (SciDAC) computational partnerships, which are being recompeted and expanded in FY 2017. This allows the other scientific programs in SC to more effectively use the current and immediate next generation HPC facilities. The focus of the SciDAC portfolio will continue to be on developing the mission critical applications of the other SC programs. These efforts will be informed by the research results emerging from the ECI and will, whenever possible, incorporate the software, methods, and tools developed by that initiative.

The Next Generation Networking for Science activity will be eliminated. Collaboratory efforts, currently supported by this activity, will be supported by computational partnerships to strengthen the interconnectivity of these efforts. Networking R&D will be supported by the High Performance Network Facilities and Testbeds activity and will focus on the unique needs of the ESnet in support of a significant upgrade of the ESnet to address the increased data flows from the exascale systems and other SC user facilities.

High Performance Computing and Network Facilities

In FY 2018, the LCFs will continue to deliver HPC capabilities for large scale applications to ensure that the U.S. research community and DOE's industry partners continue to have access to the most capable supercomputing resources in the world. The OLCF will begin operating the new IBM Summit system to allow early science users to harness up to 200 petaflops of sustained performance while beginning preparation for an exaflop upgrade in 2021. The ALCF upgrade project will shift toward an advanced architecture, particularly well-suited for machine learning applications capable of more than an exaflop performance when delivered. This will impact site preparations and requires significant new non-recurring engineering efforts with the vendor to develop features that meet ECI requirements and that are architecturally diverse from the OLCF exascale system.

The NERSC will continue operations of the NERSC-8 supercomputer, named Cori, which has expanded the capacity of the facility to approximately 30 petaflops. To keep pace with the growing demand for capacity computing to meet mission needs, the FY 2018 Request supports site preparations and non-recurring engineering to deploy NERSC-9 in 2020, which will have three to five times the capacity of NERSC-8.

Given the significant external competition for trained workforce across the ASCR portfolio and the need to develop the workforce to support the accelerated timeline for the delivery of an exascale system, the Research and Evaluation Prototypes (REP) activity will continue to support the Computational Sciences Graduate Fellowship at $10,000,000 in FY 2018. Experienced computational scientists who assist a wide range of users in taking effective advantage of the advanced computing resources are critical assets at both the LCFs and NERSC. To address this DOE mission need, ASCR continues to support, within ASCR facilities funding, post-doctoral training program for high end computational science and engineering at the facilities through ASCR facilities funding. In addition, the three ASCR HPC user facilities will continue to prepare their users for future architectures.

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

In FY 2018, ESnet will continue to provide networking connectivity for large-scale scientific data flows. The last significant upgrade of the ESnet was in 2010 and some links are reaching the end of their life-span. In addition, the near-term delivery of exascale and sharply increased data rates from several other SC facilities means that the demand for data movement will exceed the cost effective capabilities of ESnet's rapidly aging technology. Therefore, the ESnet has an approved Mission Need Statement (Critical Decision-0) to initiate a significant upgrade project in FY 2018 that will incorporate new optical technologies and increase core capacity to more than one terabit (one trillion bits) per second - an increase of 2-10 times current capacity at significantly lower per-wave deployment costs. This activity will also support all of the critical research necessary to deploy these technologies with continued 99.999% reliability and enhanced cyber security protections.

Exascale Computing

The ASCR FY 2018 Budget Request includes $346,580,000 to significantly accelerate the development of exascale-capable computing systems and with the intention to deploy these systems in 2021 to meet national needs through the SC's Exascale Computing Project (SC-ECP). 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, these research investments will impact computing at all scales, ranging from the largest scientific computers and data centers to Department-scale computing to home computers and laptops.

Exascale computing is a central component of 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 primary goal of the ECI in SC is to develop the technologies needed to deploy an exascale computing capability to advance the Department's science missions into the next decade. This will require major advances in technology, the most important of which are increased parallelism, energy efficiency, and reliability, which are needed for scalable use of these computing systems.

Recent information gathered from U. S. vendors and results from previous DOE investments in the Design Forward and Fast Forward pre-exascale activities have identified opportunities to accelerate our exascale efforts to keep pace with foreign competition. As shown in the following table, with the $346,580,000 SC ECI Request, SC intends to fund the acceleration of the research development of an exascale platform based on an advanced architecture, with the intention to deploy in 2021 at ANL, followed by a second exascale-capable system with a different advanced architecture at ORNL:

- $196,580,000 for the ECP project to accelerate research and the preparation of applications, develop a software stack for both exascale platforms, and support additional co-design centers in preparation for exascale system deployment in 2021.
- $150,000,000 in LCF activity to begin planning, non-recurring engineering, and site preparations for the intended deployment of at least one exascale system in 2021. Deployment of exascale systems will be through the LCFs as part of their usual upgrade processes.

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

FY 2018 Crosscuts ($K)

	ECI
Advanced Scientific Computing Research	346,580

Advanced Scientific Computing Research
Funding ($K)

	FY 2016 Enacted[a]	FY 2017 Annualized CR[b]	FY 2018 Request	FY 2018 vs FY 2016
Mathematical, Computational, and Computer Sciences Research				
Applied Mathematics	42,318	–	30,104	-12,214
Computer Science	39,160	–	29,296	-9,864
Computational Partnerships	34,336	–	41,268	+6,932
Next Generation Networking for Science	20,591	–	0	-20,591
SBIR/STTR	6,181	–	11,261	+5,080
Total, Mathematical, Computational, and Computer Sciences Research	**142,586**	**–**	**111,929**	**-30,657**
High Performance Computing and Network Facilities		–		
High Performance Production Computing	86,000	–	80,000	-6,000
Leadership Computing Facilities	182,517	–	249,321	+66,804
Exascale (non-add)	*0*	*0*	*(150,000)*	*+150,000*
Research and Evaluation Prototypes	156,820	–	24,452	-132,368
High Performance Network Facilities and Testbeds	38,040	–	45,000	+6,960
SBIR/STTR	15,037	–	14,728	-309
Total, High Performance Computing and Network Facilities	**478,414**	**–**	**413,501**	**-64,913**
Exascale Computing				
17-SC-20 Office of Science Exascale Computing Project (SC-ECP)	0	0	196,580	+196,580
Total, Advanced Scientific Computing Research	**621,000**	**619,819**	**722,010**	**+101,010**

SBIR/STTR funding:

- FY 2016 Enacted: SBIR $18,450,000 and STTR $2,768,000
- FY 2018 Request: SBIR $22,785,000 and STTR $3,204,000

[a] The FY 2016 Enacted level includes SBIR and STTR and reflects updates through the end of the fiscal year.
[b] FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above, below that level, a dash (-) is shown.

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

	FY 2018 vs FY 2016
Mathematical, Computational, and Computer Sciences Research: The Computer Science and Applied Mathematics activities will increase their emphasis on data-intensive science and initiate new efforts in machine learning to increase the impact of data generated in extreme-scale simulations and by Office of Science user facilities. The Computational Partnerships activity will continue to infuse the latest developments in applied math and computer science into the strategic applications of the Office of Science to get the most out of the leadership computing systems. Investments will increase for future computing technologies such as quantum information systems in partnership with BES, BER, and HEP. The Next Generation Networking for Science activity will be eliminated. Collaboratory efforts currently supported by this activity will be supported by computational partnerships to strengthen the interconnectivity of these efforts. Networking-related R&D will be supported within the High Performance Network Facilities and Testbeds and will focus on the unique needs of the ESnet in support of a significant upgrade to handle the increased data flows from the exascale systems and other Office of Science user facilities.	**-30,657**
High Performance Computing and Network Facilities: Increased facilities funding initiates activities with the intention to deploy an exascale system at the ALCF in 2021 and to begin preparations at the OLCF for an exascale system that is architecturally distinct to follow in 2022. Funding also supports operations, including increased power costs at all facilities. Research and Evaluation Prototypes funding will support quantum computing testbeds and the Computational Sciences Graduate Fellowship at current levels. High Performance Network Facilities and Testbeds supports initiation of a significant upgrade, ESnet 6, to ensure that networking and data transfer capacity keep pace with increasing demand as new facilities come online, including the first exascale machine in 2021.	**-64,913**
Exascale Computing: Delivery of at least one exascale system based on an advanced architecture is planned for 2021, with a second exascale system with a different architecture to also follow in 2022. The FY 2018 budget also supports accelerated application and software development for both architectures, together with additional co-design centers, applications, partnerships with the vendors, and testbeds to ensure development of hardware and software keep pace.	**+196,580**
Total, Advanced Scientific Computing Research	**+101,010**

Basic and Applied R&D Coordination

Coordination across disciplines and programs is a cornerstone of the ASCR program. Partnerships within SC are mature and continue to advance the use of HPC and scientific networks for science. Growing areas of collaboration will be in the area of data-intensive science and readying applications for exascale. ASCR continues to have a strong partnership with NNSA for achieving the Department's goals for exascale computing. In April 2011, ASCR and NNSA strengthened this partnership by signing a memorandum of understanding for collaboration and coordination of exascale research within the Department. Through the National Information Technology Research and Development Subcommittee of the National Science and Technology Council's (NSTC) Committee on Technology, the interagency networking and information technology R&D coordination effort, ASCR also coordinates with programs across the Federal Government. In FY 2018, cross-agency interactions and collaborations will continue in coordination with the Office of Science and Technology Policy.

Program Accomplishments

Early Exascale Investments Pay Off for U.S. Computing Industry. An exascale architecture with enhanced integration of processors and memory developed as part of the FastForward 2 program has already improved both performance and power efficiency in one vendor's data centers and graphics products. The FastForward funding allowed the vendor to take a holistic approach that includes detailed analysis of innovative computing solutions, acceleration of key hardware and software technologies, and co-design with DOE laboratories that would not otherwise have been possible. Additional anticipated benefits include development of power management techniques that will allow processors to optimize power and performance based on application and user requirements; better programming environments, tools, and libraries to simplify parallel programming and improve performance for large-scale heterogeneous systems; and outstanding opportunities for students and early-career scientists to work in industry in advanced technology areas. The partnerships between U.S. vendors and DOE simultaneously advances DOE's science and national security missions and U.S. competitiveness by helping vendors develop computing infrastructure solutions that enhance the business case for deploying platforms for HPC, data analytics, and other high-growth markets. Studies have shown that growth in computers and microelectronics yields the biggest returns in both GDP and high quality jobs[a].

Reducing the Damage Caused by Industrial Fires. Warehouse fires are the leading cause of commercial property damage, responsible for 40% of all industry property loss at a cost of approximately $188 million per year. Understanding how fires spread has the potential to save both business owners and insurance companies hundreds of millions of dollars. However, some of the most destructive fires – those that take place in mega-warehouses with ceilings up to 100 ft. high and a footprint in excess of 100,000 sq. ft.– are among the most difficult to study because they cannot be replicated in a test facility. To solve this problem, one of the world's largest commercial and industrial insurance companies partnered with the Oak Ridge Leadership Computing Facility to adapt an open-source fluid dynamics code to include the complex processes that occur during an industrial fire, including soot formation and sprinkler spray dynamics. After running their high-resolution FireFOAM code on the Oak Ridge Leadership Computing Facility's Titan machine to learn how to stack storage boxes on pallets to impede the spread of horizontal flames, the team incorporated the SciDAC-developed Adaptable I/O System (ADIOS) into FireFOAM to improve its efficiency in moving data on and off the supercomputer. The new and improved code is now being used to simulate other commodities stored in warehouses, starting with large paper rolls. Both the results and the code are shared publicly to promote the improvement of fire protection standards across industry.

New Algorithm for Incompressible Fluid Flow Modeling. The Navier-Stokes equations for fluid flow are used for applications ranging from special effects in movies to industrial design. By solving these complex equations, researchers can gain insight into how fast a fluid is moving through its environment, how much pressure it is under, and the forces it exerts on its surroundings. Using the NERSC, a researcher at LBNL reformulated the incompressible Navier-Stokes equations to make them more amenable to numerical computation and overcome challenges in resolving the intricate fluid dynamics near moving boundaries such as bubbles, swimming organisms, and surface waves. The new algorithms capture changing small-scale features near these boundaries with unprecedented detail and provide additional information about how the tiny features influence the fluid far away from the boundary. The resulting cheaper computational models and increased resolution capabilities will allow researchers to study even more complex phenomena such as blood flow in the pumping

[a] A Nov 2016 Deutsche Bank Report (Zhang and Zeng) estimated that a 10% reduction in the U.S. trade deficit in "computers and electronics" would add $18 billion to the U.S. economy.

heart, the ejection of ink droplets in consumer inkjet printers, and optimal propeller design. This work is described in the June 10, 2016 issue of Science Advances[a].

Modeling Mini-Proteins to Design More Effective Drugs with Minimal Side Effects. Therapeutic drugs typically work by attaching themselves to, and thus disabling, disease-inducing molecules in the human body. The perfect drug has a stable structure that will move easily through the body to bind to its intended target and nothing else. Many of the therapeutic drugs in common use today are small molecules that dissolve readily in the body but bind to unintended targets in a manner that can lead to harmful side effects. Drugs based on protein molecules that have a highly specific structure can minimize side effects at the cost of being too large to pass through membranes that are their entry route into the human body. Peptides – molecules derived from the same building blocks as proteins but many times smaller – may strike the perfect balance, as long as they include an additional man-made component to stabilize their structure. To evaluate a peptide for use as a therapeutic drug, researchers must perform hundreds of millions of simulations to explore how the peptide will fold and bind to disease-inducing molecules. Researchers at the University of Washington, funded by NIH and NSF, have put the ALCF's more than 780,000 cores to use to refine their technique for evaluating and optimizing over thousands of different peptide designs. The team's long-term goal is to create a database of peptides to assist in future drug design efforts. This work was published in Nature Magazine in October 2016[b].

Network Pilot Quintuples Data Transfer Rates. Over half of the researchers using the General Medical Sciences and National Cancer Institute Structural Biology (GM/CA) Facility at ANL's Advanced Photon Source access the facility from their home institutions. While remote access allows a wider range of researchers to use the facility's intense, tunable x-ray microbeams, remote users often cannot analyze their data until after their beamtime is over because it takes too long to move the large data files to a computer capable of processing them. A pilot program to implement the Science DMZ – an ESnet network model tailored to the needs of high-performance science applications – at the GM/CA facility demonstrated data transfer rates over five times faster between the facility and Purdue University for most file sizes. Additional tests are planned at five more remote sites. Integrating the lessons learned in this ESnet pilot into regular operations will simplify the facility's support for the beamline and lead to increased scientific productivity.

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[a] *Interfacial gauge methods for incompressible fluid dynamics*. Science Advances 10 Jun 2016: Vol. 2, no. 6, e1501869 DOI: 10.1126/sciadv.1501869

[b] http://www.nature.com/nature/journal/v538/n7625/abs/nature19791.html

Description

The Mathematical, Computational, and Computer Sciences Research subprogram supports research activities to effectively use the current and future generations of DOE's computer and networking capabilities. Computational science is increasingly central to progress at the frontiers of science and to our most challenging engineering problems. Accordingly, the subprogram delivers:

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

The research program will develop methods, software, and tools to use HPC systems for data-intensive and computational science at the exascale and beyond. This requires a focus on increased parallelism, data movement, resilience, and machine learning in digital computing, and exploratory research in future computing paradigms that have the potential to revolutionize scientific computing in the post-exascale era.

Deriving scientific insights from the vast amounts of data flowing from SC user facilities as well as the output of extreme-scale simulations will require a sophisticated tool suite for data manipulation, visualization, pattern recognition, and analysis. Data-intensive science additionally requires a focused research effort to develop the necessary theories, software tools, and technologies to manage the full data lifecycle from generation or collection through capturing the historic record of the data, archiving, and sharing them. In FY 2018, ASCR's research program will increase its emphasis on data-intensive science, including new efforts to exploit machine learning and other adaptive algorithms to enhance the impact of scientific data generated across SC.

Applied Mathematics

The Applied Mathematics activity supports the R&D of applied mathematical models, methods, and algorithms for understanding complex natural and engineered systems related to DOE's mission. These mathematical models, methods, and algorithms are the fundamental building blocks for describing complex physical and engineered systems computationally. This activity's research underpins all of DOE's modeling and simulation efforts. Significant innovation in applied mathematics is needed to realize the potential of future HPC systems. High-fidelity modeling and simulation require a number of new algorithmic techniques and strategies supported by this activity, including adaptive algorithms and machine learning, advanced solvers for large linear and nonlinear systems of equations, time integration schemes, multi-physics coupling, methods that use asynchrony or randomness, adaptively evolving mesh techniques, algorithmic resilience, and uncertainty quantification.

Computer Science

The Computer Science activity supports research on extreme-scale computing and extreme-scale data. Information from computer vendors indicates that because of power constraints, data movement, rather than arithmetic operations, will be a constraining factor for future systems. Memory per core is projected to decline sharply due to power requirements, and the cost of memory relative to CPUs and the performance growth of storage systems will continue to lag behind the computational capability of the systems. Multi-level storage architectures that span multiple types of memory hardware are anticipated and will require research within this activity to develop new approaches for data management and analysis.

Significant innovation in computer science is needed to realize the computational and data-analytic potential of future HPC systems and other scientific user facilities in a timeframe consistent with their anticipated availability. There will be an increased emphasis on data-intensive science challenges with particular attention to adaptive algorithms and machine learning, the intersection with exascale computing challenges, and the unique needs of DOE scientific user facilities including data management and cyber security. There also will be significant efforts in software tools, user interfaces, the HPC software stack that can dynamically deal with time-varying energy efficiency and reliability requirements–including operating systems, file systems, compilers, and performance tools–and visualization and analytics tools that scale to extremely massive datasets. These efforts are essential to ensure DOE mission applications are able to use commercially available HPC hardware.

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

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

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

Activities and Explanation of Changes

FY 2016 Enacted	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
Mathematical, Computational, and Computer Sciences Research $142,586,000	**$111,929,000**	**-$30,657,000**
Applied Mathematics $42,318,000	**$30,104,000**	**-$12,214,000**
Applied Mathematics continued efforts to develop new algorithmic techniques and strategies that extract scientific advances and engineering insights from massive data for DOE missions. Applied Mathematics addressed many of the challenges of exascale including: advanced solvers, uncertainty quantification, algorithmic resilience, and strategies for reducing global communications.	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. Adaptive algorithms and machine learning will be added to the suite of tools under development for optimizing the scientific output of data-intensive programs across SC.	Decrease reflects transfer of exascale related funding to the SC-ECP and does not constitute a change in scope for these activities.
Computer Science $39,160,000	**$29,296,000**	**-$9,864,000**
Computer Science continued efforts to develop software, new programming models and metrics for evaluating system status. This activity primarily focused on addressing the challenges of exascale and data-intensive science and emphasized efforts to promote ease of use, increased parallelism, energy efficiency, and reliability, and ensured that research efforts are tightly coupled to application requirements and developments in industry, particularly those identified by the co-design centers and developed in partnerships supported by the Research and Evaluation Prototypes activity.	Computer Science will continue efforts to develop software, new programming models, new operating systems, and efforts to promote ease of use. Activities to support development of future computing technologies will also continue, and a new effort will be initiated to exploit machine learning techniques to better understand data generated both by HPC simulations and SC facilities.	Decrease reflects transfer of exascale related funding to the SC-ECP and does not constitute a change in scope for these activities.

FY 2016 Enacted	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
Computational Partnerships $34,336,000	**$41,268,000**	**+$6,932,000**
The SciDAC Institutes were recompeted at the end of FY 2016. These Institutes continue to provide the bridge between the core research program and the DOE science applications. The development of SciDAC tools and resources by the Institutes is primarily for use on computational systems, such as those existing and planned for at the Oak Ridge and Argonne LCFs, the NERSC, and similar world-class computing facilities over the next five years.	The SciDAC institutes continue to play a key role in assisting DOE mission critical applications to effectively use ASCR's existing production and LCFs while the newly-awarded fourth-generation SciDAC partnerships focus on preparing applications to harness the potential of ASCR's planned upgrades to its computing facilities. Partnerships initiated in FY 2017 to explore potential impacts of future computing technologies across SC continue. In FY 2018, this effort also supports collaboratory partnerships previously included in Next Generation Networking for Science.	Increase reflects the transfer of some funding from the Next Generation Networking for Science activity to support collaboratory partnerships. Funding also increases to support interdisciplinary partnerships to develop algorithms and applications for quantum information systems.
Next Generation Networking for Science $20,591,000	**$0**	**-$20,591,000**
The Next Generation Networking for Science activity continued to work closely with SC user facilities and applications, to develop the necessary tools—networking software, middleware and hardware—to address the challenges of moving, sharing and validating massive quantities of data via next generation optical networking technologies. This focus allowed DOE scientists to productively collaborate regardless of the geographical distance between scientists and user facilities or the size of the data.	The Next Generation Networking for Science activity will be eliminated through consolidation with other ASCR activities and successful completion of several projects in FY 2018.	Collaboratory efforts, currently supported by this activity, will be supported by the computational partnerships activity to strengthen the interconnectivity of these efforts. Networking R&D will be supported by the High Performance Network Facilities and Testbeds activity and will focus on the unique needs of the ESnet in support of a significant upgrade of the ESnet to address the increased data flows from the exascale systems and other Office of Science user facilities.
SBIR/STTR $6,181,000	**$11,261,000**	**+$5,080,000**
In FY 2016, SBIR/STTR funding is set at 3.45% of non-capital funding.	In FY 2018, SBIR/STTR funding is set at 3.65% of non-capital funding.	

Description

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

The Research and Evaluation Prototypes (REP) activity addresses the challenges of next generation computing systems. By actively partnering with the research community, including industry, on the development of technologies that enable next-generation machines, ASCR ensures that commercially available architectures serve the needs of the scientific community. The REP activity also prepares researchers to effectively use future generations of scientific computers, including novel technologies, and seeks to reduce risk for future major procurements.

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.

High Performance Production Computing

This activity supports NERSC, which delivers high-end production computing services for the SC research community. Approximately 6,000 computational scientists in about 800 projects use NERSC annually to perform scientific research across a wide range of disciplines including astrophysics, chemistry, earth systems modeling, materials, high energy and nuclear physics, fusion, and biology. NERSC users come from nearly every state in the U.S., with about 49% based in universities, 46% in DOE laboratories, and 5% in other government laboratories and industry. NERSC's large and diverse user base requires an agile support staff to aid users entering the HPC arena for the first time, as well as those preparing codes to run on the largest machines available at NERSC and the LCFs. In FY 2015, NERSC moved into the new Computational Research and Theory building located on the LBNL campus.

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 years. NERSC regularly gathers requirements from SC domain programs through a long-established, robust process and uses these requirements to inform upgrade plans. These requirements activities are also vital to planning for SciDAC and other ASCR efforts to prioritize research directions and inform the community of new computing trends, especially as the computing industry moves toward exascale computing.

Leadership Computing Facilities

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

The Oak Ridge Leadership Computing Facility's (OLCF) 27 petaflop (pf) system was one of the most powerful computers in the world for scientific research and was ranked number three on the November 2016 Top 500 list, just below the most powerful supercomputers in China.[a] The FY 2018 upgrade of this facility to a 200 pf system will challenge the leadership of

[a] http://www.top500.org/lists/2016/11/

the world's fastest systems. Early science applications at the OLCF, including large eddy simulation of turbulent combustion in complex geometries, quantum Monte Carlo simulations for the study and prediction of materials properties, heavy element chemistry, models of astrophysical explosions, dynamical simulations of magnetic fields in high-energy-density plasmas, molecular design of next-generation nanochemistry for atomically precise manufacturing, simulation of cellular and neural signaling, simulations of neutron transport in fast-fission reactor cores, and earthquake simulations, are scaling to make effective use of the new capability. OLCF staff shares its expertise with industry to broaden the benefits of petascale computing for the nation. For example, OLCF works with industry to reduce the need for costly physical prototypes and physical tests in the development of high-technology products. These efforts often result in upgrades to in-house computing resources at these U.S. companies.

The Argonne Leadership Computing Facility (ALCF) operates a 10-pf IBM Blue Gene Q (Mira), developed through a joint research project with support from the NNSA, industry, and ASCR's REP activity. This HPC system achieves high performance with relatively lower electrical power consumption than other current petascale computers. The ALCF also operates an 8.5 pf Intel-based machine (Theta) to prepare their users for the ALCF-3 upgrade in 2019-2020.

The ALCF and OLCF systems are architecturally distinct, consistent with DOE's strategy to foster a diversity of capabilities that provides the Nation's HPC user community 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 2016 INCITE allocations at the LCFs outpaced the available resources by a factor of two with growth expected to sharply increase upon the availability of upgrades.

Research and Evaluation Prototypes

REP has a long history of partnering with U.S. vendors to develop future computing technologies and testbeds that push the state-of-the-art and allowed 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.

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) provides the national and international network and networking infrastructure connecting DOE science facilities, experiments, and SC laboratories with other institutions connected to peer academic or commercial networks. ESnet underpins large-scale, data-intensive science in the U.S. The volume of data transferred by ESnet is growing roughly 66% per year, twice the rate of the commercial Internet. ESnet supports the data requirements of all SC facilities, including the increased bandwidth and high-traffic links added in FY 2017 as well as transatlantic access to Large Hadron Collider data and direct science engagement efforts to improve end-to-end network performance between DOE facilities and U.S. universities. The costs for ESnet are dominated by operations, including maintaining the fiber optic backbone and refreshing switches and routers on the schedule needed to ensure the 99.999% reliability required for large-scale scientific data transmission. The Request includes additional funding to build a next-generation network, ESnet 6, which will meet the growing data needs of the SC facilities, including the intention to deploy the first exascale machine in 2021. This activity will also support all of the critical research necessary to deploy these technologies with continued reliability with enhanced cyber security protections.

Activities and Explanation of Changes

FY 2016 Enacted	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
High Performance Computing and Network Facilities $478,414,000	**$413,501,000**	**-$64,913,000**
High Performance Production Computing $86,000,000	**$80,000,000**	**-$6,000,000**
Supported installation, acceptance and operation of the NERSC high-end capability systems (NERSC-7 and NERSC-8) including increased power costs, lease payments, and user support and continuation of the post-doctoral training program for high-end computational science and engineering.	The NERSC-8 system, named "Cori" after Nobel Laureate Gerty Cori, will continue production operations. Demand for production computing for the SC programs continues to grow along with system capability and the rapid increase in data from experiments. In FY 2018, preparation for the 2020 delivery of NERSC-9, which will provide three to five times the capacity of NERSC-8, will continue.	Decrease reflects completion of site preparations for NERSC-8. Operation of NERSC-8 and the NERSC-9 acquisition continue as planned.
Leadership Computing Facilities $182,517,000	**$249,321,000**	**+$66,804,000**
Supported operation and allocation of the 27-pf Titan system at the OLCF and the 10-pf Mira system at the ALCF through INCITE and ALCC. This included lease payments, power, and user support. Also supported preparations—such as power, cooling and cabling at the LCFs to support 75-200 pf upgrades at each facility and continuation of the post-doctoral training program for high-end computational science and engineering.	Operation will continue at both LCF facilities while upgrades will proceed as planned. The OLCF will install, test, provide early science access, and transition the new IBM hybrid supercomputer, called Summit, to operations in early FY 2018. This upgrade will provide 200 pf of computing capability, or approximately five times the capability of the previous system, Titan. OLCF will also begin site preparations to enable deployment of an exascale system as early as 2021. In FY 2018, the ALCF will continue to provide access to the 8.5-pf Intel Xeon interim system, called Theta, deployed in early FY 2017 to transition ALCF users to the new architecture. The ALCF will begin site preparations and significant nonrecurring engineering efforts to deploy a novel architecture capable of delivering more than an exaflop of computing capability in 2022.	Increase provides for planning and the initiation of site preparation activities and non-recurring engineering to ready both facilities to deploy exascale systems, with distinct architectures in 2021-2. This approach reduces the risk of the exascale initiative and broadens the community able to of utilize these new capabilities.
Leadership Computing Facility at ANL: $77,200,000	$100,000,000	+$22,800,000

FY 2016 Enacted	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
Leadership Computing Facility at ORNL: $105,317,000	$149,321,000	+$44,004,000
Research and Evaluation Prototypes $156,820,000	**$24,452,000**	**-$132,368,000**
REP supported efforts to improve the energy efficiency and reliability of critical technologies such as memory, processors, network interfaces and interconnects. REP competitively selected R&D partnerships with U.S. vendors to initiate the design and development of compute node and system designs suitable for exascale systems, which was an essential component of the Department's exascale computing plan and a key step in the vendor's productization efforts. To emphasize the vital importance of the CSGF program to the ASCR facilities and to our exascale goals, Research and Evaluation Prototypes supported the program at $10,000,000.	Availability of experienced and knowledgeable workforce issues continues to be of vital importance to ASCR's current and planned facilities. The CSGF program will play an increasingly important role as the Exascale Initiative progresses and future computing technologies mature. Therefore, support for the CSGF within REP continues at $10,000,000 in FY 2018. This activity will also provide increased support for the future computing technology testbed focused on quantum computing established in FY 2017.	Decrease reflects transfer of exascale related funding to the SC-ECP and does not constitute a change in scope for these activities while there is an increase to support additional quantum computing testbed activities.
High Performance Network Facilities and Testbeds $38,040,000	**$45,000,000**	**+$6,960,000**
ESnet operated the national and international network infrastructure to support critical DOE science applications, SC facilities and scientific collaborations around the world through 100 gbps production network and begin upgrade to 400-gbps testbed for networking testing and research.	The Request supports operations and maintenance of the network and continued development of tools now widely deployed through the DOE and university systems in the US: Science DMZ, perfSONAR, Data Transfer Nodes, and OSCARS. Additionally, the Request supports applied networking R&D, previously supported by the Next Generation Networking for Science (NGNS) activity, necessary to maintain ESnet's status as a world-leading scientific research network, and to support a network testbed focused on prototyping and operationalizing future network architectures such as Software-Defined Networking and Named-Data Networking. ESnet was last upgraded in 2010 and some technology is no longer supported by the vendor. Additional funds are therefore requested for the upgrade to ESnet 6, which will provide a network for scientific	Increase supports the ESnet 6 upgrade required to meet SC data requirements through the mid-2020s and supports related networking research previously supported by the NGNS activity.

FY 2016 Enacted	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
	data transfer with the capacity, reliability and resilience, and flexibility to meet the needs of the Office of Science facilities and research community through the mid-2020s.	
SBIR/STTR $15,037,000	**$14,728,000**	**-$309,000**
In FY 2016, SBIR/STTR funding is set at 3.45% of non-capital funding.	In FY 2018, SBIR/STTR funding is set at 3.65% of non-capital funding.	

Description

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

The SC-ECP supports R&D for the development of exascale computers and is not a traditional construction project. The SC-ECP will be managed following the principles of DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets*, tailored for this fast-paced research effort and similar to that which has been used by SC for the planning, design, and construction of all of its major computing projects, including the LCFs at Argonne and Oak Ridge National Laboratories and NERSC at LBNL.

The FY 2018 Request includes $196,580,000 for SC-ECP. These funds support the preparation of applications; and the development of a software stack for both platforms. Funding also supports additional co-design centers, vendor partnerships, and testbeds in preparation for the intended deployment of an exascale system in 2021. Deployment of exascale systems will be through the LCFs as part of their usual upgrade processes. $150,000,000 of additional ECI funding is provided in the LCF activity to begin planning, non-recurring engineering, and site preparations for the intended delivery of at least one exascale system as early as 2021.

Activities and Explanation of Changes

FY 2016 Enacted	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
17-SC-20 Office of Science Exascale Computing Project (SC-ECP) $0	**$196,580,000[a]**	**+$196,580,000[a]**
Research efforts that are on the critical path for the ECI have previously been funded within Applied Mathematics, Computer Sciences, Computational Partnerships, and Research and Evaluation Prototypes activities.	FY 2018 funding will accelerate application and software stack development in preparation for the intended delivery of an exascale system in 2021.	The increase reflects revision of ECP for the intended delivery of at least one exascale system as early as 2021. Application and software development is accelerated, and additional codesign centers have been added to the project.

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

Office of Science
Advanced Scientific Computing Research
Performance Measures

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

	FY 2016	FY 2017	FY 2018
Performance Goal (Measure)	**ASCR Facility Operations - Average achieved operation time of ASCR user facilities as a percentage of total scheduled annual operation time**		
Target	≥ 90 %	≥ 90 %	≥ 90 %
Result	Met	TBD	TBD
Endpoint Target	Many of the research projects that are undertaken at the Office of Science's scientific user facilities take a great deal of time, money, and effort to prepare and regularly have a very short window of opportunity to run. If the facility is not operating as expected the experiment could be ruined or critically setback. In addition, taxpayers have invested millions or even hundreds of millions of dollars in these facilities. The greater the period of reliable operations, the greater the return on the taxpayers' investment.		

	FY 2016	FY 2017	FY 2018
Performance Goal (Measure)	**ASCR Research - Discovery of new applied mathematics and computer science tools and methods that enable DOE applications to deliver scientific and engineering insights with a significantly higher degree of fidelity and predictive power**		
Target	Fund two teams to develop exascale node designs.	Identify at least one multi-institutional team to develop new mathematics for DOE mission focused grand challenges at the nexus of multiple computational sub-domains such as data-driven	Support at least two machines learning efforts in both applied mathematics and computer science.

		discovery, multiscale modeling, uncertainty quantification, and adaptive algorithms.	
Result	Met	TBD	TBD
Endpoint Target	Develop and deploy high-performance computing hardware and software systems through exascale platforms		

Advanced Scientific Computing Research
Capital Summary ($K)

	Total	Prior Years	FY 2016 Enacted	FY 2017 Annualized CR[a]	FY 2018 Request	FY 2018 vs FY 2016
Capital operating expenses						
Capital equipment	n/a	n/a	5,700	–	10,000	+4,300

Funding Summary ($K)

	FY 2016 Enacted	FY 2017 Annualized CR[a]	FY 2018 Request	FY 2018 vs FY 2016
Research	293,225	–	321,700	+28,475
Scientific user facility operations	306,557	–	374,321	+67,764
Other	21,218	–	25,989	+4,771
Total, Advanced Scientific Computing Research	**621,000**	**619,819**	**722,010**	**+101,010**

[a] FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above, below that level, a dash (-) is shown.

Scientific User Facility Operations ($K)

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

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

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

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

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

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

	FY 2016 Enacted	FY 2017 Annualized CR[a]	FY 2018 Request	FY 2018 vs FY 2016
TYPE A FACILITIES				
NERSC	**$86,000**	**$–**	**$80,000**	**-$6,000**
Number of Users	5,608	–	6,000	+392
Achieved operating hours	N/A	–	N/A	
Planned operating hours	8,585	–	8,585	+0
Optimal hours	8,585	–	8,585	+0
Percent optimal hours	N/A	–	N/A	
Unscheduled downtime hours	N/A	–	N/A	

[a] FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above, below that level, a dash (-) is shown.

	FY 2016 Enacted	FY 2017 Annualized CR[a]	FY 2018 Request	FY 2018 vs FY 2016
OLCF	**$105,317**	–	**$149,321**	**+$44,004**
Number of Users	1,064	–	1,064	+0
Achieved operating hours	N/A	–	N/A	
Planned operating hours	7,008	–	7,008	+0
Optimal hours	7,008	–	7,008	+0
Percent optimal hours	N/A	–	N/A	
Unscheduled downtime hours	N/A	–	N/A	
ALCF	**$77,200**	–	**$100,000**	**+$22,800**
Number of Users	1,434	–	1,434	+0
Achieved operating hours	N/A	–	N/A	
Planned operating hours	7,008	–	7,008	+0
Optimal hours	7,008	–	7,008	+0
Percent optimal hours	N/A	–	N/A	
Unscheduled downtime hours	N/A	–	N/A	
ESnet	**$38,040**	–	**$45,000**	**+$6,960**
Number of users[b]	N/A	–	N/A	
Achieved operating hours	N/A	–	N/A	
Planned operating hours	8,760	–	8,760	+0
Optimal hours	8,760	–	8,760	+0
Percent optimal hours	N/A	–	N/A	
Unscheduled downtime hours	N/A	–	N/A	

[a] FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above, below that level, a dash (-) is shown.

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

	FY 2016 Enacted	FY 2017 Annualized CR[a]	FY 2018 Request	FY 2018 vs FY 2016
Total Facilities	**$306,557**	–	**$374,321**	**+$67,764**
Number of Users[b]	8,106	–	8,498	+392
Achieved operating hours	N/A	–	N/A	
Planned operating hours	31,361	–	31,361	+0
Optimal hours	31,361	–	31,361	+0
Percent of optimal hours[c]	N/A	–	N/A	
Unscheduled downtime hours	N/A	–	N/A	

Scientific Employment

	FY 2016 Enacted	FY 2017 Annualized CR[a]	FY 2018 Estimate	FY 2018 vs FY 2016
Number of permanent Ph.D.'s (FTEs)	584	–	601	+17
Number of postdoctoral associates (FTEs)	146	–	200	+54
Number of graduate students (FTEs)	460	–	486	+26
Other scientific employment (FTEs)[d]	247	–	257	+10

[a] FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above, below that level, a dash (-) is shown.

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

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

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

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

1. Significant Changes and Summary

Significant Changes
This Project Data Sheet (PDS) is an update of the FY 2017 PDS and does not include a new start.

The FY 2018 Request for SC-ECP is $196,580,000. The most recent DOE O 413.3B approved Critical Decision (CD) is CD-1/3A, Approve Alternative Selection and Cost Range and Approve phase one funding of hardware and software research projects and application development, was approved on January 3, 2017. The estimated Total Project Cost (TPC) range of the SC-ECP is $1.0 billion to $2.7 billion.

Summary
In FY 2016, the President's 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, the SC component of the ECI is partitioned into the Office of Science Exascale Computing Project (SC-ECP) within a new Exascale Computing subprogram in ASCR, and includes only those research and development (R&D) activities required for the development of exascale-capable computers. Other activities related to the ECI but outside of the scope of the R&D activities leading to exascale-capable computers are not within the SC-ECP, though they do remain in the scope of the ECI. In FY 2018 these include $150,000,000 to support the initiation of planning, site preparations, and non-recurring engineering at the Leadership Computing Facilities (LCFs) where the exascale machines will be housed and operated. With all of these activities and funding, DOE intends to accelerate delivery of at least one exascale-capable system in 2021. Supporting parallel development at both LCFs will reduce the overall risk of the project and broaden the range of applications able to utilize this new capability. This PDS is for the SC-ECP only; prior-year activities related to the SC-ECP are also included.

In FY 2018, SC-ECP funding will support project management; development of project documentation; conduct of co-design activities with a representative subset of mission applications; R&D of exascale systems software and tools needed for exascale programming; and vendor partnerships.

2. Critical Milestone History and Schedule

(fiscal quarter or date)

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

CD-0 – Approve Mission Need
CD-1 – Approve Alternative Selection and Cost Range
CD-2 – Approve Performance Baseline
CD-3A – Approve phase one funding of hardware and software research projects and application development.
CD-3B – Approve phase two funding of hardware and software development, and exascale system contract options.
CD-4 – Approve Project Completion

3. Project Cost History

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

4. Project Scope and Justification

Scope

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

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

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

- *Hardware Technology:* The Hardware Technology focus area supports vendor-based research and development activities required to deploy at least two exascale-capable systems with diverse architectural features. Within this focus area, a node design effort targets component technologies needed to build exascale nodes, including the required software, while a system design effort performs the engineering and R&D activities required to build a full exascale-capable computer and the required systems software.

- *System Software Technology:* The System 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.

- *Application Development:* The Application Development focus area includes: extreme parallelism, reliability and resiliency, deep hierarchies of hardware processors and memory, scaling to larger systems, and data-intensive science.

The SC-ECP will be managed following the principles of DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets*, which has been used by SC for the planning, design, and construction of all of its major projects, including the LCFs at Argonne and Oak Ridge National Laboratories and NERSC at Lawrence Berkeley National Laboratory. Computer acquisitions use a tailored version of Order 413.3B. The first four years of SC-ECP will be focused on research in software (new algorithms and methods to support application and system software development) and hardware (node and system design) and these costs will be reported as Other Project Costs. During the last three years of the project, project activities will focus on hardening the application and the system stack software, and additional hardware technologies investments and these costs will be included in the Total Estimated Costs for the project.

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

5. Financial Schedule

	(dollars in thousands)		
	Appropriations	Obligations	Costs
Total Estimated Cost (TEC) (Hardening of Applications Development System Software Technology, Hardware Technology)			
FY 2016[a]	0	0	0
FY 2019– FY 2023	390,000	390,000	390,000
Total, TEC	390,000	390,000	390,000
Other project costs (OPC) (Research for Application Development , System Software Technology and Hardware Technology)			
FY 2016	157,944	157,944	12,500
FY 2017	164,000	164,000	228,000
FY 2018	196,580	196,580	350,444
FY 2019 – FY 2023	245,000	245,000	172,580
Total, OPC	763,524	763,524	763,524
Total Project Costs (TPC)			
FY 2016	157,944	157,944	12,500
FY 2017	164,000	164,000	228,000
FY 2018	196,580	196,580	350,444
FY 2019 – FY 2023	635,000	635,000	562,580
Total, TPC	1,153,524	1,153,524	1,153,524

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

6. Project Cost Estimate

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

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Application Development	225,000	TBD	N/A
Production Ready Software	86,000	TBD	N/A
Hardware Partnerships	79,000	TBD	N/A
Total, TEC	390,000	TBD	N/A
Other Project Costs (OPC) (Research)			
Planning/Project Mgmt	118,000	8,000	N/A
Application Development	269,630	85,000	N/A
Software Research	121,423	87,000	N/A
Hardware Research	254,471	131,894	N/A
Total OPC	763,524	TBD	N/A
Total, TPC	1,153,524	TBD	N/A

7. Schedule of Appropriation Requests

($K)

Request Year		FY 2016[a]	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	Outyears	Total
FY 2017	TEC	0	0	TBD	TBD	TBD	TBD	TBD	TBD
	OPC	157,894	154,000	TBD	TBD	TBD	TBD	TBD	TBD
	TPC	157,894	154,000	TBD	TBD	TBD	TBD	TBD	TBD
FY 2018	TEC	0	0	0	0	175,000	145,000	70,000	390,000
	OPC	157,944	164,000	196,580	189,000	14,000	14,000	28,000	763,524
	TPC	157,944	164,000	196,580	189,000	189,000	159,000	98,000	1,153,524

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

8. Related Operations and Maintenance Funding Requirements

System procurement activities for the exascale-capable computers are not part of the SC-ECP. The exascale-capable computers will become part of existing facilities and operations and maintenance funds and will be included in the ASCR facilities' operations budget. In the FY 2018 President's Request, $150,000,000 is included in the Argonne Leadership Computing Facility and the Oak Ridge Leadership Computing 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 SC-ECP.

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

9. D&D Funding Requirements

N/A, no construction.

10. Acquisition Approach

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

Basic Energy Sciences

Overview

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

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

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

Highlights of the FY 2018 Budget Request

The BES FY 2018 Request of $1,554.5 million is a decrease of $294.5 million or 16% from the FY 2016 Enacted level. The Request focuses resources toward the highest priorities in early-stage fundamental research, in operation and maintenance of scientific user facilities, and in facility upgrades. The overall research funding in FY 2018 is reduced by 18% from FY 2016. The magnitude of the decrease requires a significant shift in priorities, with targeted reductions of activities that extend to later-stage fundamental research. No funding is requested for the two BES-supported Energy Innovation Hubs, Batteries and Energy Storage and Fuels from Sunlight, or for the DOE Experimental Program to Stimulate Competitive Research (EPSCoR). In the remaining core research activities, BES emphasizes basic scientific areas with potential to transform the understanding and control of matter and energy. The 2015 Basic Energy Sciences Advisory Committee (BESAC) report, "Challenges at the Frontiers of Matter and Energy: Transformative Opportunities for Discovery Science," and the follow-on Basic Research Needs workshop reports outline specific topical areas.[a] The Request continues to support the Energy Frontier Research Center (EFRC) program, which will enable basic energy-relevant research with a scope and complexity beyond that possible in standard single-investigator or small-group awards. Both the core research and the EFRC program will emphasize emerging high priorities in quantum materials and chemistry, catalysis science, synthesis, instrumentation science, and materials and chemical research related to interdependent energy-water issues.

In the Scientific User Facilities subprogram, BES targets resources to maximize capabilities and operational efficiency, with an emphasis on maintaining a balanced suite of complementary tools. Among x-ray light sources, four facilities (Advanced Light Source, Advanced Photon Source, Linac Coherent Light Source, and National Synchrotron Light Source-II) will continue operations and are supported at 6% below the FY 2016 Enacted level. The decrease in funding will reduce operating hours and user support, including shutting down selected beamlines. The Stanford Synchrotron Radiation Lightsource will operate through the first quarter of the fiscal year, then will transition to a warm standby status. Both BES-supported neutron

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

sources, the Spallation Neutron Source and High Flux Isotope Reactor, will be operational in FY 2018 and funded at 10% below the FY 2016 Enacted level with reduced hours and user support. Selected flight paths will be shut down. No funding is requested for the disposition of unused equipment for the Lujan Neutron Scattering Center. Three of the five Nanoscale Science Research Centers will be supported at 6% below the FY 2016 Enacted level, with reduced scientific thrusts and core capabilities. No funding is requested for the Center for Functional Nanomaterials at Brookhaven National Laboratory (BNL) and the Center for Integrated Nanotechnologies at Sandia (SNL) and Los Alamos (LANL) National Laboratories. No funding is requested for Long Term Surveillance and Maintenance at BNL and at SLAC National Accelerator Laboratory (SLAC).

In the Construction subprogram, the Linac Coherent Light Source-II project remains the highest priority construction project in BES and is supported in full per the project plan. The upgrade of the Advanced Photon Source, which was the top-ranked project in the 2015 BESAC facility prioritization report, will be converted from a Major Item of Equipment to a line-item construction project to reflect refinement of project scope and will continue to be supported.

Basic Energy Sciences
Funding ($K)

	FY 2016 Enacted[a]	FY 2017 Annualized CR[b]	FY 2018 Request	FY 2018 vs FY 2016
Materials Sciences and Engineering				
Scattering and Instrumentation Sciences Research	67,350	-	55,830	-11,520
Condensed Matter and Materials Physics Research	113,086	-	113,258	+172
Materials Discovery, Design, and Synthesis Research	70,273	-	64,621	-5,652
Experimental Program to Stimulate Competitive Research (EPSCoR)	14,776	-	0	-14,776
Energy Frontier Research Centers (EFRCs)	55,750	-	50,809	-4,941
Energy Innovation Hubs—Batteries and Energy Storage	24,137	-	0	-24,137
Computational Materials Sciences	12,000	-	10,927	-1,073
SBIR/STTR	12,758	-	11,192	-1,566
Total, Materials Sciences and Engineering	**370,130**	**-**	**306,637**	**-63,493**
Chemical Sciences, Geosciences, and Biosciences				
Fundamental Interactions Research	72,782	-	61,187	-11,595
Chemical Transformations Research	88,918	-	82,004	-6,914
Photochemistry and Biochemistry Research	69,113	-	63,701	-5,412
Energy Frontier Research Centers (EFRCs)	54,250	-	48,065	-6,185
Energy Innovation Hubs—Fuels from Sunlight	15,000	-	0	-15,000
General Plant Projects (GPP)	1,000	-	1,000	0
SBIR/STTR	10,732	-	9,658	-1,074
Total, Chemical Sciences, Geosciences, and Biosciences	**311,795**	**-**	**265,615**	**-46,180**
Scientific User Facilities				
X-Ray Light Sources	482,667	-	428,206	-54,461
High-Flux Neutron Sources	265,082	-	225,620	-39,462
Nanoscale Science Research Centers (NSRCs)	120,575	-	71,135	-49,440
Other Project Costs	0	-	7,900	+7,900
Major Items of Equipment	35,500	-	0	-35,500
Research	31,853	-	19,724	-12,129

[a] The FY 2016 Enacted level includes SBIR and STTR and reflects updates through the end of the fiscal year.

[b] FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above, below that level, a dash (-) is shown.

	FY 2016 Enacted[a]	FY 2017 Annualized CR[b]	FY 2018 Request	FY 2018 vs FY 2016
SBIR/STTR	31,098	-	27,563	-3,535
Total, Scientific User Facilities	**966,775**	**-**	**780,148**	**-186,627**
Subtotal, Basic Energy Sciences	**1,648,700**	**1,645,566**	**1,352,400**	**-296,300**
Construction				
Linac Coherent Light Source-II (LCLS-II), SLAC	200,300	199,919	182,100	-18,200
Advanced Photon Source Upgrade (APS-U), ANL	0	0	20,000	+20,000
Total, Construction	**200,300**	**199,919**	**202,100**	**+1,800**
Total, Basic Energy Sciences	**1,849,000**	**1,845,485**	**1,554,500**	**-294,500**

SBIR/STTR Funding:

- FY 2016 Projected: SBIR $47,468,000 and STTR $7,120,000
- FY 2018 Request: SBIR $42,444,000 and STTR $5,969,000

[a] The FY 2016 Enacted level includes SBIR and STTR and reflects updates through the end of the fiscal year.

[b] FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above, below that level, a dash (-) is shown.

Basic Energy Sciences
Explanation of Major Changes ($K)

	FY 2018 vs FY 2016
Materials Sciences and Engineering: Research will continue to support fundamental scientific opportunities, including those identified as high priorities in the BESAC report on transformative opportunities for discovery science and Basic Research Needs workshops on quantum materials and synthesis science. For the proposed budget reductions, the scope of the subprogram will be reduced to focus on early-stage fundamental research underpinning the Department's mission. The Batteries and Energy Storage Energy Innovation Hub will not be renewed. Funding is terminated for the DOE Experimental Program to Stimulate Competitive Research (EPSCoR). Research on novel materials and theory for quantum information science will be increased.	**-63,493**
Chemical Sciences, Geosciences, and Biosciences: Research will continue in support of fundamental scientific research, including grand challenge science and opportunities identified in the BESAC report on transformative opportunities for discovery science and Basic Research Needs workshops on synthesis science, instrumentation, the energy water nexus, and catalysis. The scope of the subprogram will be reduced while continuing to support those topics that push the frontiers of science and are most strongly aligned with mission drivers. No funding is requested for the Fuels from Sunlight Energy Innovation Hub. Quantum chemistry in support of quantum information science will be increased.	**-46,180**
Scientific User Facilities: Funding is requested to support three Nanoscale Science Research Centers. No funding is requested for the Center for Functional Nanomaterials or the Center for Integrated Nanotechnologies. One light source (Stanford Synchrotron Radiation Lightsource) will operate for one quarter, then transition to warm standby. All remaining scientific user facilities will operate 6–10% below the FY 2016 Enacted level, below optimal operations. Selected light source beamlines and neutron flight paths will be shut down. No funding is requested for the disposition of unused equipment for the Lujan Neutron Scattering Center. No funding is requested for long term surveillance and maintenance. The Advanced Photon Source-Upgrade (APS-U) project is transitioned from a Major Item of Equipment (MIE) to a line item construction project.	**-186,627**
Construction: Funding for the LCLS-II construction project will decrease in FY 2018 per the project plan. The APS-U project is included as a line item construction project in the FY 2018 Request.	**+1,800**
Total, Basic Energy Sciences	**-294,500**

Basic and Applied R&D Coordination

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

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

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

Program Accomplishments

Beyond Graphene for Future Electronics. Materials for next-generation electronics will take advantage of quantum effects, as enabled by the controlled reaction of electrons with other parts of the atomic structure. Atomically thin materials may be the foundation for these innovative devices.

- Researchers developed a new process to make ultrafine (5 nm in width) junctions of different semiconductors in specific patterns by combining standard lithography with laser vaporization of sulfur. Applied controllably in planar materials, this process may enable ultrathin microelectronics for smartphones, next-generation solar cells, and solid-state lighting.
- Planar 2-dimensional (2D) layered materials are highly desirable for electronics, but are challenging to form because thermodynamics favors 3D structures in normal growth processes. Atomistic simulations predicted that 2D boron layers could be grown on a reactive metal substrate due to the fact that minor adhesion of boron to the metal will prevent 3D growth. This prediction was confirmed experimentally for deposition of boron on silver, thus demonstrating the first synthesis of a 2D material that does not have its own distinct structure but instead adapts the structure of the metal substrate.
- High surface conductivity was measured on a sandwich structure of graphene and boron nitride layers along the perimeter of the graphene. The high conductivity was attributed to topological phenomena arising from special “edge states” in graphene. These topological edge states were found to coexist with superconductivity (resistance-free electron transport) when two sides of the sandwich layers are in contact with a superconductor. This new discovery brings us closer to applications in future low-power electronics, including fault-tolerant quantum computing.

Efficient Utilization of Carbon-Containing Gases. Methane and carbon dioxide (CO_2), two of the most stable carbon compounds, are greenhouse gases that present challenges as well as opportunities for discovery of new chemical approaches to their conversion into useful fuels or commodity chemicals.

- Scientists identified a new reaction mechanism for converting CO_2 to the more reactive carbon monoxide (CO) as a precursor to chemical fuels. The method involved attaching rhenium-based molecular catalysts to the surface of low-cost graphitic carbons. These novel anchored catalysts have shown activity at least 10 times greater than that of the same catalysts in solution and are more energy efficient than other electrocatalysts. Importantly, this new approach results in the production of only CO, i.e., in 100% selectivity for the desired product, and thus no waste.

- Guided by theoretical results, researchers discovered that nickel-gallium films require less energy to reduce CO_2 to ethylene, ethane, and methanol than copper-based materials, which were previously the best candidate catalysts. Neither nickel nor gallium alone exhibits similar activity; both are needed. Since similar reactions are used in the solar-driven production of hydrocarbons or alcohols from CO_2, this could aid in developing artificial photosynthetic systems that generate renewable transportation fuels.
- Methanogenic microbes are experts at CO_2 reduction. Whether producing or consuming methane, they use the same enzyme for the challenging step of making or breaking the C-H bond. Researchers combined rapid kinetic experiments and computation to provide detailed understanding of the enzymatic mechanism. These results can provide insights for the design of energy-efficient catalysts to convert methane and other one-carbon compounds into liquid fuels and other chemicals.

Electron and Nuclear Dynamics – the Core of Chemical Processes and Properties. Research on electron and atomic displacement is increasing our understanding of both unusual and common mechanisms of energy transformation. Advanced instrumentation and innovative methodology are critical to achieving these insights.

- To generate electricity in organic solar cells, negative and positive charges must be separated over relatively large distances to avoid recombination. Using new terahertz microwave detection methods, researchers found that the charges remained separated in a nanostructure only when the electron is delocalized over an ordered domain. These results suggest that ordered molecular nano-domains play an essential role in efficient organic solar cells.
- Researchers developed a method to produce ultrafast pulses of circularly polarized extreme ultraviolet light in a tabletop setup. With this approach, scientists can easily take tabletop measurements of dynamic processes occurring on ultrafast time scales, such as in novel magnetic materials, and study chiral molecules, such as proteins or DNA, that come in left- and right-handed versions.
- Scientists have confirmed experimentally and with high accuracy the long-held hypothesis that the structure of platinum catalyst nanoparticles, supported on alumina, changes during the catalytic conversion of ethylene to ethane. They designed a miniature reactor to collect nanoscale structural images simultaneously with synchrotron x-ray absorption spectra. This approach provides precise atomic-scale dynamic information to refine models and improve design of supported metal catalysts.

BES user facilities enable U.S. industries to advance technology frontiers and develop new drugs that save lives.

- BES x-ray light sources continue to play a crucial role in helping the pharmaceutical industry advance the fundamental understanding of how diseases function and how to design drugs to treat them. Recently, the U.S. Food and Drug Administration approved Venclexta (venetoclax) to treat chronic lymphocytic leukemia. During the development of this new drug, scientists used structural information obtained at the Advanced Photon Source to understand the function of the BCL-2 protein, which supports cancer growth.
- aBeam Technologies, using a suite of BES light sources and nanocenters, developed a world-leading metrology tool utilizing a fabricated pattern with linewidths down to 1.5 nanometers. aBeam Technologies, together with researchers at the BES user facilities, won an R&D 100 Award for this breakthrough. Metrology tools characterize advanced imaging systems from interferometers to electron microscopes.
- Researchers from Honeywell used the VULCAN instrument at the Spallation Neutron Source to measure residual stresses in a titanium fan jet engine blade that was manufactured by linear friction welding. Residual stress information is crucial to the manufacture of these components due to the detrimental effects the stresses can have on overall mechanical properties.

New optics, insertion device concepts, and accelerator improvements deliver advanced capabilities at BES user facilities.

- Scientists at the National Synchrotron Light Source-II (NSLS-II) developed a hard x-ray scanning microscope employing novel nanofocusing optics that produces a tiny x-ray beam with unprecedented spatial resolution. The microscope provides researchers a unique capability that opens up new scientific frontiers of high-resolution x-ray imaging, taking full advantage of the brightness of NSLS-II. This development won a 2016 Microscopy Today Innovation Award and a 2016 R&D 100 award.

- A new instrument for ultrafast electron diffraction at SLAC National Accelerator Laboratory enables groundbreaking research on complex dynamic systems. Using this superfast high-resolution "electron camera," with a record shutter speed of 100 quadrillionths of a second, researchers have captured the world's fastest images of nitrogen molecules rotating in a gas.
- Physicists at the Advanced Photon Source (APS) developed an innovative horizontal-gap vertical-polarization undulator for the Linac Coherent Light Source-II (LCLS-II) project. The new undulator satisfies stringent LCLS-II requirements for control of the magnetic gap, through the use of specially designed springs that exactly match the gap dependence of the magnetic force. Instead of the conventional vertical gap, the horizontal gap generates vertically polarized x-rays to dramatically simplify the design and performance of downstream scientific instruments.

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 the barrier to improved energy efficiencies, longer lifetimes of infrastructure and devices, or the introduction of new energy technologies. The latest BESAC report on transformative opportunities for discovery science, coupled with the Basic Research Needs workshop reports on quantum materials and synthesis science, provide further documentation of the importance of materials sciences in forefront research for next generation scientific and technology 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. 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, 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.

- **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.

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 *in operando* conditions to analyze non-equilibrium materials, conditions, and excited-state phenomena.

In addition to single-investigator and small-group research, this subprogram supports Computational Materials Sciences and EFRCs. 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, initiated in FY 2015, 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. The EFRCs support teams of investigators to perform basic research to accelerate transformative scientific advances for the most challenging topics in materials sciences. The recompetition of the EFRC program scheduled for FY 2018 will focus on the transformative opportunities related to materials sciences identified in the recent BESAC report; the research priorities identified in the Basic Research Needs reports on quantum materials, synthesis science, and instrumentation science; and tackling the scientific challenges required to enable future generations of electrical energy storage and advanced energy generation identified in community-based Basic Research Needs reports.

The Batteries and Energy Storage Hub will receive no additional funding in FY 2018. The goal of this large, tightly integrated team and research was to provide the scientific understanding to enable the next generation of electrochemical energy storage for vehicles and the electrical grid, and its research will be completed at the end of its 5-year award period.

In addition, DOE funding for EPSCoR will be terminated in FY 2018. DOE will continue its long-standing support of energy research and development (R&D) in the regions targeted by the EPSCoR program that include states that are the home of national laboratories for national security and energy research.

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

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

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

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

A central focus of this research program is to characterize and understand materials whose properties are derived from the interactions of electrons in their structure, such as unconventional superconductors and magnetic materials. An emerging topic is "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 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 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.

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. In addition to research on chemical and physical synthesis processes, an important element of this portfolio is research to understand how to use bio-mimetic and bio-inspired approaches to design and synthesize novel materials with some of the unique properties found in nature, e.g., self-repair and adaptability to the changing environment. Major research directions include the controlled synthesis and assembly of nanoscale materials into functional materials with desired properties; porous materials with customized porosities and reactivities; mimicking the energy-efficient, low temperature synthesis approaches of biology to produce materials under mild conditions; bio-inspired materials that assemble autonomously and, in response to external stimuli, dynamically assemble and disassemble to form non-equilibrium structures; and adaptive and resilient materials that also possess self-repairing capabilities. The portfolio also supports fundamental research in solid state chemistry to enable discovery of new functional materials and the development of new crystal growth methods and thin film deposition techniques to create complex materials with targeted structure and properties. An important element of this activity is the development of real-time monitoring tools, *in situ* diagnostic techniques, and instrumentation that can provide information on 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.

Experimental Program to Stimulate Competitive Research (EPSCoR)

Historically, DOE has had an ancillary role in the EPSCoR program, a small program that funded activities across all of DOE to support basic and applied research in states and territories that have historically received lower levels of Federal research funding than others. EPSCoR programs have been supported by multiple federal agencies. Eligibility determination and principal financial investment for EPSCoR are led by the National Science Foundation (NSF) and the National Institutes of Health (NIH). The goal of the various agencies' EPSCoR activities is to support development of infrastructure and research capabilities to advance their ability to successfully compete for research funding through open research solicitations.

No funding is requested for the DOE EPSCoR program for FY 2018. Analysis of DOE funding shows that outside of the EPSCoR program, DOE is providing significant investments in several EPSCoR states, including through national laboratories for both energy and national security. Overall, the states identified as EPSCoR states (based on the NSF eligibility analysis) received approximately 33% of DOE's total funding. Of this funding, the EPSCoR program represents a small fraction, only 0.1%. In addition, the Request focuses BES investments in early stage research and reduces activities like EPSCoR that extend to later-stage or applied research.

Energy Frontier Research Centers (EFRCs)

The EFRC program, initiated in FY 2009, is a unique research modality, bringing together the skills and talents of teams of investigators to perform energy-relevant, basic research with a scope and complexity beyond what is possible in standard single-investigator or small-group awards. These multi-investigator, multi-disciplinary centers foster, encourage, and enable transformative scientific advances for the most challenging topics in materials sciences. The EFRCs supported in this subprogram have historically focused on: the design, discovery, synthesis, characterization, and understanding of novel, solid-state materials that convert energy into electricity; the understanding of materials and processes that are foundational for electrical energy storage, gas separation, and defect evolution in radiation environments; and the exploration of phenomena such as superconductivity and spintronics that can optimize energy flow and transmission. After seven years of research activity, the program has produced an impressive breadth of scientific accomplishments, including over 7,500 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, meetings of the EFRC researchers are held biennially.

The recompetition of the EFRC program in FY 2018 will focus on use of the team research modality to tackle the transformative opportunities related to materials sciences that have been identified in the recent BESAC report on transformative opportunities for discovery science and the research priorities identified in the Basic Research Needs reports on quantum materials, synthesis science, instrumentation science, and next-generation electrical energy storage.

Energy Innovation Hubs—Batteries and Energy Storage

Over the past four years, the Batteries and Energy Storage Energy Innovation Hub has focused on advancing the understanding of the fundamental electrochemistry and addressing the materials challenges required for advanced electrical energy storage solutions that are critical to the Nation for a reliable electrical grid and improved batteries for vehicles. The Joint Center for Energy Storage Research (JCESR) is led by Argonne National Laboratory (ANL) in collaboration with four other national laboratories, ten universities, and five industrial participants.

JCESR research activities have focused on the development of an atomic-level understanding of reaction pathways and development of universal design rules for electrolyte function for battery systems that go beyond lithium-ion with an emphasis on discovery of new energy storage chemistries. JCESR pioneered the use of technoeconomic modeling to provide a "cost" consideration in setting its fundamental research directions for next generation batteries. JCESR created a library of fundamental scientific knowledge of the phenomena and materials of energy storage at the atomic and molecular level and demonstrated a new paradigm for battery R&D—integrating discovery science, innovative architectures, computational methodologies, and research prototyping in a single highly interactive organization. JCESR research has significantly advanced new energy storage pathways 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 of the chemical and physical processes that must be controlled to protect the inventories of active materials in lithium-sulfur batteries and greatly improve cycle life; and computational screening of over 16,000 potential electrolyte compounds using the Electrolyte Genome protocols.

The Request focuses resources toward the highest priorities in early-stage fundamental research, with targeted reductions of activities that extend to later-stage fundamental research. JCESR will complete its last year of research in 2018 using funds appropriated in FY 2017; no additional funding is requested.

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 function and properties. The goal is to leap beyond simple extensions of current theory and models of materials towards a paradigm shift in which specialized computational codes and software enable the design, discovery, and development of new materials, and in turn, create new advanced, innovative technologies. Given the importance of materials to virtually all technologies, computational materials sciences are critical for United States 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 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.

BES launched 4-year research awards to perform computational materials research in FY 2015 (3 teams) and FY 2016 (2 additional teams), which focused on the creation of computational codes and associated experimental/computational databases for the design of functional materials. This research is performed by fully integrated teams, combining the skills of experts in materials theory, modeling, computation, synthesis, characterization, and processing/fabrication. The research includes development of new *ab initio* theory, mining the data from both experimental and theoretical databases, performing advanced *in situ/in operando* characterization to generate the specific parameters needed to validate computational models, and well-controlled synthesis to confirm the predictions of the codes. It uses the unique world leading tools and instruments at DOE's user facilities, from ultrafast free electron lasers to aberration-corrected electron microscopes and neutron and x-ray scattering and includes instrumentation for atomically controlled synthesis. The computational codes will advance the predictive capability for functional materials, use DOE's leadership class computational capabilities, and be positioned to take advantage of today's petascale and tomorrow's exascale leadership class computers. This research will result in publicly accessible databases of experimental/computational data and open source, robust, validated, user friendly software that captures the essential physics and chemistry of relevant materials systems. The ultimate goal is use of these codes/data by the broader research community and by industry to dramatically accelerate the design of new functional materials.

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

Activities and Explanation of Changes

FY 2016 Enacted	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
Materials Sciences and Engineering $370,130,000	**$306,637,000**	**-$63,493,000**
Scattering and Instrumentation Sciences Research $67,350,000	**$55,830,000**	**-$11,520,000**
Research emphasized the use of advanced characterization techniques to tackle forefront science on energy-relevant materials science phenomena. Ultrafast science continued to be a priority research area. Investments emphasized hypothesis-driven research with existing ultrafast science capabilities, including lab-based and x-ray free electron laser sources, to establish a more complete understanding of materials properties and behaviors. Neutron scattering sciences stressed innovative time-of-flight scattering and imaging and their effective use in transformational research. New advances in spectroscopy, high-resolution analyses of energy-relevant soft matter, and quantitative *in situ* analysis capabilities under perturbing parameters such as temperature, stress, chemical environment, and magnetic and electric fields were pursued. Research that uses traditional diffraction, imaging, and spectroscopy techniques continued at a reduced level.	Research will continue to support the development and use of the most advanced characterization tools and techniques to address forefront scientific challenges to understand materials and related phenomena, including ultrafast science and quantum materials. Quantitative *in situ* and *in operando* analysis capabilities under perturbing parameters such as temperature, stress, chemical environment, and magnetic and electric fields will be pursued. Investments in x-ray science will emphasize hypothesis driven research with x-ray free electron laser sources, tailored excitations with pumped laser control, and coherent x-ray imaging. Neutron scattering research will emphasize research on thermodynamics of charged polymer systems and emergent quantum phenomena at interfaces and in the bulk. Electron scattering research will focus on innovative and multimodal techniques to assess charge-orbital-spin coupling and quantum phenomena, ultrafast techniques, and high energy resolution imaging and spectroscopy.	Research will continue at the forefront of instrumentation and technique development for materials science research. This activity will emphasize ultrafast techniques in electron scattering, novel and emergent quantum materials phenomena especially with neutron scattering, and assessments of high-speed dynamic phenomena and non-equilibrium systems with x-ray scattering. Imaging and characterization have been identified as key requirements for transformative research by numerous workshop reports. However, the funding decrease requires reduction in program scope. 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.
Condensed Matter and Materials Physics Research $113,086,000	**$113,258,000**	**+$172**
The program continued to support fundamental experimental and theoretical research on the properties of materials. It focused on structural, optical, and electrical properties and control of material functionality in response to external stimuli including temperature, pressure, magnetic and electric fields, and radiation. Phenomena in materials	The program will continue to support fundamental experimental and theoretical research on the properties of materials. The experimental and theoretical condensed matter physics research will emphasize quantum materials, focusing on new and emergent behavior including quantum magnetism, spintronics, topological states, and novel 2D materials.	Research will continue at the leading edge of condensed matter and materials physics research to obtain a fundamental understanding of the phenomena that control the properties of materials. This activity will emphasize experimental and theoretic assessments of new and emerging quantum materials and fundamental aspects of physical and

FY 2016 Enacted	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
were investigated from atomistic through nanoscale to mesoscale length scales. The research supported continued to address defect structures in materials and how these influence materials properties, especially in energy relevant materials. There was an ongoing emphasis on understanding the relationship between electronic structure and properties in materials that exhibit correlation effects. Research on spin physics, focusing on coupling across heterogeneous boundaries through spin orbit and exchange interactions and studies involving novel magneto-dynamics, were continued. Research involving theory and computational data coupled to experimental characterization of material properties continued to grow. Research on superconducting vortex matter, isolated nanoparticles, quantum Hall behavior, and low dimensional phenomena in carbon nanotubes and graphene continued at a reduced level.	Advancement of theory and computational tools will focus on materials discovery, including data-driven and machine learning techniques; novel approaches, and non-equilibrium systems. Physical behavior research will emphasize innovative science to understand optical, thermal and electronic phenomena. For mechanical behavior and radiation effects, there will be increased focus on understanding defect evolution in radiation environments.	mechanical behavior, including radiation effects. Research in condensed matter physics, physical behavior, and mechanical behavior are major topics for fundamental energy research and have been identified as priorities in community workshops and National Academies studies. Increases for quantum materials and quantum information science will be offset by decreases in long-standing research challenges including heavy fermion superconductivity, Bose-Einstein condensates, compound semiconductor physics, cold atom physics, surface chemistry, shape memory and piezoelectric effects, and plasmonics.
Materials Discovery, Design, and Synthesis Research $70,273,000	**$64,621,000**	**-$5,652,000**
Research continued to focus on the predictive design and synthesis of materials across multiple length scales with a particular emphasis on the mesoscale, where functionalities begin to emerge. Within this framework, a fundamental understanding of assembly, both self and directed, and interfacial phenomena, ubiquitous in all materials, were developed. Additionally, synthesis pathways were better understood by use of *in situ* diagnostics and characterization so that they can be controlled more precisely and dynamically. This research helps realize the visionary goals of atom- and energy-efficient syntheses of new forms of matter. Research on recent energy materials on the scene, such as perovskite photovoltaic materials and those with 2D topologies, was strengthened to take advantage of the	Research to develop a scientific understanding for predictive design and synthesis of materials across multiple length scales will continue. Emphasis will be on innovative approaches, including use of *in situ* and *in operando* diagnostics, to understand the mechanisms of chemical, physical, and biomimetic synthesis of materials to enhance discovery of new and improved materials. Continued emphasis will be placed on research that incorporates both experiment and theory with the goal of advancing broad mechanistic insights. Fundamentals of growth kinetics, self-assembly, directed assembly, and the role of interfaces, including organic-in organic systems, will be stressed. In materials chemistry, fundamental research related to polymer chemistry, nanomaterial synthesis, liquids, electrochemistry, and	Pioneering scientific research to advance knowledge of how to make materials and use this understanding to discover new and improved materials will continue, emphasizing innovative research on kinetics and mechanisms for synthesis. Synthesis science and biomimetic research have been the focus of several National Academies studies as well as being identified as research required to enable transformative basic research advances. However, the funding decrease requires reduction in program scope. Topics to be deemphasized include control of synthesis to direct materials properties, molecular materials chemistry, and aspects of biocentric/biohybrid research approaches.

FY 2016 Enacted	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
opportunities to realize a more thorough understanding of these materials and their potential for bringing about transformational advances in energy and information technologies. Research on nanomaterials, traditional semiconductors, liquid crystals, and thin film transistor synthesis continued at a reduced level.	control of porosity will continue. For biomolecular materials, research on assembly of materials that incorporates error correction and defect management mechanisms for beyond equilibrium, multicomponent materials will be emphasized.	
Experimental Program to Stimulate Competitive Research (EPSCoR) $14,776,000	**$0**	**-$14,776,000**
Efforts continued to span science in support of the DOE mission, with continued emphasis on science that underpins DOE energy technology programs. Implementation grants, state-laboratory partnerships, and investment in early career research staff from EPSCoR states are sustained. Single investigator research that supports topics related to DOE mission areas, especially through the state-laboratory partnerships component of the program was emphasized.	Funding for EPSCoR is terminated in FY 2018. Research will continue on grants fully funded with EPSCoR funds from prior fiscal years.	No further funding is requested for the DOE EPSCoR program. Analysis of DOE funding shows that DOE provides significant investments in several EPSCoR states, including national laboratories for both energy research and national security. Overall, the EPSCoR states (based on the NSF eligibility analysis) received 33% of DOE funding. Of this funding, the DOE EPSCoR program represents a small fraction, only 0.1%. In addition, the Request focuses investments in early stage research and reduces activities like EPSCoR that extend to later-stage or applied research.
Energy Frontier Research Centers (EFRCs) $55,750,000	**$50,809,000**	**-$4,941,000**
The EFRCs continued to perform fundamental multi-disciplinary research aimed at accelerating scientific innovation. BES conducted a mid-term review of all EFRCs in FY 2016 to assess progress toward meeting scientific research goals. DOE issued a Funding Opportunity Announcement for up to five new EFRC awards in FY 2016.	The recompetition of the EFRC program in FY 2018 will focus on use of the team research modality to tackle the transformative opportunities related to materials sciences and the research priorities identified in the Basic Research Needs reports on quantum materials, synthesis science, instrumentation science, and next-generation electrical energy storage.	The EFRC program will continue to perform fundamental multi-disciplinary research aimed at accelerating scientific innovation. In order to address the priority research directions identified in recent community-based Basic Research Needs workshops and reports, topics to be deemphasized in the FY 2018 competition include phenomena related to traditional solar photovoltaic systems, thermoelectric materials, and solid state lighting.
Energy Innovation Hubs—Batteries and Energy Storage $24,137,000	**$0**	**-$24,137,000**
The Hub, in its fourth year, continued to follow its project plan with an increasing focus on developing lab-scale prototypes to supplement the ongoing fundamental research science underpinning batteries	No funding is requested for FY 2018. JCESR will continue research funded in FY 2017 to complete the five-year award. Its research activities will continue to focus on the development of an atomic-level	The Request focuses resources toward the highest priorities in early-stage fundamental research, with targeted reductions of activities that extend to later-stage fundamental research. The Batteries and Energy

FY 2016 Enacted	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
for transportation and the grid, as well as cross-cutting research on materials characterization, theory, and modeling. JCESR completed self-consistent system analyses using techno-economic modeling of three electrochemical couples identified through materials discovery, including output from the electrolyte genome, that have the potential to meet technical performance and cost criteria.	understanding of reaction pathways and development of universal design rules for electrolyte function for battery systems that go beyond lithium-ion with an emphasis on discovery of new energy storage chemistries.	Storage Hub, established in December 2012, will complete its last year of research in 2018; no additional funding is requested.
Computational Materials Sciences $12,000,000	**$10,927,000**	**-$1,073,000**
The computational materials sciences teams that started in FY 2015 performed the first year of research in FY 2016 as outlined in their proposals focused on basic science necessary to develop research-oriented, open-source, experimentally validated software and the associated databases required to predictively design materials with specific functionality; the software utilized current and future leadership class computers. Funding supported additional multi-year awards for research teams focused on functional materials topics not supported by the FY 2015 awards. Early in the award period, each team is peer reviewed to assess management and early research activities.	Research will continue on the computational materials sciences awards focused on basic science necessary to develop research-oriented, open-source, experimentally validated software and the associated databases required to predictively design materials with specific functionality. The software utilizes leadership class computers and incorporates frameworks that are suited for future exascale computer systems. The FY 2016 awards will have their mid-term review by a panel of external peer reviewers in FY 2018. The FY 2015 awards will adjust their research plans based on the mid-term reviews held in FY 2017.	Midterm reviews will be used to assess and focus the research being performed. Lower priority research tasks within each project, based on external peer review and assessment by BES, will be deemphasized to reduce FY 2018 budget requirements.

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, molecules and nanostructures.

- **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 several synergistic and cross-cutting fundamental research themes. *Ultrafast Science* 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, separations, 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 the charge transport and reactivity are coupled. *Catalytic Mechanisms* elucidates the factors controlling chemical transformations through an understanding of the sequence of reaction steps and the catalytic functionalities that control their rates in synthetic or natural catalysts, providing foundational knowledge for the discovery of novel catalytic pathways with unprecedented activity and selectivity. *Chemistry in Aqueous Environments* addresses the unique properties of water, particularly how they manifest in extreme environments such as confinement and complex solutions, 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 complex systems, are essential for advancing fundamental science.

In addition to single-investigator and small-group research, the subprogram supports EFRCs, which are multi-investigator, multidisciplinary research efforts focused on forefront scientific challenges that relate to the DOE energy mission. The EFRCs support teams of investigators to perform basic research to accelerate transformative scientific advances for the most challenging topics in chemical sciences, geosciences, and biosciences. The recompetition of the EFRC program scheduled for FY 2018 will focus on transformative opportunities related to chemical sciences, geosciences, and biosciences identified in recent BESAC reports as well as the research topics identified in community-based Basic Research Needs reports on synthesis science, instrumentation science, catalysis science, and the role of water in energy production and use.

The Request focuses resources toward the highest priorities in early-stage fundamental research, with targeted reductions of activities that extend to later-stage fundamental research. No funding is requested for the Fuels from Sunlight Energy Innovation Hub in FY 2018. This Hub was renewed in FY 2015 with research conducted by the large, tightly integrated team focused on providing fundamental scientific understanding to enable the next generation of technologies for direct conversion of sunlight to chemical fuels.

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 atomic, molecular, and nanoscale matter. 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 *Catalytic Mechanisms,* and to understand how the dynamics of molecular environments influence reactivity and transport that is important in the *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 *Chemical Mechanisms*, *Charge Transport and Reactivity, Chemistry at Complex Interfaces,* and *Ultrafast Sciences*. 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, molecules, and nanostructures with photons, particularly intense, ultrafast x-ray pulses, to characterize and control their behavior and provide the foundation for understanding the making and breaking of chemical bonds. The goal is to develop accurate quantum mechanical descriptions of ultrafast dynamical processes such as chemical bond breaking and forming, interactions in strong fields, and electron correlation. Novel attosecond sources are used to image the dynamics of electrons and charge transport. Chemical physics research builds from the AMO foundation by examining the reactive chemistry of molecules whose chemistry is profoundly affected by the environment, especially at complex interfaces. The transition from molecular-scale chemistry to collective phenomena is explored at a molecular level in condensed phase systems, such as the effects of solvation or interfaces on chemical structure and reactivity. The goal is to understand reactivity and dynamical processes in liquid systems and at complex interfaces using model systems. Understanding of such collective behavior is critical in a wide range of energy and environmental applications, from solar energy conversion to radiolytic effects in condensed phases and interfacial systems, to catalysis. Gas-phase chemical physics emphasizes experimental and theoretical studies of the ultrafast dynamics and rates of chemical reactions, as well as the chemical and physical properties of key intermediates relevant to catalysis. Computational and theoretical research supports the development and integration of new and existing theoretical and computational approaches for accurate and efficient descriptions of ultrafast processes relevant to catalysis and charge transport. 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.

Chemical Transformations Research

Fundamentally, Chemical Transformations Research emphasizes advancing the knowledge of chemical reactivity, matter transport, and chemical separation and stabilization processes that will ultimately impact fuel science, separations science, heavy element chemistry and geosciences. The research uses tools from *Ultrafast Sciences* 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 separations systems; and develops understanding of *Chemistry in Aqueous Environments* that play important roles in separations, particularly for heavy elements. This research breadth demands a broad coverage of scientific disciplines and analytical tools. Hence, Chemical Transformations comprise four core areas: Catalysis Science, Separations Science, Heavy Element Chemistry and Geosciences.

Catalytic Mechanisms represent a major fraction of the research in this activity, particularly focused on achieving predictability and control of catalytic conversions, which are dominated by correlated structural and electronic dynamics under reaction conditions. This chemistry encompasses interfacial dynamics of catalytic particles, transient or reactive interfacial species, multifunctional membranes, nanostructured electrodes, and multiphase electrolytes. This activity supports development and application of theoretical and computational approaches to achieve a deeper understanding of reaction and separation pathways and processes; design new catalysts, membranes or separation media; and predict transport and reaction processes in the Earth's subsurface. This activity contains the largest federally funded program in non-biological Catalysis Science.

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.

Fundamental studies of the structure and reactivity of actinide-containing molecules provide foundational knowledge for future nuclear energy approaches. 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. A breadth of approaches and unique tools, such as those in *Ultrafast Sciences*, are developed and used to investigate the structural and chemical dynamics of energy absorption, transfer, conversion and storage across multiple spatial and temporal scales to better understand *Charge Transport and Reactivity*. Such efforts target the basic understanding of mechanisms and dynamics of chemical processes such as water oxidation, charge transfer, and redox interconversion of small molecules (e.g. carbon dioxide/methane, nitrogen/ammonia, and protons/hydrogen). Crosscutting research underpins a fundamental understanding of the synthesis, dynamics, and function of natural and artificial membranes and nano- to mesoscale-structures and develops new knowledge of the *Chemistry at Complex Interfaces* as well as *Chemistry in Aqueous Environments*. Structural, functional and mechanistic properties of enzymes, enzyme systems, and energy-relevant biological reactions are studied to identify principles important for catalyst function, selectivity, and stability. This synergistic research in *Catalytic Mechanisms* is illustrated by studies of the mechanism of the complex water splitting reaction catalyzed by the metallocluster of the oxygen evolving complex in natural photosynthesis. The fundamental chemical and physical concepts resulting from studies of both natural systems (e.g. photosynthetic and affiliated downstream biological processes) and man-made chemical systems provide crucial foundational knowledge on processes of energy capture, conversion, and storage.

Studies of natural photosynthesis provide an understanding of the dynamic mechanisms of solar energy capture and conversion in biological systems, from the atomic scale through the mesoscale. Research efforts encompass light harvesting, electron and proton transport, and the assembly, repair, and regulation of photosynthetic complexes. Physical science tools are used extensively to elucidate the molecular and chemical mechanisms of biological energy transduction, including complex multielectron redox reactions and processes beyond primary photosynthesis such as carbon dioxide reduction and subsequent deposition of the reduced carbon into energy-dense carbohydrates and lipids. Complementary research on solar energy conversion in chemical and artificial systems incorporates organic and inorganic photochemistry, electrochemistry, light-driven energy and electron transfer processes, and molecular assemblies for electricity generation and artificial photosynthetic fuel production.

Energy Frontier Research Centers (EFRCs)

The EFRC program, initiated in FY 2009, is a unique research modality, bringing together the skills and talents of teams of investigators to perform energy-relevant, basic research with a scope and complexity beyond what is possible in standard single-investigator or small-group awards. These multi-investigator, multi-disciplinary centers foster, encourage, and accelerate basic research to enable transformative scientific advances for the most challenging topics in chemical sciences, geosciences, and biosciences. The EFRCs supported in this subprogram have historically focused on the following topics: the design, discovery, characterization, and control of the chemical, biochemical, and geological moieties and processes for the advanced conversion of solar energy into chemical fuels and for improved electrochemical storage of energy; the understanding of catalytic chemistry and biochemistry that are foundational for fuels, chemicals, and separations; and advanced interrogation and characterization of the earth's subsurface. After seven years of research activity, the program has produced an impressive breadth of accomplishments, including over 7,500 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, meetings of the EFRC researchers are held biennially.

The recompetition of the EFRC program in FY 2018 will focus on use of the team research modality to tackle the transformative opportunities related to chemical sciences, geosciences, and biosciences that have been identified in the recent BESAC report on transformative opportunities for discovery science and the research topics identified in Basic Research Needs reports on synthesis science, instrumentation science, and energy-water issues (e.g., the efficient use of water in energy production and energy-intensive industrial processes and the efficient use of energy in water production).

Energy Innovation Hubs—Fuels from Sunlight

Established in September 2010 and renewed in 2015, 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 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.

During the initial award, JCAP achieved the scientific and technical advances needed to reach its five-year goal to design and construct a photocatalytic prototype that could generate fuel from sunlight, developing a stable integrated prototype that split water to produce hydrogen at greater than 10% efficiency. Based on the outcome of external peer review, JCAP was renewed by BES for a final five-year award term starting on September 30, 2015, at an annual funding level of $15M. In the second award, JCAP is focusing on the fundamental science of carbon dioxide reduction to establish the foundation for production of hydrocarbon fuels using only sunlight, carbon dioxide, and water as inputs. Research objectives for the JCAP renewal project include discovery and understanding of highly selective catalytic mechanisms for carbon dioxide reduction and oxygen evolution; accelerated discovery of electrocatalytic and photoelectrocatalytic materials and light-absorber photoelectrodes for selective and efficient carbon dioxide reduction; and, using JCAP prototypes, demonstration of highly efficient and selective artificial photosynthetic carbon dioxide reduction and oxygen evolution components.

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

No funding is requested for JCAP in FY 2018. The Request focuses resources toward the highest priorities in early-stage fundamental research, with targeted reductions of activities that extend to later-stage fundamental research.

General Plant Projects (GPP)

GPP funding is provided for minor new construction, for other capital alterations and additions, and for improvements to land, buildings, and utility systems at the Ames Laboratory. Funding of this type is essential for maintaining the productivity and usefulness of Department-owned facilities and for meeting requirements for safe and reliable facilities operation. The total estimated cost of each GPP project will not exceed $10,000,000.

Activities and Explanation of Changes

FY 2016 Enacted	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
Chemical Sciences, Geosciences, and Biosciences $311,795,000	**$265,615,000**	**-$46,180,000**
Fundamental Interactions Research $72,782,000	**$61,187,000**	**-$11,595,000**
Research continued to develop and apply forefront ultrafast x-ray and optical probes of matter, utilizing the LCLS, BES synchrotron light sources, and table-top laser-based ultrafast light sources, to probe and control atomic, molecular, nanoscale and mesoscale matter. The program continued to develop advanced theoretical methods to guide and interpret ultrafast measurements and to design new experiments. It also continued to emphasize time-resolved electron and x-ray probes of matter at unprecedented short time scales and in systems of increasing complexity. Computational efforts stressed the development of improved methods to calculate electronically excited states in molecules and extended mesoscale systems. Work continued on advanced combustion research to accelerate the predictive simulation of highly efficient and clean internal combustion engines. Increased emphasis was on investigating properties of combustion in high-pressure or multiphase systems. The program deemphasized research at the interface of nanoscience with molecular physics.	This program will continue to develop and apply forefront ultrafast x-ray and optical probes of matter, utilizing the LCLS, BES synchrotron light sources, and table-top laser-based ultrafast light sources, to probe and control atomic, molecular, nanoscale and mesoscale matter. Attosecond light sources will be used to image the dynamics of electrons and charge transport in increasingly complex systems. The program continues to develop advanced theoretical methods to guide and interpret ultrafast measurements and catalysts such as metal-organic frameworks. Computational efforts stress the development of improved methods to calculate electronically excited states in molecules and extended mesoscale systems that can be scaled to operate on exascale computers. Research will extend efforts to understand and control chemical processes and dynamics in aqueous systems and at complex interfaces at a molecular level. Gas phase research will examine the structure and dynamics of reactive intermediates important to catalysis.	Research will continue leading efforts to discover the factors controlling chemical reactivity and dynamics in the gas phase, condensed phases and at interfaces, based upon fundamental knowledge of the interactions among photons, electrons, atoms, molecules and nanostructures. This activity will emphasize quantum chemistry, imaging studies of molecular dynamics using ultrafast BES light sources, research to understand increasingly complex interfacial systems, and advanced computational and theoretical tools for exascale computing. This activity is a major supporter of ultrafast chemical sciences and chemical physics, underpinning energy conversion and transformation phenomena. However, the funding decrease requires reduction in program scope. The activity will de-emphasize aspects of nanoscience and combustion research in favor of higher priorities.
Chemical Transformations Research $88,918,000	**$82,004,000**	**-$6,914,000**
Synthesis, guided by theory and computation, continued to explore novel catalytic materials at the nano- and mesoscale for the efficient conversion of traditional and new feedstocks into higher-value fuels and other chemicals. The program emphasized catalytic conversion of biomass to fuels and other energy related chemical products as well as the search for catalysts for new ammonia production routes that	This activity will continue to support predictive fundamental research on the design and synthesis of novel catalysts to efficiently convert chemical feedstocks, particularly small hydrocarbons (e.g., with 1-4 carbon atoms) and bio-derived molecules, to high-value fuels and chemicals. New routes to the efficient synthesis of hydrogen, ammonia, methanol, syngas, and others, will continue to be pursued. Fundamental	Research will continue to lead the development of fundamental knowledge of mechanisms of chemical catalysis, synthesis, separation, stabilization and transport required to control chemical processes in complex systems. This activity will emphasize advancing catalytic mechanisms that operate efficiently at lower temperatures and pressures, enhance efforts in electro-catalytic synthesis, and

FY 2016 Enacted	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
avoid the generation of greenhouse gases. To support these new emphases, the program deemphasized the development of mass spectrometric techniques. Likewise, coupled predictive theory and synthesis of designer mesoporous membranes and filter materials sought more efficient separation of carbon dioxide from power plant effluents or of oxygen from air relevant to oxycombustion approaches. Subsurface geochemistry and geophysics sought to provide data and mechanistic interpretation for models of reactive flow and transport important for carbon sequestration and extraction of tight gas and oil. Actinide research continued to emphasize new insights in actinides chemical bonding enabling new chemistry for separation and related nuclear fuels and waste form processes especially using ionic liquids. Fundamental research activities in geochemistry and geophysics of the subsurface continued in parallel with efforts in other offices as coordinated by the Subsurface Science, Technology and Engineering R&D (Subsurface) crosscut.	separations science research will continue on efficient processes for separating chemical mixtures. Operando characterization of chemical conversions and separations will continue to be supported, as will predictive theory for separation processes molecular recognition, transport and resolution. Geochemistry and geophysics will continue to develop mechanisms of reaction and transport processes of substances introduced to the subsurface environments. Heavy Element research will continue to pursue new chemistry of actinide reactivity, bonding, synthesis, and separation.	initiate studies of integrated catalytic-separation approaches. This activity is the major supporter of catalysis and heavy element chemistry that have been the focus of community workshops and National Academies studies. However, the funding decrease requires reduction in program scope. The activity will de-emphasize research on chiral catalysis and catalytic synthesis of nanomaterials, geophysics of microfluidics in natural porous system, and chemical analysis not aligned with separations science.
Photochemistry and Biochemistry Research **$69,113,000**	**$63,701,000**	**-$5,412,000**
Research continued to emphasize a fundamental understanding of light energy capture and conversion in non-biological and biological (photosynthetic) systems. These studies established a foundation for direct conversion of solar energy to electricity, fuels, and high value chemicals. The program continued to support efforts in computation and modeling as such approaches can facilitate design and fabrication of semiconductor/polymer interfaces, dye-sensitized solar cells, inorganic-organic molecular complexes, and bio-inspired/biohybrid light harvesting complexes. The program continued to emphasize research to understand the fundamental mechanisms of water-splitting, redox, cell wall biosynthesis, and	The program will continue to support fundamental research on light energy capture and conversion into chemical and electrical energy through non-biological (chemical) and biological (photosynthetic) pathways. Studies of light absorption, energy transfer, and charge transport and separation will continue to be emphasized. Research to uncover the fundamental mechanisms of photocatalysis and biocatalysis will continue to be a focus of the program and will make use of innovative ultrafast methodologies as well as computation and modeling. Enhanced efforts will target a fundamental understanding of reactivity across complex interfaces and in aqueous environments. Research will address a greater	Cutting-edge research will continue to develop fundamental knowledge and innovative approaches to understand physical and chemical processes of light energy capture and conversion in non-biological and biological systems. Research on charge transport, energy transfer, and catalytic mechanisms will be enhanced by increased efforts that address the chemistry of complex interfaces and water-driven processes. This activity is important for understanding chemical processes and dynamics during energy conversion and is viewed by community workshops as key for transformative science. However, the funding decrease requires reduction in program scope. Efforts in plant cell wall biosynthesis and structure, light

FY 2016 Enacted	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
other energy-relevant biological (enzymatic) reactions, from the nano- to the mesoscale. These studies provided new insights for developing novel bio-inspired catalysts based on earth-abundant materials and for controlling and optimizing chemical reactions important for energy capture, conversion, and storage. The program deemphasized research on fundamental mechanisms of carbon capture.	understanding of how water drives formation of mesoscale structures for energy capture and conversion in natural systems and the chemistry and structure of water within the field of highly ionizing radiation.	signaling in plant development, and combinatorial studies of catalytic semiconductors will be de-emphasized in favor of higher priorities.
Energy Frontier Research Centers (EFRCs) $54,250,000	**$48,065,000**	**-$6,185,000**
The EFRCs continued to perform fundamental multi-disciplinary research aimed at accelerating scientific innovation. BES conducted a mid-term review of all EFRCs in FY 2016 to assess progress toward meeting scientific research goals. DOE issued a Funding Opportunity Announcement for up to five new EFRC awards in FY 2016.	The recompetition of the EFRC program in FY 2018 will focus on use of the team research modality to tackle the transformative opportunities related to chemical sciences, geosciences and biosciences and the research priorities identified in the Basic Research Needs reports on synthesis science, instrumentation science, and energy-water issues.	The EFRC program will continue to perform fundamental multi-disciplinary research aimed at accelerating scientific innovation. In order to address the priority research directions identified in recent community-based Basic Research Needs workshops and reports, topics to be deemphasized in the FY 2018 competition include phenomena related to radioactive waste management, CO_2 sequestration, aspects of cellulosic degradation, and more mature areas of solar photovoltaics.
Energy Innovation Hubs—Fuels From Sunlight $15,000,000	**$0**	**-$15,000,000**
The Fuels from Sunlight Hub was renewed for a final award term of up to 5 years starting in September 2015. Research in the renewal focuses on the fundamental science needed to enable efficient, sustainable and scalable photochemical reduction of carbon dioxide for production of liquid transportation fuels. The renewal allows JCAP to further advance research efforts addressing critical needs in solar fuels development and to capitalize on its achievements and infrastructure development from the initial funding period. BES conducted scientific and merit review in FY 2016 to assess progress toward meeting project milestones and goals.	No funding is requested for FY 2018. JCAP will continue research funded in FY 2017. These activities will focus on the renewal project goal to conduct fundamental research for a mechanistic understanding of the photochemical reduction of carbon dioxide for fuel production.	The Request focuses resources toward the highest priorities in early-stage fundamental research, with targeted reductions of activities that extend to later-stage fundamental research. The Fuels from Sunlight Hub was established in December 2010 and renewed in FY 2015. No funding is requested in FY 2018.

FY 2016 Enacted	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
General Plant Projects $1,000,000	**$1,000,000**	**$0**
Funding supports minor facility improvements at Ames Laboratory.	Funding supports minor facility improvements at Ames Laboratory.	Funding is flat with the FY 2016 Enacted level.

Description

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

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

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

In FY 2016, the BES scientific facilities were used by more than 15,000 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, Advanced Photon Source (APS) at ANL, Stanford Synchrotron Radiation Lightsource (SSRL) at SLAC, and the newly constructed National Synchrotron Light Source-II (NSLS-II) at BNL. BES also provides funds to support facility operations, enable cutting-edge research and technical support, and to administer the user program at these facilities, which are made available to all researchers with access determined via peer review of user proposals.

High Flux Neutron Sources

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

- they have a wavelength similar to the spacing between atoms, allowing atomic resolution studies of structure, and have an energy similar to the elementary excitations of atoms and magnetic spins in materials, thus allowing an investigation of material dynamics;

- they have no charge, allowing deep penetration into a bulk material;

- they are scattered to a similar extent by both light and heavy atoms but differently by different isotopes of the same element, so that different chemical sites can be distinguished via isotope substitution experiments, for example in organic and biological materials;

- they have a magnetic moment, and thus can probe magnetism in condensed matter systems; and

- their scattering cross-section is precisely measurable on an absolute scale, facilitating straightforward comparison with theory and computer modeling.

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

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

Nanoscale Science Research Centers (NSRCs)

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

The NSRCs focus on interdisciplinary research at the nanoscale, serving as the basis for a national program that encompasses new science, new tools, and new computing capabilities. They are a different class of facility than the x-ray and neutron sources, as NSRCs are not based on a large accelerator or reactor but are comprised of a suite of smaller unique tools and expert scientific staff. The five NSRCs are the Center for Nanoscale Materials at ANL, Center for Functional Nanomaterials at BNL, Molecular Foundry at LBNL, Center for Nanophase Materials Sciences at ORNL, and 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.

Other Project Costs

The total project cost (TPC) of DOE's construction projects comprises 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; and 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. Generally, other project costs are incurred during the project's initiation and definition phase for planning, conceptual design, research, and development, and during the execution phase for R&D, startup, and commissioning. OPC is always funded via operating funds.

Major Items of Equipment

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

Research

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

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

Activities and Explanation of Changes

FY 2016 Enacted	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
Scientific User Facilities $966,775,000	**$780,148,000**	**-$186,627,000**
Synchrotron Radiation Light Sources $482,667,000	**$428,206,000**	**-$54,461,000**
Funding supported near optimal operations of the five BES light sources, including the first full year of operations for the newly constructed NSLS-II. $5M is for R&D in support of the Advanced Light Source Upgrade.	The FY 2018 Request prioritizes funding for four BES light sources (APS, ALS, NSLS-II, and LCLS). These facilities will reduce operating hours and user support, including shutting down selected beamlines. Maintenance, upgrades, and procurement activities will be deferred. SSRL will operate through the first quarter of the fiscal year, then the facility will transition to a warm standby status.	The funding decrease will support below optimal operations for four BES light sources. SSRL will operate for limited hours and then transition to a warm standby status. SSRL has the lowest user demand of the BES light sources in steady-state operations. No funding is requested for the Advanced Light Source Upgrade.
High-Flux Neutron Sources $265,082,000	**$225,620,000**	**-$39,462,000**
Funding supported the operation of HFIR and SNS at near optimal levels. Limited funding is included for the Lujan Neutron Scattering Center for the removal of hazardous materials and planning of the disposition of unused equipment. $10M is provided to accelerate the progress towards critical decision-1 for the Second Target Station at SNS.	The FY 2018 Request provides funding for HFIR and SNS. These facilities will reduce operating hours and user support, including shutting down selected flight paths. Maintenance, upgrades, and procurement activities will be deferred. No funding is requested to the Lujan Neutron Scattering Center for the disposition of unused equipment.	The funding decrease will support below optimal operations for HFIR and SNS. No funding is requested for the Lujan Neutron Scattering Center or for the Second Target Station at SNS.
Nanoscale Science Research Centers $120,575,000	**$71,135,000**	**-$49,440,000**
Funding supported operations at the NSRCs at near optimal levels. Program emphasis continued to cultivate and expand the user base from universities, national laboratories, and industry. Planning efforts continued to advance the cutting-edge nanostructure characterization capabilities, with an emphasis on coupling multi-probes of photon, neutron, and electron, and planning for future electron scattering needs that could address scientific roadblocks toward observing ultrafast chemical and physical phenomena at ultra-small size scales in different sample environments.	The Request provides funding for three BES Nanoscale Science Research Centers (CNM, CNMS, and TMF). These centers will reduce the number of scientific thrusts and core capabilities, and eliminate user support in selected areas. Maintenance and procurement activities will be deferred. No funding is requested for operations at CINT and CFN.	The funding decrease will support below optimal operations for three NSRCs. No funding is requested for operations at CINT and CFN.

FY 2016 Enacted	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
Other Project Costs $0	**$7,900,000**	**+$7,900,000**
No funds are requested for Other Project Costs.	Funds are requested for Other Project Costs for the LCLS-II project at SLAC National Accelerator Laboratory per the project plan.	Other Project Costs increases according to the LCLS-II project plan.
Major Items of Equipment $35,500,000	**$0**	**-$35,500,000**
The Advanced Photon Source-Upgrade (APS-U) project continued with planning and facility design, magnet prototyping, and R&D related to implementation of the multi-bend achromat lattice during FY 2016.	APS-U is transitioned from a Major Item of Equipment (MIE) to line item construction project. No MIE funds are requested for APS-U.	APS-U is included as a construction project in the FY 2018 Request.
The NSLS-II Experimental Tools (NEXT) project continued with the design, procurements, construction/fabrication, installation, testing and commissioning of equipment during FY 2016.	No funds are requested for NEXT in FY 2018.	FY 2016 was the last year of funding for NEXT per the project plan.
Research $31,853,000	**$19,724,000**	**-$12,129,000**
The research funding for the scientific user facilities continued to support selected, high-priority research activities. This funding supported activities to ensure that the scientific user facilities continue to demonstrate performance excellence, with focused efforts to address next generation facilities research needs. Emphasis is placed on detectors and optics instrumentation to allow full utilization of neutron and photon beams. Funding continued the long term surveillance and maintenance responsibilities at BNL and SLAC is included.	The FY 2018 Request will support limited high-priority research activities for detectors and optics instrumentation. No funding is requested for long term surveillance and maintenance at BNL and SLAC.	The funding decrease will support limited accelerator and detector research activities. No funding is requested for long term surveillance and maintenance.

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.

Critical Decision-3B (CD-3B), Approve Long Lead Procurements, was approved for the LCLS-II project on May 28, 2015, authorizing long lead and advanced procurements for key components of the cryoplant and the superconducting linac which were on the critical path for the project. The project received approval for CD-2, Approve Performance Baseline, and CD-3, Approve Start of Construction, on March 21, 2016, establishing a Total Project Cost (TPC) of $1,045,000,000 and a CD-4, Project Completion date of June 30, 2022.

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

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

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

Activities and Explanation of Changes

FY 2016 Enacted	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
Construction $200,300,000	**$202,100,000**	**+$1,800,000**
Linac Coherent Light Source-II (LCLS-II) $200,300,000	**$182,100,000**	**-$18,200,000**
The project continued with facility design, initiated critical long-lead procurements of technical materials and cryogenic systems, continued R&D and prototyping activities, and fabricated technical equipment.	FY 2018 funding will support the completion of the major cryomodule and undulator productions lines and the start of critical installation activities requiring the shutdown of the LCLS facility. Commissioning activities for some technical systems will begin in FY 2018. In addition, the design, long lead and advance procurements, R&D, prototyping, site preparation activities, fabrication, installation and testing activities continue until they have been completed.	Funding for the LCLS-II construction project will decrease in FY 2018 per the project plan.
Advanced Photon Source-Upgrade (APS-U) $0	**$20,000,000**	**+$20,000,000**
APS-U was included as a Major Item of Equipment project in FY 2016.	In FY 2018, APS-U will continue with R&D, engineering design, equipment prototyping, fabrication, and long lead and advance procurements. In November 2016, the APS-U project completed the prioritization of project beamlines needed to conduct cutting edge science with the upgraded source. Two of these 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. As a result, the FY 2018 Request proposes to convert the APS-U project into a line item construction project.	The project is converted to a line-item construction project in the FY 2018 Request; the increase is offset by a corresponding decrease in research, where the project was funded as an MIE. APS-U funding continues at the FY 2016 level, consistent with the approved project plan.

Basic Energy Sciences
Performance Measures

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

	FY 2016	FY 2017	FY 2018
Performance Goal (Measure)	**BES Construction/MIE Cost & Schedule - Cost-weighted mean percentage variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects**		
Target	< 10 %	< 10 %	< 10 %
Result	Met	TBD	TBD
Endpoint Target	Adhering to the cost and schedule baselines for a complex, large scale, science project is critical to meeting the scientific requirements for the project and for being good stewards of the taxpayers' investment in the project.		
Performance Goal (Measure)	**BES Energy Storage - Deliver two high-performance research energy storage prototypes for transportation and the grid that project at the battery pack level to be five times the energy density at 1/5 the cost of the 2011 commercial baseline.**		
Target	Complete self-consistent system analyses using techno-economic modeling of three electrochemical couples, identified through materials discovery including output from the electrolyte genome, that have the potential to meet technical performance and cost criteria.	Develop and demonstrate energy storage research prototypes that are scalable for transportation and grid applications using concepts beyond lithium ion (multivalent ions, chemical transformation, and non-aqueous redox flow), as identified through materials discovery and techno-economic modeling.	N/A
Result	Met	TBD	N/A
Endpoint Target	Three specific outcomes: 1) A library of the fundamental science of the materials and phenomena of energy storage at atomic and molecular levels; 2) two prototypes, one for transportation and one for the electricity grid, that, when scaled up to manufacturing, have the potential to meet the Joint Center for Energy Storage Research's (JCESR) 5-5-5 goals; 3) A new paradigm for battery R&D that integrates discovery science, battery design, research prototyping and manufacturing collaboration in a single highly interactive organization.		
Performance Goal (Measure)	**BES Facility Operations - Average achieved operation time of BES user facilities as a percentage of total scheduled annual operation time**		
Target	≥ 90 %	≥ 90 %	≥ 90 %
Result	Met	TBD	TBD
Endpoint Target	Many of the research projects that are undertaken at the Office of Science's scientific user facilities take a great deal of time, money, and effort to prepare and regularly have a very short window of opportunity to run. If the facility is not operating as expected the experiment could be ruined or critically setback. In addition, taxpayers have invested millions or even hundreds of millions of dollars in these facilities. The greater the period of reliable operations, the greater the return on the taxpayers' investment.		
Performance Goal (Measure)	**BES Research - Conduct discovery-focused research to increase our understanding of matter, materials and their properties**		

	FY 2016	FY 2017	FY 2018
Target	N/A	N/A	Expand computational materials and chemical discovery through increased data production and additional online computational resources: add elastic and electronic properties data for 5000 compounds and 5,000 reaction energies for catalytic reactions to publicly available databases; add new or expanded functionality to on-line, high performance computer software/codes for prediction of materials properties.
Result	N/A	N/A	TBD
Endpoint Target	Understand, predict, and ultimately control matter and energy at the electronic, atomic, and molecular levels		

Basic Energy Science
Capital Summary ($K)

	Total	Prior Years	FY 2016 Enacted	FY 2017 Annualized CR*[a]	FY 2018 Request	FY 2018 vs FY 2016
Capital Operating Expenses Summary						
Capital Equipment	n/a	n/a	86,475	-	21,500	-64,975
General Plant Projects (GPP)	n/a	n/a	11,000	-	1,000	-10,000
Accelerator Improvement Projects (AIP)	n/a	n/a	8,540	-	3,500	-5,040
Total, Capital Operating Expenses	**n/a**	**n/a**	**106,015**	**-**	**26,000**	**-80,015**
Capital Equipment						
Major Items of Equipment						
Advanced Photon Source Upgrade (APS-U), ANL (TPC TBD)	—	80,000	20,000	-	0	-20,000
Linac Coherent Light Source-II (LCLS-II), SLAC[b,c]	—	85,600	0	-	0	0
NSLS-II Experimental Tools (NEXT), BNL (TPC $90,000)	90,000	52,000	15,500	-	0	-15,500
Total, Major Items of Equipment	n/a	n/a	35,500	-	0	-35,500
Total, Non-MIE Capital Equipment	n/a	n/a	50,975	-	21,500	-29,475
Total, Capital equipment	**n/a**	**n/a**	**86,475**	**-**	**21,500**	**-64,975**
General Plant Projects (GPP)						
Other general plant projects under $5 million TEC	n/a	n/a	11,000	-	1,000	-10,000
Accelerator Improvement Projects (AIP)						
Accelerator improvement projects under $5 million TEC	n/a	n/a	8,540	-	3,500	-5,040

[a]FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above, below that level, a dash (-) is shown.
[b] LCLS-II is requested as a line item construction project beginning in FY 2014.
[c] LCLS-II received $85,600,000 in FY 2010–FY 2013 as an MIE.

Construction Projects Summary ($K)

	Total	Prior Years	FY 2016 Enacted	FY 2017 Enacted	FY 2018 Request	FY 2018 vs FY 2016
13-SC-10, Linac Coherent Light Source-II (LCLS-II), SLAC						
TEC	993,100	142,700	200,300	190,000	182,100	-18,200
OPC	51,900	28,600	0	-	7,900	+7,900
TPC	**1,045,000**	**171,300**[a]	**200,300**	**190,000**	**190,000**	**-10,300**
18-SC-10, Advanced Photon Source Upgrade (APS-U), ANL						
TEC	—	0	0	0	20,000	+20,000
OPC	—	0	0	0	0	0
TPC	**770,000**	**0**	**0**	**0**	**20,000**	**+20,000**
Total, Construction						
TEC	n/a	n/a	200,300	190,000	202,100	+1,800
OPC	n/a	n/a	0	0	7,900	+7,900
TPC	**n/a**	**n/a**	**200,300**	**190,000**	**210,000**	**+9,700**

Funding Summary ($K)

	FY 2016 Enacted	FY 2017 Annualized CR[b]	FY 2018 Request	FY 2018 vs FY 2016
Research	689,288	-	570,126	-119,162
Scientific User Facilities Operations	868,324	-	732,861	-135,463
Major Items of Equipment	35,500	-	0	-35,500
Construction Projects (includes OPC)	200,300	-	202,100	+1,800
Other[c]	55,588	-	49,413	-6,175
Total, Basic Energy Sciences	**1,849,000**	**1,845,485**	**1,554,500**	**-294,500**

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

[b] FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above, below that level, a dash (-) is shown.

[c] Includes SBIR/STTR funding and non-Facility related GPP.

Scientific User Facility Operations ($K)

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

Definitions:

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

Planned Operating Hours –

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

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

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

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

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

	FY 2016 Enacted	FY 2017 Annualized CR*	FY 2018 Request	FY 2018 vs FY 2016
TYPE A FACILITIES				
Advanced Light Source	**$68,240**	-	**$59,010**	**-$9,230**
Number of Users	2,317	-	2,000	-317
Achieved operating hours	5,017	-	N/A	N/A
Planned operating hours	4,550	-	4,500	-50
Optimal hours	5,300	-	5,300	0
Percent optimal hours	94.7%	-	84.9%	N/A
Unscheduled downtime hours	<10%	-	<10%	N/A

* FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above, below that level, a dash (-) is shown.

	FY 2016 Enacted	FY 2017 Annualized CR*	FY 2018 Request	FY 2018 vs FY 2016
Advanced Photon Source	**$130,670**	**-**	**$122,075**	**-$8,595**
Number of Users	5,521	-	4,800	-721
Achieved operating hours	4,934	-	N/A	N/A
Planned operating hours	5,000	-	4,300	-700
Optimal hours	5,000	-	5,000	0
Percent optimal hours	98.7%	-	86.0%	N/A
Unscheduled downtime hours	<10%	-	<10%	N/A
National Synchrotron Light Source-II, BNL	**$110,000**	**-**	**$102,952**	**-$7,048**
Number of Users	477	-	800	+323
Achieved operating hours	3,446	-	N/A	N/A
Planned operating hours	3,740	-	4,300	+560
Optimal hours	3,300	-	5,000[a]	+1,700
Percent optimal hours	104.4%	-	86.0%	N/A
Unscheduled downtime hours	N/A	-	<10%	N/A
Stanford Synchrotron Radiation Lightsource	**$41,088**	**-**	**$20,000**	**-$21,088**
Number of Users	1,641	-	400	-1,241
Achieved operating hours	4,892	-	N/A	N/A
Planned operating hours	5,000	-	1,300	-3,700
Optimal hours	5,400	-	5,400	0
Percent optimal hours	90.6%	-	24.1%	N/A
Unscheduled downtime hours	<10%	-	<10%	N/A

[a] Optimal hours increased as the facility is in a ramp up phase.

	FY 2016 Enacted	FY 2017 Annualized CR*	FY 2018 Request	FY 2018 vs FY 2016
Linac Coherent Light Source	**$132,669**	**-**	**$124,169**	**-$8,500**
Number of Users	1,062	-	850	-212
Achieved operating hours	5,277	-	N/A	N/A
Planned operating hours	5,500	-	4,300	-1,200
Optimal hours	5,500	-	5,000	-500
Percent optimal hours	95.9%	-	86.0%	N/A
Unscheduled downtime hours	<10%	-	<10%	N/A
High Flux Isotope Reactor	**$63,419**	**-**	**$56,773**	**-$6,646**
Number of Users	450	-	370	-80
Achieved operating hours	4,076	-	N/A	N/A
Planned operating hours	3,700	-	3,100	-600
Optimal hours	3,700	-	3,700	0
Percent optimal hours	110.2%	-	83.8%	N/A
Unscheduled downtime hours	<10%	-	<10%	N/A
Lujan Neutron Scattering Center	**$3,000**	**-**	**$0**	**-$3,000**
Achieved operating hours	N/A	-	N/A	N/A
Planned operating hours	0	-	0	0
Optimal hours	0	-	0	0
Percent optimal hours	N/A	-	N/A	N/A
Unscheduled downtime hours	N/A	-	N/A	N/A
Spallation Neutron Source	**$198,663**	**-**	**$168,847**	**-$29,816**
Number of Users	893	-	650	-243
Achieved operating hours	4,972	-	N/A	N/A
Planned operating hours	4,700	-	3,700	-1,000
Optimal hours	4,700	-	4,500[a]	-200
Percent optimal hours	105.8%	-	82.2%	N/A
Unscheduled downtime hours	<10%	-	<10%	N/A

[a] Optimal hours decreased for scheduled maintenance.

	FY 2016 Enacted	FY 2017 Annualized CR*	FY 2018 Request	FY 2018 vs FY 2016
TYPE B FACILITIES				
Center for Nanoscale Materials	**$24,877**	**-**	**$22,913**	**-$1,964**
Number of users	566	-	400	-166
Center for Functional Nanomaterials	**$21,344**	**-**	**$0**	**-$21,344**
Number of users	505	-	0	-505
Molecular Foundry	**$28,017**	**-**	**$25,823**	**-$2,194**
Number of users	774	-	500	-274
Center for Nanophase Materials Sciences	**$24,232**	**-**	**$22,399**	**-$1,833**
Number of users	601	-	400	-201
Center for Integrated Nanotechnologies	**$22,105**	**-**	**$0**	**-$22,105**
Number of users	574	-	0	-574
Total, All Facilities	**$868,324**	**-**	**$724,961**	**-$143,363**
Number of Users	15,381	-	11,170	-4,211
Achieved operating hours	32,614	-	N/A	N/A
Planned operating hours	32,190	-	25,500	-6,690
Optimal hours	32,900	-	33,900	+1,000
Percent of optimal hours	101.1%	-	82.8%	N/A
Unscheduled downtime hours	<10%	-	<10%	N/A

Scientific Employment

	FY 2016 Enacted	FY 2017 Annualized CR[a]	FY 2018 Estimate	FY 2018 vs FY 2016
Number of permanent Ph.D.'s (FTEs)	4,330	-	3,730	-600
Number of postdoctoral associates (FTEs)	1,120	-	1,020	-100
Number of graduate students (FTEs)	1,660	-	1,580	-80
Other[b]	2,900	-	2,360	-540

[a]FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above, below that level, a dash (-) is shown.
[b]Includes technicians, support staff, and similar positions.

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

1. Significant Changes and Summary

Significant Changes

This Construction Project Data Sheet (CPDS) is an update of the FY 2017 CPDS and does not include a new start for the budget year.

The FY 2018 Request for the Linac Coherent Light Source-II (LCLS-II) is $182,100,000. In March 2016, the project received approval of CD-2, Approve Performance Baseline and CD-3, Approve Start of Construction. The total project cost (TPC) is $1,045,000,000 and CD-4 is June 2022.

Summary

The most recent DOE 413.3B approved Critical Decisions (CD) are CD-2/3, (Approve Performance Baseline and Approve Start of Construction) that were approved on March 21, 2016.

A Federal Project Director has been assigned to this project and has approved this CPDS.

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

FY 2016 funding continued activities for design, long lead and advance procurements (LLP/APs), R&D, prototyping, site preparation activities (which includes the removal of original linac equipment), fabrication, installation, and construction activities after CD-2/CD-3 approval. FY 2017 funding is critical for the procurement of materials and equipment needed to maintain the project schedule and expand the construction efforts. Design, LLP/APs, R&D, prototyping, site preparation activities, fabrication, and installation also continue in FY 2017. FY 2018 funding will support the completion of the major cryomodule and undulator production lines and the start of critical installation activities requiring the shutdown of the LCLS facility. Commissioning activities for some technical systems will begin in FY 2018. In addition, the design, LLP/APs, R&D, prototyping, site preparation activities, fabrication, installation, and testing activities from FY 2017 will carry forward into FY 2018 and beyond until they have been completed.

2. Critical Milestone History

(fiscal quarter or date)

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

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

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

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

3. Project Cost History

(dollars in thousands)

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

4. Project Scope and Justification

Scope

The SLAC National Accelerator Laboratory's (SLAC) advances in the creation, compression, transport, and monitoring of bright electron beams have spawned a new generation of x-ray radiation sources based on linear accelerators rather than on storage rings. The Linac Coherent Light Source (LCLS) produces a high-brightness x-ray beam with properties vastly exceeding those of current x-ray sources in three key areas: peak brightness, coherence, and ultrashort pulses. The peak brightness of the LCLS is 10 billion times greater than current synchrotrons, providing up to 10^{12} x-ray photons in a pulse with duration in the range of 3–500 femtoseconds. These characteristics of the LCLS have opened new realms of research in the chemical, material, and biological sciences. LCLS-II will build on the success of LCLS by expanding the spectral range of hard x-rays produced at the facility by adding a new high repetition rate, spectrally tunable x-ray source. The repetition rate for x-ray production in the 0.2–5 keV range will be increased by at least a factor of 1,000 to yield unprecedented high average brightness x-rays that will be unique worldwide.

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

LCLS is based on the existing SLAC linear accelerator (linac), which is not a superconducting linac. The linac was originally designed to accelerate electrons and positrons to 50 GeV for colliding beam experiments and for nuclear and high energy physics experiments on fixed targets. It was later adapted for use as a free electron laser (FEL, the LCLS facility) and for advanced accelerator research. At present, the last third of the 3 kilometer linac is being used to operate the LCLS facility, and the first 2 kilometers are used for advanced accelerator research.

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

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

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

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

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

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

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

Justification

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

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

The project is being conducted in accordance with the project management requirements in DOE 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. If project performance is sustained and funds are available, the project will strive to attain the Objective KPPs.

Preliminary LCLS-II Key Performance Parameters

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

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

5. Preliminary Financial Schedule

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
Total Estimated Cost (TEC)			
Design phase			
MIE funding			
FY 2012	2,000	2,000	2,000
FY 2013[b]	5,000	5,000	5,000
Total, MIE funding	7,000	7,000	7,000
Line item construction funding			
FY 2014	4,000	4,000	2,040
FY 2015	21,000	21,000	9,089
FY 2016	15,000	15,000	20,500
FY 2017	0	0	8,371
Total, Line item construction funding	40,000	40,000	40,000
Total, Design phase	47,000	47,000	47,000
Construction phase			
MIE funding			
FY 2012	42,500[c]	20,000	13,862
FY 2013[c]	17,500	40,000	33,423
FY 2014	0	0	12,256
FY 2015	0	0	455
FY 2016	0	0	0
FY 2017	0	0	4
Total, MIE funding	60,000	60,000	60,000
Line item construction funding			
FY 2014	71,700	71,700	16,673
FY 2015	117,700	117,700	65,442
FY 2016	185,300	185,300	125,476
FY 2017	190,000	190,000	312,079
FY 2018	182,100	182,100	221,374
FY 2019	139,300	139,300	139,600
FY 2020	0	0	5,456
Total, Line item construction funding	886,100	886,100	886,100
Total, Construction phase	946,100	946,100	946,100

[a] Costs through FY 2016 reflect actual costs; costs for FY 2017 and the outyears are estimates. The split between design costs and construction costs were updated for FY 2014 and FY 2015.

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

[c] FY 2012 funding shown includes $22,500,000 of prior year balances from FY 2012 that was reallocated to the LCLS-II project during FY 2013.

[b] Costs through FY 2016 reflect actual costs; costs for FY 2017 and the outyears are estimates. The split between design costs and construction costs were updated for FY 2014 and FY 2015.

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

[d] Amounts shown include MIE funding of $67,000,000 in the TEC, $18,600,000 in the OPC, and $85,600,000 in the TPC.

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
TEC			
MIE funding			
FY 2012	44,500[a]	22,000	15,862
FY 2013 [c]	22,500	45,000	38,423
FY 2014	0	0	12,256
FY 2015	0	0	455
FY 2016	0	0	0
FY 2017	0	0	4
Total, MIE funding	67,000	67,000	67,000
Line item construction funding			
FY 2014	75,700	75,700	18,713
FY 2015	138,700	138,700	74,531
FY 2016	200,300	200,300	145,976
FY 2017	190,000	190,000	320,450
FY 2018	182,100	182,100	221,374
FY 2019	139,300	139,300	139,600
FY 2020	0	0	5,456
Total, Line item construction funding	926,100	926,100	926,100
Total, TEC[d]	993,100	993,100	993,100
Other Project Cost (OPC)			
OPC except D&D			
MIE funding			
FY 2010	1,126	1,126	938
FY 2011	9,474	9,474	8,033
FY 2012	8,000	8,000	8,893
FY 2013[a]	0	0	116
FY 2014	0	0	439
FY 2015	0	0	10
FY 2016	0	0	0
FY 2017	0	0	171
Total, MIE funding	18,600	18,600	18,600
Line item construction funding			
FY 2014	10,000	10,000	8,142
FY 2015	9,300	9,300	2,650
FY 2016	0	0	34
FY 2017	0	0	2,000
FY 2018	7,900	7,900	10,000
FY 2019	6,100	6,100	9,966
FY 2020	0	0	508
Total, Line item construction funding	33,300	33,300	33,300
Total, OPC	51,900	51,900	51,900

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

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
Total Project Cost (TPC)			
MIE funding			
FY 2010	1,126	1,126	938
FY 2011	9,474	9,474	8,033
FY 2012	52,500[c]	30,000	24,755
FY 2013[a]	22,500	45,000	38,539
FY 2014	0	0	12,695
FY 2015	0	0	465
FY 2016	0	0	0
FY 2017	0	0	175
Total, MIE funding	85,600	85,600	85,600
Line item construction funding			
FY 2014	85,700	85,700	26,855
FY 2015	148,000	148,000	77,181
FY 2016	200,300	200,300	146,010
FY 2017	190,000	190,000	322,450
FY 2018	190,000	190,000	231,374
FY 2019	145,400	145,400	149,566
FY 2020	0	0	5,964
Total, Line item construction funding	959,400	959,400	959,400
Total, TPC[d]	1,045,000	1,045,000	1,045,000

6. Details of Project Cost Estimate

	(dollars in thousands)		
	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	42,400	40,750	42,125
Contingency	4,600	6,250	4,875
Total, Design	47,000	47,000	47,000
Construction			
Site Preparation	24,700	24,700	24,700
Equipment	692,742	672,900	678,205
Other Construction	58,500	58,500	58,500
Contingency	170,158	190,000	184,695
Total, Construction	946,100	946,100	946,100
Total, TEC[b]	993,100	993,100	993,100
Contingency, TEC	174,758	196,250	189,570
Other Project Cost (OPC)			
OPC except D&D			

[b] Costs through FY 2016 reflect actual costs; costs for FY 2017 and the outyears are estimates. The split between design costs and construction costs were updated for FY 2014 and FY 2015.
[c] FY 2012 funding shown includes $22,500,000 of prior year balances from FY 2012 that was reallocated to the LCLS-II project during FY 2013.
[d] Costs through FY 2016 reflect actual costs; costs for FY 2017 and the outyears are estimates.
[b] Amounts shown include MIE funding of $67,000,000 in the TEC, $18,600,000 in the OPC, and $85,600,000 in the TPC.

	(dollars in thousands)		
	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Conceptual Planning	1,980	1,980	1,980
Conceptual Design	23,408	23,408	23,408
Research and Development	1,972	1,972	1,972
Start-Up	15,790	15,790	15,790
Contingency	8,750	8,750	8,750
Total, OPC	51,900	51,900	51,900
Contingency, OPC	8,750	8,750	8,750
Total, TPC[b]	1,045,000	1,045,000	1,045,000
Total, Contingency	183,508	205,000	198,320

7. Schedule of Appropriations Requests

(dollars in thousands)

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

8. Related Operations and Maintenance Funding Requirements

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

(Related Funding Requirements)

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

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

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

9. D&D Information

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

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

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

10. Acquisition Approach

DOE has determined that the LCLS-II 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 project has been completed and will be revised based on the new technical parameters. Key design activities, requirements, and high-risk subsystem components will be identified to reduce cost and schedule risk to the project and expedite the startup. The necessary project management systems are fully up-to-date, operating, and are maintained as a SLAC-wide resource.

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

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

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

18-SC-10, Advanced Photon Source-Upgrade
Argonne National Laboratory, Argonne, Illinois
Project Data Sheet is for PED/Construction

1. Significant Changes and Summary

Significant Changes
This is the first project data sheet submitted for the Advanced Photon Source-Upgrade (APS-U) as a line item construction project. APS-U was first proposed as a Major Item of Equipment (MIE) project in the FY 2012 President's Budget Request. In November 2016, the APS-U project completed the prioritization of project beamlines needed to conduct cutting edge science with the upgraded source. Two of these 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. As a result, the FY 2018 Request proposes to convert the APS-U MIE project into a line item construction project.
Summary

The most recent DOE O 413.3B approved Critical Decision, CD-3B (Approve Long-Lead Procurements), was approved on October 6, 2016. The project has a preliminary Total Project Cost (TPC) range of $700,000,000-$1,000,000,000 and TPC point estimate of $770,000,000. The proposed CD-4, Approve Project Completion, is FY 2026.

A Federal Project Director has been assigned to this project and is certified to level IV.

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

In FY 2016, APS-U continued activities associated with research and development (R&D), engineering design, equipment prototyping, and equipment fabrication in preparation for long lead procurements. In FY 2017, APS-U continues with R&D, engineering design, pre-production prototyping, fabrication, and long lead and advance procurements (LLP/APs) of critical systems. In FY 2018, APS-U continues with R&D, engineering design, equipment prototyping, fabrication, and LLP/APs.

2. Critical Milestone History

(fiscal quarter or date)

	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2018[a]	4/22/2010	9/18/2015	2/04/2016	1Q FY 2019	2Q FY 2020	4Q FY 2019	N/A	1Q FY 2026

CD-0 – Approve Mission Need for a construction project with a conceptual scope and cost range
Conceptual Design Complete – Actual date the conceptual design was completed (if applicable)
CD-1 – Approve Design Scope and Project Cost and Schedule Ranges
CD-2 – Approve Project Performance Baseline
Final Design Complete – Estimated/Actual date the project design will be/was complete(d)
CD-3 – Approve Start of Construction

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

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

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

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

3. Project Cost History

(dollars in thousands)

	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D	OPC, D&D	OPC, Total	TPC
FY 2018[a]	141,015	577,985	719,000	51,000	N/A	51,000	770,000

4. Project Scope and Justification

Scope

There is a growing need to study materials under real conditions in real time through the use of groundbreaking scientific techniques. These techniques must provide the capability to observe, understand, and ultimately control the functions of materials down to the nanoscale and beyond with atomic resolution. To sustain U.S. leadership in this technology frontier, 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 on the existing APS facility at Argonne National Laboratory (ANL), for significantly less than the replacement cost of APS, the APS-U will provide a world-leading hard x-ray synchrotron radiation facility, which will be a unique asset in the U.S. portfolio of scientific user facilities. The APS-U is a critical and cost effective next step in the photon science strategy that will keep the U.S. at the forefront of scientific research, combining with other facilities to give the U.S. a complementary set of storage ring and free-electron laser x-ray light sources.

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

The APS-U project includes a new storage ring incorporating a multi-bend achromat (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 radio frequency (RF) systems. The MBA lattice will provide 100-1000 times increased brightness and coherent flux. The project will construct new beamlines and incorporate substantial refurbishment of existing beamlines, along with new optics and detectors that will enable the beamlines to take advantage of the improved accelerator performance. Two best-in-class beamlines require conventional civil construction to extend the beamlines beyond the existing APS Experimental Hall to achieve the desired nano-focused beam spot size.

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

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

Justification

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

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

The APS-U will upgrade the APS by replacing the existing 20 year old storage ring with a multi-bend achromat (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 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 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 strive to 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 Project Performance Baseline.

Preliminary APS-U Key Performance Parameters

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

Performance Measure	Threshold	Objective

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

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

5. Preliminary Financial Schedule

	(dollars in thousands)		
	Appropriations	Obligations	Costs
Total Estimated Cost (TEC)			
Design phase			
MIE funding			
FY 2012	19,200	19,200	8,679
FY 2013	15,000	15,000	17,825
FY 2014	17,015	17,015	13,122
FY 2015	20,000	20,000	19,678
FY 2016	20,000	20,000	22,529
FY 2017	30,000	30,000	27,000
FY 2018	0	0	11,000
FY 2019	0	0	1,382
Total, MIE funding	121,215	121,215	121,215
Line item construction funding			
FY 2018	9,300	9,300	8,500
FY 2019	23,000	23,000	22,500
FY 2020	3,500	3,500	3,000
FY 2021	0	0	1,400
FY 2022	0	0	400
Total, Line item construction funding	35,800	35,800	35,800
Total, Design phase	157,015	157,015	157,015
Construction phase			
MIE funding			
FY 2012	800	800	416
FY 2013	5,000	5,000	3,391
FY 2014	2,985	2,985	4,301
FY 2015	0	0	677
FY 2016	0	0	0
FY 2017	12,500	12,500	11,800
FY 2018	0	0	700
Total, MIE funding	14,785	14,785	14,785
Line item construction funding			
FY 2018	10,700	10,700	9,500
FY 2019	68,691	68,691	65,000
FY 2020	161,500	161,500	153,000
FY 2021	160,000	160,000	151,000
FY 2022	82,500	82,500	80,000
FY 2023	79,809	79,809	74,000
FY 2024	0	0	24,000
FY 2025	0	0	6,700
Total, Line item construction funding	563,200	563,200	563,200
Total, Construction phase	577,985	577,985	577,985

	(dollars in thousands)		
	Appropriations	Obligations	Costs
TEC			
MIE funding			
FY 2012	20,000	20,000	9,095
FY 2013	20,000	20,000	21,216
FY 2014	20,000	20,000	17,423
FY 2015	20,000	20,000	20,355
FY 2016	20,000	20,000	22,529
FY 2017	20,000	20,000	23,300
FY 2018	0	0	4,700
FY 2019	0	0	1,382
Total, MIE funding	120,000	120,000	120,000
Line item construction funding			
FY 2018	20,000	20,000	18,000
FY 2019	91,691	91,691	87,500
FY 2020	165,000	165,000	156,000
FY 2021	160,000	160,000	152,400
FY 2022	82,500	82,500	80,400
FY 2023	79,809	79,809	74,000
FY 2024	0	0	24,000
FY 2025	0	0	6,700
Total, Line item construction funding	599,000	599,000	599,000
Total, TEC	719,000	719,000	719,000
Other Project Cost (OPC)			
OPC except D&D			
MIE funding			
FY 2010	1,000	1,000	587
FY 2011	7,500	7,500	3,696
FY 2012	0	0	4,217
Total MIE funding	8,500	8,500	8,500
Line item construction funding			
FY 2021	5,000	5,000	4,500
FY 2022	27,500	27,500	26,500
FY 2023	10,000	10,000	9,400
FY 2024	0	0	1,700
FY 2025	0	0	400
Total, Line item construction funding	42,500	42,500	42,500
Total, OPC	51,000	51,000	51,000

	(dollars in thousands)		
	Appropriations	Obligations	Costs
Total Project Cost (TPC)			
MIE funding			
FY 2010	1,000	1,000	587
FY 2011	7,500	7,500	3,696
FY 2012	20,000	20,000	13,312
FY 2013	20,000	20,000	21,216
FY 2014	20,000	20,000	17,423
FY 2015	20,000	20,000	20,355
FY 2016	20,000	20,000	22,529
FY 2017	20,000	20,000	23,300
FY 2018	0	0	4,700
FY 2019	0	0	1,382
Total, MIE funding	128,500	128,500	128,500
Line item construction funding			
FY 2018	20,000	20,000	18,000
FY 2019	91,691	91,691	87,500
FY 2020	165,000	165,000	156,000
FY 2021	165,000	165,000	156,900
FY 2022	110,000	110,000	106,900
FY 2023	89,809	89,809	83,400
FY 2024	0	0	25,700
FY 2025	0	0	7,100
Total, Line item construction funding	641,500	641,500	641,500
Total, TPC	770,000	770,000	770,000

6. Details of Project Cost Estimate

	(dollars in thousands)		
	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	135,375	N/A	N/A
Contingency	5,640	N/A	N/A
Total, Design	141,015	N/A	N/A
Construction			
Equipment	411,625	N/A	N/A
Other Construction	12,700	N/A	N/A
Contingency	153,660	N/A	N/A
Total, Construction	577,985	N/A	N/A
Total, TEC	719,000	N/A	N/A
Contingency, TEC	159,300	N/A	N/A
Other Project Cost (OPC)			
OPC except D&D			
Conceptual Planning	1,000	N/A	N/A
Conceptual Design	7,500	N/A	N/A
Start-Up	31,800	N/A	N/A
Contingency	10,700	N/A	N/A
Total, OPC	51,000	N/A	N/A

	(dollars in thousands)		
	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Contingency, OPC	10,700	N/A	N/A
Total, TPC	770,000	N/A	N/A
Total, Contingency	170,000	N/A	N/A

7. Schedule of Appropriations Requests

(dollars in thousands)

Request		Prior Years	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	Outyears	Total
FY 2018[a]	TEC	80,000	20,000	20,000	20,000	91,691	165,000	160,000	162,309	719,000
	OPC	8,500	0	0	0	0	0	5,000	37,500	51,000
	TPC	88,500	20,000	20,000	20,000	91,691	165,000	165,000	199,809	770,000

8. 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)	25
Expected Future Start of D&D of this capital asset (fiscal quarter)	1Q FY 2051

(Related Funding Requirements)

	Annual Costs		Life Cycle Costs	
	Current Total Estimate	Previous Total Estimate	Current Total Estimate	Previous Total Estimate
Operations and Maintenance	$0M	N/A	$0M	N/A

The numbers presented are the incremental lifecycle operations and maintenance costs above the existing APS. The operations and maintenance costs are not anticipated to increase. The estimate will be updated and additional details will be provided after CD-2, Approve Project Performance Baseline.

9. D&D Information

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

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

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

10. Acquisition Approach

The APS-U project will be acquired by 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 a multi-bend achromat (MBA) magnet lattice, insertion devices, front ends, beamlines/experimental stations, and any required modifications to the linac, booster, and radio frequency (RF) systems. 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.

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 and resilience.

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 the 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 for improved energy resilience and sustainability, including improved biofuels and bioproducts, improved carbon storage capabilities, and controlled biological transformation of materials such as nutrients and contaminants 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 required for predictive tools and approaches needed to inform policies and plans for future energy and resource needs.

Over the last two decades, BER's scientific impact has been transformative. Mapping the human genome through the U.S.-supported international Human Genome Project that DOE initiated in 1990 ushered in a new era of modern biotechnology and genomics-based systems biology. Today, researchers in the BER Genomic Sciences activity and the Joint Genome Institute (JGI) are using the powerful tools of plant and microbial systems biology to pursue the fundamental breakthroughs needed to advance the frontiers in energy-relevant systems biology. The three DOE Bioenergy Research Centers (BRCs) presently lead the world in fundamental biofuels-relevant research.

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, dating back to the 1950s, 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; 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. BER-supported systematic and objective model intercomparisons provide U.S. government policy makers up-to-date insight of the relative quality and capabilities of U.S. versus foreign earth-systems models, necessary for science-based international policy discussions.

Highlights of the FY 2018 Budget Request

The FY 2018 BER Budget Request implements Administration decisions to prioritize more fundamental research, overall, and to focus research on advancing the core missions of the DOE while maintaining American leadership in the area of scientific inquiry. BER 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 places a priority on the DOE high-resolution earth system model, with significantly reduced contributions to the interagency Community Earth System Model (CESM) that is co-funded by DOE and the National Science Foundation (NSF). BER activities continue to support core research and scientific user facilities in key areas of bioenergy, earth systems modeling and observations, and environmental sciences. Activities eliminated or significantly reduced in the Earth and Environmental Systems Sciences subprogram (formerly known as the "Climate and Environmental Sciences" subprogram) include integrated assessments, support of the U.S. Global Change Research Program (USGCRP), climate feedbacks, anthropogenic aerosols and black carbon, analysis of the Atmospheric Radiation Measurement Research Facility (ARM) observations, field activity in the tropics, and user support to the northern peatland field site focused on functional responses to climate variability and atmospheric stressors.

The federally chartered BER Advisory Committee (BERAC) advises BER on its future development of effective research strategies for sustained leadership in biological and environmental research. BERAC holds targeted workshops, periodic reviews and forward looking overviews of BER relevant science, and the outcomes of these activities inform BER's ongoing and future research.

Biological Systems Science

Investments in the Biological Systems Science subprogram will provide the fundamental understanding to underpin transformative science in sustainable bioenergy production and to gain a predictive understanding of carbon, nutrient, and metal transformation in support of DOE's environmental missions. The subprogram prioritizes Genomic Sciences research activities to continue with core research that will provide a scientific basis for sustainable and cost effective bioproducts and bioenergy production. This includes reduced scope of the recompeted next phase DOE BRCs, which will initiate new research to provide a broad scientific underpinning to the production of fuels and chemicals from sustainable biomass resources and speed the translation of basic research results to industry. The subprogram directs efforts towards advanced biofuels and bioproducts research as it closes out completed research targeted on cellulosic ethanol. Biosystems design research continues to develop the knowledge necessary to engineer specific beneficial traits into plants and microbes for making biofuels or bioproducts from renewable biomass. Investment in microbiome research continues to build on BER's considerable experience in fundamental genomic science of plants and microbes and extend that expertise to understand the fundamental principles governing microbiome establishment, function, and interactions in diverse environments. Gaining a predictive understanding of how microbiomes control the availability of materials such as carbon and nutrients, and respond to changes in the environment or interact with plants, is crucial to advancing DOE's biotechnology and environmental research. The subprogram supports these fundamental genomic science activities with ongoing efforts to combine molecular and genomic scale information within the DOE Systems Biology Knowledgebase and to develop integrated networks and computational models of system dynamics and behavior.

Mesoscale research continues to provide spatial and temporal understanding of functional genomics within living cells; new efforts to explore use of quantum materials for advanced bioimaging and characterization will contribute towards a systems-level predictive understanding of biological processes.

The DOE Joint Genome Institute (JGI) remains 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 continues 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 energy and products, and environmental research. With this range of capabilities, JGI is also uniquely positioned to support and advance DOE bioenergy and environmental microbiome research.

Earth and Environmental Systems Sciences

Earth and Environmental Systems Sciences research activities will focus on scientific analysis of how physical and biogeochemical processes impact the sensitivity and uncertainty of earth system predictions, with continued field studies on the Arctic through the Next Generation Ecosystem Experiment (NGEE) in Alaska. The Subsurface Biogeochemistry Research activity continues to focus on modeling and experimentation of the flows of subsurface nutrients and materials. Investments 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 computer architectures, and enhanced usability, testing, adaptability, multi-scale treatments, and provenance. The modeling efforts will be validated against new atmospheric and terrestrial observations.

ARM will continue to provide new observations selected to represent the diversity of environmental conditions necessary to advance earth system models. ARM continues long-term measurements at fixed sites in Alaska and Oklahoma. Operations at the fixed site in the Azores will be limited. An ARM mobile observatory will be deployed for focused and targeted measurements in the Southern Ocean.

EMSL will focus on a research agenda aligned with BER program research areas and highlighting opportunities with the High Resolution and Mass Accuracy Capability (HRMAC) instrument. With greatly improved dynamic range and sensitivity, HRMAC will enable a characterization and quantification of the chemical constituents and dynamics of complex natural systems in the environment including microbial communities, and soil and rhizosphere ecosystem.

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

Biological and Environmental Research
Funding ($K)

	FY 2016 Enacted[a]	FY 2017 Annualized CR[b]	FY 2018 Request	FY 2018 vs FY 2016
Biological Systems Science				
Genomic Science				
Foundational Genomics Research	76,125	–	75,000	-1,125
Genomics Analysis and Validation	9,248	–	7,474	-1,774
Metabolic Synthesis and Conversion	16,262	–	7,250	-9,012
Computational Biosciences	16,395	–	13,116	-3,279
Bioenergy Research Centers	75,000	–	40,000	-35,000
Total, Genomic Science	**193,030**	–	**142,840**	**-50,190**
Mesoscale to Molecules	**9,623**	–	**8,701**	**-922**
Radiological Sciences				
Radiochemistry and Imaging Instrumentation	1,000	–	0	-1,000
Radiobiology	1,000	–	0	-1,000
Total, Radiological Sciences	**2,000**	–	**0**	**-2,000**
Biological Systems Facilities and Infrastructure				
Structural Biology Infrastructure	10,000	–	8,000	-2,000
Joint Genome Institute	69,500	–	57,570	-11,930
Total, Biological Systems Facilities and Infrastructure	**79,500**	–	**65,570**	**-13,930**
SBIR/STTR	10,118	–	8,194	-1,924
Total, Biological Systems Science	**294,271**	–	**225,305**	**-68,966**
Earth and Environmental Systems Sciences				
Atmospheric System Research	**26,392**	–	**12,000**	**-14,392**
Environmental System Science		–		
Terrestrial Ecosystem Science	40,035	–	10,000	-30,035
Subsurface Biogeochemical Research	23,207	–	10,000	-13,207
Total, Environmental System Science	**63,242**	–	**20,000**	**-43,242**
Earth and Environmental Systems Modeling		–		
Climate Model Development and Validation	15,448	–	0	-15,448
Regional and Global Model Analysis	30,108	–	12,610	-17,498
Earth System Modeling	35,530	–	12,595	-22,935

[a] The FY 2016 Enacted level includes SBIR and STTR and reflects updates through the end of the fiscal year.
[b] The FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above, below that level, a dash (-) is shown.

	FY 2016 Enacted[a]	FY 2017 Annualized CR[b]	FY 2018 Request	FY 2018 vs FY 2016
Integrated Assessment	17,583	–	2,000	-15,583
Total, Earth and Environmental Systems Modeling	**98,669**	–	**27,205**	**-71,464**
Earth and Environmental Systems Sciences Facilities and Infrastructure				
Atmospheric Radiation Measurement Research Facility	65,429	–	34,000	-31,429
Environmental Molecular Sciences Laboratory	43,191	–	25,000	-18,191
Data Management	7,069	–	1,000	-6,069
Total, Earth and Environmental Systems Sciences Facilities and Infrastructure	**115,689**	–	**60,000**	**-55,689**
SBIR/STTR	10,737	–	4,440	-6,297
Total, Earth and Environmental Systems Sciences	**314,729**	–	**123,645**	**-191,084**
Total, Biological and Environmental Research	**609,000**	**607,842**	**348,950**	**-260,050**

SBIR/STTR Funding:

- FY 2016 transferred: SBIR $18,135,000; STTR $2,720,000
- FY 2018 Request: SBIR $11,076,000; STTR $1,558,000

[a] The FY 2016 Enacted level includes SBIR and STTR and reflects updates through the end of the fiscal year.

[b] The FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above, below that level, a dash (-) is shown.

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

	FY 2018 vs FY 2016
Biological Systems Science: Genomic Sciences research activities are prioritized to continue with core research that will provide a scientific basis for sustainable and cost effective bioproducts and bioenergy production. Genomic Science will continue to build on BER's fundamental genomic science research and will support development of a select range of platform microorganisms, plants and fungi to expand available biological systems for bioenergy and biotechnology. The recompeted BRCs will initiate the next phase of BER's bioenergy research to underpin efforts to produce cost effective biofuels and bioproducts from sustainable biomass resources. Biosystems design activities will continue research to modify plants and microorganisms with beneficial traits relevant to bioenergy and bioproduct production. Work on cellulosic ethanol under Metabolic Synthesis and Conversion is completed as efforts focus on advanced biofuels and bioproduct research. Microbiome research addresses understanding how microbes and plants interact in a range of microbiomes of relevance to DOE's biotechnology and environmental missions. Development of new bioimaging, measurement and characterization technology through the Mesoscale to Molecules activity will create new integrative imaging and analysis platforms, including using quantum materials, to understand the expression and function of genome information encoded within cells.	**-68,966**
Earth and Environmental Systems Sciences: Focused investments continue to develop an earth system model capability focused on DOE mission needs for energy and infrastructure resilience and security. Environmental System Science, Subsurface Biogeochemistry Research sub-element activity continues a focus on fate and transport of nutrients. ARM continues to advance knowledge and improving model representations of atmospheric gases, aerosols, and clouds on the Earth's energy balance. Two mobile facilities will be placed in reserve; the Azores fixed site will have limited operations. EMSL continues a more focused set of scientific topics that exploit recently installed capabilities involving HRMAC and live cell imaging; data from EMSL instrumentation will be integrated into process and systems models and simulations to address challenging problems in the biological and environmental sciences. Climate Model Development and Validation (exascale activities) is completed in FY 2017 and Integrated Assessment activities begin close-out in FY 2018.	**-191,084**
Total, Biological and Environmental Research	**-260,050**

Basic and Applied R&D Coordination
BER research underpins the needs of DOE's energy and environmental missions. 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, as outlined in the Federal Activities Report on the Bioeconomy (FARB[a]) and highlighted in the National Academy of Sciences study on the Industrialization of Biology (NAS 2015[b]). BER fundamental bioenergy science underpins and is relevant to other DOE offices and agencies. Coordination 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. Additionally, memoranda of agreement (MOAs) have been signed with the National Science Foundation (NSF) and the National Institute of Allergy and Infectious Diseases (NIAID) to cooperate on computational biology and bioinformatic developments within the DOE Systems Biology Knowledgebase (KBase).

BER research on the transport and transformation of energy-related substances in subsurface environments provides understanding that can enable DOE's Office of Environmental Management (EM) to develop new strategies for the remediation of weapons-related and other contaminants at DOE sites, as informed by a recent workshop on Basic Research Needs for EM. 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.

Coordination with other federal agencies on priority earth system science needs occurs through regular interagency dialogue and the USGCRP program.

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

Lignin is a major structural component of plants, and a major focus for bioenergy research. The recalcitrance of lignin to degradation and lack of methods to convert it to useful products is a major impediment to cost-effective production of fuels and chemicals from plant biomass. Results have identified naturally occurring modified lignin structures in native tree species and key enzymes controlling lignin formation in grasses that could be enhanced or modified to develop bioenergy crops with superior cell wall deconstruction traits. Detailed structural biology studies of key enzymes involved in lignin bond cleavage are developing a burgeoning suite of enzymatic tools to create valuable chemicals and fuels from lignin. Also, combined studies pairing modified microorganisms and new biomass deconstruction methods are demonstrating novel paths to convert ionic-liquid treated biomass into jet fuel precursor compounds.

Biosystems Design Research. Biotechnology is evolving rapidly and BER's systems biology research efforts are at the forefront of this field, particularly for bioenergy related research. Results targeting fundamental principles of genome engineering will have far-reaching impacts not only on biofuel and bioproduct development but on biotechnology development as a whole. Genome recoding offers the ability to design new beneficial functions into microorganisms. Recent results show how a microorganism can be modified to convert non-standard amino acids into proteins. The research opens up the possibility to design parallel metabolic pathways within microorganisms for bioproducts production that do not interfere with normal metabolism.

The systems biology research community needs a broader range of platform organisms on which to build engineered biological systems for beneficial purposes. A genetic transformation technique for diatoms is now available that allows additional genetic engineering of this group of organisms for a host of bioenergy and biotechnology purposes. Diatoms and other photosynthetic organisms are potential biocatalysts for converting carbon dioxide and sunlight into biofuels and bioproducts. Researchers using the Joint Genome Institute user facility successfully adapted a yeast DNA recombination system to engineer the entire pathway of a soil bacterial pigment into a plant as well as to drop in an entire biodiesel

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[a] https://biomassboard.gov/pdfs/farb 2_18_16.pdf
[b] http://www.nap.edu/catalog/19001/industrialization-of-biology-a-roadmap-to-accelerate-the-advanced-manufacturing

metabolic pathway. The work is a significant advance towards developing new biotechnology tools for use in a broad range of plants by radically simplifying stacking of genes from different sources and engineering them into a different organism.

Modeling the Earth System. Advanced modeling concepts, high performance computing, and new observations allow emerging earth system models to more confidently capture extreme weather events and to better understand how these events interact with the atmospheric, oceanic, and terrestrial components of the Earth system. A new DOE high-resolution earth system model will be released in December 2017 as the world's highest resolution capability to study interdependencies involving the atmosphere, oceans, and terrestrial processes. With the power of DOE's fastest supercomputers, this Energy Exascale Earth System Model (E3SM) will be able to conduct complex uncertainty analyses using spatial data resolutions down to 500m. This capability has resulted in identification and reduction of significant errors and biases in earth system models that use coarser spatial data inputs. In addition, super parameterization of clouds in the high resolution atmospheric component of E3SM can more accurately capture extreme precipitation patterns and rainfall events. Results also indicate that the amount of precipitation can vary over the course of successive El Niño Southern Oscillation (ENSO) events of different strengths, thereby producing even more confident projections of extreme precipitation in the future.

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

Understanding Global Ecosystem Dynamics. Arctic and tropic field experiments are delivering new insights on ecosystem-climate interactions, including methane release in the Arctic and vegetation response to drought in the tropics, to advance Earth system understanding and models.

Arctic permafrost soils have the potential to release vast amounts of carbon dioxide and methane into the atmosphere; however, understanding and predicting this release is challenging due to environmental differences across the landscape. Ongoing experiments conducted in northern Alaska have utilized stable carbon isotopes to estimate the portioning and transformation of carbon dioxide and methane within the coupled soil-plant portion of permafrost ecosystems. Results indicate that the majority of subsurface natural methane can easily be transported upward to the atmosphere by soils and plants, without being converted to carbon dioxide. Because the partition between naturally occurring carbon dioxide and methane emissions in permafrost landscapes influences the rate of permafrost thaw, this finding suggests that permafrost thaw may lead to a more rapid transformation of Arctic landscapes that in turn influences Alaskan infrastructure.

Previous observations suggested that evergreen tropical forests may increase photosynthesis during the dry season, but the causes have been unknown. To address this scientific mystery, DOE scientists combined measurements of atmosphere-plant gas fluxes with an innovative visual monitoring technology able to observe leaf changes throughout the canopy. They discovered that old leaves die back during the dry season and are replaced by more efficient new leaves. Using these results, ecosystem models within high-resolution earth system models such as E3SM can now be adjusted to represent more dynamic canopy greenness, feedbacks with wet and dry seasons, and more accurate global feedbacks between tropical ecosystems and the Earth system.

Description

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

Key questions that drive these studies include:

- What information is encoded in the genome sequence?
- How is information exchanged between different subcellular constituents?
- What molecular interactions regulate the response of living systems and how can those interactions be understood dynamically and predictively?

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

The subprogram supports the operation of a scientific user facility, the DOE JGI, and the use of structural biology facilities through the development of instrumentation at DOE's national scientific user facilities. It also provides support for research at the interface of the biological and physical sciences, and instrumentation to develop new methods for real-time, high-resolution imaging of dynamic biological processes.

<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 long-term national challenges in sustainable energy production, breakthroughs in genome-based biotechnology, and understanding the role of biological systems in the environment.

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.

A major effort within the portfolio seeks to provide a fundamental understanding of the biology of plants and microbes as a basis for developing cost effective processes for bioenergy production from cellulosic biomass. The DOE BRCs are central to this effort and have provided a substantial body of scientific literature and intellectual property towards this goal. Initiation of recompeted BRC research focuses efforts to develop a range of advanced biofuels and bioproducts from sustainable biomass resources and transition the research results to industry. Through extensive community engagement, scientific workshops, and external studies and reports from the National Academies, BER developed scientific priorities for the recompeted BRC activity. The Genomic Science activity will develop an increased range of microorganisms and plants as platform organisms to expand and complement available biological systems for bioenergy and biotechnology research. The activity also supports fundamental research on identification and introduction of desired traits for new bioenergy crops and microbes, as well as understanding soil microbial communities and how they impact the cycling and fate of carbon, nutrients and contaminants in the environment. Efforts in biosystems design and microbiome research continue to build on and complement existing genomics-based research, through development of new genomic design techniques for microbes and plants, and 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 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 function.

Finally, the ongoing development of bioinformatics and computational biology capabilities within the DOE Systems Biology Knowledgebase (KBase) support these systems biology efforts. 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.

Mesoscale to Molecules

BER approaches to systems biology 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 Mesoscale to Molecules activity will enable development of new bioimaging, measurement and characterization technologies to visualize the spatial and temporal relationships of key metabolic processes governing phenotypic expression in plants and microbes. The activity will include new efforts to use quantum materials for high-resolution imaging. 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

Biological Systems Science supports unique scientific facilities and infrastructure related to genomics and structural biology that are widely used by researchers in academia, the national laboratories, and industry. 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. 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 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 Systems Biology KBase. These advanced capabilities are part of the JGI's latest strategic plan to provide users with additional, highly efficient, capabilities supporting biosystems design efforts for biofuels and environmental process research. The 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. These new metagenomics capabilities will be crucial to supporting efforts in microbiome research.

BER also supports development and use of specialized instrumentation for biology at major DOE user facilities, such as synchrotron light sources and neutron facilities. These research facilities enable science aimed at understanding the structure and properties of biological molecules at resolutions and scales not accessible with instrumentation available in universities, research institutes, or industrial laboratories. This information is critical in contributing to our understanding of the relationship between genome, biological structure, and function. BER is also taking steps to ensure that the data will be integrated into the DOE KBase to help accelerate practical applications of this knowledge for energy and the environment.

Activities and Explanation of Changes

FY 2016 Enacted	FY 2018 Request	Explanation of Change FY 2018 vs FY 2016
Biological Systems Science $294,271,000	**$225,305,000**	**-$68,966,000**
Genomic Science $193,030,000	**$142,840,000**	**-$50,190,000**
Genomic Science continued to remain a top priority. Foundational Genomics increased research to develop biosystems design techniques for plants and microbial systems relevant to bioenergy production and research on key parameters influencing the sustainability of bioenergy crops. Genome Analysis and Validation continued research on improving the functional characterization of microorganisms and microbial communities relevant to biofuel production. Metabolic Synthesis and Conversion continued research to broaden the range of model plant and microbial systems available for bioenergy research and, to understand the impact of microbial communities on the fate of carbon, nutrients and contaminants in the environment. At least 5% of the funding for biodesign efforts provided for studies on the environmental, ethical, legal, and societal impacts. Computational Biosciences continued to advance the bioinformatics and computational biology techniques needed within the DOE Systems Biology KBase to accelerate systems biology research. Bioenergy research at the DOE Bioenergy Research Centers continued to provide a fundamental scientific basis for cellulosic biofuels production.	The funding for Foundational Genomics will enable BER to lead the anticipated growth in synthetic biology and biosystems design efforts for biofuels and bioproducts. This includes establishing selected sets of well-defined model microbes, plants and fungi as platforms for synthetic biology, with a robust set of tools tailored to industrially-relevant conditions and a range of environmental variables. Microbiome research will focus on improved bioinformatic tools for microbiome gene annotation, high-throughput approaches to cultivate organisms of interest, characterize their physiological properties, and develop genetic tool kits for their experimental manipulation across a range of different plant hosts and soil types. Computational Biosciences continues and integrates new datasets for protein structure, genome-based biomaterials and biosystems design toolkits and software. BER will begin the next funding period of the BRCs selected from recompetition in FY 2017, but at a reduced funding level.	. Investment in Genomic Science will build on BER's fundamental genomic science research to develop a broader range of platform organisms supporting bioenergy and biotechnology research. The subprogram shifts research focus toward more advanced biofuels and bioproducts research as it closes out successfully completed research on cellulosic ethanol under Metabolic Synthesis and Conversion. It will also initiate new efforts on microbiome gene annotation and genetic toolkit development, along with an expansion of Biosystems design research to improve model microbes, plants, and fungal systems. The recompeted Bioenergy Research Centers activity will begin its first year with a reduced scope.
Mesoscale to Molecules $9,623,000	**$8,701,000**	**-$922,000**
The program continued to develop new enabling technologies to visualize key metabolic processes in plants and microbes. These new techniques provided integrative information on the spatial and temporal relationships of metabolic processes occurring within and among cells. This information is crucial to	Bioimaging funding will continue to augment advanced imaging capabilities for biological systems through strategic investments in endstations and beamlines for the BES-supported light sources and neutron sources. BER will continue to need new capabilities beyond x-ray crystallography, such as cryo-	The decrease requires the subprogram to reduce the development of new bioimaging technology through the Mesoscale to Molecules activity, with efforts to create new integrative imaging, measurement, and characterization platforms, including the use of quantum materials, to understand the expression and

FY 2016 Enacted	FY 2018 Request	Explanation of Change FY 2018 vs FY 2016
integrating molecular scale understanding of metabolic processes into the context of the dynamic whole cell environment and to the development of predictive models of cell function.	EM and other bioimaging techniques, including the use of quantum materials, to support BER's systems-level approach to understanding biological processes. Advanced multi-functional imaging techniques provide spatial and temporal understanding of functional genomics within living cells; this information can be integrated to gain a systems-level predictive understanding of biological processes.	function of genome information encoded within cells. The subprogram will support new cryo-EM bioimaging technology.
Radiological Sciences $2,000,000	**$0**	**-$2,000,000**
Funding supported the orderly closeout of Radiological Science activities in FY 2016.		
Biological Systems Science Facilities and Infrastructure $79,500,000	**$65,570,000**	**-$13,930,000**
The JGI remains an essential component for genomic research within BER. The facility continued to implement its latest strategic plan and provide scientific users with plant and microbial genome sequences of the highest quality and advanced capabilities to analyze, interpret, and manipulate genes in support of bioenergy, biosystems design and environmental research. The JGI continued to collaborate closely with the DOE KBase to provide not only community access to sequenced genomes but access to computational systems to experimentally interrogate those genomes.	JGI continues to focus on sequencing very large and complex plant genomes and metagenomics samples, especially from complex field environments. It will continue to advance its capabilities to interpret genomes and provide the research community with a broad variety of new and cutting functional genomics techniques that increase efficiency. Funding will also allow for incorporation of JGI bioinformatics techniques.	JGI will reduce DNA sequencing, analysis and synthesis support to the BRCs; funding supports slower incorporation of new technologies to help validate genome sequence/ functional characterization. Reduced funding also results in reduced user access to the Community Science Program, with less frequent calls for small scale sequencing and synthesis proposals.
Access to the Structural Biology Infrastructure at the DOE synchrotron light and neutron sources continued to provide information on the structural features of biomolecules and continue to make this information available to the larger research community through the Protein Data Base and the DOE KBase.	Access to the Structural Biology Infrastructure at the DOE Synchrotron light and Neutron sources continues for high-resolution structural characterization of biomolecules. Efforts begin to link data resources (i.e., PDB) with the DOE KBase.	The decrease in funding will reduce the level of effort devoted to cooperative and integrative access/activities with other DOE User Facilities. The subprogram will terminate user support at the Structural Molecular Biology Resource at SSRL while partnering with the Mesoscale to Molecules activity to initiate new investments, such as high-resolution cryo-EM imaging instrumentation.
SBIR/STTR $10,118,000	**$8,194,000**	**-$1,924,000**

FY 2016 Enacted	FY 2018 Request	Explanation of Change FY 2018 vs FY 2016
In FY 2016, SBIR/STTR funding is set at 3.45% of non-capital funding.	In FY 2018, SBIR/STTR funding is set at 3.65% of non-capital funding.	

Biological and Environmental Research
Earth and Environmental Systems Sciences

Description

The Earth and Environmental Systems Sciences subprogram supports fundamental science and research capabilities that enable major scientific developments in earth system-relevant atmospheric and ecosystem process and modeling research in support of DOE's mission goals for transformative science for energy and national security. This includes research on components such as clouds, aerosols, and the terrestrial ecology; modeling of component interdependencies under a variety of forcing conditions; interdependence of climate and ecosystem 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, 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 and is aimed at developing predictive, systems-level understanding of the fundamental science associated with environmental and energy-related challenges associated with e.g. extreme phenomena. The Department will continue to advance the science necessary to further develop an understanding of earth system models of variable sophistication, targeting resolution at the regional spatial scale and interannual to multi-decadal time scales and to focus on areas of critical uncertainty including Arctic ecology and permafrost thaw. All research is performed in close coordination with the USGCRP and the international science community. In addition, environmental research activities will support fundamental research to explore advances in environmental cleanup and reductions in life cycle costs.

The subprogram supports three primary research activities, two national scientific user facilities, and a data activity. The two national 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 develop and test understanding of the central role of clouds and aerosols on a variety of spatial scales, extending from local to global. EMSL provides integrated experimental and computational resources researchers need to understand the physical, biogeochemical, chemical, and biological processes that underlie DOE's energy and environmental mission. The data activity encompasses observations collected by dedicated field experiments, routine and long term observations accumulated by user facilities, and model generated information derived from earth models of variable complexity and sophistication.

<u>Atmospheric System Research</u>

Atmospheric System Research (ASR) is the primary U.S. activity addressing two major areas of uncertainty in earth system models: the role of clouds and the effects of aerosols on precipitation, and the atmospheric radiation balance. ASR coordinates with ARM, using the facility's continuous long-term datasets that 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, predictive understanding of terrestrial surface and subsurface ecosystems, including the effects of interannual variability and change, from the subsurface to the top of the vegetated canopy and from molecular to global scales.

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 experimental and modeling research, ranging from molecular to field scales, to understand and predict the role that biogeochemical processes play in controlling the cycling and mobility of energy-relevant materials in the subsurface and across key surface-subsurface interfaces in the environment, including environmental contamination from past nuclear weapons production.

Earth and Environmental Systems Modeling

Earth and Environmental Systems Modeling develops physical, chemical, and biological model components, as well as fully coupled Earth system models. The research specifically focuses on quantifying and reducing the uncertainties in Earth system models based on more advanced model development, diagnostics, and system analysis. Priority model components include the ocean, sea-ice, land-ice, aerosols, atmospheric chemistry, terrestrial carbon cycling, multi-scale dynamical and physical interdependencies, and dynamical cores.

Climate Model Development and Validation activities are completed in 2017. The activity focused on model architecture restructuring, exploiting new software engineering and computational upgrades, and incorporating scale-aware high resolution physics with uncertainty quantification in all model components, as part of the DOE-wide Exascale Computing Initiative (ECI). BER core earth system modeling activities will continue development of modularized components that can act either alone or as a system, able to run on current and next generation supercomputers, thus allowing greater confidence in earth system analysis for a variety of scenarios and in a flexible structure.

To rapidly and efficiently advance model capabilities, BER supports the Program for Climate Model Diagnosis and Intercomparison (PCMDI), a unique and powerful intercomparison resource for earth system model development, validation, diagnostics, and outputs, using over 50 world-leading earth system models. This set of diagnostic and intercomparison activities, combined with scientific analysis, ensures that BER funded researchers can exploit the best available science and practice within each of the world's leading earth system research programs.

The Earth System Modeling (ESM) activity in BER will continue to coordinate with the National Science Foundation (NSF) to provide limited support for the ESM that is co-funded by DOE and NSF. ESM is designed by the research community with open access and broad use by researchers worldwide. In addition, DOE will continue to advance a branch of, the Energy Exascale Earth System Model (E3SM), as a computationally efficient model adaptable to emerging computer 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 investment decision-making processes for infrastructure associated with future large-scale deployment of energy supply and transmission and national security.

The Integrated Assessment activities in BER will focus on completion of fundamental research developing multi-scale models for earth systems, including components on land use relevant to bioenergy crops.

Earth and Environmental Systems Sciences Facilities and Infrastructure

The Earth and Environmental Systems Sciences Facilities and Infrastructure support two scientific user facilities and data management 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 precise observations of clouds and aerosols. 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 2018, ARM will reduce operations to only the two fixed sites in Alaska and Oklahoma and one mobile observatory, which will be deployed for targeted observations and measurements in the Southern Ocean. This will reduce the number of on-site users and reduce opportunities for intensive observation deployments and studies. Researchers use observations from all ARM observatories to improve earth system models as well as to help calibrate other agency satellites. The ARM fixed sites and mobile measurement campaigns are often distributed around the world in locations where the scientific community most critically needs data to incorporate into earth system models, thereby improving model performance, enhanced understanding, and analysis capabilities. Each of the ARM sites includes scanning radars, lidar systems, and *in situ* meteorological observing capabilities; the sites are also used to demonstrate technologies as they are developed by the community. ARM experiments 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 incorporate very high resolution Large Eddy

Simulations (LES) 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 lower uncertainty.

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, aerosol chemistry, and interfacial and surface science relevant to energy and environmental challenges facing DOE and the nation. This includes science supporting improved catalysts and materials for industrial applications and subsurface biogeochemical drivers. In FY 2018, EMSL will address a more focused set of scientific topics that capitalize on recently installed capabilities involving 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, environmental, and Earth 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 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. Access to and uses of these data are fundamental to supporting decision-making, scientific discovery, technological innovation, and National security.

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

Activities and Explanation of Changes

FY 2016 Enacted	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
Earth and Environmental Systems Sciences $314,729,000	**$123,645,000**	**-$191,084,000**
Atmospheric System Research (ASR) $26,392,000	**$12,000,000**	**-$14,392,000**
ASR continued to focus on atmospheric cloud and aerosol issues that limit earth system modeling capabilities with a particular emphasis on Arctic mixed phase clouds and tropical systems with large variations of aerosol characterization. ASR utilized a combination of observations and LES modeling to explore strongly heterogeneous environments, as observed in the Arctic and the Tropics, to advance the range of conditions applicable to nonhydrostatic parameterizations (models with less than 10 km resolution).	ASR will conduct research on cloud, aerosol, and thermodynamic processes using data collected during observations conducted in FY 2018 by Unmanned Aerial Systems, and the full suite of data from campaigns conducted in Alaska, Oklahoma, Antarctica, the Southern Ocean, and Azores, will be utilized.	Research activities will focus on early research studies on the physics governing cloud-aerosol-precipitation interactions in Antarctica and the Southern Oceans, i.e., two regions that are high priority earth system modeling challenges yet have lacked field data until now. There is no funding included for analysis of anthropogenic aerosols and black carbon.
Environmental System Science (ESS) $63,242,000	**$20,000,000**	**-$43,242,000**
Research continued with NGEE Arctic Phase II, with multiple sites in northern Alaska involved in observation and modeling. NGEE Tropics begins early observations to test new modeling architectures, appropriate for tropical terrestrial systems. The subsurface biogeochemistry investments involve a combination of advanced modeling architectures and field research, with existing data used to test predictive modeling concepts. AmeriFlux supported efforts to improve terrestrial land modeling component, to test new concepts and build testbeds for high resolution land model validation.	Within Environmental System Science, NGEE will continue to provide new observations for model development and validation. The Subsurface Biogeochemistry Research subprogram will focus on fate and transport of subsurface elements and hydrological cycling, uptake, and acquisition by plants and microbes, which will allow for improved integration with the Terrestrial Ecosystem Science subprogram and facilitate multi-scale, very high resolution process modeling from the bedrock to the canopy.	Terrestrial Ecosystem Science research activity will focus efforts on long-term Arctic field experiments to study Alaskan permafrost, maintenance operations only for AmeriFlux national tower network, reduced scope of terrestrial ecosystem studies to prioritize focus on synthesis of ecosystem data from watershed studies and mechanistic modeling of wetland systems including vegetation, nutrient dynamics and flux. There is no funding included for field activities at the SPRUCE (Minnesota) field site focused on functional responses to climate variability and atmospheric stressors for research activities related to climate feedbacks and carbon, or for field studies in the tropics. Subsurface research activities focus reduced efforts on experimental and modeling efforts, prioritizing on

FY 2016 Enacted	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
		core areas of understanding dynamics of subsurface biogeochemistry and watershed modeling.
Earth and Environmental Systems Modeling $98,669,000	**$27,205,000**	**-$71,464,000**
Research continued to extend capabilities for the high-resolution E3SM project to include nonhydrostatic atmospheric modeling (less than 10 km resolution), more sophisticated ice sheet physics, and a new approach for terrestrial modeling that uses plant functional traits instead of plant "types" for more physical representation of biology. The program initiated investments to advance software and physics describing the interface between ice-sheets and other components (ocean, land and atmosphere) and new methods for capturing the statistics of earth system change. Regional modeling analysis addressed interdependencies involving the water and energy sectors, using details on existing and projected infrastructures. In addition, funding for this program supported the development of new multi-ensemble statistical methods for vulnerability analysis applied to the energy-water-land nexus with special focus on regional coastal inundation and storm-surge, changes in water availability for a coupled climate-human system, and energy implications of extreme events. Interdependencies of the energy-water nexus are explored within a full earth system analysis, as well as developing vulnerability analysis techniques to treat the energy-water nexus with existing and projected infrastructure.	Earth and Environmental Systems Modeling — Earth System Modeling will continue investment in the high-resolution E3SM project, with research to introduce a non-hydrostatic dynamical core, dynamic coupling of ocean and ice, and basin and sub-basin treatments for the land models. Activities will align with anticipated exascale developments in high-performance computing platforms and algorithms. The E3SM version 1 (v1) will be released during FY 2018, with both existing and new users conducting basic research using results derived from the newest DOE computer architectures.	Research is continued at a reduced level and a new and novel non-hydrostatic dynamical core will be incorporated into the E3SM model.
Climate Model Development and Validation focused on model architecture restructuring, exploiting new software engineering and computational upgrades, incorporating scale-aware physics in all model components and enhanced efforts to assess and validate model results.	Climate Model Development and Validation is completed.	Climate Model Development and Validation is completed in FY 2017.

FY 2016 Enacted	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
Core research in Regional and Global Model Analysis and Integrated Assessment continued to underpin high-resolution predictability using adaptive grids and uncertainty characterization, and more sophisticated data management.	Core research in model intercomparison and diagnostics will continue. Research will continue to explore how modes of variability affect spatial and temporal patterns of weather and extreme events, including the roles of atmospheric rivers and droughts. The incorporation of uncertainty and performance benchmarks will increasingly become part of research efforts.	Higher resolution models, including the new E3SM v1 model to be released in FY 2018, will allow a new level of scientific study involving high resolution process interactions and interdependencies. Models focus on new science on sea ice variability and biogeochemistry coupling with atmospheric and dynamical forcing. Research is eliminated for integrated modeling of impacts, adaptation, and vulnerability as well as for coupled climate-human system interdependencies of the energy-water nexus.
Earth and Environmental Systems Sciences Facilities and Infrastructure $115,689,000	**$60,000,000**	**-$55,689,000**
ARM continued to support its long-term measurements at fixed sites and the mobile observatories are deployed to three climate-sensitive regions that demanded targeted measurements. The first mobile facility remained in the Amazon Basin for the first quarter, and thereafter underwent maintenance; the second was deployed to Antarctica; and the third continued the experiment in Oliktok, Alaska. These observations, combined with dedicated modeling and simulation, are key to reducing the earth system model uncertainties attributed to clouds and aerosols. The ARM second mobile facility deployment to Antarctica represents the first major ARM campaign in the southern hemisphere. ARM initiated the incorporation of modeling and simulation as part of data acquisition.	ARM will continue to provide new observations, through long-term measurements at fixed sites in Alaska and Oklahoma and limited operations at the Eastern North Atlantic fixed site in the Azores. ARM will deploy a mobile observatory for targeted measurements, while holding two mobile units in reserve. ARM will also maintain an aerial capability and explore the science driven need for equipment refresh for archive upgrades, aerial capabilities, and the mobile and fixed observatories. All ARM activities will be prioritized for critical observations necessary to advance earth system models.	ARM will hold two mobile units in reserve, closing the operations in Oliktok, Alaska. An ARM mobile observatory will be deployed for targeted measurements in the Southern Ocean. Operations will be limited at the fixed site in the Azores.
EMSL continued to support users and their research in biological systems, biogeochemistry, aerosol chemistry, and interfacial and surface science relevant to climate, energy, and environmental challenges facing DOE and the nation. The subprogram placed emphasis on utilization of new capabilities in the	EMSL focuses on scientific topics that exploit recently installed capabilities involving HRMAC, live cell imaging, and more extensive use of integrating data from other EMSL instrumentation into process and systems models and simulations to address	EMSL will eliminate user access for research related to climate feedbacks and carbon.

FY 2016 Enacted	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
Radiological Annex and Quiet wing. In FY 2016, the integrated HRMAC system became available for new research. The installation and availability of the HRMAC, with its 21Tesla magnet, provided unique enhancements to EMSL's capabilities available to the research community.	challenging problems in the biological and environmental sciences.	
The Earth and Environmental Systems Sciences Data Analysis and Visualization activity continued to advance high resolution earth system models and data management capabilities, with a greater focus on nonhydrostatic dynamical cores, extreme events, and the assimilation of LES ensembles to provide statistics of sub-grid parameterizations for a wider range of conditions involving extreme events. Research explored model-data fusion with new visualization technologies.	The Earth and Environmental Systems Sciences Data Management activity will emphasize the first phase of metadata compatibility and consolidation via common protocols and standards, involving environmental observations and the Earth System Grid Federation. Essential data archiving and storing protocols, capacity, and provenance will be achieved, as part of an effort to simplify scientific community access to observed and model generated data produced by DOE.	The subprogram will prioritize data archiving and storage for ARM, AmeriFlux, Earth System Grid Federation, and Next Generation Ecosystem Experiments. No funding is provided for data curation, integration, and analysis.
SBIR/STTR $10,737,000	**$4,440,000**	**-$6,297,000**
In FY 2016, SBIR/STTR funding is set at 3.45% of non-capital funding.	In FY 2018, SBIR/STTR funding is set at 3.65% of non-capital funding.	

Biological and Environmental Research
Performance Measures

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

	FY 2016	FY 2017	FY 2018
Performance Goal (Measure)	**BER Earth System Model - Develop a coupled earth system model with fully interactive water, carbon and sulfur cycles, as well as dynamic vegetation to enable simulations of earth system responses to change.**		
Target	Develop and apply a fully coupled ice-sheet model to estimate near-term changes to the West Antarctic ice sheet.	Extend the capabilities of the DOE's high-resolution Earth System Model to simulate and evaluate human-natural interdependencies for the carbon and water cycles.	Demonstrate improved ocean model simulations with the new high-resolution MPAS-Ocean.
Result	Met	TBD	TBD
Endpoint Target	BER supports the leading U.S. high-resolution earth system model, and addresses two of the most critical areas of uncertainty in contemporary earth system science—the impacts of clouds and aerosols that combine with biogeochemical and cryospheric processes. Delivery of improved scientific data and models (with quantified uncertainties) about the earth's atmospheric, oceanic, cryospheric, and terrestrial system to more accurately predict the earth system responses to change. The information is essential to plan for future national security, energy and infrastructure needs, water resources, and land use. DOE will continue to advance the science necessary to further develop predictive earth system models at the regional spatial scale and multiple time scales, involving close coordination with the U.S. and international science community.		
Performance Goal (Measure)	**BER Predictive Understanding - Advance an iterative systems biology approach to the understanding and manipulation of plant and microbial genomes as a basis for biofuels development and predictive knowledge of carbon and nutrient cycling in the environment.**		
Target	Develop an improved metabolic engineering method for modifying microorganisms for biofuel production from cellulosic sugars.	Develop improved open access platforms for computational analysis of large genomic datasets.	Using genomics-based techniques, develop an approach to explore the functioning of plant-microbe interactions.
Result	Met	TBD	TBD
Endpoint Target	BER will advance understanding of the operating principles and functional properties of plants, microbes, and complex biological communities relevant to DOE missions in energy and the environment. Deciphering the genomic blueprint of organisms and determining how this information is translated to integrated biological systems permits predictive modeling of bioprocesses and enables targeted redesign of plants and microbes. BER research will address fundamental knowledge gaps and provide foundational systems biology information necessary to advance development of biotechnology and predict impacts of changing environmental conditions on carbon cycling and other biogeochemical processes.		

Biological and Environmental Research
Capital Summary ($K)

	Total	Prior Years	FY 2016 Enacted	FY 2017 Annualized CR*	FY 2018 Request	FY 2018 vs FY 2016
Capital Operating Expenses Summary						
Total Non-MIE Capital equipment (projects under $5 million TEC)	n/a	n/a	2,543	–	2,800	+257

Funding Summary ($K)

	FY 2016 Enacted	FY 2017 Annualized CR*	FY 2018 Request	FY 2018 vs FY 2016
Research	400,025	–	211,746	-188,279
Scientific user facilities operations and research	188,120	–	124,570	-63,550
Other[a]	20,855	–	12,634	-8,221
Total, Biological and Environmental Research	**609,000**	**607,842**	**348,950**	**-260,050**

Scientific User Facility Operations ($K)

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

	FY 2016 Enacted	FY 2017 Annualized CR*	FY 2018 Request	FY 2018 vs FY 2016
TYPE B FACILITIES				
Atmospheric Radiation Measurement Research Facility (ARM)	**$65,429**	–	**$34,000**	**-$31,429**
Number of users	1,061	–	700	-361
		–		
Joint Genome Institute	**$69,500**	–	**$57,570**	**-$11,930**
Number of users	1,391	–	1,000	-391
		–		
Environmental Molecular Sciences Laboratory	**$43,191**	–	**$25,000**	**-$18,191**
Number of users	644	–	450	-194

[a] Includes SBIR and STTR.

*The FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above, below that level, a dash (-) is shown.

	FY 2016 Enacted	FY 2017 Annualized CR*	FY 2018 Request	FY 2018 vs FY 2016
Structural Biology Infrastructure[a]	**$10,000**	–	**$8,000**	**-$2,000**
Total Facilities	**$188,120**	–	**$124,570**	**-$63,550**
Number of users	3,096	–	2,150	-946

Scientific Employment

	FY 2016 Enacted	FY 2017 Annualized CR*	FY 2018 Estimate	FY 2018 vs FY 2016
Number of permanent Ph.D.'s	1,350	–	1,000	-350
Number of postdoctoral associates	330	–	234	-96
Number of graduate students	450	–	350	-100
Other[b]	330	–	230	-100

[a] Structural Biology Infrastructure activities are at Basic Energy Sciences user facilities and the user statistics are included in the BES user statistics.
[b] Includes technicians, engineers, computer professionals and other support staff.
*The FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above, below that level, a dash (-) is shown.

Fusion Energy Sciences

Overview

The Fusion Energy Sciences (FES) program mission 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.

The next frontier for all of the major fusion research programs around the world is the study of the burning plasma state, in which the fusion process itself provides the dominant heat source for sustaining the plasma temperature (i.e., self-heating). Production of strongly self-heated fusion plasma will allow the discovery and study of new scientific phenomena relevant to fusion energy. These include the effects of highly energetic fusion-produced alpha particles on plasma stability and confinement; the strongly nonlinear coupling that will occur among fusion alpha particles, pressure-driven self-generated current, turbulent transport, and boundary-plasma behavior; the properties of materials in the presence of high heat and particle fluxes and neutron irradiation; and the self-organized nature of plasma profiles over long time scales.

To achieve these research goals, FES invests in flexible U.S. experimental facilities of various scales, international partnerships leveraging U.S. expertise, large-scale numerical simulations based on experimentally validated theoretical models, development of advanced fusion-relevant materials, and invention of new measurement techniques.

FES also supports discovery plasma science, including research in laboratory plasma astrophysics, low-temperature plasmas, small-scale magnetized plasma experimental platforms, and high-energy-density laboratory plasmas. Some of this work is jointly supported with the National Science Foundation (NSF).

Highlights of the FY 2018 Budget Request

Strategic choices in this Budget Request were informed by the reductions in the overall FY 2018 Office of Science Budget Request, priorities described in "The Office of Sciences' Fusion Energy Sciences Program: A Ten-Year Perspective" (submitted to Congress in 2015), and the research opportunities identified in a series of community engagement workshops held in 2015. Priorities include keeping FES user facilities world-leading, increasing investment in massively parallel computing, supporting high-impact research in fusion materials, strengthening partnerships for access to international facilities with unique capabilities, learning how to predict and control transient events in fusion plasmas, and continuing stewardship of discovery plasma science (e.g., via intermediate-scale basic facilities). Building on the workshops and the ten-year strategic perspective, FES has recently commissioned a study by the National Academies of Science about research priorities for burning plasma science. Also, SC has charged the Fusion Energy Sciences Advisory Committee (FESAC) to investigate the potential for transformative developments in fusion science and technology.

Notable changes in the FY 2018 Request include:

- *Increased support for DIII-D program*—Total funding for the DIII-D program is increased to address the high-priority fusion science issues identified by the community research needs workshops held in FY 2015 and to support enhanced involvement of collaborating university and laboratory researchers in these programs. Funding will support 18 weeks of operation and greater involvement of the National Spherical Torus Experiment Upgrade (NSTX-U) scientists in the DIII-D program while repairs of NSTX-U are underway. It will also support increased collaborations by Massachusetts Institute of Technology (MIT) researchers following the closure of the Alcator C-Mod facility in FY 2017.
- *Continued support for NSTX-U program research and recovery activities*—The NSTX-U facility is down for recovery (assessment and repair) during FY 2017, and this will continue in FY 2018. In FY 2016, a series of deficiencies were found in the design and construction of the NSTX-U device, which prompted the Princeton Plasma Physics Laboratory (PPPL) to cease operation and carry out thorough design verification and validation reviews. The FY 2018 NSTX-U Operations budget will support high-priority activities to implement repairs and corrective actions required to obtain robust, reliable research operations. The NSTX-U Research budget will fund the continued analysis of high-impact data acquired during the FY 2016 run campaign, a focused effort on physics topics that directly support the recovery of

robust NSTX-U plasma operations, and enhanced involvement of university collaborative research at other facilities to support NSTX-U research program priorities.

- *Reduced support for ITER*—This reduction reflects the decrease in the DOE science budget and U.S. concerns about the cost and schedule of ITER.
- *Increased support for Scientific Discovery through Advanced Computing* (*SciDAC)*—Funding for SciDAC is increased to address high-priority research in tokamak disruptions and boundary physics as identified in the 2015 community workshops, and to accelerate development of a whole-device modeling capability, in partnership with the Advanced Scientific Computing Research (ASCR) program.
- *Continued support for Long Pulse Tokamak and Stellarator research*—Funding for Long Pulse Tokamak is maintained for research opportunities for U.S. scientists on superconducting tokamaks with world-leading capabilities. Funding for Long Pulse Stellarator will enable U.S. research teams to take full advantage of U.S. hardware investments on Wendelstein 7-X (W7-X) and enhance the scientific output on this device.
- *Support for Fusion Nuclear Science and Materials Research*—Funding for Fusion Nuclear Science and Materials Research is refocused on fundamental science.
- *Support for Discovery Plasma Science*—Research and operations on intermediate-scale user facilities will be emphasized to pursue opportunities identified in the 2015 community workshops.

Fusion Energy Sciences
Funding ($K)

	FY 2016 Enacted[a]	FY 2017 Annualized CR[b]	FY 2018 Request	FY 2018 vs FY 2016
Fusion Energy Sciences				
Burning Plasma Science: Foundations				
Advanced Tokamak	101,754	-	86,000	-15,754
Spherical Tokamak	76,195	-	59,100	-17,095
Theory & Simulation	33,810	-	32,500	-1,310
GPE/GPP/Infrastructure	5,875	-	0	-5,875
Total, Burning Plasma Science: Foundations	**217,634**	**-**	**177,600**	**-40,034**
Burning Plasma Science: Long Pulse				
Long Pulse: Tokamak	8,944	-	8,500	-444
Long Pulse: Stellarators	7,079	-	7,000	-79
Materials & Fusion Nuclear Science	24,053	-	19,823	-4,230
Total, Burning Plasma Science: Long Pulse	**40,076**	**-**	**35,323**	**-4,753**
Discovery Plasma Science				
Plasma Science Frontiers	46,504	-	23,600	-22,904
Measurement Innovation	3,568	-	900	-2,668
SBIR/STTR & Other	15,218	-	9,517	-5,701
Total, Discovery Plasma Science	**65,290**	**-**	**34,017**	**-31,273**
Subtotal, Fusion Energy Sciences	**323,000**	**-**	**246,940**	**-76,060**
Construction				
14-SC-60 International Thermonuclear Experimental Reactor (ITER)	115,000	-	63,000	-52,000
Total, Fusion Energy Sciences	**438,000**	**-**	**309,940**	**-128,060**

SBIR/STTR:

- FY 2016 Transferred: SBIR: $9,333,000; STTR: $1,400,000
  FY 2018 Request: SBIR $XXX and STTR $XXX

[a] The FY 2016 Enacted level includes SBIR and STTR and reflects updates through the end of the fiscal year.
[b] FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above, below that level, a dash (-) is shown.

Fusion Energy Sciences
Explanation of Major Changes ($K)

	FY 2018 vs FY 2016
Burning Plasma Science: Foundations: Funding for tokamak research decreases due to the shutdown of the Alcator C-Mod facility in FY 2017. DIII-D program funding increases to support the enhanced collaboration by university and laboratory personnel, including MIT and NSTX-U scientists, in the DIII-D program. Funding for SciDAC increases to accelerate progress toward whole-device modeling. Funding for the NSTX-U program will support the repair of the facility, while DIII-D funding will enable 18 weeks of operations. All GPE/GPP funding is deferred.	-$40,034
Burning Plasma Science: Long Pulse: Funding for Materials and Fusion Nuclear Science decreases with an emphasis on addressing the highest priority issues in both program elements.	-$4,753
Discovery Plasma Science: Overall funding is decreased. For General Plasma Science and Exploratory Magnetized Plasma, research and operations of intermediate-scale, scientific user facilities are emphasized. For High Energy Density Laboratory Plasma, the focus remains on supporting research utilizing the Matter in Extreme Conditions instrument of the Linac Coherent Light Source facility at the SLAC National Accelerator Laboratory at Stanford University.	-$31,273
Construction: Funding decreases for the U.S. Contributions to ITER project.	-$52,000
Total Funding Change, Fusion Energy Sciences	**-$128,060**

Basic and Applied R&D Coordination
FES coordinates within DOE and with other federal agencies on science and technology issues related to fusion and plasma science. Within SC, FES operates the Matter in Extreme Conditions (MEC) instrument at the Linac Coherent Light Source (LCLS) user facility operated by Basic Energy Sciences (BES). In addition, FES carries out a discovery-driven plasma science research program in partnership with the 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. Also, FES operates a joint program with the National Nuclear Security Administration (NNSA) in High Energy Density Laboratory Plasma (HEDLP) physics. Both programs involve coordination of solicitations, peer reviews, and workshops. The FESAC provides technical and programmatic advice to FES and NNSA for the joint HEDLP program.

Program Accomplishments
Important for fusion reactors: novel stable, efficient operating scenario with low-rotation developed—Most current-day tokamaks have plasmas with significant rotation, due to the large torque applied by neutral ion beams used for heating. However, future fusion power plants will operate with almost no rotation. The DIII-D tokamak facility at General Atomics, with its ability to balance the neutral beam torque while still heating (with up to 10 megawatts of power), has unique capabilities to study low-torque regimes. Normally, rotation is needed to suppress plasma instabilities. Recently, however, scientists on DIII-D found that fusion performance while operating in the Quiescent H-Mode scenario (which is free of dangerous edge localized mode instabilities) actually improved as the rotation was decreased. The improvement occurs because the plasma undergoes a bifurcation into a new state characterized by increased pedestal height and width, resulting in enhanced global confinement.

Towards a possible breakthrough for reactor wall materials: lithium wall contains plasma without cooling it—In large tokamaks with tungsten walls, the edge plasma must be cooled to low temperatures (a few tens of electron-volts) in order to reduce sputtering of the wall, which can lead to heavy tungsten impurities beginning to accumulate in the plasma. But lower temperatures at the edge cause the plasma to be less hot in the core, which then degrades fusion performance. The Lithium Tokamak Experiment, a medium-scale tokamak at PPPL, found that lithium-coated walls can handle edge plasma temperatures higher than 200 electron-volts, with little influx of lithium and no impact on performance. Another advantage is that the resulting temperature profile is essentially flat from the edge to the core, which potentially avoids deleterious instabilities driven by a temperature gradient.

Massively parallel computation enables essential step towards predictive capability: simulations of electrical current generation in tokamaks—The conventional understanding of how intrinsic electrical current (the so-called bootstrap current) is generated is that the current is carried by charged particles that flow around the doughnut-shaped tokamak without getting magnetically trapped at the outboard side of the confinement configuration. New massively parallel numerical simulations, performed by scientists in the SciDAC Edge Physics Simulation Center (a partnership with ASCR) have, however, shown that the bootstrap current in the boundary region of the plasma is carried predominately by the magnetically trapped particles. This new understanding will greatly improve the prediction of the properties of the boundary plasma, including the important "pedestal" region, which plays a critical role in determining the overall fusion performance of the plasma.

Extending the reach of U.S. fusion science: collaborative research during the initial operation of W7-X—The U.S. is an international partner in the new Wendelstein 7-X facility, the world's largest stellarator, which began operation in early FY 2016. U.S. scientists helped map out the magnetic field line surfaces with an electron beam, to confirm magnetic coil alignment. During the first plasma operation period, the U.S. collaboration team used the set of five trim coils it had constructed to measure intrinsic field errors, calibrate magnetic measuring instruments, and perturb the plasma. Also, the U.S. scientists used their x-ray imaging crystal spectrometer instrument to make the first measurements of time-resolved ion temperature profiles, together with high-quality electron temperature profiles. The spectrometer also measured plasma flow and core impurity transport – critical for reactor design. The U.S. participated in the March 2016 celebration event at which German Chancellor Angela Merkel officially dedicated this new fusion research facility.

Essential for developing attractive materials for fusion reactors: first-of-a-kind materials irradiation experiments—The U.S. and Japan have a five-year collaboration project to study the feasibility of using a helium-cooled divertor made out of tungsten material for future fusion devices. Recently, the collaborating scientists began a landmark series of irradiation experiments on the High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory (ORNL). A shielded gadolinium rod is used to absorb the high thermal-neutron flux in the water-cooled HFIR reactor and thus achieve the appropriate ratio between displacement damage and transmutation content that is expected in a fusion power plant. The tungsten material samples thus being irradiated will yield unique understanding about the effects of fusion-type neutrons on their thermo-mechanical and fuel retention properties.

U.S. Contributions to ITER First Plasma subproject more than 50% complete—The U.S. completed the fabrication and delivery of over 21,000 feet of superconductor cable, more than enough to wind one of the eighteen Toroidal Field coils. Four U.S. industrial companies produced this superconductor. Additionally, the U.S. completed the fabrication and delivery of all of its components for the Steady State Electrical Network, needed to provide power for construction activities, as well as for plasma operations at ITER. Lastly, successful winding of the first two Central Solenoid superconducting magnet modules was completed. Each Central Solenoid module is fabricated from approximately 6,000 meters of niobium-tin superconductor. After winding and assembly, each completed module will undergo heat treatment, insulation, vacuum pressure impregnation, and final testing at the cryogenic operating temperature (4 degrees Kelvin). The Central Solenoid, an enormous electromagnet that is considered the "heartbeat of the ITER device," consists of six stacked magnet modules surrounded by a support structure. When assembled, the entire Central Solenoid and associated structures will be over 42 feet tall, weigh over 1,100 U.S. tons, and produce a very strong magnetic field (13 Tesla).

Exotic solar phenomena explained in the lab: pulsating reconnection driven by three-dimensional (3D) flux-rope interactions—In high-temperature plasmas, magnetic field lines can reconnect and release stored energy as the magnetic field undergoes topological changes. Although the two-dimensional dynamics of magnetic reconnection has been extensively studied, most applications in space and astrophysical plasmas are inherently three-dimensional. In a laboratory experiment at UCLA, researchers measured the 3D electric and magnetic fields resulting from the interaction of two magnetic flux “ropes” generated between a cathode and anode. The ropes were observed to bounce and reconnect in a periodic pulsating fashion. These results provide the first direct experimental test of reconnection within a quasi-separatrix layer (where magnetic field lines separate rapidly).

Science of the interior of giant planets accessed in the lab: liquid metallic hydrogen observed for the first time—The planet Jupiter is 70% composed of hydrogen, with the outer layer made of familiar molecular hydrogen (as on Earth), but surrounding the core an exotic state of hydrogen, called liquid metallic hydrogen, that requires extremely high pressures to exist. Researchers have been trying to observe this metallic state in the laboratory ever since it was predicted 80 years ago. High-power lasers can provide the high pressures necessary to induce the insulator-to-metal transition of hydrogen. Recently, SLAC scientists and their collaborators were able to observe this transition at a pressure of 250,000 atmospheres, using one laser beam to compress deuterium (a hydrogen isotope) and another laser beam to produce very short-wavelength x-rays that can probe the hydrogenic transition. These results provide insight into the physical properties of giant planets and also into the design of inertially confined fusion experiments with deuterium as a fuel.

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 torus 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 Office of Science laboratories conducting fusion research.

Research in the Burning Plasma Science: Foundations area in FY 2018 will focus on high-priority challenges and opportunities in the areas of transients in tokamaks, plasma-material interactions, and integrated modeling, as identified by the community research needs workshops held in FY 2015.

Advanced Tokamak

The DIII-D user facility at General Atomics in San Diego, California, is the largest magnetic fusion research experiment in the U.S. and can magnetically confine plasmas at temperatures relevant to burning plasma conditions. 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 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 fusion reactors. Another high-priority DIII-D research area is foundational fusion science, pursuing a basic scientific understanding across all fusion plasma topical areas.

The Alcator C-Mod facility at the Massachusetts Institute of Technology operated in FY 2016 to complete student research and experimental work and ceased operations at the end of that fiscal year. The facility was placed in a safe shutdown state in FY 2017.

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.

Small-scale tokamak plasma research projects provide data in regimes of relevance to the FES mainline tokamak magnetic confinement efforts and 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 consists of small-scale focused experiments.

Spherical Tokamak

The NSTX-U user facility at PPPL is designed to explore the physics of plasmas confined in a spherical torus (ST) configuration. With its unusually strong magnetic curvature, powerful heating systems, and advanced diagnostics, NSTX-U will uniquely enable the detailed study of plasmas at ratios of plasma pressure to the pressure of the confining magnetic field, or plasma beta, many times higher than are accessible in the world’s other tokamaks. The implications of a successful NSTX-U research program are therefore significant: high plasma pressures translate to high fusion reactivity, making the NSTX-U geometry a candidate for a future neutron source for scientific study of fusion materials and components. Also, the high beta plasmas and measurement capabilities on NSTX-U will enable first-of-a-kind detailed laboratory study of plasma processes that are relevant to extraordinary astrophysical systems, such as the turbulence in accretion discs surrounding black holes. The upgraded neutral beam heating systems will combine with the plasma properties to make NSTX-U and ideal test bed for studying interactions between plasma waves and fast fuel ions that are relevant to burning plasma science. The liquid metal divertor research program planned for NSTX-U also will enable assessment of a potential break-out path for fusion heat and particle exhaust handling.

Following an extensive series of reviews (e.g. design validation and verification, extent of condition) in FY 2017, NSTX-U activities will focus on recovery efforts to repair or replace essential components during FY 2018-19.

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

Theory and Simulation

The Theory and Simulation element contributes to the FES goal of developing the predictive capability needed for a sustainable fusion energy source. This element includes two main interrelated but distinct activities: the Theory activity and the SciDAC activity.

The Theory activity is focused on advancing the scientific understanding of the fundamental physical processes governing the behavior of magnetically confined plasmas. The efforts supported by this activity range from small single-investigator grants, mainly at universities, to large coordinated teams at national laboratories, universities, and private industry, while the supported research ranges from fundamental analytic theory to mid- and large-scale computational work using high-performance computing resources. In addition to its scientific discovery mission, the Theory activity provides the scientific grounding for the physics models implemented in the advanced simulation codes developed under the SciDAC activity described below and supports validation efforts at major experiments.

The FES SciDAC activity, a component of the SC-wide SciDAC program, is aimed at advancing scientific discovery in fusion plasma science by exploiting leadership-class computing resources and associated advances in computational science. Massively parallel computing, grounded in experimentally validated theoretical models, will be extremely valuable for enabling whole-device modeling that can integrate simulations of physics phenomena across a wide range of disparate time and space scales. The eight multi-institutional and interdisciplinary centers in the FES SciDAC portfolio address challenges in magnetic confinement science and computational fusion materials science and are well-aligned with the research needs in burning plasma science. Most of the FES SciDAC portfolio, in partnership with ASCR is up for recompetition in FY 2017. The portfolio that will emerge from this competition will address the leading-priority research directions identified in the 2015 community workshops.

GPE/GPP/Infrastructure

Funding will support repairs of critical general infrastructure (e.g., utilities, roofs, roads, facilities) at the PPPL site. This funding level will assure appropriate maintenance of safety requirements, equipment reliability, and research-related infrastructure needs.

Activities and Explanation of Changes

FY 2016 Enacted	FY 2018 Request	Explanation of Change FY 2018 vs FY 2016
Advanced Tokamak $101,754,000	**$86,000,000**	**-$15,754,000**
DIII-D Research ($34,643,000) *DIII-D Operations ($44,764,000)* Operations funding supported seventeen weeks of research operations at the DIII-D facility, with experiments focusing on high-priority advanced tokamak issues and research needs as identified by the 2015 community workshops. Areas of research included studies of transport and radiative processes in detached divertor conditions, disruption physics and mitigation systems, and stability control strategies for robust high performance operation. Targeted enhancements to the facility involved installation of a set of high-Z coated tile rings in the divertor region to study impurity generation and transport installation of a new magnet power supply for the 3D and shaping coils, and a low-power helicon antenna.	*DIII-D Research ($38,000,000)* *DIII-D Operations ($45,000,000)* Operations funding will support eighteen weeks of research at the DIII-D facility. Research will focus on determining the optimal path to steady-state tokamak plasmas, exploring techniques to avoid and mitigate transients in tokamaks, and developing the plasma material interaction boundary solutions necessary for future devices. Experiments will continue to exploit a new upper divertor configuration and explore plasma wall coupling and dissipative divertor physics. Specific research goals will involve examining the processes that determine the edge pedestal density structure, assessing models of runaway electron evolution during disruptions, and utilizing new diagnostics to probe the divertor and edge region to challenge and validate theoretical models.	*+$3,357,000* *+$236,000* Funding will allow for greater involvement of university and laboratory collaborators in the DIII-D national program, including the MIT staff previously involved in Alcator C-Mod research, as well as NSTX-U scientists.

FY 2016 Enacted	FY 2018 Request	Explanation of Change FY 2018 vs FY 2016
C-Mod Research ($9,374,000) *C-Mod Operations ($8,675,000)* Operations funding supported over seventeen weeks of research operations at the Alcator C-Mod facility in its final year of operation in FY 2016. Research was focused on research needs as identified by the FY 2015 community workshops. Experiments were conducted to study disruption physics and mitigation techniques, develop the database for the critical interactions between the plasma and material components under ITER and reactor-relevant conditions, explore robust high-performance stationary regimes free of Edge Localized Modes, and advance radiofrequency heating and current drive technology and physics understanding. The facility was closed after final operations. The scientific staff worked on completing analysis of existing C-Mod data and began making a transition to collaborative research activities on other research facilities.	*C-Mod Research ($0)* *C-Mod Operations ($0)* This facility was closed in FY 2016.	*-$9,374,000* *-$8,675,000*
Enabling R&D ($3,165,000) Support continued to be provided for research in superconducting magnet technology and fueling and plasma heating technologies to enhance the performance for existing and future magnetic confinement fusion devices.	*Enabling R&D ($2,000,000)* Support will continue to be provided for research in superconducting magnet technology and plasma fueling and heating technologies required to enhance the performance for existing and future magnetic confinement fusion devices.	*-$1,165,000* Research efforts will be focused on the highest-priority enabling R&D issues.
Small-scale Experimental Research ($1,133,000) Small-scale tokamak plasma research provided experimental data in regimes of relevance to the mainline advanced tokamak magnetic confinement efforts and helped confirm theoretical models and simulation codes in support of the goal to develop an experimentally validated predictive capability for magnetically confined fusion plasmas.	*Small-scale Experimental Research ($1,000,000)* Support will continue to be provided for research on experimental data in regimes relevant to mainline tokamak confinement and experimental validation of models and codes.	*-$133,000* Experimental research and modeling efforts will be continued.

FY 2016 Enacted	FY 2018 Request	Explanation of Change FY 2018 vs FY 2016
Spherical Tokamak $76,195,000	**$59,100,000**	**-$17,095,000**
NSTX-U Research ($27,860,000) *NSTX-U Operations ($44,708,000)* NSTX-U began operations after completion of the upgrade. Machine performance was extended to higher field and current and longer pulse lengths than what had been achievable prior to the upgrade, with results being benchmarked with prior data. Current drive and fast ion instabilities resulting from the new neutral beam line were studied. The machine operated for 10 weeks in FY 2016 before experiencing a coil failure.	*NSTX-U Research ($20,000,000)* *NSTX-U Operations ($35,600,000)* Operations funding will support the repair of the NSTX-U facility. Research will be focused on the study of ST confinement improvements observed during the FY 2016 experimental run campaign. Modeling and new measurements will allow elucidation of the detailed physical mechanisms responsible for these confinement improvements. In the absence of plasma operations at the NSTX-U facility, researchers will carry out experiments on both domestic and international spherical tokamaks, and continue analysis and publication of data obtained in FY 2016.	*-$7,860,000* *-$9,108,000* The NSTX-U Research funds will support continued analysis of high-impact data acquired during the FY 2016 run campaign and a focused effort on physics topics that directly support the recovery of robust NSTX-U plasma operations. Researchers will also collaborate on other spherical tokamak facilities to advance high-priority research needs that were identified by the 2015 community workshops. The NSTX-U Operations budget supports high-priority activities to implement repairs and corrective actions required to obtain robust, reliable research operations. While consumable expenditures are reduced due to the non-operation of NSTX-U in FY 2018, the additional anticipated costs associated with the repair and replacement of components (e.g., material procurements) offset these savings.
Small-scale Experimental Research ($3,627,000) Small-scale spherical torus plasma research provided experimental data in regimes of relevance to the mainline spherical torus magnetic confinement efforts and helped confirm theoretical models and simulation codes in support of the goal to develop an experimentally validated predictive capability for magnetically confined fusion plasmas.	*Small-scale Experimental Research ($3,500,000)* Experimental studies of plasmas surrounded by liquid lithium material surfaces, which was identified as a priority research direction in the 2015 plasma materials interactions workshop, will be conducted. Developing techniques to operate STs without the use of a central solenoid will be experimentally tested. If successful, these small-scale, high-risk lines of research may provide underlying scientific insights for future devices.	*-$127,000* Funding will support experimental research efforts on small scale spherical tokamak facilities in support of NSTX-U program priorities.
Theory & Simulation $33,810,000	**$32,500,000**	**-$1,310,000**
Theory ($24,439,000) The program continued to advance the scientific understanding of the fundamental physical processes governing the behavior of magnetically confined plasmas. Emphasis on addressing ITER priorities	*Theory ($15,500,000)* The program will continue to support theoretical and computational research addressing fundamental questions of magnetic confinement science. Emphasis will be placed on projects maximizing synergy with the FES SciDAC portfolio and addressing the	*-$8,939,000* The program will be refocused to emphasize SciDAC activities.

FY 2016 Enacted	FY 2018 Request	Explanation of Change FY 2018 vs FY 2016
continued to guide the selection of new and renewal awards via competitive merit reviews.	recommendations from the 2015 community workshops.	
SciDAC ($9,371,000) The five SciDAC centers entered the final year of their research activities, while the three FES–ASCR SciDAC-3 partnerships continued their efforts in the areas of boundary physics, materials science, and multiscale integrated modeling. FES and ASCR developed a plan emphasizing integration for the science areas represented by the entire FES SciDAC portfolio and initiated preparations for a competitive merit review.	*SciDAC ($17,000,000)* The entire FES SciDAC portfolio will continue to focus on integrated simulations and whole device modeling, addressing the leading priority research directions identified in the 2015 community workshops. Synergy with whole-device modeling activities supported by the DOE Exascale Computing Project will be strengthened.	*+$7,629,000* Increase in funding will enable the development and implementation of additional critical computational modules, accelerating the development of the whole-device modeling capability. It will also allow the continuation and strengthening of efforts in the critical area of runaway electron avoidance and mitigation.
GPE/GPP/Infrastructure $5,875,000	**$0**	**-$5,875,000**
Continued support of NSTX-U operations, as well as enhanced International Collaborations, was provided through improvements to the Princeton Plasma Physics Laboratory Computer Center (PPPLCC) and establishment of remote collaboration room configurations. Environmental monitoring needs at PPPL continued to be supported.	All GPE/GPP funding is deferred.	All GPE/GPP funding is deferred.

Description

The Burning Plasma Science: Long Pulse subprogram explores new and unique scientific regimes that can be achieved 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. When advantageous, these efforts will be augmented by research into long-pulse related physics issues on overseas tokamaks and spherical tokamaks with nonsuperconducting coil systems.

Long Pulse: Stellarator

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

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

Materials and Fusion Nuclear Science

The fusion environment is extremely harsh in terms of temperature, particle flux, and neutron irradiation. The Materials and Fusion Nuclear Science element supports the development, characterization, and modeling of structural, plasma-facing, and blanket materials for use in future fusion devices. Materials that can withstand this environment, under the long-pulse or steady-state conditions anticipated in fusion experiments, are a prerequisite to the future of fusion research and development activities. Studies that help identify the various scientific challenges to fusion energy deployment and that determine how to address them in a safe and environmentally responsible manner are a key component of the Materials and Fusion Nuclear Science element.

Activities and Explanation of Changes

FY 2016 Enacted	FY 2018 Request	Explanation of Change FY 2018 vs FY 2016
Long Pulse: Tokamak $8,944,000	**$8,500,000**	**-$444,000**
U.S. scientists have developed, installed, and commissioned improved plasma control feedback systems for China's Experimental Advanced Superconducting Tokamak (EAST) and Korea's Superconducting Tokamak Advanced Research (KSTAR). ITER operating scenarios were explored and evaluated on EAST and KSTAR. Radio-frequency heating and current drive and neutral beam injection actuator models for EAST and KSTAR were developed and validated.	Three multi-institutional collaborative teams will continue their activities on the superconducting tokamaks, EAST and KSTAR, focusing on the high-priority areas of control and extension of steady-state plasma scenarios to long-pulse, disruption physics, and control of plasma-material interfaces for long-pulse. Research efforts on international conventional tokamaks will continue to address burning plasma physics issues relevant to achieving long pulse plasma operation.	Funding will continue support for U.S. scientists on superconducting tokamaks with unique, world-leading capabilities, as well as research on international conventional tokamaks.
Long Pulse: Stellarators $7,079,000	**$7,000,000**	**-$79,000**
Superconducting Stellarator Research ($4,168,000) U.S. scientists participated in the first plasma operating campaign of W7-X. The U.S. team was involved with characterizing the 3-D magnetic configuration and performing the first tests of U.S.-supplied equipment during plasma operation. The team also prepared the Test Divertor Unit (TDU) scraper element for the second operating campaign.	*Superconducting Stellarator Research ($4,500,000)* U.S. research teams will utilize new W7-X capabilities to enhance the scientific output of the first major experimental campaign. Experiments will investigate controlling the interface between the magnetic field and plasma-facing components, provide measurements of temperature and poloidal rotation profiles, and use a stellarator- optimization code for plasma equilibrium reconstruction from experimental measurements.	*+$332,000* Funding will enable U.S. scientists to take advantage of U.S. hardware investments to investigate important physics issues in long-pulse plasma confinement, such as edge and impurity transport and pellet fueling for steady-state operation. Gas puff and phase contrast imaging studies will be extended.
Compact Stellarator Research ($2,911,000) Compact stellarator research provided experimental data in regimes of relevance to the mainline stellarator magnetic confinement efforts and helped confirm theoretical models and simulation codes in support of the goal to develop an experimentally validated predictive capability for magnetically confined fusion plasmas.	*Compact Stellarator Research ($2,500,000)* Research will continue on experiments that are providing data in regimes relevant to mainline stellarator confinement and experimental validation of models and codes.	*-$411,000* Research efforts will be focused on the highest-priority stellarator issues.

FY 2016 Enacted	FY 2018 Request	Explanation of Change FY 2018 vs FY 2016
Materials & Fusion Nuclear Science $24,053,000	**$19,823,000**	**-$4,230,000**
Fusion Nuclear Science ($11,271,000) The focus remained on the utilization of existing experimental capabilities to conduct research in the areas of plasma-facing materials and plasma-material interactions consistent with the high-priority research needs identified by the FY 2015 community workshops. Research toward understanding tritium retention and permeation, neutronics, and material-corrosion issues for blankets continued. Scoping studies continued on characterizing significant research gaps in the materials and fusion nuclear sciences program.	*Fusion Nuclear Science ($8,823,000)* Research will continue in the areas of plasma-facing components, safety, tritium fuel cycle, and breeder blanket technologies. The program will continue to utilize existing facilities in support of foundational science as emphasized by the 2015 community workshops and the FES strategic plan. Additionally, the program will continue to evaluate the potential for high-priority research on liquid metal plasma-facing components through a systems-level study.	*-$2,448,000* Research efforts will be focused on the highest-priority fusion nuclear science issues.
Materials Research ($12,782,000) The focus remained on the utilization of existing experimental capabilities to conduct research in the area of material response to simulated fusion neutron irradiation consistent with the high-priority research needs identified by the FY 2015 community workshops. Research toward structural materials that can withstand high levels of damage, increasing the ductility of tungsten, and modeling of helium damage in numerous materials continues.	*Materials Research ($11,000,000)* Research efforts will continue to emphasize the utilization of existing experimental capabilities, as well as explore opportunities for developing new ones, to conduct research in the area of fusion material science. The research effort will continue to focus on the development of materials that can withstand long term exposure to unprecedented fluxes of high-energy neutrons and particles, intense thermomechanical stresses, and novel, high temperatures coolants.	*-$1,782,000* Research efforts will be focuses on the highest-priority fusion material science issues.

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 energy efficient lighting, sterilization and improved wound healing, combustion enhancement, and carbon storage.

This subprogram supports a portfolio of research projects and small- and mid-scale experimental user facilities for exploring the diverse frontiers of plasma science. The activities of this subprogram are carried out through inter- and intra-agency partnerships at academic institutions, industry research groups, and national laboratories across the country.

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 activities involve research in largely unexplored areas of plasma science, with a combination of theory, computer modeling, and experimentation. These frontiers are often, but not limited to, the 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) 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.

The Plasma Science Frontiers portfolio includes coordinated research activities in the following three areas:

- *General Plasma Science* – Research in frontier areas of basic and low temperature plasma science and engineering, including advancing our understanding of the behavior of non-neutral and single-component plasmas, ultra-cold plasmas, dusty plasmas, and micro-plasmas, as well as the study of dynamical processes in classical plasmas including turbulence, thermal, radiative and particle transport, waves, structures, flows and their interactions.

- *High Energy Density Laboratory Plasmas* – Research directed at exploring the behavior of matter at extreme conditions of temperature, density, and pressure, including laboratory astrophysics and planetary science, structure and dynamic of matter at the atomic scale, laser-plasma interactions and relativistic optics, magneto hydrodynamics (MHD) and magnetized plasmas, and plasma atomic physics and radiation transport.

- *Exploratory Magnetized Plasma* – Basic and applied research directed at developing the understanding of laboratory magnetized-plasma behavior necessary to advance innovative solutions and capabilities for the creation, control, and manipulation of magnetically confined plasmas for terrestrial and space applications.

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

<u>Measurement Innovation</u>

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

SBIR/STTR & Other

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

Activities and Explanation of Changes

FY 2016 Enacted	FY 2018 Request	Explanation of Change FY 2018 vs FY 2016
Plasma Science Frontiers $46,504,000	**$23,600,000**	**-$22,904,000**
General Plasma Science ($14,196,000) Research continued in fundamental science areas of plasma turbulence and transport, interactions of plasmas and waves, statistical mechanics of plasmas, and self-organization and reconnection. Research on major FES user facilities was enhanced.	*General Plasma Science ($12,750,000)* Core research areas of this activity will continue with a program focus on intermediate-scale, plasma science user facilities, as well as research in areas identified in the 2015 Frontiers of Plasma Science Workshops Report.	*-$1,446,000* Research and operations on intermediate-scale user facilities will be emphasized to pursue opportunities identified in the 2015 community workshops.
High Energy Density Laboratory Plasmas ($21,495,000) Research emphasized utilizing the Matter in Extreme Conditions (MEC) instrument at the LCLS facility, including continued operational support for the MEC instrument and the HEDLP research group at SLAC as well as grants for external HED science users of MEC. Fundamental HEDLP science was supported through new research grants as part of the SC/NNSA Joint Program in HEDLP and the NSF/DOE Partnership in Basic Plasma Science and Engineering, as well as operation of the Neutralized Drift Compression Experiment-II.	*High Energy Density Laboratory Plasmas ($6,850,000)* Research will emphasize utilizing the MEC at LCLS, including continued support for the MEC beam-line science team and the experimental and theoretical HEDP research groups at SLAC.	*-$14,645,000* Support will be focused on research and operations for the MEC.
Exploratory Magnetized Plasma ($10,813,000) This portfolio was evaluated through a competitive peer-review process.	*Exploratory Magnetized Plasma ($4,000,000)* Research efforts will focus on discovery at the frontier of laboratory magnetized-plasma physics, emphasizing research in areas identified in the 2015 community workshops.	*-$6,813,000* Research and operations on intermediate-scale user facilities will be emphasized to pursue opportunities identified in the 2015 community workshops.

FY 2016 Enacted	FY 2018 Request	Explanation of Change FY 2018 vs FY 2016
Measurement Innovation $3,568,000	**$900,000**	**-$2,668,000**
Core research elements of the Measurement Innovation activity continued with enhanced effort on diagnostic development important to addressing the scientific issues identified in the community workshops held in FY 2015.	Measurement Innovation research activities will continue with special emphasis on diagnostics for plasma transient instabilities, plasma-materials interactions, modeling validation, and basic plasma science identified in the 2015 community workshops.	Funding will support activities initiated through the FY 2017 measurement innovation solicitation.
SBIR/STTR & Other $15,218,000	**$9,517,000**	**-$5,701,000**
Funding continued to support USBPO activities, HBCUs, peer reviews for solicitations, and FESAC. SBIR/STTR funding is statutorily set at 3.45 percent of noncapital funding in FY 2016.	Funding will continue to support USBPO activities, HBCUs, peer reviews for solicitations, and FESAC. SBIR/STTR funding is statutorily set at 3.45 percent of noncapital funding in FY 2018.	Funding supports SBIR/STTR and other activities.

Fusion Energy Sciences
Construction

Description

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

Fusion Energy Sciences
Construction

Activities and Explanation of Changes

FY 2016 Enacted	FY 2018 Request	Explanation of Change FY 2018 vs FY 2016
U.S. Contributions to ITER Project $115,000,000 Funding supported continued progress on in-kind hardware contributions, including: central solenoid superconducting magnet modules and structures, toroidal field magnet conductor, steady-state electrical network components, and tokamak cooling water system components.	**$63,000,000** Funding is provided for ITER.	**-$52,000,000** Funding is reduced for the ITER project. No funding is provided for the annual IO monetary contribution for FY 2018.

Fusion Energy Sciences
Performance Measures

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

	FY 2016	FY 2017	FY 2018
Performance Goal (Measure)	**FES Facility Based Experiments - Experiments conducted on major fusion facilities [DIII-D National Fusion Facility (DIII-D) and National Spherical Torus Experiment Upgrade (NSTX)-U] leading toward predictive capability for burning plasmas and configuration optimization**		
Target	Conduct research to detect and minimize the consequences of disruptions in present and future tokamaks. Coordinated research will deploy a disruption prediction/warning algorithm on existing tokamaks, assess approaches to avoid disruptions, and quantify plasma and radiation asymmetries resulting from disruption mitigation measures, including both preexisting and resulting MHD activity, as well as the localized nature of the disruption mitigation system. The research will employ new disruption mitigation systems, control algorithms, and hardware to help avoid disruptions, along with measurements to detect disruption precursors and quantify the effects of disruptions.	Conduct research to examine the effect of configuration on operating space for dissipative divertors. Handling plasma power and particle exhaust in the divertor region is a critical issue for future burning plasma devices. The very narrow edge power exhaust channel projected for tokamak devices that operate at high poloidal magnetic field is of particular concern. Increased and controlled divertor radiation, coupled with optimization of the divertor configuration, are envisioned as the leading approaches to reducing peak heat flux on the divertor targets and increasing the operating window for dissipative divertors. Data obtained from DIII-D and NSTX-U and archived from Alcator C-Mod will be used to assess the impact of edge magnetic configurations and divertor geometries on dissipative regimes, as well as their effect on the width of the power exhaust channel, thus providing essential data to test and validate leading boundary plasma models.	Conduct research to test predictive models of fast ion transport by multiple Alfvén eigenmodes. Fusion alphas and injected energetic neutral particle beams provide an important source of heating and current drive in advanced tokamak operating scenarios and burning plasma regimes. Alfvén eigenmode instabilities can cause the redistribution or loss of fast ions and driven currents, as well as potentially decreasing fusion performance and leading to localized losses. Measured fast ion fluxes in DIII-D and NSTX-U plasmas with different levels of Alfvén eigenmode activity will be used to determine the threshold for significant fast ion transport, assess mechanisms and models for such transport, and quantify the impact on beam power deposition and current drive. Measurements will be compared with theoretical predictions, including quantitative fluctuation data and fast ion density, in order to validate models and improve understanding of underlying mechanisms. Model predictions will guide the development of attractive operating regimes.
Result	Met	TBD	TBD
Endpoint Target	Magnetic fields are the principal means of confining the hot ionized gas of a plasma long enough to make practical fusion energy. The detailed shape of these magnetic containers leads to many variations in how the plasma pressure is sustained within the magnetic bottle and the degree of control that experimenters can exercise over the plasma stability. These factors, in turn, influence the functional and economic credibility of		

	the eventual realization of a fusion power reactor. The key to their success is a detailed physics understanding of the confinement characteristics of the plasmas in these magnetic configurations. The major fusion facilities can produce plasmas that provide a wide range of magnetic fields, plasma currents, and plasma shapes. By using a variety of plasma control tools, appropriate materials, and having the diagnostics needed to measure critical physics parameters, scientists will be able to develop optimum scenarios for achieving high performance plasmas in future burning plasma devices and, ultimately, in power plants.		
Performance Goal (Measure)	**FES Facility Operations - Average achieved operation time of FES user facilities as a percentage of total scheduled annual operation time**		
Target	≥ 90 %	≥ 90 %	≥ 90 %
Result	Met	TBD	TBD
Endpoint Target	Many of the research projects that are undertaken at the Office of Science's scientific user facilities take a great deal of time, money, and effort to prepare and regularly have a very short window of opportunity to run. If the facility is not operating as expected the experiment could be ruined or critically setback. In addition, taxpayers have invested millions or even hundreds of millions of dollars in these facilities. The greater the period of reliable operations, the greater the return on the taxpayers' investment.		
Performance Goal (Measure)	**FES Theory and Simulation - Performance of simulations with high physics fidelity codes to address and resolve critical challenges in the plasma science of magnetic confinement**		
Target	Predicting the magnitude and scaling of the divertor heat load width in magnetically confined burning plasmas is a high priority for the fusion program. One of the key unresolved physics issues is what sets the heat flux width at the entrance to the divertor region. Perform massively parallel simulations using 3D edge kinetic and fluid codes to determine the parameter dependence of the heat load width at the divertor entrance and compute the divertor plate heat flux applicable to moderate particle recycling conditions. Comparisons will be made with data from DIIID, NSTX-U, and C-Mod.	Lower hybrid current drive (LHCD) will be indispensable for driving off-axis current during long-pulse operation of future burning plasma experiments, since it offers important leverage for controlling damaging transients caused by magnetohydrodynamic instabilities. However, the experimentally demonstrated high efficiency of LHCD is incompletely understood. In FY 2017, massively parallel, high-resolution simulations with 480 radial elements and 4095 poloidal modes will be performed using full-wave radiofrequency field solvers and particle Fokker-Planck codes to elucidate the roles of toroidicity and full-wave effects. The simulation predictions will be compared with experimental data from the superconducting EAST tokamak.	The interaction of the boundary plasma with the material surfaces in magnetically confined plasmas is among the most critical problems in fusion energy science. In FY 2018, perform high-performance computational simulations with coupled boundary plasma physics and materials surface models to predict the fuel recycling and tritium retention of the divertor for deuterium-tritium burning plasma conditions, accounting for erosion, re-deposition and impurity transport in the plasma boundary, and an initial evaluation of the influence of material deposition on the recycling and retention.
Result	Met	TBD	TBD
Endpoint Target	Advanced simulations based on high physics fidelity models offer the promise of advancing scientific discovery in the plasma science of magnetic fusion by exploiting the Office of Science high performance computing resources and associated advances in computational science. These simulations are able to address the multiphysics and multiscale challenges of the burning plasma state and contribute to the FES goal of advancing the fundamental science of magnetically confined plasmas to develop the predictive capability needed for a sustainable fusion energy source.		

Fusion Energy Sciences
Capital Summary ($K)

	Total	Prior Years	FY 2016 Enacted	FY 2017 Annualized CR[a]	FY 2018 Request	FY 2018 vs FY 2016
Capital Operating Expenses Summary						
Capital equipment	n/a	n/a	7,566	-		-7,566
General plant projects (GPP)	n/a	n/a	5,521	-	0	-5,521
Accelerator Improvement Projects (AIP) (<$5M)				-		
Total, Capital Operating Expenses	**n/a**	**n/a**	**13,087**	**-**	**0**	**-13,087**
Capital Equipment						
Major items of equipment[b]						
National Spherical Torus Experiment Upgrade (TPC $94,300)	83,665	80,195	0	-	0	0
Total MIEs	**n/a**	**80,195**	**0**	**-**	**0**	**0**
Total Non-MIE Capital Equipment	n/a	n/a	7,566	-		
Total, Capital equipment	**n/a**	**n/a**	**7,566**	**-**		
General Plant Projects[c]						
General Plant Projects under $2 million TEC	n/a	n/a	5,521	-		

[a]FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above, below that level, a dash (-) is shown.
[b] Each MIE located at a DOE facility Total Estimated Cost (TEC) >$5M and each MIE not located at a DOE facility TEC > $2M.
[c] Each Plant Project (GPP/GPE) Total Estimated Cost (TEC) > $5M

Fusion Energy Sciences
Construction Projects Summary ($K)

	Total	Prior Years	FY 2016 Enacted	FY 2017 Enacted	FY 2018 Request	FY 2018 vs FY 2016
14-SC-60, U.S. Contributions to ITER Project						
Total Estimated Cost (TEC)	TBD	947,905	115,000	50,000	63,000	-52,000
Other Project Cost (OPC)	TBD	74,980	0		0	0
Total, Project Cost (TPC), 14-SC-60	**TBD**	**1,022,885**	**115,000**	**50,000**	**63,000**	**-52,000**

Fusion Energy Sciences
Funding Summary ($K)

	FY 2016 Enacted	FY 2017 Annualized CR[a]	FY 2018 Request	FY 2018 vs FY 2016
Research	218,978	-	166,340	-52,638
Scientific user facility operations	98,147	-	80,600	-17,547
Major items of equipment	0	-	0	0
Other (GPP, GPE, and infrastructure)	5,875	-	0	-5,875
Construction	115,000	-	63,000	-52,000
Total, Fusion Energy Sciences	**438,000**	**437,167**	**309,940**	**-128,060**

[a] FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above, below that level, a dash (-) is shown.

Scientific User Facility Operations and Research ($K)

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

Definitions:

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

Planned Operating Hours –

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

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

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

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

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

	FY 2016 Enacted	FY 2017 Annualized CR[a]	FY 2018 Request	FY 2018 vs FY 2016
TYPE A FACILITIES				
DIII-D National Fusion Facility	**$79,407**	**-**	**$83,000**	**+$3,593**
Number of Users	618	-	650	+32
Achieved operating hours	691	-	N/A	
Planned operating hours	600	-	720	+120
Optimal hours	1,000	-	720	-280
Percent optimal hours	69.1%	-	100%	+31%
Unscheduled downtime hours	0	-	N/A	N/A

[a]FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above, below that level, a dash (-) is shown.

	FY 2016 Enacted	FY 2017 Annualized CR[a]	FY 2018 Request	FY 2018 vs FY 2016
Alcator C-Mod	**$18,049**	**-**	**0**	**-$18,049**
Number of Users	140	-	0	0
Achieved operating hours	N/A	-	N/A	N/A
Planned operating hours	160	-	0	0
Optimal hours	800	-	0	0
Percent optimal hours	20%	-	0	0
Unscheduled downtime hours	N/A	-	N/A	N/A
National Spherical Torus Experiment-Upgrade	**$72,568**	**-**	**$55,600**	**-$16,968**
Number of Users	362	-	297	-65
Achieved operating hours	402	-	N/A	N/A
Planned operating hours	720	-	0	-720
Optimal hours	1,000	-	0	-1,000
Percent optimal hours	40%	-	N/A	-40%
Unscheduled downtime hours	318	-	N/A	N/A
Total Facilities	**$170,024**	**-**	**138,600**	**-$31,424**
Number of Users	1,206	-	970	+8
Achieved operating hours	1,650	-	N/A	N/A
Planned operating hours	1,480	-	720	-760
Optimal hours	2,800	-	720	-1,800
Percent of optimal hours[b]	55.9%	-	100%	+44.1%
Unscheduled downtime hours	318	-	N/A	N/A

[a] FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above, below that level, a dash (-) is shown.

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

Scientific Employment

	FY 2016 Enacted	FY 2017 Annualized CR[a]	FY 2018 Request	FY 2018 vs FY 2016
Number of permanent Ph.D.'s (FTEs)	767	-	510	-253
Number of postdoctoral associates (FTEs)	98	-	65	-33
Number of graduate students (FTEs)	293	-	160	-133
Other[b]	1,025	-	785	-240

[a] FY 2017 amounts shown reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above, below that level, a dash (-) is shown.

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

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

1. Significant Changes and Summary

Significant Changes

This Construction Project Data Sheet (CPDS) is an update of the FY 2017 CPDS and does not include a new start for FY 2018. The DOE Order 413.3B approved Critical Decision (CD) CD-1, "Approve Alternative Selection and Cost Range" was approved on January 25, 2008 with a preliminary cost range of $1.45–$2.2 billion. Since 2008, the estimated cost range for the project increased such that the upper bound of the approved CD-1 cost range increased by more than 50% triggering the need for a reassessment of the project cost range and re-approval by the Project Management Executive (PME). The Project Management Executive for the U.S. ITER project is the Deputy Secretary of Energy. The cost range reassessment was completed in November 2016 and it was then subsequently approved by the PME in January 13, 2017. The CD-1 Revised cost range is now $4.7B to $6.5B.

DOE has divided the U.S. ITER project hardware scope into two distinct subprojects, which represent the two phases of the project: subproject 1 is the hardware scope leading to First Plasma (FP), and subproject 2 is hardware for the post-First Plasma project. This CPDS focuses only on the FP subproject activities. A review of CD-2, "Approve Performance Baseline" for the First Plasma subproject was completed in November 2016 and then subsequently approved by the PME on January 13, 2017, with a total project cost of $2.5B, with a CD-4, "Project Completion" date of December 2027.

The FP subproject scope consists of: 1) completing the design for all twelve subsystems the U.S. was contributing to ITER; 2) complete fabrication and delivery of the Toroidial Field (TF) coil superconductor, Steady State Electrical Network (SSEN), and the Central Solenoid (CS) superconducting magnet modules and associated structures; and 3) partial fabrication and delivery of seven other subsystems: Tokamak Cooling Water, Roughing Pumps, Vacuum Auxillary, Pellet Injection, Ion Cyclotron Heating, Electron Cyclotron Heating, Diagnostics.

Summary

ITER is a major fusion research facility being constructed in St. Paul-lez-Durance, France by an international partnership of seven governments. Since it will not result in a facility owned by the U.S. or located in the U.S., the U.S. Contributions to ITER (U.S. ITER) project is not classified as a Capital Asset project, but is classified as a Major System Project. The U.S. ITER project is a U.S. Department of Energy project to provide the U.S. share of the ITER project (in-kind hardware i.e., subsystems, equipment, and components, as well as monetary resources to support the ITER Organization (IO) in France). Sections of this CPDS have been tailored accordingly to reflect the nature of this project.

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

As of the end of September, 2017, the U.S. ITER FP project is more than 50% complete; design of hardware needed for FP technical systems is 86% complete; and 19% of the hardware deliveries are complete. Active fabrication is underway in five of the U.S. twelve hardware systems (TCWS, Steady State Electric Network [SSEN] Components, Toroidal Field [TF] Conductor and CS Magnets and Vacuum Auxiliary Systems [VAS]). The U.S. has also procured major high-voltage electric power components (e.g., transformers, switch gear, circuit breakers, and voltage regulators). Deliveries of U.S. electric power components to the ITER site in France began in FY 2014 and were completed in FY 2017. Fabrication of the TF coil superconductor was also competed in FY 2017. The U.S. ITER project has subcontracted with General Atomics (GA) for the fabrication of the world's largest pulsed superconducting magnets for the ITER CS magnet system. In FY 2017, commissioning was completed for all of the eleven work stations in the CS magnet module fabrication facility for the fabrication of the seven (six production and one spare) magnet modules the U.S. is responsible for delivering to the international ITER project. The U.S. completed fabrication of a mockup (non-superconducting) copper coil which was to provide assurance of all the CS manufacturing processes. Also, GA completed the winding of the first two magnet modules in FY 2017. By the end of CY 2017, five of seven modules will be in fabrication. To date the U.S. ITER project has awarded and obligated over $860 million to U.S. industry, universities, and DOE laboratories.

FY 2018 funding will support ITER Project Office operations including project management. Additional planning will follow discussions with Congress and ITER partners.

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

2. Critical Milestone History

(fiscal quarter or date)

	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2006	7/5/2005		TBD	TBD		TBD	N/A	TBD
FY 2007	7/5/2005		TBD	TBD		TBD	N/A	2017
FY 2008	7/5/2005		1/25/2008	4Q FY 2008		TBD	N/A	2017
FY 2009	7/5/2005	09/30/2009[a]	1/25/2008	4Q FY 2010		TBD	N/A	2018
FY 2010	7/5/2005	07/27/2010[b]	1/25/2008	4Q FY 2011		TBD	N/A	2019
FY 2011	7/5/2005	05/30/2011[c]	1/25/2008	4Q FY 2011	04/12/2011[d]	TBD	N/A	2024
FY 2012	7/5/2005	07/10/2012[e]	1/25/2008	3Q FY 2012	05/02/2012[f]	TBD	N/A	2028
FY 2013	7/5/2005	12/11/2012[g]	1/25/2008	TBD[h]	04/10/2013[i]	TBD	N/A	2033
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, Cost Range, and Start of Long-lead Procurements
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 (06/2017); Roughing Pumps I&C (06/2017); VAS 03 Supply I&C (04/2017); CS AT Bus Bar Alignment and Coaxial Heater (04/2017); VAS Main Piping L3/L4 (03/2017); VAS 02 CGVS (&C Part 1 (06/2017).

	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	1Q2027	2034-2038

3. Project Cost History

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

4. Project Scope and Justification

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

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.

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

5. Financial Schedule

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
Total Estimated Cost (TEC)			
Hardware			
FY 2006	13,754	13,754	6,169
FY 2007	34,588	34,588	24,238
FY 2008	25,500	25,500	24,122
FY 2009	85,401	85,401	26,278
FY 2010	85,266	85,266	46,052
FY 2011	63,875	63,875	84,321
FY 2012[b]	91,441	91,407	99,215
FY 2013	107,635	107,669	110,074
FY 2014[c]	161,605	161,605	153,368
FY 2015	128,682	128,682	105,908
FY 2016[d]	115,000	115,000	102,561
FY 2017	50,000	50,000	158,942
FY 2018	63,000	63,000	73,000
Subtotal	1,025,747	1,025,747	1,014,248
Total, Hardware	TBD	TBD	TBD
Cash Contributions[e]			
FY 2006	2,112	2,112	2,112
FY 2007	7,412	7,412	7,412
FY 2008	2,644	2,644	2,644
FY 2009	23,599	23,599	23,599
FY 2010	29,734	29,734	29,734
FY 2011	3,125	3,125	3,125
FY 2012	13,214	13,214	13,214
FY 2013	13,805	13,805	13,805
FY 2014[b]	32,895	32,895	32,895
FY 2015	15,957	15,957	15,957
FY 2016[f]	0	0	0
FY 2017	0	0	0
FY 2018	0	0	0
Subtotal	144,497	144,497	144,497
Total, Cash Contributions	TBD	TBD	TBD
Total, TEC	TBD	TBD	TBD
Other project costs (OPC)			
FY 2006	3,449	3,449	1,110
FY 2007	18,000	18,000	7,607
FY 2008	-2,074	-2,074	7,513
FY 2009	15,000	15,000	5,072
FY 2010	20,000	20,000	7,754

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

(dollars in thousands)

	Appropriations	Obligations	Costs[a]
FY 2011	13,000	13,000	10,032
FY 2012[a]	345	345	22,336
FY 2013	2,560	2,560	5,984
FY 2014[b]	5,000	5,000	2,717
FY 2015	5,361	5,361	5,500
FY 2016	0	0	3,958
FY 2017	0	0	1,058
FY 2018	0	0	0
Subtotal	80,641	80,641	80,641
Total, OPC	TBD	TBD	TBD
Total Project Costs (TPC)			
FY 2006	19,315	19,315	9,391
FY 2007	60,000	60,000	39,257
FY 2008	26,070	26,070	34,279
FY 2009	124,000	124,000	54,949
FY 2010	135,000	135,000	83,540
FY 2011	80,000	80,000	97,478
FY 2012[a]	105,000	104,966	134,765
FY 2013	124,000	124,034	129,863
FY 2014[b]	199,500	199,500	188,980
FY 2015	150,000	150,000	127,365
FY 2016	115,000	115,000	106,519
FY 2017	50,000	50,000	160,000
FY 2018	63,000	63,000	73,000
Subtotal	1,250,885	1,250,885	1,239,386
Total, TPC	TBD	TBD	TBD

6. Details of the 2018 Project Cost Estimate

An Independent Project Review 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 FP as well as the proposed updated CD-1 Cost Range. Outcomes from the IPR indicated that the project was ready for approval of FP 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.

7. Schedule of Appropriation Requests

		Prior Years	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	Outyears	Total
FY 2006	TEC	1,009,000	29,000	0	0	0	0	0	0	1,038,000
	OPC	80,600	3,400	0	0	0	0	0	0	84,000
	TPC	1,089,600	32,400	0	0	0	0	0	0	1,122,000
FT 2007	TEC	930,151	116,900	30,000	0	0	0	0	0	1,077,051
	OPC	44,949	0	0	0	0	0	0	0	44,949
	TPC	975,100	116,900	30,000	0	0	0	0	0	1,122,000

[a] Prior actuals adjusted to incorporate project funds utilized at PPPL and DOE. Obligation adjusted to reflect year-end PPPL settlement funding.

[b] Appropriations prior to FY 2014 reflect major item of equipment funding. Starting in FY 2014, this project is funded as a Congressional control point.

		Prior Years	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	Outyears	Total
FY 2008	TEC	931,330	116,900	30,000	0	0	0	0	0	1,078,230
	OPC	43,770	0	0	0	0	0	0	0	43,770
	TPC	975,100	116,900	30,000	0	0	0	0	0	1,122,000
FY 2009[a]	TEC	266,366	0	0	0	TBD	TBD	TBD	TBD	TBD
	OPC	38,075	0	0	0	TBD	TBD	TBD	TBD	TBD
	TPC	304,441	0	0	0	TBD	TBD	TBD	TBD	TBD
FY 2010	TEC	294,366	0	0	0	TBD	TBD	TBD	TBD	TBD
	OPC	70,019	0	0	0	TBD	TBD	TBD	TBD	TBD
	TPC	364,385	0	0	0	TBD	TBD	TBD	TBD	TBD
FY 2011	TEC	379,366	0	0	0	TBD	TBD	TBD	TBD	TBD
	OPC	65,019	0	0	0	TBD	TBD	TBD	TBD	TBD
	TPC	444,385	0	0	0	TBD	TBD	TBD	TBD	TBD
FY 2012[b]	TEC	394,566	0	0	0	TBD	TBD	TBD	TBD	TBD
	OPC	75,019	0	0	0	TBD	TBD	TBD	TBD	TBD
	TPC	469,585	0	0	0	TBD	TBD	TBD	TBD	TBD
FY 2013[c]	TEC	476,296	140,965	0	0	TBD	TBD	TBD	TBD	TBD
	OPC	73,089	9,035	0	0	TBD	TBD	TBD	TBD	TBD
	TPC	549,385	150,000	0	0	TBD	TBD	TBD	TBD	TBD
FY 2014[d]	TEC	476,296	105,572	225,000	0	TBD	TBD	TBD	TBD	TBD
	OPC	73,089	70	0	0	TBD	TBD	TBD	TBD	TBD
	TPC	549,385	105,642	225,000	0	TBD	TBD	TBD	TBD	TBD
FY 2015	TEC	481,940	121,465	194,500	144,639	TBD	TBD	TBD	TBD	TBD
	OPC	67,445	2,535	5,000	5,361	TBD	TBD	TBD	TBD	TBD
	TPC	549,385	124,000	199,500	150,000	TBD	TBD	TBD	TBD	TBD
FY 2016	TEC	481,940	121,465	194,500	144,639	150,000	TBD	TBD	TBD	TBD
	OPC	67,445	2,535	5,000	5,361	0	TBD	TBD	TBD	TBD
	TPC	549,385	124,000	199,500	150,000	150,000	TBD	TBD	TBD	TBD
FY 2017[a]	TEC	481,940	121,499	194,500	144,639	115,000	125,000	TBD	TBD	TBD
	OPC	67,445	2,535	5,000	5,361	0	0	TBD	TBD	TBD
	TPC	549,385	124,034	199,500	150,000	115,000	125,000	TBD	TBD	TBD
FY 2018	TEC	481,665	121,440	194,500	144,639	115,000	50,000	63,000	TBD	TBD
	OPC	67,720	2,560	5,000	5,361	0	0	0	TBD	TBD
	TPC	549,385	124,000	199,500	150,000	115,000	50,000	63,000	TBD	TBD

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

High Energy Physics

Overview

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

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

A world-wide program of particle physics research is underway to discover what lies beyond the Standard Model. Five intertwined science drivers of particle physics provide compelling lines of inquiry that show 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 and aligned with three HEP subprograms:

- Energy Frontier, where researchers accelerate particles to the highest energies ever made by humanity and collide them to produce and study the fundamental constituents of matter. This requires some of the largest machines ever built. The Large Hadron Collider (LHC) at the European Organization for Nuclear Research, known as CERN, is 17 miles in circumference, accelerates and collides high-energy protons while sophisticated detectors, some the size of apartment buildings, observe newly produced particles that provide insight into fundamental forces of nature and the conditions of the early universe.

- Intensity Frontier, where researchers use a combination of intense particle beams and highly sensitive detectors to make extremely precise measurements of particle properties, study some of the rarest particle interactions predicted by the Standard Model of particle physics, and search for new physics. Measurements of the mass and other properties of neutrinos may have profound consequences for understanding the evolution and ultimate fate of the universe.

- Cosmic Frontier, where researchers use naturally occurring cosmic particles and phenomena to reveal the nature of dark matter, understand the cosmic acceleration caused by dark energy and inflation, infer certain neutrino properties, and explore the unknown. The highest-energy particles ever observed have come from cosmic sources, and the ancient light from the early universe and distant galaxies allows the distribution of dark matter to be mapped and perhaps the nature of dark energy and inflation to be unraveled. Ultra-sensitive detectors deep underground may glimpse the dark matter passing through Earth. Observations of the cosmic frontier may reveal a universe far stranger than ever thought possible.

This program of scientific discovery is formulated and enabled through the support of the Theoretical and Computational Physics and the Advanced Technology Research and Development (R&D) subprograms. Theoretical and Computational Physics 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 that are necessary for designing, operating, and interpreting experiments while performing the computational science and simulations on extremely large data sets that enable discovery research in the three frontiers. Advanced Technology R&D 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 impact activities outside the traditional HEP boundaries. The activities of the Stewardship subprogram include: improving access to Office of Science (SC) accelerator R&D infrastructure for industrial 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. 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 industry, medicine, and national security.

Highlights of the FY 2018 Budget Request

The U.S. particle physics community developed a long-term strategic plan through a multi-year process that culminated in the May 2014 report of the Particle Physics Project Prioritization Panel (P5), Building for Discovery: Strategic Plan for U.S. Particle Physics in the Global Context[a]. The P5 report was unanimously approved by the High Energy Physics Advisory Panel (HEPAP) to serve the DOE and National Science Foundation (NSF) as the ten-year strategic plan for U.S. high energy physics in the context of a 20-year global vision. Guided by the vision of the P5 report, the FY 2018 Budget Request focuses support on the highest priority elements of the P5 strategy. 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 the Long Baseline Neutrino Facility and Deep Underground Neutrino Experiment (LBNF/DUNE) as the highest-priority large project in its timeframe. The Request supports these high-priority projects with the least adjustment possible to their planned scope and schedule. Other efforts across Research, Facility Operations, and Projects will have their scope reduced or schedules delayed, based on factors including the P5 report strategy and project maturity. The FY 2018 Request supports the Large Synoptic Survey Telescope camera (LSSTcam), Muon to Electron Conversion Experiment (Mu2e), and the Large Underground Xenon (LUX)-ZonEd Proportional scintillation in LIquid Nobles gases (ZEPLIN) experiment (LZ) projects consistent with the planned fabrication funding profiles. The Dark Energy Spectroscopic Instrument (DESI) project, which received CD-3 approval for start of fabrication, will be rebaselined in coordination with DOE's partnering agency, NSF, so that it can be completed on a delayed timescale. The Request provides funding for a new Major Item of Equipment (MIE), the Facility for Advanced Accelerator Experimental Tests II (FACET-II), for the design and fabrication of the Super Cryogenic Dark Matter Search at Sudbury Neutrino Observatory Laboratory (SuperCDMS-SNOLAB) project, and for research and conceptual design of the Proton Improvement Plan II (PIP-II) construction project. Most research activities will be reduced; higher priority will be given to support the laboratory research programs that are critical to executing the P5 recommendations, and for R&D that requires long-term investments including Accelerator Stewardship, Detector R&D, and Quantum Information Science (QIS). The Request provides reduced funding for the Fermi National Accelerator Laboratory (Fermilab) Accelerator Complex to operate and support the neutrino and muon experiments.

<u>Energy Frontier Experimental Physics</u>
The LHC has exceeded its goals as it operates at collision energies of 13 teraelectronvolt (TeV), setting new performance records and delivering at an unprecedented pace the number of particle collisions, or luminosity, to the ATLAS and CMS experiments. Physics results from this higher-energy and higher-luminosity data will continue through FY 2018, critically

[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

informing future HEP research directions and opportunities. HEP will continue investment in the LHC by contributing to the U.S. share of the HL-LHC accelerator and detector upgrades.

Intensity Frontier Experimental Physics

The FY 2018 Request supports activities necessary to establish a U.S.-hosted, world-leading neutrino physics program, consisting of LBNF/DUNE, the related Short-Baseline Neutrino (SBN) program at Fermilab, and R&D efforts surrounding the prototypes for DUNE (protoDUNE) at CERN. This includes continued funding for the PIP-II project that will upgrade the Fermilab linear accelerator to increase beam power and sustain high reliability of the Fermilab Accelerator Complex. These upgrades are necessary to provide proton beam intensity of greater than one megawatt for LBNF/DUNE, as recommended in the P5 report. Fermilab will plan for an extended shutdown of the accelerator complex in FY 2018.

Cosmic Frontier Experimental Physics

Two complementary next-generation experiments will advance our understanding of dark energy. The LSSTcam will scan half of the sky repeatedly with optical imaging sensors, building up a "cosmic cinematography" of the changing universe, while DESI will study 30 million galaxies and quasars by creating three-dimensional maps of the distribution of matter over two-thirds of the age of the universe. The LSSTcam and DESI projects will be in their fabrication phases in FY 2018. Two second-generation direct-detection dark matter experiments, LZ and SuperCDMS-SNOLAB, will carry out complementary searches for dark matter candidates over a broad range of masses. LZ will use a liquid xenon detector located at the Sanford Underground Research Facility (SURF) in Lead, South Dakota, and will continue its fabrication phase in FY 2018. SuperCDMS-SNOLAB will use cryogenic semi-conductor detectors located at SNOLAB in Sudbury, Canada and will move into final design and then start the fabrication phase in FY 2018.

Theoretical and Computational Physics

The FY 2018 Request will support major theoretical research thrusts that focus on the P5 science drivers, intertwining the physics of the Higgs boson, neutrino masses, the dark universe, and exploring the unknown. Computational physics efforts focus on emerging computational science techniques that advance the HEP mission and new computing models and technology that will address projected needs in data management and computing resources across the program. The FY 2018 Request includes new funding for QIS research in which HEP has an important role in the national program.

Advanced Technology R&D

The LHC Accelerator Research Program (LARP) ramps down as development and prototyping efforts for powerful new focusing magnets for the LHC transition into production efforts as part of the HL-LHC Accelerator Upgrade Project (HL-LHC AUP). The FACET-II project will continue design and development for the positron beam system. The Detector R&D subprogram develops cutting-edge instrumentation to enable experimental research at the forefront of the field while training the next generation of detector experts. The FY 2018 Request supports R&D to inform the planning and selection of next-generation HEP experiments.

Accelerator Stewardship

The Accelerator Stewardship subprogram supports R&D where advances potentially impact both physical science research and other applications of benefit to the general public, and where there is no private sector R&D activity. The FY 2018 Request reduces support for the Brookhaven National Laboratory's (BNL) Accelerator Test Facility (ATF).

Construction

The FY 2018 Request will increase support for LBNF/DUNE, the highest-priority large project in its timeframe in the P5 report. The requested investment will support the Critical Decision (CD)-3A approved scope of early far-site construction, including site preparation and cavern excavation. The Muon to Electron Conversion Experiment (Mu2e) continues with construction in FY 2018 according to its approved baseline funding profile.

High Energy Physics
Funding ($K)

	FY 2016 Enacted[a b]	FY 2017 Annualized CR[c]	FY 2018 Request	FY 2018 vs FY 2016
Energy Frontier Experimental Physics				
Research	73,505	—	56,290	-17,215
Facility Operations and Experimental Support	54,779	—	44,290	-10,489
Projects	21,085	—	39,000	+17,915
SBIR/STTR	4,659	—	4,265	-394
Total, Energy Frontier Experimental Physics	**154,028**	**—**	**143,845**	**-10,183**
Intensity Frontier Experimental Physics				
Research	54,683	—	42,220	-12,463
Facility Operations and Experimental Support	148,863	—	129,304	-19,559
Projects	36,036	—	14,100	-21,936
SBIR/STTR	7,235	—	6,944	-291
Total, Intensity Frontier Experimental Physics	**246,817**	**—**	**192,568**	**-54,249**
Cosmic Frontier Experimental Physics				
Research	47,326	—	35,530	-11,796
Facility Operations and Experimental Support	13,777	—	8,199	-5,578
Projects	67,780	—	31,600	-36,180
SBIR/STTR	2,337	—	1,800	-537
Total, Cosmic Frontier Experimental Physics	**131,220**	**—**	**77,129**	**-54,091**
Theoretical and Computational Physics				
Research				
Theory	48,615	—	33,850	-14,765
Computational HEP	8,829	—	23,213	+14,384
Total, Research	57,444	—	57,063	-381
Projects	2,000	—	0	-2,000
SBIR/STTR	2,092	—	2,162	+70
Total, Theoretical and Computational Physics	**61,536**	**—**	**59,225**	**-2,311**

[a] The FY 2016 Enacted level includes SBIR and STTR and reflects updates through the end of the fiscal year.
[b] SBIR/STTR is requested in FY 2018 within the various subprograms instead of a consolidated requested as an independent subprogram, as it has been in previous years. The FY 2016 column has been adjusted for comparison purposes.
[c] FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above; below that level, a dash (-) is shown.

	FY 2016 Enacted[a b]	FY 2017 Annualized CR[c]	FY 2018 Request	FY 2018 vs FY 2016
Advanced Technology R&D				
Research				
HEP General Accelerator R&D	44,608	—	32,701	-11,907
HEP Directed Accelerator R&D	21,020	—	5,000	-16,020
Detector R&D	16,587	—	16,450	-137
Total, Research	82,215	—	54,151	-28,064
Facility Operations and Experimental Support	36,300	—	28,670	-7,630
Projects	2,100	—	2,000	-100
SBIR/STTR	4,210	—	3,043	-1,167
Total, Advanced Technology R&D	**124,825**	**—**	**87,864**	**-36,961**
Accelerator Stewardship				
Research	5,643	—	8,953	+3,310
Facility Operations and Experimental Support	4,517	—	3,350	-1,167
SBIR/STTR	314	—	466	+152
Total, Accelerator Stewardship	**10,474**	**—**	**12,769**	**+2,295**
Subtotal, High Energy Physics	**728,900**	**727,514**	**573,400**	**-155,500**
Construction				
11-SC-40, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment	26,000	25,951	54,900	+28,900
11-SC-41, Muon to Electron Conversion Experiment	40,100	40,024	44,400	+4,300
Total, Construction	**66,100**	**65,975**	**99,300**	**+33,200**
Total, High Energy Physics	**795,000**	**793,489**	**672,700**	**-122,300**

SBIR/STTR Funding:

- FY 2016 Enacted: SBIR: $18,128,000; STTR: $2,719,000
- FY 2018 Requested: SBIR: $16,377,000; STTR: $2,303,000

High Energy Physics
Explanation of Major Changes ($K)

	FY 2018 vs FY 2016
Energy Frontier Experimental Physics: The Request prioritizes support for National Laboratory research programs critical to executing the P5 recommendations. Increased project funding supports the HL-LHC AUP MIE (new start), as well as conceptual design activities for the HL-LHC ATLAS and HL-LHC CMS Detector Upgrade projects. FY 2017 is the final year of funding planned for LHC ATLAS and LHC CMS Detector Upgrade projects. The Request reduces funding for research activities at universities. Decreases in operations funding will require a reduction of support to detector maintenance and data management and a delay to planned procurement of compute nodes and data storage.	-10,183
Intensity Frontier Experimental Physics: The Request includes project funding reductions due to the scheduled completion of Muon g-2 project funding in FY 2017 and reductions in pre-conceptual R&D for PIP-II and early investments in the Fermilab SBN program. Operations reductions are driven by the extended shutdown of the Fermilab accelerator complex. The Request supports higher priority laboratory research programs critical to executing the P5 recommendations and reduces funding for research activities at universities.	-54,249
Cosmic Frontier Experimental Physics: The Request includes reductions driven by the planned conclusion of the LSSTcam project. LZ will continue planned fabrication, DESI will be rebaselined, and SuperCDMS-SNOLAB will transition from design to fabrication. The Request supports higher priority laboratory research programs critical to executing the P5 recommendations and reduces funding for research activities at universities. Decreases in funding for currently operating experiments will partially be offset by an increase for early operations of the LSSTcam.	-54,091
Theoretical and Computational Physics: The Request supports higher priority laboratory research programs critical to executing the P5 recommendations and reduces funding for research activities at universities. The Lattice Quantum Chromodynamics (LQCD) project receives final funding in FY 2017. Increased funding will support QIS efforts in quantum computing and quantum sensor development.	-2,311
Advanced Technology R&D: The Request supports reduced funding for research activities at universities and national laboratories. Higher priority will be given to support laboratory research programs critical to executing the P5 recommendations and for R&D that requires long-term investments, including Detector R&D. Funding will decrease as LARP development and prototyping efforts for the LHC focusing magnets transition into production efforts as part of the HL-LHC AUP. The Muon Accelerator Program (MAP) receives final funding in FY 2017. The FACET facility has completed its run and operations funding for it will be minimal until the completion of FACET-II.	-36,961
Accelerator Stewardship: Funding for research will increase to support targeted R&D efforts to develop new uses of accelerator technology with broad applicability, offset by a decrease to support for BNL ATF operations.	+2,295
Construction: The funding request supports the planned profile for construction of Mu2e. The increase to LBNF/DUNE Construction funding will support cavern excavation for LBNF/DUNE as approved at approved CD-3A, and will establish the facility and enable the scheduled delivery of contributions from international partners.	+33,200
Total, High Energy Physics	**-122,300**

Basic and Applied R&D Coordination
Accelerator Stewardship enables development of real-world 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 universities, national laboratories, and industry to help identify specific research areas and infrastructure gaps where HEP investments would have sizable impacts beyond the SC research mission. This program is closely coordinated with the SC's Basic Energy Sciences (BES) and Nuclear Physics (NP) programs and partner agencies[a] to ensure federal stakeholders have input in crafting funding opportunity announcements, reviewing applications, and evaluating the efficacy and impact of funded activities. Use-inspired accelerator R&D for medical applications has been closely coordinated with the NIH/National Cancer Institute (NCI); ultrafast laser technology R&D with the Department of Defense (DOD) and the National Aeronautics and Space Administration (NASA); and microwave and high power accelerator R&D coordinated with the DOD, the Department of Homeland Security's Domestic Nuclear Detection Office (DHS/DNDO), the NSF/ Chemical, Bioengineering, Environmental and Transport (CBET) Systems Division, and the DOE's Office of Environmental Management (EM).

The Accelerator Stewardship conducts use-inspired basic R&D at stages Technology Readiness Levels (TRL)-1 through TRL-4; ensuring the investments will eventually result in high-impact applications requires close coordination with other agencies who will carry on the development. The implementation strategy is to work with applied R&D agencies to define priority research directions at Basic Research Needs Workshops, and through direct participation of applied agency program managers in merit reviews. 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 gantries (joint with Varian Medical Systems), advanced proton sources for therapy (joint with ProNova Solutions), advanced detectors for therapy (joint with Best Medical International) advanced microwave source development (joint with Communications Power Industries), and technical design studies for high power accelerators for environmental cleanup, wastewater treatment (joint with Metropolitan Water Reclamation District of Greater Chicago, General Atomics, Advanced Energy Systems, and Euclid Techlabs). Funded R&D awards have drawn an average of 20% of voluntary cost sharing over the first two years of the program, providing evidence of the potential impact.

Program Accomplishments
Record-breaking LHC performance leads to data accumulation 60% beyond goal for 2016 (Energy Frontier). The LHC is the highest energy particle collider in the world and has nearly doubled its particle collision energy since it was used to discover the Higgs boson particle in 2012. The LHC far exceeded its goal for producing particle collisions in 2016 while continually breaking performance records. While it will take time for the ATLAS and CMS experiment collaborations to analyze the data, early results are already probing the Higgs boson for any sign of new physics. In August 2016, the ATLAS collaboration used data from the highest energy LHC collisions to confirm that Higgs boson's rate of production at 13 TeV collision energy agrees with the predictions of the Standard Model of particle physics. The LHC aims to continue running at its record pace for the next two years and more than double the delivered particle collisions to the experiments, which will enable more detailed measurements of the Higgs boson and more sensitive searches for new physics.

Combined analysis from MINOS and Daya Bay experiments constrain possible sterile neutrino properties (Intensity Frontier). The discovery of neutrino oscillations, which garnered the 2015 Nobel Prize in Physics, proves not only that neutrinos have mass but that the Standard Model of particle physics is incomplete. While three types of neutrinos have been discovered so far, results from some previous experiments are consistent with a theoretical fourth type of neutrino. This additional "sterile" neutrino would not interact with other matter and would only be accessible by studying neutrino oscillations. If a sterile neutrino were discovered, it would be the first discovery of an unexpected fundamental particle since the Standard Model was established. A combined result from the MINOS experiment at Fermilab and the Daya Bay Reactor Neutrino experiment in China released in 2016 yielded the world's most stringent constraints on the properties of a sterile neutrino

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

and narrows the region where scientists must hunt. The remaining allowed region will be searched by the SBN program at Fermilab and other experiments to obtain a definite answer to the question of whether light sterile neutrinos exist.

U.S. Belle II project recognized with DOE Project Management Achievement Award (Intensity Frontier). The U.S. Belle II project, at the Pacific Northwest National Laboratory, successfully developed, assembled, and delivered advance detector systems to the Japanese High Energy Accelerator Research Organization (KEK) laboratory in Tsukuba, Japan, that are essential for efficiently collecting high-precision data on positron-electron collisions within the SuperKEKB accelerator. The $14.8 million project will be part of one of the premier experiments exploring “new physics” beyond the Standard Model through high-precision measurements over the coming decade. The project met Belle II’s very tight schedule for integration and completed successfully in July 2016, two months ahead of schedule and under budget while meeting or exceeding the objective Key Performance Parameters.

Fermilab achieves milestone beam power for neutrino experiments (Intensity Frontier). On January 24, 2017, Fermilab’s flagship particle accelerator delivered a sustained 700-kilowatt proton beam over one hour at an energy of 120 billion electronvolts (GeV). Achieving this record-setting performance required scientists and engineers to apply their expertise to the technical and physics challenges of high-intensity particle beams. With more beam power, Fermilab can provide more neutrinos in a given amount of time and advance the scientific reach of the neutrino experiments served by the Neutrinos at the Main Injector (NuMI) beam, including the NuMI Off-axis electron Neutrino Appearance (NOvA) Experiment and the Main Injector Experiment for ν-A (MINERvA).

World’s most sensitive search performed for direct evidence of dark matter (Cosmic Frontier). The Large Underground Xenon (LUX) experiment completed the world’s most sensitive search for direct evidence of dark matter in 2016, improving upon its own previous world’s best search by a factor of four and narrowing the hiding space for an important class of theoretical dark matter particles. Located a mile beneath the Black Hills of South Dakota, the LUX experiment directly searched for the dark matter particles that may be continually passing through Earth. These results set the stage for a suite of complementary next-generation experiments, LZ and SuperCDMS-SNOLAB, that the U.S. community is already beginning to build, which aim to improve the detection sensitivity by an order of magnitude to reveal the nature of dark matter.

First demonstration of laser-plasma accelerator staging at the Berkeley Lab Laser Accelerator (BELLA) at Lawrence Berkeley National Laboratory (LBNL) (Advanced Technology R&D). An experiment at BELLA successfully accelerated an electron beam through two back-to-back laser-plasma accelerator modules in 2016. Plasma wakefield particle acceleration is an advanced technology that may boost the energy and shrink the size of future linear particle accelerators and have broad impact within the SC. Single-stage laser plasma wakefield acceleration has been previously demonstrated at BELLA using a drive pulse of a high-power laser that generates a plasma wake and a trailing electron pulse that is accelerated by “surfing” on the plasma wake. The staging of multiple acceleration modules is needed to implement this technology in a future Energy Frontier collider.

High Energy Physics
Energy Frontier Experimental Physics

Description

The Energy Frontier will focus on the Large Hadron Collider (LHC). Data collected will be used to address at least three of the five science drivers identified by the P5 report:

- *Use the Higgs boson as a new tool for discovery*
- In the Standard Model of particle physics, the Higgs boson is responsible for generating the mass for all fundamental particles. Since the 2012 Nobel-winning discovery, experiments at the LHC continue to actively measure the Higgs's properties to establish its exact character and discover if there are additional effects that are the result of new physics beyond the Standard Model.
- *Explore the unknown: new particles, interactions, and physical principles*
- Researchers at the LHC probe for evidence of what lies beyond the Standard Model or significantly constrain postulated modifications to it, such as supersymmetry, mechanisms for black hole production, extra dimensions, and other exotic phenomena. The LHC detectors will be increasingly more sensitive to potential deviations from the Standard Model that may be exposed by the high collision energy of at least 13 TeV.
- *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 by inference, since they interact only weakly with normal matter. This "indirect" detection of dark matter is complementary to, and a powerful cross-check on, the ultra-sensitive "direct" detection experiments on the Cosmic Frontier.

The LHC hosts two large multi-purpose particle detectors, CMS and ATLAS, which are partially supported by DOE and the NSF and used by large international collaborations of scientists. U.S. researchers make up approximately 20% of the ATLAS collaboration and approximately 30% of the CMS collaboration, and play critical leadership roles in all aspects of each experiment.

Research

The Energy Frontier experimental research subprogram consists of groups at U.S. academic and research institutions and physicists from national laboratories. These groups, as part of the CMS and ATLAS 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. The subprogram selects research efforts with the highest scientific impact and potential based on a competitive peer-review process. HEP conducted an external peer review of laboratory research groups in this activity in 2015, and findings from this review are being used to inform the funding decisions in subsequent years. HEP plans to review this activity again in 2019 and evaluate progress.

Facility Operations and Experimental Support

U.S. LHC Detector Operations funding supports the maintenance of U.S.-supplied detector systems for the CMS and ATLAS detectors at the LHC and for the U.S.-based computer infrastructure used by U.S. physicists to analyze LHC data, including Tier 1 computing centers at Fermilab and BNL. The Tier 1 centers provide round-the-clock support for the LHC Computing Grid and are responsible for storing a portion of raw and processed data, as well as performing large-scale data reprocessing and storing the corresponding output. This program also supports transatlantic networking capabilities that enable U.S. scientists to analyze the large amount of data produced at the LHC.

Projects

The ongoing LHC ATLAS and LHC CMS Detector Upgrade MIE projects receive final funding in FY 2017.

During the next decade, CERN plans a major upgrade to the LHC machine to further increase the instantaneous luminosity by a factor of three times its design value to explore new physics beyond the reach of the current LHC program. The new MIE for the High-Luminosity LHC Accelerator Upgrade Project (HL-LHC AUP) will deliver LHC components for which U.S. scientists have the critical expertise. After the upgrade, the HL-LHC beam will make the conditions in which the ATLAS and CMS detectors must operate challenging. Conceptual design continues in FY 2018 for the HL-LHC ATLAS and HL-LHC CMS Detector Upgrades that will enable them to operate for an additional decade and collect a factor of ten more data.

Energy Frontier Experimental Physics

Activities and Explanation of Changes

FY 2016	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
Energy Frontier Experimental Physics $154,028,000	**$143,845,000**	**-$10,183,000**
Research $73,505,000	**$56,290,000**	**-$17,215,000**
U.S. university and laboratory scientists started analyzing the newly acquired data from LHC's 13 TeV run. Research activities focused on addressing key areas within the science drivers outlined in the P5 report, which include using the Higgs boson as a new tool for discovery, searching for dark matter, and exploring new particles and their interactions.	Funding for the Energy Frontier research will continue to support U.S. scientists leading high-profile analysis topics using the data collected by the ATLAS and CMS experiments at the LHC.	Decrease will require reduced research activities at universities and national laboratories. Higher priority will be given to support laboratory research programs critical to executing the P5 recommendations.
Facility Operations and Experimental Support $54,779,000	**$44,290,000**	**-$10,489,000**
Funding supported the operation of the LHC ATLAS and CMS detectors during LHC's 13 TeV run. Major activities included continuing the routine maintenance and calibration of the detectors as well as the processing of newly acquired data. Initial investments supported critical R&D activities for longer-term operations of the LHC detectors at higher luminosities.	Funding will support critical ATLAS and CMS detector maintenance and operations during LHC's 13 TeV run as well as the U.S.-based computing infrastructure and resources used by U.S. scientists to analyze LHC data.	Decreases in operations funding will require a reduction of support to detector maintenance and data management and a delay to planned procurement of compute nodes and data storage.
Projects $21,085,000	**$39,000,000**	**+$17,915,000**
The LHC ATLAS and CMS Detector Upgrade projects were baselined in FY 2015 and fabrication activities continued. Conceptual design activities commenced for HL-LHC AUP and HL-LHC ATLAS and HL-LHC CMS detectors.	Funding will be provided for a new HL-LHC AUP MIE (new start) to advance that concept and design. Funding will also be provided to continue conceptual design activities for HL-LHC ATLAS and HL-LHC CMS Detector Upgrade projects.	Increased funding supports the HL-LHC AUP MIE (new start), as well as conceptual design activities for the HL-LHC ATLAS and HL-LHC CMS Detector Upgrade projects. FY 2017 is the final year of funding planned for LHC ATLAS and LHC CMS Detector Upgrade projects.
SBIR/STTR $4,659,000	**$4,265,000**	**-$394,000**
In FY 2016, SBIR/STTR funding was set at 3.45% of non-capital funding.	In FY 2018, SBIR/STTR funding will be assumed to be 3.65% of non-capital funding.	Decreased funding represents mandated percentages for non-capital funding.

Description

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

- *Pursue the physics associated with neutrino mass*
  Of all known particles, neutrinos are perhaps the most enigmatic and certainly the most elusive. HEP researchers working at U.S. facilities discovered all of the three known varieties of neutrinos. HEP supports research into fundamental neutrino properties that may reveal important clues about the unification of forces and the very early history of the universe. The Intensity Frontier-supported portfolio of neutrino experiments will advance neutrino physics while serving as an international platform for the R&D activities necessary to establish the U.S.-hosted international LBNF/DUNE.
- *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 "dark" particles and forces which have ultra-weak couplings to normal matter. These particles and forces are effectively invisible to conventional experiments, but may be connected to the cosmic dark matter. Using intense accelerator beams at national laboratories outfitted with highly efficient high-rate detectors allows for probes of these models via subtle quantum mechanical mixing effects.
- *Explore the unknown, new particles, interactions, and physical principles*
  Prominent in this category are experiments addressing the poorly understood large scale absence of antimatter in the universe and the puzzling three generation family structure of the fundamental constituents of matter.

Research

The Intensity Frontier experimental research subprogram consists of groups at U.S. academic and research institutions and national laboratories that perform experiments. These groups, as part of scientific collaborations, typically have a broad portfolio of responsibilities and leadership roles in support of R&D, experimental design, fabrication, commissioning, operations, and maintenance, as well as perform scientific simulations and physics data analyses on the experiments in the subprogram. The subprogram selects research efforts with the highest scientific merit and potential impact based on a competitive peer-review process. HEP is conducting an external peer review of all laboratory research groups in this subprogram in 2017, and the recommendations will be used to inform funding decisions in subsequent years.

The largest component of the Intensity Frontier subprogram supports 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 NOvA experiment uses the Neutrinos at the Main Injector (NuMI) beam, and the Booster Neutrino Beam (BNB) will be used to study different aspects of neutrino physics. The other major component to the Intensity Frontier is the muon program at Fermilab where rare processes in muons are studied to detect physics beyond the reach of the LHC. The Muon g-2 experiment is being commissioned and a full physics run will follow in FY 2018. The Intensity Frontier subprogram also supports U.S. physicists to participate in select experiments at foreign facilities, including neutrino experiments in China and Japan. There is also a U.S. contingent working on the Belle II experiment at KEK in Japan.

Facility Operations and Experimental Support

There are several distinct facility operations and experimental support efforts in the Intensity Frontier subprogram. The largest is the Fermilab Accelerator Complex User Facility. This activity includes computing and the operation of the accelerator and detectors. General Plant Project (GPP) and Accelerator Improvement Project (AIP) funding supports improvements to facilities. The FY 2018 Request includes funding to continue refurbishment of the oldest parts of the complex, including the linear particle acceleration (linac) and the Booster in order to maintain the reliability and efficiency of the complex. Fermilab manages a contract with the South Dakota Science and Technology Authority for the operation of Sanford Underground Research Facility (SURF) where the Nuclear Physics-supported Majorana Demonstrator is operated and the LZ experiment will be installed. SURF will also be the home of the DUNE far detectors built by the LBNF/DUNE project.

Projects

The P5 report recommended an increase in power for the Fermilab accelerator complex so that PIP-II will provide a 1.2 megawatt beam to LBNF/DUNE, which is higher than the 0.7 megawatt beam used by NOvA. The FY 2018 Request includes Other Project Cost (OPC) funding for conceptual design of the PIP-II upgrade to the front-end of the Fermilab Accelerator complex. The front-end is the oldest part of the complex and needs to be replaced to improve reliability and to produce higher intensity muon and neutrino beams. Fermilab is developing a conceptual design and establishing partnerships with institutions in India and Italy to contribute to the project.

Intensity Frontier Experimental Physics

Activities and Explanation of Changes

FY 2016	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
Intensity Frontier Experimental Physics $246,817,000	**$192,568,000**	**-$54,249,000**
Research $54,683,000	**$42,220,000**	**-$12,463,000**
The first physics analyses from the NOvA experiment were published and new results presented at conferences. LBNF/DUNE physics studies and detector optimization advanced under the umbrella of a new, fully internationalized program. R&D in support of the Fermilab SBN program increased. Physics studies to optimize the operation of the under construction Mu2e experiment continued. Muon g-2 physics commissioning efforts ramped up in preparation for first data in FY 2017. Physics commissioning of the Belle II detector at KEK began.	The NOvA experiment, currently the world's longest-baseline neutrino experiment using the world's most powerful neutrino beam at Fermilab, will be in its fourth year of data taking as the collaboration seeks to resolve the neutrino mass hierarchy. The Fermilab SBN program will continue to advance as MicroBooNE produces new physics results, Imaging Cosmic And Rare Underground Signals (ICARUS) begins physics data taking, and Short Baseline Near Detector (SBND) starts physics commissioning. ProtoDUNE will take data in the CERN beam in FY 2018. The Fermilab Muon g-2 experiment will present first physics data at conferences. R&D, physics studies, and detector simulations will continue for Mu2e and LBNF/DUNE. The Belle II experiment will take first data at the SuperKEKB accelerator in Japan to search for new physics through precision measurements of composite particles made of bottom quarks.	Decrease will require reduced research activities at universities and national laboratories. Higher priority will be given to support laboratory research programs critical to executing the P5 recommendations.

FY 2016	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
Facility Operations and Experimental Support $148,863,000	**$129,304,000**	**-$19,559,000**
The Fermilab Accelerator complex continued to operate to support neutrino physics. The operations of the Main Injector Neutrino Oscillation Search (MINOS+) experiment concluded in June 2016. FY 2016 was an important funding year for two AIPs that provided enhancements for the future operations program: the delivery ring AIP, which modified the antiproton accumulator to store protons for the muon program, and the Recycler RF AIP, which upgraded the RF power in the recycler to handle high intensity proton beams for both the muon program and the short baseline neutrino program at Fermilab. Funding for the SBN Far Hall GPP was completed. SURF operations continued as LUX completed its data-taking and the Majorana demonstrator continued.	The Fermilab Accelerator Complex will operate to support the neutrino and muon experiments. Construction of the Industrial Central Building addition GPP project will finish in FY 2018. SURF operations will support the ongoing Majorana demonstrator activities and preparations for the LZ experiment and LBNF/DUNE construction.	Decreases will result from an extended shutdown of the Fermilab accelerator complex with commensurate reductions in operations support for detectors and computing. The decrease will also delay completion of the first phase of the Proton Improvement Plan, and no new AIPs or GPPs will be started.
Projects $36,036,000	**$14,100,000**	**-$21,936,000**
Funding for the Muon g-2 MIE project continued accelerator modifications and fabrication of the beamline and detectors. A combination of OPC funding and preconceptual R&D funding supported the development of PIP-II, a new superconducting proton linac to replace the more than 40-year-old existing front-end linac at Fermilab. Funding for the SBN program supported subsystems integration and infrastructure needed for the program.	Funding will support the OPC for plant support costs at SURF during LBNF/DUNE construction. In addition OPC is provided to continue the conceptual design for the PIP-II project.	The Request includes no funding for the Muon g-2 project, or for future project R&D.
SBIR/STTR $7,235,000	**$6,944,000**	**-$291,000**
In FY 2016, SBIR/STTR funding was set at 3.45% of non-capital funding.	In FY 2018, SBIR/STTR funding will be assumed to be 3.65% of non-capital funding.	Decreased funding represents mandated percentages for non-capital funding.

Description

The Cosmic Frontier supports the study of high energy physics through measurements of naturally occurring cosmic particles and observations of the universe. The activities in this subprogram use diverse tools and technologies, from ground-based telescopes and space-based experiments to large detectors deep underground, to probe fundamental physics questions and offer new insight about the nature of dark matter, dark energy, inflation in the early universe and other phenomena. Data collected from Cosmic Frontier experiments during this period will be used to address at least three of the five key science drivers identified in the P5 report:

Understand cosmic acceleration: dark energy and inflation

Steady progress continues in studying the nature of dark energy since the Nobel Prize in Physics in 2011 awarded for the

discovery of the acceleration of the expansion of the universe. The Baryon Oscillation Spectroscopic Survey (BOSS) measured galactic distances to a precision of 1% and growth rates through galaxy clustering. Cosmology results from the Dark Energy Survey (DES) includes precision results from Weak lensing cosmic shear, galaxy-galaxy lensing, galaxy clustering, and cross-correlations with cosmic microwave background (CMB) data from the third-generation South Pole Telescope (SPT-3G) experiment, which began operations in February 2017. Inflation, a period of rapid expansion in the universe at extremely high energy shortly after the Big Bang, is the target of the increasing sensitivity of operating and planned CMB experiments seeking direct detection of its quantum fluctuations in space-time. The LSSTcam and DESI projects are in their fabrication phase and will enable complementary, next-generation "Stage-IV" imaging and spectroscopic surveys respectively that will provide over a factor of ten better precision in comparison to current experiments.

Identify the new physics of dark matter

Measurements of motions within galaxies, weighing the universe as a whole, and the primordial abundance of elements all show that dark matter, which is not explained by the Standard Model, accounts for five times as much of the universe as ordinary matter. Direct-detection experiments in the laboratory provide the primary method to search for cosmic dark matter particles' rare interactions with atomic nuclei, while indirect-detection observatories measuring high energy gamma rays search for the products of dark matter annihilation in the core of galaxies. The first generation of direct-detection experiments have completed operations and have significantly tightened the limits on dark matter properties, including world-leading results by the Large Underground Xenon (LUX) experiment. The second generation of experiments, which are currently in various phases of design and fabrication, will achieve an order of magnitude or more improvement in sensitivity to detect direct dark matter. These experiments complemented those searching for dark matter performed in the Intensity Frontier subprogram using accelerator-based experiments and in the Energy Frontier subprogram using LHC data.

Explore the unknown: new particles, interactions, and physical principles

High-energy cosmic and gamma rays probe energy scales well beyond what can be produced with man-made particle accelerators, albeit not in a controlled experimental setting. Searches for new phenomena and for indirect signals of dark matter in high-energy cosmic surveys may yield surprising discoveries about the fundamental nature of the universe.

Research

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

Facility Operations and Experimental Support

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

Projects

The visible matter in the universe accounts for only 5% of the mass and energy of the universe; therefore, P5 recommended robust programs to search for dark matter particles and study the nature of dark energy and the inflationary epoch on the early universe. Two experiments will use different technologies 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 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 cryogenic semiconductor detectors. LZ is better at detecting heavier dark matter particles while SuperCDMS-SNOLAB will be sensitive to lighter dark mass particles, so the two combine to provide the largest search currently feasible.

Cosmic Frontier Experimental Physics

Activities and Explanation of Changes

FY 2016	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
Cosmic Frontier Experimental Physics $131,220,000	**$77,129,000**	**-$54,091,000**
Research $47,326,000	**$35,530,000**	**-$11,796,000**
Research activities focused on addressing key areas within the science drivers outlined in the P5 report. The LUX direct-detection dark matter experiment completed its planned data-taking run and produced the world's best search results for Weakly Interacting Massive Particles (WIMPs). BOSS published the most precise measurements yet of the effects of dark energy in the expansion of the universe by collecting data from 1.2 million galaxies. The SPT-3G experiment achieved first light in its four year survey of CMB polarization data to study cosmic inflation.	Funding will continue to support scientific efforts to analyze current dark matter and cosmic acceleration experiments and for the design and physics optimization for next-generation projects in those areas.	Decrease will require reduced research activities at universities and national laboratories. Higher priority will be given to support laboratory research programs critical to executing the P5 recommendations.
Facility Operations and Experimental Support $13,777,000	**$8,199,000**	**-$5,578,000**
Funding supported underground, surface-based, and space-based experiments in the data-taking phase, including direct-detection dark matter experiments, cosmic acceleration experiments, and cosmic-ray and gamma-ray experiments.	Funding will support early operations activities necessary for projects near completion, such as LSSTcam, and reduced operations of on-going experiments in the physics data-taking phase.	Decreases in operations funding for currently operating experiments will be partially offset by an increase for early operations of LSSTcam.
Projects $67,780,000	**$31,600,000**	**-$36,180,000**
Funding was provided for LSSTcam according to its approved baseline funding profile. DESI and LZ were baselined. SuperCDMS-SNOLAB funding supported design work towards project baseline.	Funding for the LSSTcam project will complete in FY 2018. Funding will support fabrication of the LZ direct-detection dark matter experiment as a priority. DESI fabrication will continue with reduced support. SuperCDMS-SNOLAB will transition from design to fabrication.	The LSSTcam and the LZ projects are funded according to their planned profiles, with a decrease for the LSSTcam and an increase for LZ in FY 2018. Additional decreases result from rebaselining DESI to be consistent with reduced allocation, and reducing SuperCDMS-SNOLAB funding that slows the project.
SBIR/STTR $2,337,000	**$1,800,000**	**-$537,000**
In FY 2016, SBIR/STTR funding was set at 3.45% of non-capital funding.	In FY 2018, SBIR/STTR funding will be assumed to be 3.65% of non-capital funding.	Decreased funding represents mandated percentages for non-capital funding.

Description

The Theoretical and Computational Physics subprogram provides the mathematical, phenomenological, and computational framework to understand and extend our knowledge of the dynamics of particles and fields, and the nature of space and time. This research is essential for proper interpretation and understanding of the experimental research activities described in other HEP subprograms. Major theoretical research thrusts focus on the P5 science drivers, intertwining the physics of the Higgs boson, neutrino masses, and the dark universe along with exploring the unknown. Theory and computation cut across all the five science drivers and the Energy, Intensity, and Cosmic Frontier Experimental Physics subprograms.

Theory

The HEP theory subprogram supports 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, with laboratory groups typically more focused on data-driven theoretical investigations and precise calculations of experimental observables and university groups focused on building models of physics beyond the Standard Model and studying their phenomenology as well as on formal and mathematical theory. The subprogram selects research efforts with the highest scientific impact and potential based on a competitive peer-review process with. HEP conducted an external peer review of all laboratory research groups in Theory in 2014 and the next review will be in 2018. Findings are used to inform the funding decisions in intervening years.

Computational HEP

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

In addition, to supporting the science and technology thrusts, Computational HEP fosters advanced simulations and computational science that extends the boundaries of scientific discovery to regions not directly accessible by experiments, observations, or traditional theory. One focus area in FY 2018 is to use Quantum Information Science (QIS) and advanced computing for discovery along the P5 science drivers. Precision measurements using quantum sensors may yield information on fundamental Beyond the Standard Model physics and the dark sector. Technologies being developed for quantum computing are also candidates for sophisticated sensors for particle physics experiments.

Projects

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

Theoretical and Computational Physics

Activities and Explanation of Changes

FY 2016	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
Theoretical and Computational Physics $61,536,000	**$59,225,000**	**-$2,311,000**
Theory $48,615,000	**$33,850,000**	**-$14,765,000**
Funding continued to support a balanced theoretical research program at universities and national laboratories for the interpretation of experimental results, the development of new ideas for future projects, and the advancement of our theoretical understanding of nature.	Funding will be focused on providing theoretical research support along P5 science drivers.	Decrease will require reduced research activities at universities and national laboratories. Higher priority will be given to support laboratory research programs critical to executing the P5 recommendations.
Computational HEP $8,829,000	**$23,213,000**	**+$14,384,000**
Funding continued to support R&D for computational tools that enable scientific advances in the HEP program. SciDAC 3 projects selected in FY 2015 continued in FY 2016.	Funding will be focused on QIS and advanced computing initiatives. Funding will be provided for SciDAC 4 projects that were competed in FY 2017.	Increased funding will support new QIS and advanced computing initiatives.
Projects $2,000,000	**$0**	**-$2,000,000**
Funding provided for the acquisition of new LQCD hardware.	No funding will be requested for this activity.	LQCD receives final funding in FY 2017.
SBIR/STTR $2,092,000	**$2,162,000**	**+$70,000**
In FY 2016, SBIR/STTR funding was set at 3.45% of non-capital funding.	In FY 2018, SBIR/STTR funding will be assumed to be 3.65% of non-capital funding.	Increased funding represents mandated percentages for non-capital funding.

High Energy Physics
Advanced Technology R&D

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

HEP General Accelerator R&D
HEP General Accelerator R&D (GARD) focuses on understanding the science underlying the technologies used in particle accelerators and storage rings, as well as the fundamental physics of charged particle beams. Long-term research goals include developing technologies to enable breakthroughs in particle accelerator size, cost, beam intensity, and control. The GARD program consists of groups at U.S. academic and research institutions and national laboratories performing research activity categorized into five thrust areas: accelerator and beam physics; advanced acceleration concepts; particle sources and targetry; radio-frequency acceleration technology; and superconducting magnet and materials. GARD prioritizes research topics based on input from the April 2015 HEPAP Accelerator R&D subpanel report. The subprogram selects research efforts with the highest scientific impact and potential based on a competitive peer-review process. HEP conducted an external peer review of all GARD laboratory research groups in 2013 and the next review will be in 2018. The findings of these reviews inform the funding decisions in intervening years.

HEP Directed Accelerator R&D
HEP Directed Accelerator R&D supports strategic investments in innovative technologies for possible future HEP accelerator projects, with proof-of-principle demonstrations, prototype component development, and advancing technical readiness. The LHC Accelerator Research Program (LARP) is carrying out R&D needed to produce prototypes for U.S. deliverables to the HL-LHC accelerator upgrade that CERN is planning to begin building late in this decade.

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

Facility Operations and Experimental Support
This activity provides funding for GARD laboratory experimental and test facilities, including BELLA at LBNL and superconducting radio-frequency (SRF) and magnet facilities at Fermilab. This activity also funds detector test beams at SLAC National Accelerator Laboratory (SLAC) and detector test and fabrication facilities like the Microsystem System Laboratory at LBNL and the Silicon Detector Facility at Fermilab.

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 provide compact or more energetic particle beams for the same lower costs as current ones. FACET-II will support the continuation of the plasma wakefield research started at FACET which was displaced by the construction of Linac Coherent Light Source II (LCLS-II).

Advanced Technology R&D

Activities and Explanation of Changes

FY 2016	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
Advanced Technology R&D $124,825,000	**$87,864,000**	**-$36,961,000**
HEP General Accelerator R&D $44,608,000	**$32,701,000**	**-$11,907,000**
Funding supported the topics that were emphasized in the April 2015 HEPAP Accelerator R&D Subpanel report[a].	The program will execute the research roadmaps developed with the community, and research support will focus in the areas of advanced accelerator concepts and superconducting magnets.	Decrease will require reduced research activities at universities and national laboratories. Higher priority will be given to support laboratory research programs critical to executing the P5 recommendations and for R&D that requires long-term investments, including Detector R&D.
HEP Directed Accelerator R&D $21,020,000	**$5,000,000**	**-$16,020,000**
LARP increased effort to develop a prototype superconducting quadrupole magnets with the large apertures needed to increase luminosity at the LHC. MAP effort ramped down as recommended by P5.	LARP will complete the R&D needed to produce prototypes for U.S. deliverables to the HL-LHC accelerator upgrade at CERN.	Funding will decrease as LARP development and prototyping efforts for the LHC focusing magnets transition into production efforts as part of the HL-LHC AUP. MAP receives final funding in FY 2017.
Detector R&D $16,587,000	**$16,450,000**	**-$137,000**
Research activities continued at universities and national laboratories, with resources shifted towards near-term requirements of the high-priority efforts and towards strengthening the university activities, as recommended in the P5 report.	Research activities will continue at universities and national laboratories, with increased emphasis on long-term, high-risk, high potential impact R&D efforts and strengthening of the university efforts.	Funding will decrease due to reduced support for the Large Area Picosecond Photo-Detector effort, partially offset by increased support for advanced sensor development.
Facility Operations and Experimental Support $36,300,000	**$28,670,000**	**-$7,630,000**
Funding supported the continued operation of BELLA, superconducting magnet fabrication, and fabrication of test-beam facilities. FACET was supported at a reduced level due to a shorter run dictated by a shutdown for LCLS-II construction.	Operations of the BELLA facility and the SRF infrastructure at Fermilab will continue. AIP project, Sector 10 Injector Infrastructure continues which started in FY 2017.	Funding of FACET operations will decrease because the FACET facility cannot run due to LCLS-II construction. Technical support, materials and supplies, and access to SRF, detector fabrication and test-beam facilities will be reduced. This is partially offset by the increase for the Sector 10 Injector Infrastructure AIP project.

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

FY 2016	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
Projects $2,100,000	**$2,000,000**	**-$100,000**
Approve Mission Need (CD-0) for the FACET-II MIE project was approved in September 2015, and the project began receiving funding for OPC in FY 2016.	During the LCLS-II shutdown, work on FACET-II will concentrate on what is needed to prepare for installation.	The program will reduce project funding for FACET-II as support is provided to higher priority projects in FY 2018.
SBIR/STTR $4,210,000	**$3,043,000**	**-$1,167,000**
In FY 2016, SBIR/STTR funding was set at 3.45% of non-capital funding.	In FY 2018, SBIR/STTR funding will be assumed to be 3.65% of non-capital funding.	Decreased funding represents mandated percentages for non-capital funding.

Description

The Accelerator Stewardship subprogram has three principal activities: improving access to SC accelerator R&D infrastructure for industrial and other users; near-term translational R&D to adapt accelerator technology for medical, industrial, security, and defense applications; and long-term R&D for the science and technology needed to build future generations of accelerators. HEP manages this program in close consultation with other SC programs, including NP and BES, and in consultation with other federal stakeholders of accelerator technology, most notably NSF, the DOD, NIH, and NASA.

Accelerator Stewardship pursues targeted R&D to develop new uses of accelerator technology with broad applicability. Initial workshops and a request for information identified target application areas with broad impact in accelerator technologies for ion beam therapy of cancer and laser technologies for accelerators. As the program evolves, it will identify new cross-cutting areas of research based on input from the federal stakeholders, R&D performers, and U.S. industry.

Research

Accelerator Stewardship research is conducted at national laboratories, universities, and in industry. The stewardship program supports both near-term translational R&D and long-term basic accelerator R&D. Near-term R&D funding is structured to produce practical prototypes of new applications in five to seven years. The needs for applications chosen for this category have been specifically identified by federal stakeholders and developed further by workshops. Near-term R&D funding opportunities are specifically structured to strengthen academic-industrial collaboration. Long-term R&D funding is targeted at scientific innovations enabling breakthroughs in particle accelerator size, cost, beam intensity, and control.

Facility Operations and Experimental Support

The Accelerator Stewardship subprogram supports the BNL's 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 a merit-based peer review process.

Accelerator Stewardship

Activities and Explanation of Changes

FY 2016	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
Accelerator Stewardship $10,474,000	**$12,769,000**	**+$2,295,000**
Research $5,643,000	**$8,953,000**	**+$3,310,000**
Research continued at laboratories, universities, and in industry. New research support was initiated for selected technology areas identified by SC workshops such as technologies for particle beam therapy and ultrafast laser technology R&D.	The Request will support research activities at laboratories, universities, and in industry for technology R&D areas such as laser, ion-beam therapy, and accelerator technology.	R&D on high power electron beam technologies for science and other applications will ramp up.
Facility Operations and Experimental Support $4,517,000	**$3,350,000**	**-$1,167,000**
Support continued for BNL ATF operations and the relocation of the ATF to a larger building.	The Request will support the BNL ATF operations.	The ATF relocation completes in FY 2017. Funding will support reduced ATF operating hours.
SBIR/STTR $314,000	**$466,000**	**+$152,000**
In FY 2016, SBIR/STTR funding was set at 3.45% of non-capital funding.	In FY 2018, SBIR/STTR funding will be assumed to be 3.65% of non-capital funding.	Increased funding represents mandated percentages for non-capital funding.

Description

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

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

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 matter-antimatter asymmetry of the universe.

Fermilab is leading the construction of the LBNF project and is responsible for design, construction, and operation of the LBNF beamline; design, construction, and operation of the conventional facilities and experiment infrastructure on the Fermilab site required for the near detector; and design, construction, and operation of the conventional facilities and experiment infrastructure at SURF, including the cryostats and cryogenics systems, required for the far detector. DUNE is an international collaboration that has formed to carry out the neutrino experiment enabled by the LBNF facility. The DUNE collaboration will be responsible for: the definition of the scientific goals; the design, construction, commissioning, and operation of the near detector at Fermilab and the far detectors at the Sanford Underground Research Facility (SURF); and the scientific research program conducted with the DUNE detectors. The DUNE collaboration currently consists of about 1,000 physicists from nearly 160 institutes from 30 countries. Each of the collaborating institutions is responsible for delivering in-kind detector components that they have proven to have the expertise to build and install. Presently, the DOE contribution to the detectors will be a minority portion of the scope. Fermilab, as host, will oversee all LBNF/DUNE construction. Fermilab's oversight of the neutrino detectors includes technical coordination to ensure the various pieces will fit and operate together and arrive on time. The technical coordination group will document all work scope assignments, uphold a schedule, and provide design, production readiness, and operational readiness reviews in cooperation with the collaboration.

The construction of a particle beam at Fermilab and the infrastructure for DUNE detectors at SURF are being managed as a single project called LBNF/DUNE. The critical path item for LBNF/DUNE is excavation of the equipment caverns. Installation of the cryogenic systems and detectors cannot start until the caverns are ready. Critical site preparations such as safety and reliability refurbishments for the underground infrastructure as well as a waste-rock handling system must be completed before excavation can begin. The preparation work was started with funding received in FY 2016. CD-3A approval for initiating excavation of the equipment caverns at SURF was approved September 1, 2016. The FY 2017 construction funds are being used to complete the final design of the underground detector caverns, continue site preparation, develop detector prototypes for testing at CERN, and initiate a contract with a construction manager/general contractor who will oversee the civil construction. The FY 2018 Request is $54,900,000 and will support completion of the site preparation and detector prototypes, continue the detector and beam line designs needed for CD-2, and begin excavation of the underground detector caverns.

Muon to Electron Conversion Experiment (Mu2e)

Mu2e, under construction at Fermilab, will utilize a proton beam to produce muons and determine whether those muons, on rare occasions, can transform into electrons in apparent violation of lepton flavor symmetry. Evidence of muon-to-electron flavor change would further probe physics beyond the Standard Model at very high energy scales. The project received approval for its performance baseline (CD-2) and for civil construction and long-lead procurement of the most challenging superconducting solenoid magnets (CD-3B) on March 4, 2015. The Mu2e Project completed its technical design phase (CD-3) on July 14, 2016 and moved into full construction at that time. FY 2017 construction funds are being used to modify the Fermilab accelerator complex to deliver muons to Mu2e, to fabricate the two remaining superconducting solenoid magnets, and to fabricate the particle detection systems for Mu2e. The FY 2018 Request is $44,400,000 and will support continued procurement and fabrication work.

Construction

Activities and Explanation of Changes

FY 2016	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
Construction $66,100,000	**$99,300,000**	**+$33,200,000**
11-SC-40, Long Baseline Neutrino Facility/ Deep Underground Neutrino Experiment $26,000,000	**$54,900,000**	**+$28,900,000**
Total Estimated Cost (TEC) funding supported the following: civil and geotechnical engineering design of the detector cavern in South Dakota; technical design of the neutrino-production beam line and related facilities at Fermilab; site preparation; and modifications to the technical design of the experimental facility, infrastructure, and detectors in light of the new international participation.	The Request will support the completion of site preparation activities, and will initiate the procurement of civil construction for excavation of the underground equipment caverns. Funding will also support design activities for the cryogenics system, detectors, and neutrino beam.	The increase is a result of the major transition from design and site preparation to the initiation of underground construction. Funding will also support design activities for the cryogenics system, detectors, and neutrino beam.
11-SC-41, Muon to Electron Conversion Experiment $40,100,000	**$44,400,000**	**+$4,300,000**
Funding continued for the civil construction and to initiate accelerator modifications and fabrication of technical components (solenoid magnets and particle detectors).	The Request will support continued accelerator modifications and fabrication of technical components.	The increase will be consistent with the baseline plan for continuation of fabrication of the accelerator modifications, magnets, and particle detectors.

High Energy Physics
Performance Measures

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

	FY 2016	FY 2017	FY 2018
Performance Goal (Measure)	**HEP Construction/MIE Cost & Schedule - Cost-weighted mean percentage variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects**		
Target	< 10 %	< 10 %	< 10 %
Result	Met	TBD	TBD
Endpoint Target	Adhering to the cost and schedule baselines for a complex, large scale, science project is critical to meeting the scientific requirements for the project and for being good stewards of the taxpayers' investment in the project.		
Performance Goal (Measure)	**HEP Facility Operations - Average achieved operation time of HEP user facilities as a percentage of total scheduled annual operation time**		
Target	≥ 80 %	≥ 80 %	≥ 80 %
Result	Met	TBD	TBD
Endpoint Target	Many of the research projects that are undertaken at the Office of Science's scientific user facilities take a great deal of time, money, and effort to prepare and regularly have a very short window of opportunity to run. If the facility is not operating as expected the experiment could be ruined or critically setback. In addition, taxpayers have invested millions or even hundreds of millions of dollars in these facilities. The greater the period of reliable operations, the greater the return on the taxpayers' investment.		
Performance Goal (Measure)	**HEP Neutrino Model - Carry out series of experiments to test the standard 3-neutrino model of mixing**		
Target	Physics analyses results from data taking will be presented by the NOvA and MicroBooNE experimental collaborations at the FY 2016 summer conferences.	Fermilab switches operations mode over from neutrino beam to antineutrino beam delivery to the NOvA experiment. NOvA accumulates physics data in antineutrino mode.	MicroBooNE data taking will complete final year of phase-1. NOvA will publish the first muon and electron anti-neutrino oscillation results. ICARUS data taking will begin. SBND physics commissioning will continue.
Result	Met	TBD	TBD
Endpoint Target	Similar to quarks, the mixing between neutrinos is postulated to be described by a unitary matrix. Measuring the independent parameters of this matrix in different ways and with adequate precision will demonstrate whether this model of neutrinos is correct. Such a model is needed to correctly extract evidence for CP violation in the neutrino sector.		

High Energy Physics
Capital Summary ($K)

	Total	Prior Years	FY 2016 Enacted	FY 2017 Annualized CR[a]	FY 2018 Request	FY 2018 vs FY 2016
Capital Operating Expenses Summary						
Capital equipment	n/a	n/a	105,205	—	57,800	-47,405
General plant projects (GPP)	n/a	n/a	9,160	—	2,310	-6,850
Accelerator improvement projects (AIP) (<$5M)	n/a	n/a	8,280	—	1,500	-6,780
Total, Capital Operating Expenses	**n/a**	**n/a**	**122,645**	**—**	**61,610**	**-61,035**
Capital Equipment						
Major items of equipment[b]						
Energy Frontier Experimental Physics						
LHC ATLAS Detector Upgrades[c]	20,821	2,821	9,500	—	0	-9,500
LHC CMS Detector Upgrades[d]	22,629	5,162	9,500	—	0	-9,500
HL-LHC AUP[e]	206,380	0	0	—	27,000	+27,000
Intensity Frontier Experimental Physics						
Muon g-2 Experiment[f]	27,549	11,000	10,200	—	0	-10,200
Cosmic Frontier Experimental Physics						
Large Synoptic Survey Telescope Camera (LSSTcam)[g]	150,300	54,700	40,800	—	9,800	-31,000
Dark Energy Spectroscopic Instrument[h] (DESI)	40,122	500	9,800	—	1,900	-7,900
LUX-ZEPLIN[i] (LZ)	52,050	500	10,500	—	14,100	+3,600
SuperCDMS-SNOLAB[j]	16,725	0	2,375	—	2,000	-375

[a] FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above; below that level, a dash (-) is shown.
[b] Each MIE located at a DOE facility Total Estimated Cost (TEC) > $5M and each MIE not located at a DOE facility TEC > $2M.
[c] Critical Decisions CD-2 and 3 for the LHC ATLAS Detector Upgrade Project were approved on November 12, 2014. The TPC is $33,250,000.
[d] Critical Decisions CD-2 and 3 for the LHC CMS Detector Upgrade Project were approved on November 12, 2014. The TPC is $33,217,000.
[e] Critical Decision CD-0 for HL-LHC AUP was approved April 13, 2016. The estimated cost range was $180,000,000 to $250,000,000.
[f] Critical Decision CD-2 and 3 for Muon g-2 Experiment were approved August 20, 2015. The TPC is $46,400,000.
[g] Critical Decision CD-3 for the LSSTcam project was approved on August 27, 2015. The TPC is $168,000,000.
[h] Critical Decision CD-3 for DESI project was approved on June 22, 2016, with a TPC of $56,328,000, project will be rebaselined.
[i] Critical Decisions CD-2 and 3B for LZ were approved August 9, 2016. The TPC is $55,500,000.
[j] The estimated cost range for SuperCDMS-SNOLAB at Critical Decision CD-1 approved December 21, 2015 was $16,000,000–$21,500,000.

	Total	Prior Years	FY 2016 Enacted	FY 2017 Annualized CR[a]	FY 2018 Request	FY 2018 vs FY 2016
Advanced Technology R&D						
FACET II[a]	53,000	0	0	—	2,000	+2,000
Total MIEs	n/a	n/a	92,675	—	56,800	-35,875
Total Non-MIE Capital Equipment	n/a	n/a	12,530	—	1,000	-11,530
Total, Capital equipment	**n/a**	**n/a**	**105,205**	**—**	**57,800**	**-47,405**
General Plant Projects (GPP)						
Short-Baseline Neutrino Far Hall	8,700	6,298	2,402	—	0	0
Short-Baseline Neutrino Near Hall	5,250	2,050	3,200	—	0	0
Industrial Center Building addition	9,760	0	1,760	—	1,500	-260
Other projects under $5 million TEC	n/a	n/a	1,798	—	810	-988
Total, Plant Project (GPP)	**n/a**	**n/a**	**9,160**	**—**	**2,310**	**-6,850**
Accelerator Improvement Projects (AIP)						
Muon Campus Cryogenics	9,600	7,500	700	—	0	-700
Recycler RF Upgrades	7,450	5,200	2,250	—	0	-2,250
Beam Transport	6,500	6,400	100	—	0	-100
Delivery Ring	9,600	5,200	4,400	—	0	-4,400
ATF-II Upgrade	5,000	2,500	830	—	0	-830
Sector 10 Injector Infrastructure	5,000	0	0	—	1,500	+1,500
Total, Accelerator Improvement Projects	**n/a**	**n/a**	**8,280**	**—**	**1,500**	**-6,780**

[a] The estimated cost range for FACET II at CD-1 approved on December 21, 2015 was $46,000,000–$60,000,000.

Major Items of Equipment Descriptions

Energy Frontier Experimental Physics MIEs:

The *LHC ATLAS Detector Upgrade Project* started as a new MIE in FY 2015 and the subsequent ramp-up of fabrication activities for U.S. built detectors continues through FY 2017. The U.S. scope includes upgrades to the muon subsystem, the liquid argon calorimeter detector, and the trigger and data acquisition system to take advantage of the increased LHC luminosity. The LHC ATLAS Detector Upgrade Project was baselined (CD-2) and approved for a fabrication start (CD-3) on November 12, 2014, with a total project cost of $33,250,000 and project completion date (CD-4) in FY 2019. The project is currently producing subsystem components and will begin to install them in FY 2018. The FY 2018 Request does not include funding for this project. It has sufficient funds to complete all remaining deliverables.

The *LHC CMS Detector Upgrade Project* started as a new MIE in FY 2015 and will complete the bulk of its deliverables in FY 2017. The planned U.S. scope includes upgrades to the pixelated inner tracking detector, the hadron calorimeter detector, and trigger system to take advantage of the increased LHC luminosity. The LHC CMS Detector Upgrade Project was baselined (CD-2) and approved for a fabrication start (CD-3) on November 12, 2014, with a total project cost of $33,217,000 and project completion date in FY 2020. The project has successfully installed the pixelated inner tracking detector and portions of the trigger and hadron calorimeter. The remaining components are being produced now and will be installed in FY 2018. The FY 2018 Request does not include funding for this project. It has sufficient funds to complete all remaining deliverables.

The *High Luminosity Large Hadron Collider Accelerator Upgrade Project (HL-LHC AUP)* starts as a new MIE in FY 2018 with initial TEC funding. Following the major upgrade, the CERN LHC machine will further increase the instantaneous luminosity by a factor of three times its design value to explore new physics beyond the reach of the current LHC program. The project will deliver components for which the U.S. scientists have critical expertise: interaction region focusing quadrupole magnets and special superconducting RF crab cavities, capable of generating transverse electric fields that rotate each bunch longitudinally such that they collide effectively head on, overlapping perfectly at the collision points. The HL-LHC AUP received CD-0 on April 13, 2016 with an estimated cost range of $180,000,000 to $250,000,000. The FY 2018 Request includes TEC funding of $27,000,000 for HL-LHC AUP.

Intensity Frontier Experimental Physics MIE:

The *Muon g-2* project received CD-2 and CD-3 approval on August 20, 2015, with a TPC of $46,400,000 and project completion date in FY 2019. The FY 2018 Request does not include funding for this project. It has sufficient funds to complete all remaining deliverables.

Cosmic Frontier Experimental Physics MIEs:

The *Large Synoptic Survey Telescope Camera (LSSTcam*) project fabricates a state-of-the-art three billion pixel digital camera for a next-generation, wide-field, ground-based optical and near-infrared LSST observatory, located in Chile, and is designed to provide deep images of half the sky every few nights. The project is carried out in collaboration with NSF, which leads the project, along with private and foreign contributions. DOE will provide the camera for the facility. CD-2 for the LSSTcam project was approved 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 currently producing many of the camera components, which are being tested and integrated before shipment to Chile in 2020. The FY 2018 Request of TEC funding for the LSSTcam is $9,800,000, which is $31,000,000 lower than the FY 2016 Enacted level of $40,800,000 and consistent with the approved baseline funding profile.

The *Dark Energy Spectroscopic Instrument (DESI)* project started fabrication in FY 2015. The project is fabricating an instrument that will measure the effect of dark energy on the expansion of the universe using spectroscopic measurements. The DESI survey will provide different, complementary measurements to those of the LSST survey. The instrument will be mounted on NSF's Mayall 4-meter telescope at Kitt Peak National Observatory in Arizona, with operations of the telescope supported by DOE. DESI remains unique in its use of dedicated spectroscopic measurements to measure dark energy at its planned precision. It provides a strong complement to the LSST being built by NSF and DOE. CD-2 was approved 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. The project is currently producing many of the camera components, which are being tested and integrated. The FY

2018 Request of TEC funding is $1,900,000, which is $7,900,000 below the FY 2016 Enacted level of $9,800,000. HEP plans to rebaseline the project when the FY 2017 appropriations are finalized.

The LUX-ZEPLIN (LZ) project started MIE fabrication in FY 2015. This MIE is one of two 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 (TPC) 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. CD-2 and CD-3b were approved on August 8, 2016 with a project completion data in FY 2022. CD-3 was approved in February 2017, and the project is producing components and testing them before integration in 2019. The FY 2018 Request of TEC funding for LZ is $14,100,000, which is $3,600,000 above the FY 2016 Enacted level of $10,500,000 and consistent with the approved baseline funding profile.

The *Super Cryogenic Dark Matter Search at Sudbury Neutrino Observatory Laboratory (SuperCDMS-SNOLAB)* is one of the two MIEs selected to meet the Dark Matter Second Generation Mission Need. The project will fabricate an instrument 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. The detector will be located 2 km deep in the SNOLAB facility in Sudbury, Ontario, Canada. SuperCDMS will be optimized to detect low mass WIMPs and will cover a range of WIMP mass complementary to that of LZ's sensitivity. CD-1 was approved on December, 21, 2015. The project will be completing its preliminary design and preparing of CD-2. The FY 2018 Request of TEC funding for SuperCDMS-SNOLAB is $2,000,000, which is $375,000 below the FY 2016 Enacted level of $2,375,000. The project has not yet been baselined so the project does not have an official CD-4 date, but the project will be slowed compared to the estimated schedule at CD-1.

Advanced Technology R&D MIE:

The *Facility for Accelerator and Experimental Tests II (FACET-II)* is a new MIE fabrication start in FY 2018. It will succeed FACET as the world's premier beam driven plasma wakefield facility and provide intense ultra-short electron beams for other applications in accelerator and related sciences. The successful FACET program ended due to the construction of the Linac Coherent Light Source II (LCLS-II) in a portion of the SLAC tunnel used by FACET. FACET-II will be designed to deliver beams using only one third of the SLAC linac. CD-0 was approved September 18, 2015. CD-1 was approved December 21, 2015. The FY 2018 Request of TEC funding for FACET-II is $2,000,000. At this funding level, work will continue on the critical infrastructure that needs to be installed during the shutdown of the linac for the LCLS-II installation.

High Energy Physics Construction Project Summary ($K)

	Total	Prior Years	FY 2016 Enacted	FY 2017 Enacted	FY 2018 Request	FY 2018 vs FY 2016
11-SC-40, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment						
TEC	1,433,375	35,781	26,000	50,000	54,900	+28,900
OPC	102,625	85,539	86	—	100	+14
TPC	1,536,000	121,320	26,086	50,000	55,000	+28,914
11-SC-41, Muon to Electron Conversion Experiment						
TEC	250,000	92,000	40,100	43,500	44,400	+4,300
OPC	23,677	23,677	0	—	0	0
TPC	273,677	115,677	40,100	43,500	44,400	+4,300
Total, Construction						
TEC	n/a	n/a	66,100	93,500	99,300	+33,200
OPC	n/a	n/a	86	—	100	+14
TPC	n/a	n/a	66,186	93,500	99,400	+33,214

Funding Summary ($K)

	FY 2016 Enacted	FY 2017 Annualized CR[a]	FY 2018 Request	FY 2018 vs FY 2016
Research	341,663	—	272,887	-68,776
Facilities Operations				
Scientific User Facilities Operations	135,848	—	112,439	-23,409
Other Facilities	122,388	—	101,374	-21,014
Total, Facilities Operations	**258,236**	**—**	**213,813**	**-44,423**

[a] FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above; below that level, a dash (-) is shown.

	FY 2016 Enacted	FY 2017 Annualized CR[a]	FY 2018 Request	FY 2018 vs FY 2016
Projects				
Major Items of Equipment[b]	95,900	—	72,600	-23,300
Other Projects	14,300	—	0	-14,300
Construction[b]	84,901	—	113,400	+28,499
Total, Projects	**195,101**	**—**	**186,000**	**-9,101**
Total, High Energy Physics	**795,000**	**793,489**	**672,700**	**-122,300**

[b] Includes Other Project Costs.

Scientific User Facility Operations ($K)

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

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

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

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

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

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

	FY 2016 Enacted	FY 2017 Annualized CR[a]	FY 2018 Request	FY 2018 vs FY 2016
TYPE A FACILITIES				
Fermilab Accelerator Complex	**$125,481**	**—**	**$109,089**	**-$16,392**
Number of Users	2,246	—	1,945	-301
Achieved operating hours	5,983	—	N/A	N/A
Planned operating hours	4,800	—	1,800	-3,000
Optimal hours	4,800	—	4,800	0
Percent optimal hours	124.6%	—	37.5%	-87.1%
Unscheduled downtime hours	590	—	N/A	N/A

[a] FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above; below that level, a dash (-) is shown.

	FY 2016 Enacted	FY 2017 Annualized CR[a]	FY 2018 Request	FY 2018 vs FY 2016
FACET (SLAC)	**$5,850**	**—**	**$0**	**-$5,850**
Number of Users	96	—	0	-96
Achieved operating hours	2,146	—	N/A	N/A
Planned operating hours	3,096	—	0	-3,096
Optimal hours	4,448	—	0	-4,448
Percent optimal hours	48.2%	—	N/A	N/A
Unscheduled downtime hours	485	—	N/A	N/A
Accelerator Test Facility (BNL)	**$4,517**	**—**	**$3,350**	**-$1,167**
Number of Users	50	—	52	+2
Achieved operating hours	2,113	—	N/A	N/A
Planned operating hours	2,189	—	1,681	-508
Optimal hours	2,500	—	2,050	-450
Percent optimal hours	84.5%	—	82.0%	-2.5%
Unscheduled downtime hours	0	—	N/A	N/A
Total Facilities	**$135,848**	**—**	**$112,439**	**-$23,409**
Number of Users	2,392	—	1,997	-395
Achieved operating hours	10,242	—	N/A	N/A
Planned operating hours	10,085	—	3,481	-6,604
Optimal hours	11,748	—	6,850	-4,898
Percent of optimal hours[a]	120.0%	—	38.8%	-81.2%
Unscheduled downtime hours	1,075	—	N/A	N/A

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

Scientific Employment

	FY 2016 Enacted	FY 2017 Annualized CR[a]	FY 2018 Estimate	FY 2018 vs FY 2016
Number of permanent Ph.D.'s (FTEs)	940	—	720	-220
Number of postdoctoral associates (FTEs)	300	—	240	-60
Number of graduate students (FTEs)	460	—	345	-115
Other[b]	1,875	—	1,810	-65

[a] FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above; below that level, a dash (-) is shown.
[b] Includes technicians, engineers, computer professionals, and other support staff.

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

1. Significant Changes and Summary

Significant Changes

This Construction Project Data Sheet (CPDS) is an update of the FY 2017 CPDS and does not include a new start for FY 2018.

Development of the design and cost estimates have been refined and the U.S. DOE contributions to the multinational effort are now better understood. Additional design activities and prototypes have been identified by the project team.

Summary

The FY 2018 Request for LBNF/DUNE is $54,900,000. The most recent DOE Order 413.3B approved is CD-3A, approval for Initial Far Site Construction: initiating excavation and construction for the LBNF Far Site conventional facilities in order to mitigate risks and minimize delays for providing a facility ready to accept detectors for installation. CD-3A was approved September 1, 2016 with a preliminary total project cost (TPC) range of $1,260,000,000 to $1,860,000,000 and CD-4 date of 4Q FY 2030. The range includes the full cost of the LBNF host facility excluding foreign contributions, as well as the full cost of the DOE contribution to the DUNE experimental apparatus.

DOE entered into a land lease with the South Dakota Science and Technology Authority (SDSTA) on May 20, 2016 covering the area on which the DOE funded facilities housing and supporting the LBNF and DUNE detector will be built. The lease provides the framework for DOE and Fermilab to construct federally funded buildings and facilities on non-federal land, and to establish a long-term (multi-decade) arrangement for DOE and Fermilab to use SDSTA space to host the neutrino detector. Other Project Costs (OPC) funding has been identified in years FY 2018-FY 2026 for plant support costs provided by SDSTA...

The Long-Baseline Neutrino Facility (LBNF) and the Deep Underground Neutrino Experiment (DUNE) comprise 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 HEPAP-Particle Physics Project Prioritization Panel (P5) recommendations, the LBNF/DUNE Project consists of two multinational collaborative efforts:

- LBNF (the facility) 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 (the experiment) 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.

DUNE will analyze transformations of muon neutrinos in a beam from Fermilab to a large detector in South Dakota, 800 miles away. The experiment will analyze the rare, flavor-changing transformations of neutrinos in flight, from one lepton flavor to another, that are expected to help elucidate the fundamental physics of neutrinos and may explain the puzzling matter-antimatter asymmetry that enables our existence in a matter-dominated universe.

DOE HEP 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 MW-class neutrino source and related facilities at Fermilab (the “near site”), as well as underground cavern(s) and cryogenic facilities in South Dakota (the “far site) needed to house the DUNE detector(s). DUNE has international leadership and participation by about 1000 scientists and engineers from more than 160 institutions in 30 countries. The detector mass totaling 40 kilotons will be distributed in four cryostats housed in large caverns at SURF. An additional cavern at SURF will accommodate the cryogenic and other utility systems. DOE will fund less than a third of DUNE. Development of the design and cost estimates have been refined and the U.S. DOE contributions to the multinational effort are now better understood. Additional design activities and prototypes have been identified.

Contributions from the international partners to LBNF/DUNE are currently being negotiated by Fermilab and DOE. For the DUNE detector, the process is being driven from the principal investigator level up to the funding agencies as was done for U.S. contributions to the Large Hadron Collider (LHC) accelerator and detectors. Proposals are under review by the other funding agencies. CERN put funding into its medium-term budget plan for one detector cryostat worth $90 million in U.S. accounting. All DOE contributions to the facility and the detectors will be managed according to DOE Order 413.3B, and Fermilab will provide unified project management reporting.

Fermilab has initiated site preparation at SURF with maintenance and refurbishment activities to the mine shaft, hoists, ventilation systems, and general support infrastructure to allow for safe and reliable access prior to initiating excavation and underground construction.

The FY 2018 Request will support initiating the excavation of the underground equipment caverns.

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

2. Critical Milestone History

(fiscal quarter or date)

	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2011	1/8/2010		1Q FY 2011	TBD	4Q FY 2013	TBD	TBD	TBD
FY 2012	1/8/2010		2Q FY 2012	TBD	2Q FY 2015	TBD	TBD	TBD
FY 2016[a]	1/8/2010	12/10/2012	12/10/2012	4Q FY 2017	4Q FY 2019	4Q FY 2019	N/A	4Q FY 2027
FY 2017	1/8/2010	11/5/2015[b]	11/5/2015[b]	1Q FY 2020	1Q FY 2020	1Q FY 2020	N/A	4Q FY 2030
FY 2018	1/8/2010	11/5/2015[b]	11/5/2015[b]	1Q FY 2021	1Q FY 2022	1Q FY 2022	N/A	4Q FY 2030

CD-0 – Approve Mission Need
Conceptual Design Complete – Actual date the conceptual design was completed
CD-1 – Approve Design Scope and Project Cost and Schedule Ranges
CD-2 – Approve Project Performance Baseline
Final Design Complete – Estimated date the project design will complete
CD-3 – Approve Start of Construction
D&D Complete – Completion of D&D work (see section 9)
CD-4 – Approve Start of Operations or Project Closeout

(fiscal quarter or date)

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

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.

[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.

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.)

3. Project Cost History

(dollars in thousands)

	TEC, Design	TEC, Construction	TEC, Total	OPC Except D&D	OPC, D&D	OPC, Total	TPC
FY 2011	102,000	TBD	TBD	22,180	TBD	TBD	TBD
FY 2012	133,000	TBD	TBD	42,621	TBD	TBD	TBD
FY 2016[a]	127,781	655,612	783,393	89,539	N/A	89,539	872,932
FY 2017	123,781	1,290,680	1,414,461	85,539	N/A	85,539	1,500,000
FY 2018[bc]	234,375	1,199,000	1,433,375	102,625	N/A	102,625	1,536,000

4. Project Scope and Justification

Scope
LBNF/DUNE will be composed of a neutrino beam created by new construction as well as modifications to the existing Fermilab accelerator complex, massive neutrino detectors (at least 40,000 tons in total) and associated cryogenics infrastructure located in one or more large underground caverns to be excavated at least 800 miles "downstream" from the neutrino source, and a much smaller neutrino detector at Fermilab for monitoring the neutrino beam near its source. A primary beam of protons will produce a neutrino beam directed into a target for converting the protons into a secondary beam of particles (pi mesons and muons) that decay into neutrinos, followed by a decay tunnel hundreds of meters long where the decay neutrinos will emerge and travel through the earth to the massive detector. The Neutrinos at the Main Injector (NuMI) beam at Fermilab is an existing example of this type of configuration for a neutrino beam facility. The new LBNF beam line will provide a neutrino beam of lower energy and greater intensity than the NuMI beam, and would point to a far detector at a greater distance than is used with NuMI experiments.

For the LBNF/DUNE project, Fermilab will be responsible for design, construction and operation of the major components of LBNF including: the primary proton beam, neutrino production target, focusing structures, decay pipe, absorbers and corresponding beam instrumentation; the conventional facilities and experiment infrastructure on the Fermilab site required for the near detector; and the conventional facilities and experiment infrastructure at SURF for the large detector 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.

[a] No CPDS was submitted for FY 2013, FY 2014 or FY 2015 because no TEC funds were requested; however, design funds were provided in each year's appropriation.
[b] The project is Pre-CD-2 and has not been baselined. All estimates are preliminary. The preliminary TPC range at CD-1 is $1,260,000,000 to $1,860,000,000. The TPC point estimate is $1,536,000,000.
[c] No construction, other than site preparation, approved civil construction or long-lead procurement will be performed prior to validation of the Performance Baseline and approval of CD-3.

Among the technical issues addressed in the alternatives analysis were the preferred detector technology and the neutrino beamline design. After a thorough study, both technologies were found to be capable of meeting the performance requirements if located underground, only liquid argon could work on the surface, and is less expensive. A low energy 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 O 413.3B, Program and Project Management for the Acquisition of Capital Assets.

The preliminary Key Performance Parameters (KPPs) for project completion that were approved by CD-1 in FY 2015 include the primary beam and neutrino beam production systems as well as underground caverns excavated for four separate, 10 kton detector modules (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 detector modules, which will be installed and tested with cosmic rays, and components of the cryogenic systems for the detectors, which will be installed and pressure tested. The KPPs will be finalized at CD-2.

Preliminary Key Performance Parameters

Scope	Threshold KPP	Objective KPP
Primary Beam to produce neutrinos directed to the far detector site	Beamline hardware commissioning complete and demonstration of protons delivered to the target	In addition to Threshold KPPs, system enhancements to maximize neutrino flux, enable tunability in neutrino energy spectrum or to improve neutrino beam capability
Far Site-Conventional Facilities	Caverns excavated for 40 kiloton fiducial detector mass[a]; beneficial occupancy granted for cavern space to house 20 kiloton fiducial detector mass[a]	In addition to Threshold KPPs, Beneficial Occupancy granted for remaining cavern space
Detector Cryogenic Infrastructure	DOE-provided components for Cryogenic subsystems installed and pressure tested for 20 kiloton fiducial detector mass	In addition to Threshold KPPs, additional DOE contributions to cryogenic subsystems installed and pressure tested for additional 20 kiloton fiducial detector mass; DOE contributions to cryostats
Long-Baseline Distance between neutrino source and far detector	1,000-1,500 kilometers	
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

5. Financial Schedule[b]

[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.

[b] The project is Pre-CD-2 and has not been baselined. All estimates are preliminary. The preliminary TPC range at CD-1 is $1,260,000,000 to $1,860,000,000. The TPC point estimate is $1,536,000,000. Design and international collaboration plans are currently being developed; outyears are preliminary.

(dollars in thousands)

	Appropriations	Obligations	Recovery Act Costs	Costs[a]
Total Estimated Cost (TEC)				
Design Only[b]				
FY 2012	4,000	4,000	0	0[c]
FY 2013	3,781	3,781	0	801
FY 2014	16,000	16,000	0	7,109
FY 2015	12,000	12,000	0	15,791
FY 2016	0	0	0	12,080
Subtotal, Design Only	35,781	35,781	0	35,781
Design (Design and Construction)				
FY 2016	N/A	N/A	0	26,436[d]
FY 2017	N/A	N/A	0	45,021
FY 2018	N/A	N/A	0	11,000[e]
Outyears	N/A	N/A	0	116,137
Subtotal, Design (Design and Construction)	N/A	N/A	0	198,594
Total, Design	N/A	N/A	0	234,375
Construction				
FY 2017	N/A	N/A	0	0
FY 2018	N/A	N/A	0	43,900[f]
Outyears	N/A	N/A	0	1,155,100
Total, Construction	N/A	N/A	0	1,199,000
TEC				
FY 2012	4,000	4,000	0	0
FY 2013	3,781	3,781	0	801
FY 2014	16,000	16,000	0	7,109
FY 2015	12,000	12,000	0	15,791
FY 2016	26,000	26,000	0	38,516
FY 2017	50,000	50,000	0	50,000
FY 2018	54,900	54,900	0	54,900
Outyears	1,266,694	1,266,694	0	1,266,258
Total, TEC	1,433,375	1,433,375	0	1,433,375

[a] Costs through FY 2016 reflect actual costs; costs for FY 2017 and the outyears are estimates.
[b] 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.
[c] $1,078,000 was erroneously costed to this project in FY 2012, the accounting records were adjusted in early FY 2013.
[d] Costs were for Far Site preparation including safety and reliability refurbishment of the underground infrastructure, which is needed prior to initiating excavation of the equipment caverns.
[e] Estimated costs are for continuing project engineering design in preparation for CD-2.
[f] Estimated costs are for initiating excavation of the equipment caverns at the Far Site as approved by CD-3A.

	(dollars in thousands)			
	Appropriations	Obligations	Recovery Act Costs	Costs[a]
Other Project Cost (OPC)				
OPC except D&D				
FY 2009 Recovery Act	12,486[a]	12,486	0	0
FY 2010	14,178	14,178	4,696	6,336
FY 2011	7,768	7,750	7,233	11,321
FY 2012	17,000	17,018[b]	557[c]	17,940
FY 2013	14,107	14,107	0	13,232
FY 2014	10,000	10,000	0	11,505
FY 2015	10,000	10,000	0	10,079
FY 2016	86	86	0	2,284
FY 2017	0	0	0	442
FY 2018	100	100	0	100
Outyears	16,900	16,900	0	16,900
Total, OPC	102,625	102,625	12,486	90,139
Total Project Cost (TPC)				
FY 2009 Recovery Act	12,486	12,486	0	0
FY 2010	14,178	14,178	4,696	6,336
FY 2011	7,768	7,750	7,233	11,321
FY 2012	21,000	21,018	557	17,940
FY 2013	17,888	17,888	0	14,033
FY 2014	26,000	26,000	0	18,614
FY 2015	22,000	22,000	0	25,870
FY 2016	26,086	26,086	0	40,800
FY 2017	50,000	50,000	0	50,442
FY 2018	55,000	55,000	0	55,000
Outyears	1,283,594	1,283,594	0	1,283,158
Total, TPC	1,536,000	1,536,000	12,486	1,523,514

[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.

6. Details of Project Cost Estimate[a]

	(dollars in thousands)		
	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	201,375	100,000	N/A
Contingency	33,000	23,781	N/A
Total, Design	234,375	123,781	N/A
Construction			
Site Preparation[b]	0	20,000	N/A
Far Site Civil Construction[c]	300,000	300,000	N/A
Fermilab Site Civil Construction[d]	281,000	270,000	N/A
Far Site Technical Infrastructure[e]	98,000	110,000	N/A
Fermilab Site Beamline[e]	110,000	130,000	N/A
DUNE Detectors	75,000	120,000	N/A
Contingency	335,000	340,680	N/A
Total, Construction	1,199,000	1,290,680	N/A
Total, TEC	1,433,375	1,414,461	N/A
Contingency, TEC	368,000	364,461	N/A
Other Project Cost (OPC)			
OPC except D&D			
R&D	20,625	18,000	N/A
Conceptual Planning	30,000	30,000	N/A
Conceptual Design	35,000	36,689	N/A
Plant Support Costs	17,000	0	N/A
Contingency	0	850	N/A
Total, OPC	102,625	85,539	N/A
Contingency, OPC	0	850	N/A
Total, TPC	1,536,000	1,500,000	N/A
Total, Contingency	368,000	365,311	N/A

[a] The project is Pre-CD-2 and has not been baselined. All estimates are preliminary. The TPC point estimate is $1,536,000,000. The preliminary TPC range at CD-1 was $1,260,000,000 to $1,860,000,000.
[b] Construction work now approved under CD-3A is included in the next row.
[c] Far Site civil construction involves excavation of caverns at SURF, 4850 ft below the surface, for technical equipment including particle detectors and cryogenic systems.
[d] Fermilab Site civil construction involves construction of the housing for the neutrino-production beam line and the near detector.
[e] Technical equipment in the DOE scope, estimated here, will be supplemented by in-kind contributions of additional technical equipment, for the accelerator beam and particle detectors, from non-DOE partners as described in Section 1.

7. Schedule of Appropriation Requests[a]

Request Year		Prior Years	FY 2015	FY 2016	FY 2017	FY 2018	Outyears	Total
		(dollars in thousands)						
FY 2011	TEC	102,000	0	0	0	0	0	102,000
	OPC	22,180	0	0	0	0	0	22,180
	TPC	124,180	0	0	0	0	0	124,180
FY 2012	TEC	91,000	42,000	0	0	0	0	133,000
	OPC	42,621	0	0	0	0	0	42,621
	TPC	133,621	42,000	0	0	0	0	175,621
FY 2016	TEC	23,781	12,000	16,000	TBD	TBD	TBD	783,393
	OPC	75,539	10,000	4,000	TBD	TBD	TBD	89,539
	TPC	99,320	22,000	20,000	TBD	TBD	TBD	872,932
FY 2017	TEC	23,781	12,000	26,000	45,021	TBD	1,307,659	1,414,461
	OPC	75,539	10,000	0	0	0	0	85,539
	TPC	99,320	22,000	26,000	45,021	TBD	1,307,659	1,500,000
FY 2018[b]	TEC	23,781	12,000	26,000	50,000	54,900	1,266,694	1,433,375
	OPC	75,539	10,000	86	0	100	16,900	102,625
	TPC	99,320	22,000	26,086	50,000	55,000	1,283,594	1,536,000

8. Related Operations and Maintenance Funding Requirements

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

Operations and maintenance funding of this experiment will become part of the existing Fermilab accelerator facility. Annual related funding estimates include the incremental cost of 20 years of full operation, utilities, maintenance and repairs with the accelerator beam on. The estimates also include operations and maintenance for the remote site of the large detector.

(Related Funding Requirements)

	(dollars in thousands)			
	Annual Costs		Life Cycle Costs	
	Current Total Estimate	Previous Total Estimate	Current Total Estimate	Previous Total Estimate
Operations	9,000	9,000	180,000	180,000
Utilities	8,000	8,000	160,000	160,000
Maintenance & Repair	1,000	1,000	20,000	20,000
Total	18,000	18,000	360,000	360,000

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

[b] The project is Pre-CD-2 and has not been baselined. All estimates are preliminary. The preliminary TPC range at CD-1 was $1,260,000,000 to $1,860,000,000. The TPC point estimate is $1,536,000,000.

9. Required D&D Information

	Square Feet
Area of new construction	142,000 SF
Area of existing facility being replaced and D&D'd by this project	0
Area of other D&D outside the project	0
Area of any additional D&D space to meet the "one-for-one" requirement taken from the banked area.	142,000 SF

The one-for-one replacement has been met through banked space. A waiver from the one-for-one requirement to eliminate excess space at Fermilab to offset the LBNF/DUNE project was approved by DOE Headquarters on November 12, 2009. The waiver identified and transferred to Fermilab 575,104 square feet of excess space to accommodate the new LBNF/DUNE facilities and other as yet unbuilt facilities from space that was banked at other DOE facilities.

10. Acquisition Approach

The LBNF and the DUNE detector apparatus comprise a unique, geographically distributed, complex system of scientific equipment consisting of a beam source at Fermilab and particle detectors both nearby at Fermilab and at a remote site 800 miles away in Lead, South Dakota. The overall DOE Project defined for delivery of LBNF and DUNE is referred to as LBNF/DUNE. 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.

In leading the LBNF/DUNE Project, Fermilab will collaborate and work with many institutions, including several DOE national laboratories (BNL, LBNL and LANL), dozens of universities, foreign research institutions, SURF, and the SDSTA. Fermilab will be responsible for overall project management, near site conventional facilities, and the beamline. Fermilab will work with SDSTA and SURF to complete the conventional facilities construction at the remote site needed to house and outfit the DUNE far detector. With the DUNE collaboration, Fermilab is also responsible for technical and resource coordination to support the DUNE far and near detector design and construction. DOE will be providing in-kind contributions to the DUNE collaboration for detector systems, as agreed upon with the international DUNE collaboration.

International participation in the design, construction, and operation of LBNF and DUNE will be of essential importance because the field of High Energy Physics is international by nature; necessary talent and expertise are globally distributed, and DOE does not have the procurement or technical resources to self-perform all of the required construction and fabrication work. Contributions from other nations will be predominantly through the delivery of components built in their own countries by their own researchers. DOE will negotiate agreements in cooperation with the Department of State on a bilateral basis with all contributing nations to specify their expected contributions and the working relationships during the construction and operation of the experiment. For the DUNE detector, the process of developing in-kind contributions is being driven by the principal investigators and being reviewed by their funding agencies.

DOE funding for the LBNF/DUNE Project will be provided directly to Fermilab and collaborating DOE national laboratories via approved financial plans, and under management control of the LBNF Project Office. The LBNF Project Office will also manage and control DOE funding to the other LBNF/DUNE institutions contributing to detector design and construction. In addition to the work performed by DOE national laboratories, a combination of university subcontracts and direct fixed-price purchases with vendors is anticipated to design, fabricate, and install the LBNF and DUNE technical components. The DUNE-U.S. Project Office at Fermilab will manage and control DOE funding to the other U.S. institutions contributing to DUNE detector design and construction. All actions will be in accordance with the DOE approved procurement policies and procedures.

Much of the neutrino beamline component design, fabrication, assembly, and installation will be done by Fermilab staff or by subcontract temporary staff working directly with Fermilab personnel. The acquisition approach includes both new procurements based on existing designs, and re-purposed equipment from the Fermilab accelerator complex. Some highly specialized components will be designed and fabricated by or in consultation with long-standing Fermilab collaborators having proven experience with such components.

Delivery of LBNF conventional facilities at the Fermilab near site and SURF far site will be via the Construction Manager/General Contractor (CM/GC) model. This strategy was chosen to reduce risk, enhance quality and safety performance, provide a more collaborative approach to construction, and offer the opportunity for reduced cost and shortened construction schedules.

For the LBNF near site conventional facilities at Fermilab, procurement is through existing Fermilab master subcontracts with national architect/engineering companies for design services and contracts will be incrementally phase-funded since they will span multiple years.

For the LBNF far site conventional facilities at SURF, Fermilab will work with SDSTA, the owner of the site and land, which has been donated to SDSTA by the Homestake Mining Company for the sole purpose of facilitating scientific and technological research and development. Fermilab will contract directly with SDSTA to provide pre-construction services and with an A&E firm for design of LBNF far site conventional facilities at SURF. Fermilab will solicit bids for CM/GC services to manage the construction of LBNF far site facilities. The CM/GC subcontractor will furnish all labor, equipment and materials for far site conventional facilities construction management. Work includes pre-construction construction management services and an option for executing the construction and management of the construction. The CM/GC subcontractor staff will have proven experience in the area of construction management and construction of industrial and heavy construction projects. The CM/GC firm will provide support services to the LBNF and A/E teams, including input regarding the selection of materials, building systems and equipment, construction feasibility, value engineering, and factors related to construction, plus cost estimates and schedules, including estimates of alternative designs or materials. The CM/GC will also provide recommendations of actions designed to minimize adverse effects of labor or material shortages, time requirements for procurement and installation and construction completion.

The overall approach to both near and far site enables Fermilab to gain construction management expertise early in the design phase to produce well-integrated designs and well understood constructability, with potential cost and management efficiencies and reduced construction risk as a result.

DOE has entered into a land lease with SDSTA on May 20, 2016 covering the area on which the DOE funded facilities housing and supporting the LBNF and DUNE detector will be built. The lease provides the framework for DOE and Fermilab to construct federally funded buildings and facilities on non-federal land, and to establish a long-term (multi-decade) arrangement for DOE and Fermilab to use SDSTA space to host the DUNE experiment. Modifications, repairs, replacements, and improvements to SDSTA infrastructure will be funded by the project to ensure safe and reliable operations of the systems required to carry out the DOE mission. Protections for DOE's real property interests in these infrastructure tasks are acquired through the lease with SDSTA, contracts and other agreements such as easements. DOE plans for Fermilab to have responsibility for managing and operating the LBNF and DUNE far detector and facilities for a useful lifetime of 20 year duration, and may contract with SDSTA for day-to-day management and maintenance services. At the end of useful life, federal regulations permit transfer of ownership to SDSTA, which is willing to accept ownership as a condition for the lease. An appropriate decommissioning plan will be developed prior to lease signing.

11-SC-41, Muon to Electron Conversion Experiment (Mu2e), Fermi National Accelerator Laboratory, Batavia, Illinois
Project is for Design and Construction

1. Significant Changes and Summary

Significant Changes
This Construction Project Data Sheet (CPDS) is an update of the FY 2017 CPDS and does not include a new start for FY 2018.

Summary
The FY 2018 Request for the Muon to Electron Conversion Experiment (Mu2e) is $44,400,000, consistent with the approved baseline funding profile. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-3 (Approve Start of Construction) concurrent with completion of the final design, approved on July 14, 2016. In FY 2015, CD-2 established the scope, cost, and schedule baseline and CD-3B initiated civil construction and long-lead procurement of the Transport Solenoid modules. Total Project Cost was approved at $273,677,000. The funding profile supports this TPC. The CD-4 milestone is 1Q FY 2023.

A Federal Project Director with Certification Level 2 has been assigned to this project and has approved this CPDS. The FPD will complete the Level-3 Certification requirements in FY 2017.

The Mu2e project provides the accelerator beam and experimental apparatus to unambiguously identify neutrinoless muon-to-electron conversion events. The conversion of a muon to an electron in the field of a nucleus would probe new physics for discovery at mass scales far beyond the reach of any existing or proposed experiment. Civil construction was completed in FY 2017. Throughout FY 2017 and FY 2018, procurement and fabrication activities for the accelerator, beamline, superconducting magnets and particle detector technical systems will continue.

2. Critical Milestone History

(fiscal quarter or date)

	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2011	11/24/2009		4Q FY 2010	TBD	4Q FY 2012	TBD	TBD	TBD
FY 2012	11/24/2009		4Q FY 2011	TBD	4Q FY 2013	TBD	TBD	TBD
FY 2013	11/24/2009		4Q FY 2012	4Q FY 2013	4Q FY 2014	4Q FY 2014	N/A	4Q FY 2018
FY 2014	11/24/2009		7/11/2012	2Q FY 2014	2Q FY 2015	4Q FY 2015	N/A	2Q FY 2021
FY 2013 Repro-gramming	11/24/2009		7/11/2012	2Q FY 2014	2Q FY 2015	4Q FY 2015	N/A	2Q FY 2021
FY 2015	11/24/2009		7/11/2012	4Q FY 2014	2Q FY 2015	4Q FY 2014	N/A	2Q FY 2021
FY 2016	11/24/2009	7/11/2012	7/11/2012	2Q FY 2015	3Q FY 2016	3Q FY 2016	N/A	1Q FY 2023
FY 2017 PB	11/24/2009	7/11/2012	7/11/2012	3/4/2015	3Q FY 2016	3Q FY 2016	N/A	1Q FY 2023
FY 2018	11/24/2009	7/11/2012	7/11/2012	3/4/2015	7/14/2016	7/14/2016	N/A	1Q FY 2023

CD-0 – Approve Mission Need
Conceptual Design Complete – Actual date the conceptual design was completed
CD-1 – Approve Design Scope and Project Cost and Schedule Ranges
CD-2 – Approve Project Performance Baseline
Final Design Complete – Estimated/Actual date the project design will be/was completed
CD-3 – Approve Start of Construction
D&D Complete – Completion of D&D work (see section 9)
CD-4 – Approve Start of Operations or Project Closeout
PB – Indicates the Performance Baseline

	Performance Baseline Validation	CD-3A	CD-3B	CD-3(C)
FY 2014		3Q FY 2013		
FY 2013 Reprogramming		3Q FY 2013		
FY 2015		3Q FY 2014		
FY 2016	2Q FY 2015	7/10/2014	2Q FY 2015	3Q FY 2016
FY 2017 PB	3/4/2015	7/10/2014	3/4/2015	3Q FY 2016
FY 2018	3/4/2015	7/10/2014	3/4/2015	7/14/2016

CD-3A – Approve Long-Lead Procurement of superconducting wire for the magnet systems.
CD-3B – Approve Long-Lead Procurement for superconducting solenoid magnet modules and for construction of the detector hall.
CD-3(C) – Approve All Construction and Fabrication (same as CD-3)

3. Project Cost History

(dollars in thousands)

	TEC, Design	TEC, Construction	TEC, Total	OPC Except D&D	OPC, D&D	OPC, Total	TPC
FY 2011	35,000	TBD	TBD	10,000	TBD	TBD	TBD
FY 2012	36,500	TBD	TBD	18,777	TBD	TBD	TBD
FY 2013	44,000	N/A	N/A	24,177	0	24,177	68,177
FY 2014	61,000	162,000	223,000	26,177	0	26,177	249,177
FY 2013 Reprogram-ming	49,000	162,000	211,000	23,677	0	23,677	234,677
FY 2015	47,000	162,900	209,900	23,677	0	23,677	233,577
FY 2016	57,000	193,000	250,000	23,677	N/A	23,677	273,677
FY 2017 PB	57,000	193,000	250,000	23,677	N/A	23,677	273,677[a]
FY 2018	60,598[b]	189,402	250,000	23,677	N/A	23,677	273,677

4. Project Scope and Justification

Scope

The Mu2e project includes accelerator modifications, fabrication of superconducting magnets and particle detector systems, and construction of a civil facility with the special capabilities necessary for the experiment. The scope of work in the Project Data Sheet has not changed. The muon beam for the Mu2e experiment will be produced by an intense 8-GeV proton beam, extracted from the Fermilab Booster accelerator, striking a tungsten target. The Mu2e project is modifying the existing Fermilab accelerator complex (Booster, Recycler and Debuncher Rings) to deliver the primary proton beam to a muon production target, and will efficiently collect and transport the produced muons to a stopping target. The stopping target is surrounded by the Mu2e detector system that can identify muon-to-electron conversions and reject background contamination from muon decays, which produce neutrinos, in contrast to muon conversions which are neutrinoless.

[a] No construction, other than approved long-lead procurement and detector hall civil construction, was performed prior CD-3 approval.

[b] Increased final design development work in FY 2016 reduced the estimated construction cost with modest delay of final design completion and Critical Decision CD-3.

The project has designed and is constructing the detector system (consisting of a tracker, calorimeter, cosmic ray veto and data acquisition subsystem), a new beam line to the detector system from the former Debuncher Ring, and three superconducting solenoid magnets (a Production Solenoid, Transport Solenoid and Detector Solenoid) that will serve as the beam transport channel for collecting the muons and transporting them into the detector system.

The project designed and is constructing a 25,000 square foot civil facility with the special capabilities required to house the primary beam target and transport systems for producing the muons and stopping them in the detector system. The civil construction consists of an underground detector enclosure and a surface building, for containing the necessary equipment and infrastructure that can be accessed while the multikilowatt proton beam is being delivered to the experiment. The building includes radiation shielding and design features for safe operation of the beam line and experimental apparatus.

Justification

The conversion of a muon to an electron in the Coulomb field of an atomic nucleus provides a unique experimental signature for discovery of charged-lepton flavor-symmetry violation (CLFV), which may be accessible to this experiment of unprecedented sensitivity and would allow access to new physics at very high mass scales beyond the reach of the LHC. In 2008, the Particle Physics Project Prioritization Panel (P5), a subpanel of the High Energy Physics Advisory Panel (HEPAP), recommended: "Development of a muon-to-electron conversion experiment should be strongly encouraged under all budget scenarios considered by the panel."[a] Again, in 2014, the most recent P5 Subpanel emphasized the priority of the current "Mu2e" experimental construction project in its new report to HEPAP, saying the Mu2e project is an "immediate target of opportunity in the drive to search for new physics and will help inform future choices of direction." "The scientific case is undiminished relative to its earlier prioritization."[b]

Key Performance Parameters

System	Threshold Performance	Objective Performance
Accelerator		
	Accelerator components are acceptance tested at nominal voltages and currents. Components necessary for single-turn extraction installed. Shielding designed for 1.5 kW operation delivered to Fermilab and ready for installation. All target station components are complete, delivered to Fermilab and tested. Heat and Radiation Shield is installed in Production Solenoid. Other components are ready to be installed after field mapping.	Protons are delivered to the diagnostic absorber in the M4 beamline. Shielding designed for 8 kW operation delivered to Fermilab and ready for installation.
Superconducting Solenoid Magnets		
	The Production, Transport and Detector Solenoids have been cooled and powered to the settings necessary to take physics data.	The Production, Transport and Detector Solenoids have been cooled and powered to their nominal field settings.
Detector Components		
	Cosmic Ray Tracks are observed in the Tracker, Calorimeter and a subset of the Cosmic Ray Veto and acquired by the Data Acquisition System after they are installed in the garage position behind the Detector Solenoid. The balance of the Cosmic Ray Veto counters are at Fermilab and ready for installation.	The cosmic ray data in the detectors is acquired by the Data Acquisition System, reconstructed in the online processors, visualized in the event display and stored on disk.

[a] "US Particle Physics: Scientific Opportunities, A Strategic Plan for the Next 10 Years," Report of the Particle Physics Project Prioritization Panel (May 2008).

[b] "Building for Discovery, Strategic Plan for U.S. Particle Physics in the Global Context," Report of the Particle Physics Project Prioritization Panel (May 2014).

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

5. Financial Schedule

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
Total Estimated Cost (TEC)			
Design			
FY 2013	N/A	N/A	14,653
FY 2014	N/A	N/A	15,404
FY 2015	N/A	N/A	16,892
FY 2016	N/A	N/A	13,649
Total, Design	N/A	N/A	60,598
Construction			
FY 2014	N/A	N/A	0
FY 2015	N/A	N/A	9,907
FY 2016	N/A	N/A	24,300
FY 2017	N/A	N/A	40,000
FY 2018	N/A	N/A	40,000
FY 2019	N/A	N/A	40,000
FY 2020	N/A	N/A	24,000
FY 2021	N/A	N/A	10,000
FY 2022	N/A	N/A	1,195
Total, Construction	N/A	N/A	189,402
TEC			
FY 2012	24,000	24,000	0
FY 2013	8,000[b]	8,000	14,653
FY 2014	35,000[c]	35,000	15,404
FY 2015	25,000[d]	25,000	26,799
FY 2016	40,100	40,100	37,949
FY 2017	43,500	43,500	40,000
FY 2018	44,400	44,400	40,000
FY 2019	30,000	30,000	40,000
FY 2020	0	0	24,000
FY 2021	0	0	10,000
FY 2022	0	0	1,195
Total, TEC	250,000	250,000	250,000
Other Project Costs (OPC)			
OPC except D&D			
FY 2010	4,777	4,777	3,769
FY 2011	8,400	8,400	8,940

[a] Costs through FY 2016 reflect actual costs; costs for FY 2017 and the outyears are estimates.
[b] Congress approved a reprogramming that reduced the FY 2013 funding to $8,000,000 from the $22,685,000 that was originally appropriated.
[c] $5,162,907 was for long-lead procurements of superconducting wire for the magnet systems.
[d] $25,000,000 was for long-lead procurements for the superconducting solenoid magnet modules and for civil construction of the detector hall.

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
FY 2012	8,000	8,000	6,740
FY 2013	2,500	2,500	1,020
FY 2014	0	0	2,136
FY 2015	0	0	159
FY 2016	0	0	252
FY 2017	0	0	661
Total, OPC	23,677	23,677	23,677
Total Project Cost (TPC)			
FY 2010	4,777	4,777	3,769
FY 2011	8,400	8,400	8,940
FY 2012	32,000	32,000	6,740
FY 2013	10,500	10,500	15,673
FY 2014	35,000	35,000	17,540
FY 2015	25,000	25,000	26,958
FY 2016	40,100	40,100	38,201
FY 2017	43,500	43,500	40,661
FY 2018	44,400	44,400	40,000
FY 2019	30,000	30,000	40,000
FY 2020	0	0	24,000
FY 2021	0	0	10,000
FY 2022	0	0	1,195
Total, TPC	273,677	273,677	273,677

6. Details of Project Cost Estimate

	(dollars in thousands)		
	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	60,598	52,000	49,000
Contingency	0	5,000	8,000
Total, Design	60,598	57,000	57,000
Construction			
Site Work	2,000	2,000	2,000
Construction	13,000	13,000	13,000
Equipment	129,400	133,000	133,000
Contingency	45,002	45,000	45,000
Total, Construction	189,402	193,000	193,000
Total, TEC	250,000	250,000	250,000
Contingency, TEC	45,002	50,000	53,000
Other Project Cost (OPC)			
OPC except D&D			
R&D	8,200	8,200	8,200
Conceptual Planning	2,300	2,300	2,300
Conceptual Design	13,177	13,177	13,177
Total, OPC	23,677	23,677	23,677

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total, TPC	273,677	273,677	273,677
Total, Contingency	45,002	50,000	53,000

7. Schedule of Appropriation Requests

(dollars in thousands)

Request Year		Prior Years	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	Total
FY 2011	TEC	5,000	30,000	0	0	0	0	0	0	0	35,000
	OPC	10,000	0	0	0	0	0	0	0	0	10,000
	TPC	15,000	30,000	0	0	0	0	0	0	0	45,000
FY 2012	TEC	0	24,000	12,500	0	0	0	0	0	0	36,500
	OPC	12,777	6,000	0	0	0	0	0	0	0	18,777
	TPC	12,777	30,000	12,500	0	0	0	0	0	0	55,277
FY 2013	TEC	0	24,000	20,000	0	0	0	0	0	0	44,000
	OPC	13,177	6,000	5,000	0	0	0	0	0	0	24,177
	TPC	13,177	30,000	25,000	0	0	0	0	0	0	68,177
FY 2014	TEC	0	24,000	24,147	35,000	32,000	44,000	45,000	23,000	0	223,000
	OPC	13,177	8,000	8,049	0	0	0	0	0	0	26,177
	TPC	13,177	32,000	32,196[a]	35,000	32,000	44,000	45,000	23,000	0	249,177
FY 2013 Repro-gram-ming	TEC	0	24,000	8,000[b]	35,000	32,000	44,000	45,000	23,000	0	211,000
	OPC	13,177	8,000	2,500	0	0	0	0	0	0	23,677
	TPC	13,177	32,000	10,500	35,000	32,000	44,000	45,000	23,000	0	234,677
FY 2015	TEC	0	24,000	8,000	35,000	25,000	42,000	43,000	32,900	0	209,900
	OPC	13,177	8,000	2,500	0	0	0	0	0	0	23,677
	TPC	13,177	32,000	10,500	35,000	25,000	42,000	43,000	32,900	0	233,577
FY 2016	TEC	0	24,000	8,000	35,000	25,000	40,100	43,500	44,400	30,000	250,000
	OPC	13,177	8,000	2,500	0	0	0	0	0	0	23,677
	TPC	13,177	32,000	10,500	35,000	25,000	40,100	43,500	44,400	30,000	273,677
FY 2017 PB	TEC	0	24,000	8,000	35,000	25,000	40,100	43,500	44,400	30,000	250,000
	OPC	13,177	8,000	2,500	0	0	0	0	0	0	23,677
	TPC	13,177	32,000	10,500	35,000	25,000	40,100	43,500	44,400	30,000	273,677
FY 2018	TEC	0	24,000	8,000	35,000	25,000	40,100	43,500	44,400	30,000	250,000
	OPC	13,177	8,000	2,500	0	0	0	0	0	0	23,677
	TPC	13,177	32,000	10,500	35,000	25,000	40,100	43,500	44,400	30,000	273,677

8. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	FY 2023
Expected Useful Life	10 years

[a] The FY 2013 amount shown reflected the P.L. 112-175 continuing resolution level annualized to a full year. The TEC, OPC, and TPC total and outyear appropriation assumptions were not adjusted to reflect the final FY 2013 level; the FY 2013 Request level of $25,000,000 ($20,000,000 TEC and $5,000,000 OPC) were assumed instead.

[b] Congress approved a reprogramming that reduced the FY 2013 funding to $8,000,000 from the $22,685,000 that was originally appropriated.

Expected Future Start of D&D of this capital asset	FY 2033

Operations and maintenance of this experiment will become part of the existing Fermilab accelerator facility. Annual related funding estimates are for the incremental cost of five years of full operation, utilities, maintenance and repairs with the accelerator beam on. Five subsequent years are planned for further analysis of the data while the detector and beam line are maintained in a minimal maintenance state (with annual cost of approximately 3% of full operations) to preserve availability for future usage with much smaller annual cost.

(Related Funding Requirements)

(dollars in thousands)

	Annual Costs		Life Cycle Costs	
	Current Total Estimate	Previous Total Estimate	Current Total Estimate	Previous Total Estimate
Operations	3,100	3,100	16,000	16,000
Utilities	2,400	2,400	12,400	12,400
Maintenance & Repair	100	100	600	600
Total	5,600	5,600	29,000	29,000

9. Required D&D Information

	Square Feet
Area of new construction	~25,000
Area of existing facility being replaced and D&D'd by this project	0
Area of other D&D outside the project	0
Area of any additional D&D space to meet the "one-for-one" requirement taken from the banked area.	~25,000

The one-for-one replacement has been met through banked space. A waiver from the one-for-one requirement to eliminate excess space at Fermilab to offset the Mu2e project was approved by DOE Headquarters on November 12, 2009. The waiver identified and transferred to Fermilab 575,104 square feet of excess space to accommodate the new Mu2e facilities and other as yet unbuilt facilities from space that was banked at other DOE facilities.

10. Acquisition Approach

The acquisition approach is fully documented in the Acquisition Strategy approved as part of CD-1. This is a high-level summary of material from that document.

DOE awarded the prime contract for the Mu2e project to the Fermi Research Alliance (FRA), the Fermilab Management and Operating (M&O) contractor, rather than have the DOE compete a contract for fabrication to a third party. FRA has a strong relationship with the high energy physics community and its leadership, including many Fermilab scientists and engineers. This arrangement will facilitate close cooperation and coordination between the Mu2e scientific collaboration and an experienced team of project leaders managed by FRA, which will have primary responsibility for oversight of all subcontracts required to execute the project. These subcontracts are expected to include the purchase of components from third party vendors as well as subcontracts with university groups to fabricate detector subsystems.

The largest procurements are the magnet systems and the civil construction. The superconducting solenoid magnets are divided into three systems that could be procured independently but which must ultimately perform as a single integrated magnetic system. Two of the systems are similar to systems that have been successfully built in private industry, so the engineering design and fabrication for two of the solenoids was subcontracted to a third party vendor after a study of industrial vendor capabilities confirmed that the technical risks were acceptable. The third solenoid is unique because of its rather large size and unusual configuration, and no good industrial analog exists. This solenoid was designed at Fermilab and is being fabricated by a third-party vendor in multiple modular components, each of which is well matched to existing industrial capabilities.

There were two major subcontracts for the civil construction. An architectural and engineering contract was placed on a firm-fixed-price basis for Preliminary (Title I) Design, and Final (Title II) Design with an option for construction support (Title III). The general construction subcontract was placed on a firm-fixed-price basis and was completed successfully.

All subcontracts have been competitively bid and awarded based on best value to the government. Fermi Site Office provides contract oversight for FRA's plans and performance. Project performance metrics for FRA are included in the M&O contractor's annual performance evaluation and measurement plan.

Nuclear Physics

Overview

One of the enduring mysteries of the universe is the nature of matter—what are its basic constituents and how do they interact to form the properties we observe? The largest contribution by far to the mass of the visible matter we are familiar with comes from protons and heavier nuclei. The mission of the Nuclear Physics (NP) program is to discover, explore, and understand all forms of nuclear matter. Although the fundamental particles that compose nuclear matter—quarks and gluons—are themselves relatively well understood, exactly how they interact and combine to form the different types of matter observed in the universe today and during its evolution remains largely unknown. Nuclear physicists seek to understand not just the familiar forms of matter we see around us, but also exotic forms such as those which 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** that can be probed by studying neutrons and nuclei.

- **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 both theoretical and experimental efforts. 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. 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. Comparing experimental observations and theoretical predictions tests the limits of our understanding of nuclear matter and suggests new directions for experimental and theoretical research.

At the heart of the NP program are highly trained scientists who conceive, plan, execute, and interpret transformative experiments. NP supports university and national laboratory scientists and U.S. participation in select international collaborations. It provides more than 90 percent of the nuclear science research funding in the U.S., resulting in an average of approximately 90 Ph.D. degrees awarded annually to students for research supported by the program. As documented in the 2015 Nuclear Science Advisory Committee (NSAC) Long Range Plan 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. NP research is guided by DOE's mission and priorities. It develops the core competencies and expertise needed to achieve the goals of the NP program and trains the next generation of nuclear scientists. National laboratory scientists work and collaborate with academic scientists and other national laboratory experimental and theoretical researchers to collect and analyze data and to construct, support, and maintain the advanced instrumentation and world-class facilities used in experiments. The national laboratories provide state-of-the-art resources for targeted detector and accelerator research and development (R&D) for future upgrades 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).

new facilities. This research develops knowledge, technologies, and trained scientists to design and build next-generation NP accelerator facilities. It is also 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 NP's budget. Three scientific user facilities are currently supported, each with unique capabilities: 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). In FY 2017, these facilities provide particle beams for an international user community of over 3,000 research scientists. Approximately 30 percent of these researchers are from institutions outside of the U.S. and they provide very significant benefits to leverage the U.S. program through contributed capital, human capital, experimental equipment, and intellectual contributions. Researchers supported by other SC programs such as High Energy Physics (HEP) and Basic Energy Sciences (BES), DOE Offices such as National Nuclear Security Administration (NNSA) and Nuclear Energy (NE), Federal agencies such as the National Science Foundation (NSF), National Aeronautics and Space Administration (NASA), and Department of Defense (DOD), and industries also use NP scientific user facilities and their core competencies to carry out research programs important for their respective missions. The 12 GeV CEBAF Upgrade project will be completed in 2017 and the highly anticipated science program it enables will be initiated. Construction of a world-class nuclear physics scientific user facility with unique capabilities in nuclear structure and astrophysics, the Facility for Rare Isotope Beams (FRIB), continues at Michigan State University (MSU). This project started in FY 2014 and it is already over 70% complete.

The 2015 NSAC Long Range Plan (LRP) for Nuclear Science recommended that a high-energy, high-luminosity polarized Electron Ion Collider (EIC) be considered the highest priority for new facility construction following the completion of FRIB. Consistent with that vision, NP developed a strategic plan in 2016 to assess the uniqueness and scientific merit of such a facility via a National Academy of Sciences (NAS) study by an independent panel of external experts. Further, NP convened a panel of experts to carry out a community-based review to identify critical R&D needed to reduce risk and establish the basic feasibility of various machine concepts for an electron-ion collider. EIC related R&D efforts will align with the priorities identified in this report.

Involving students in the development and construction of NP facilities and advanced instrumentation, and the development of 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- or 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 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.

Highlights of the FY 2018 Budget Request

The 2018 President's Request funding level of $502,700,000 is a decrease of 18.54% relative to the FY 2016 Enacted level. The FY 2018 Budget Request continues support for high priority efforts and capabilities in nuclear science to optimize scientific productivity within available resources. Critical infrastructure, scientific user facilities, and R&D efforts are prioritized to maintain U.S. leadership in some areas of nuclear science for continuing high priority activities, while the funding decrease requires a reduction in program scope. Support will continue for 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. In addition, the DOE Isotope Program will continue to introduce new medical isotopes to the community for clinical trials and cancer therapy, and modest support is provided for stable isotope enrichment capabilities in the United States to replenish U.S. inventory and reduce foreign dependence on isotopes of strategic importance for the nation.

The Request for *Research* supports university and laboratory researchers so that critical core competencies are preserved and enables high priority theoretical and experimental activities to pursue compelling scientific opportunities at the frontier of nuclear science. Laboratory research activities focus on domestic nuclear science programs and on optimizing existing scientific instrumentation in the nuclear science enterprise in the federal complex. The rescoped university research program is focused on priorities of the restructured nuclear physics program. A reduction in university and laboratory scientists is expected. The FY 2018 Request supports world-class research in multiple scientific thrusts of nuclear science. These include:

- Initial 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;
- Challenging new experiments at ATLAS to study nuclear structure and nuclear reactions occurring under extreme conditions in the cosmos that are conjectured to play a central role in the synthesis of heavy elements;
- High priority, critically needed accelerator R&D to retire potentially "show-stopping" technical challenges to the realization of a possible U.S.-based Electron-Ion Collider (EIC);
- Pioneering R&D in neutrino-less double beta decay to determine whether the neutrino is its own anti-particle, a discovery that could fundamentally change current understanding of the physical universe;
- Forefront isotope R&D to develop new production methods for critical isotopes in high demand for the nation, including isotopes for medicine that could revolutionize therapy for metastasized cancer, and the development of enriched stable isotope production capabilities to reduce the nation's dependence on foreign supplies.

The Request for *Facility Operations* includes funding for the operations of the NP scientific user facilities. A reduction in operations staff is expected. In the short-term, investments in maintaining and/or improving operational reliability and new facility capabilities, such as capital equipment and accelerator improvement projects, are paused, and efforts are redirected to operations of the facility to enable world-class science and the optimization of existing capabilities:

- RHIC operates for 1,470 hours (~10-weeks). The Low Energy RHIC e-Cooler (LEReC) project, an accelerator improvement project that will be soon completed, is implemented in the accelerator, enabling 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;
- CEBAF operates for 1,070 hours (~10 weeks) to launch the highly anticipated science program of the newly constructed 12 GeV machine and associated experimental instrumentation;
- ATLAS operates as the world's premiere stable ion beam facility for 2,620 hours (~23 weeks) to enable compelling experiments in nuclear structure and astrophysics;
- Isotope production facilities are supported, with maintenance deferred in the short term, in order to ensure mission readiness for isotope production. These facilities produce isotopes in short supply that are critical to the nation's federal complex, research enterprise and industry. University isotope production capabilities begin to be networked into the DOE Isotope Program for the eventual coordination of regional production of high priority short-lived isotopes. Operation of the Enriched Stable Isotope Prototype Plant (ESIPP) is maintained and poised to begin to replenish U.S. inventory and reduce dependence on foreign suppliers.

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

- Construction of the Facility for Rare Isotope Beams (FRIB), which will provide world-leading capabilities for nuclear structure and nuclear astrophysics, continues; the project has made impressive progress since it started in FY 2014 and it is over 70% complete. The project will be rebaselined to reflect an increased Total Project Cost and schedule delay as a result of a decrease in its funding in FY 2018 relative to the current funding baseline profile.
- The Gamma-Ray Energy Tracking Array (GRETA) MIE, proposed to be initiated in the FY 2017 President's Request, is funded at a reduced level relative to original plans. GRETA will enable provision of advanced, high resolution gamma ray detection capabilities for FRIB;
- The Stable Isotope Production Facility (SIPF) MIE, which is supported at a reduced pace relative to original plans. Proposed to be initiated in the FY 2017 President's Request, SIPF will provide increased domestic capability for production of critically needed enriched stable isotopes, and reduce the nation's dependence on foreign supply.

Nuclear Physics
Funding ($K)

	FY 2016 Enacted[a]	FY 2017 Annualized CR[b]	FY 2018 Request	FY 2018 vs FY 2016
Medium Energy Nuclear Physics				
Research	34,411	—	25,316	-9,095
Operations	99,672	—	88,598	-11,074
SBIR/STTR and Other	18,457	—	16,253	-2,204
Total, Medium Energy Nuclear Physics	**152,540**	**—**	**130,167**	**-22,373**
Heavy Ion Nuclear Physics				
Research	36,036	—	20,943	-15,093
Operations	172,088	—	164,738	-7,350
Total, Heavy Ion Nuclear Physics	**208,124**	**—**	**185,681**	**-22,443**
Low Energy Nuclear Physics				
Research	54,263	—	33,233	-21,030
Operations	27,402	—	19,222	-8,180
Total, Low Energy Nuclear Physics	**81,665**	**—**	**52,455**	**-29,210**
Nuclear Theory				
Theory Research	37,616	—	27,749	-9,867
Nuclear Data	8,022	—	5,537	-2,485
Total, Nuclear Theory	**45,638**	**—**	**33,286**	**-12,352**
Isotope Development and Production for Research and Applications				
Research	6,329	—	5,307	-1,022
Operations	15,304	—	15,804	+500
Total, Isotopes[c]	**21,633**	**—**	**21,111**	**-522**
Subtotal, Nuclear Physics	**509,600**	**508,631**	**422,700**	**-86,900**

[a] The FY 2016 Enacted level includes SBIR and STTR and reflects updates through the end of the fiscal year.

[b] FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above, below that level, a dash (-) is shown.

[c] All appropriations for the Isotope Development and Production for Research and Applications subprogram fund a payment into the Isotope Production and Distribution Program Fund as required by P.L. 101–101 and as modified by P.L. 103–316.

	FY 2016 Enacted[a]	FY 2017 Annualized CR[b]	FY 2018 Request	FY 2018 vs FY 2016
Construction				
06-SC-01, 12 GeV CEBAF Upgrade, TJNAF	7,500	7,486	0	-7,500
14-SC-50, Facility for Rare Isotope Beams	100,000	99,810	80,000	-20,000
Total, Construction	**107,500**	**107,296**	**80,000**	**-27,500**
Total, Nuclear Physics	**617,100**	**615,927**	**502,700**	**-114,400**

SBIR/STTR Funding:

- FY 2016 Transferred: SBIR: $14,040,000; STTR: $2,106,000
- FY 2018 Request: SBIR $12,941,000 and STTR $1,820,000

Nuclear Physics
Explanation of Major Changes ($K)

	FY 2018 vs FY 2016
Medium Energy Nuclear Physics: Funding is provided for operation of the recently upgraded CEBAF accelerator to support 1,070 operating hours and experimental activities in some of the newly upgraded experimental halls to launch the highly anticipated 12 GeV CEBAF physics program. The focus of the 12 GeV science program is to advance the understanding of strongly interacting matter and its description in QCD, and to search for evidence of new physics beyond the Standard Model. 12 GeV researchers from national laboratories and universities implement, commission, and operate new experiments at CEBAF. National laboratory and university research support is reduced and several activities within the Medium Energy program are ended to enable the high priority 12 GeV science program. These include the RHIC Spin program focused on understanding the spin structure of the proton, and the Research and Engineering Center at the Massachusetts Institute of Technology, a University Center of Excellence within the nuclear science portfolio. Funding decreases for mandatory SBIR/STTR for the NP program.	**-22,373**
Heavy Ion Nuclear Physics: Funding for operations of RHIC is provided to enable world-leading research in heavy ion nuclear physics in order to answer fundamental questions about the properties of the quark-gluon plasma discovered there and about the scientific explanation of intriguing new phenomena resulting from that discovery. A 1,470 hour run in FY 2018 will focus on measurements to explore how magnetic fields generated in RHIC collisions, as strong as any in the known universe, influence the properties of the quark-gluon plasma, a state of matter that existed in the infant universe. A collateral goal of the FY 2018 run is the first direct confirmation of the restoration of chiral symmetry - the symmetry of nature responsible for the generation of the mass of the visible universe. U.S. participation in the complementary CERN Large Hadron Collider (LHC) heavy ion program is ended, and national laboratory and university research is reduced. Research efforts focus to support the domestic heavy ion program at RHIC – data taking, analysis and the enhancement of existing scientific instrumentation and infrastructure.	**-22,443**
Low Energy Nuclear Physics: The ATLAS facility continues to provide critical capabilities for nuclear structure and astrophysics research and operates approximately 2,620 hours in FY 2018. Funding decreases, as planned, for disposition activities of the closed down Holifield Radioactive Ion Beam Facility (HRIBF), which are completed in FY 2017. National laboratory and university research support is reduced to support highest priority efforts and core competencies. Research in neutrinoless double beta decay focusses on completing existing experiments such as the CUORE experiment and the Majorana Demonstrator; efforts to develop new candidate technologies for a next generation neutrinoless double beta decay experiment are paused. Operations of two University Centers of Excellence, Texas A&M and The High Intensity Gamma Source (HIGS) at Duke University, are paused. Operations of the 88” Cyclotron at LBNL for an in-house nuclear science program are paused and efforts focus on the implementation of new capabilities for the Super Heavy Element program that aims to discover new elements on the periodic table. The pause in operations will impact the Department of Defense Space radiation Effects Electronics (SEE) testing program. Development of small scientific instrumentation for FRIB is paused to focus efforts on construction of the facility itself. The GRETA MIE, proposed to start in the FY 2017 President’s Request, continues in FY 2018 at a pace determined by available resources to address certain aspects of engineering design and long-lead procurement; a successful implementation of this detector will represent a major advance in gamma-ray tracking detector technology that will impact nuclear science as well as detection techniques in homeland security and medicine. GRETA is a high resolution gamma array tracking device that will provide a combination of high efficiency, good background suppression, and excellent energy and position resolution in order to fully exploit the opportunities at FRIB for both fast fragmentation and reaccelerated beams.	**-29,210**

	FY 2018 vs FY 2016
Nuclear Theory: Support for theory research efforts at laboratories and universities, as well as for the U.S. Nuclear Data Program and SCIDAC, is reduced. University and laboratory scientists refocus their efforts on activities within the nation's nuclear physics portfolio that are supported in the FY 2018 Request. Investments in Lattice Quantum Chromodynamics Dynamics computing hardware is paused to enable focus on high priority theoretical efforts.	**-12,352**
Isotope Development and Production for Research and Applications: Operations funding provided to support mission readiness for production activities at national laboratory facilities is decreased. Arrangements are continued to position the isotope program to network a suite of university accelerators and reactors for cost-effective, regional production of short-lived isotopes for research and medical applications. The first member of the university network, the University of Washington, began producing astatine-211 for cancer therapy research in FY 2016. Modest funding for operations of the ESIPP is provided to produce small quantities of enriched stable isotopes for research applications. The Stable Isotope Production Facility (SIPF) MIE, proposed to initiate in the FY 2017 President's Request, continues at a pace determined by available resources. When completed, SIPF will produce needed domestic capability for producing enriched stable isotopes for research, defense and industry. Isotope research funding at universities and laboratories is decreased and will focus on the development of new production techniques for high priority isotopes. In particular, effort continues on the production of Ac-225, a promising therapeutic for metastasized cancers, to the levels needed for clinical trials.	**-522**
Construction: Construction funding continues according to a re-baselined profile for the Facility for Rare Isotope Beams in FY 2018. Support for the 12 GeV Upgrade at CEBAF, which is completed in 2017, is ended in accordance with its construction profile.	**-27,500**
Total, Nuclear Physics	**-114,400**

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 HEP, NP, and Advanced Scientific Computing Research (ASCR) programs coordinate and leverage forefront computing resources and technical expertise through the Lattice Quantum Chromodynamics (LQCD) and SciDAC projects to determine the properties of as-yet unobserved exotic particles predicted by the theory of Quantum Chromodynamics, advance progress towards a model of nuclear structure with predictive capability, and dramatically improve modeling of neutrino interactions during core collapse supernovae. The U.S. Nuclear Data Program, which recently stood up an Inter-Agency working group including NE, NNSA, the Department of Homeland Security (DHS), and the Domestic Nuclear Detection Office (DNDO), provides evaluated cross-section and decay data relevant to a broad suite of Federal missions and topics such as reactor design (e.g., of interest to the NE and Fusion Energy Sciences [FES] programs), materials under extreme conditions (of interest to the BES and FES programs), and nuclear forensics (NNSA, DHS, and Federal Bureau of Investigations [FBI]). NP research develops technological advances relevant to the development of advanced fuel cycles for next generation nuclear reactors (NE); advanced cost-effective accelerator technology and particle detection techniques for medical diagnostics and treatment (NIH, HEP); and research in developing neutron, gamma, and particle beam sources with applications in cargo screening and nuclear forensics (NNSA, DHS, DNDO, and FBI).

R&D coordination and integration are hallmarks of the NP Isotope Development and Production for Research and Applications subprogram (DOE Isotope Program), which produces commercial and research isotopes in short supply that are critical for basic research and applications. It also supports research on the development of new or improved production and separation techniques for stable and radioactive isotopes. NP continues to further align the Federal, industrial, and research stakeholders of the DOE Isotope Program and has strong communication between the various communities. To ascertain current and future demands of the research and applied communities, NP organizes working groups, workshops, symposia, and discussions with Federal agencies and community and industrial stakeholders on a continuous basis. It also works collaboratively with other DOE Offices (NNSA and NE) to help ensure adequate supplies of isotopes needed for their missions, such as lithium-7 (Li-7), which is used by nuclear power plants as a coolant reagent. The DOE Isotope Program conducts annual Federal workshops to identify isotope demand and supply across a broad range of Federal agencies (including NIH, NASA, FBI, DOD, DHS, DOT, NSF, and DOE) to ensure that isotopes are available for the federal complex to accomplish its missions.

Program Accomplishments

First 12 GeV Electrons from the Newly Upgraded Continuous Beam Accelerator Facility (CEBAF). The newly commissioned CEBAF delivered its first 12 GeV electrons on December 14, 2015, to its new experimental Hall D complex, as planned. The successful achievement came as part of the ongoing 12 GeV CEBAF Upgrade project scheduled to be completed in September 2017. Hall D, the new and fourth experimental hall at CEBAF, is the home of the GLUEX detector focused on landmark measurements of exotic, heretofore unseen subatomic particles thought to result from excitations of gluons that interact with the up and down quarks inside protons and neutrons. Observations of such exotic particles will provide unprecedented opportunity to advance understanding of quantum chromodynamics (QCD), the theory of the strong force. Thanks to a recent upgrade to allow simultaneous four-hall operation for science data taking, Hall D will contribute not only to new scientific reach, but record levels of scientific productivity when CEBAF begins full operation.

Heavy Quarks at RHIC Go Tubing in the Quark-Gluon Plasma. One of the earliest signature discoveries at RHIC was that in the Quark-Gluon Plasma (QGP), a form of matter which existed microseconds after the Big Bang, all particles containing light up and down quarks collectively flow together out of the hot, dense region where the QPG is formed. Early predictions suggested the same flow would not be observed for the much more massive charm and beauty quarks because they were too heavy to be pushed along with the flow of the expanding plasma. Surprisingly, however, recent results from RHIC, enabled by record luminosity and new state-of-the-art silicon tracking detectors, show that heavy quarks do indeed flow, although they do not fully keep up with their lighter quark counterparts. These measurements give new insights into the remarkable strength of the collective motion of quarks inside the QGP formed at RHIC, and its transport properties at the instant of formation.

Newcomers Join the Official Table of the Elements. After a rigorous effort to confirm their discovery, the International Union for Pure and Applied Chemistry recently accepted claims for the observation of *four* new elements, with atomic numbers 113, 115, 117, and 118. The discovery of these “superheavies” is particularly exciting as positive indication that a long-postulated “island of stability”, where superheavy elements with lifetimes on the scale of seconds or days, may indeed exist. In recognition of the long standing NP supported U.S. collaboration and contribution to this research at ORNL, one of the new elements (117) has been named Tennessine (Ts), forever changing the Table of the Elements displayed on the walls of classrooms everywhere. Isotopes that enabled this historic research were provided by the DOE Isotope Program.

Important Milestone Reached Deep Under Ground: Final Module Commissioning for the Majorana Demonstrator. One of the most urgent Grand Challenge questions of modern physics is why the neutrino mass is so small, and whether the neutrino is its own anti-particle. A proposed candidate experiment to answer these questions, capable of detecting rare decays predicted to happen for a single nucleus only once every 10^{28} years, is currently undergoing a scaled-down feasibility study named the Majorana Demonstrator (MJD) to demonstrate the sensitivity and background levels that are needed for a larger ton-scale experiment. MJD, an experiment jointly funded by DOE-NP and NSF, is currently being implemented at the Sanford Underground Research Facility in Lead, SD. It comprises two cryostat modules, each containing more than 20 kg of high-purity germanium detectors. Two-thirds of these detectors are made from germanium that has been isotopically enriched to be 87% pure 76Ge. The project recently passed a major milestone as it began commissioning the second and final module of detectors.

Baby Steps Promise Giant Leaps in Nuclear Theory Computing: Inelastic Nuclear Reaction Calculated from First Principles Quantum Chromodynamics. Starting from first principles Quantum Chromodynamics (the theory of the strong force), the Nuclear Physics Lattice QCD (NPLQCD) Collaboration has now calculated for the first time, the rate for the capture of a low-energy neutron by a proton to produce a deuteron and a gamma ray, the $np \rightarrow d\gamma$ radiative capture process. Although one of the simplest, most basic inelastic nuclear reactions, this process has enormous consequences for understanding the process of nucleo-synthesis following the Big Bang which initiated the production of most light nuclei in the cosmos. To accomplish this landmark result, the Collaboration relied heavily on recent advances in high-performance computing (HPC), determining the short-distance two-nucleon interactions with the electromagnetic field and extrapolating the results to the physical pion mass.

Thin Skinned Calcium-48. In order to build a Ca-48 nucleus (20 protons and 28 neutrons) “from the ground up”, an international team led by ORNL used ORNL’s Titan supercomputer was assembled to solve this emergent, strongly correlated, many-body system, and to compute the neutron distribution in the Ca-48 nucleus. Surprisingly, they found that the predicted difference between the radii of the neutron and proton distributions in Ca-48 (called the “neutron skin”) is considerably smaller than previously postulated. These groundbreaking calculations now become the subject of planned experimental measurements at TJNAF. The outcomes will have particular relevance to nuclear astrophysics, as the neutron skin thickness of such nuclei directly impacts the predicted size of neutron stars.

Tri-Laboratory Effort to Develop a Cancer-Fighting Isotope Passes a Major Milestone. Actinium-225 is an alpha-emitting radioisotope that has enormous promise as a therapeutic agent against metastatic and diffuse cancers and infectious diseases. Early studies of pharmaceuticals which incorporate Ac-225 have demonstrated extraordinary efficacy against these types of cancers and certain kinds of infection. The present supply of Ac-225 is extremely limited and barely sufficient to support these early clinical trials. In April of 2015 a collaborative effort was formed among Brookhaven National Laboratory, Los Alamos National Laboratory, and Oak Ridge National Laboratory to develop a new production route using proton accelerators. A recent review of progress determined that the research team is ahead of schedule in developing the targetry, chemistry, and transportation logistics for production of sufficient amounts of Ac-225 to support advanced research and clinical trials. The tri-laboratory team was approved to continue the effort with a focus on optimization of the technologies to create a routine and reliable supply of the isotope to support developing clinical applications.

A New Spin on the Proton. New data from high-energy polarized proton collisions at RHIC (the world’s only polarized proton collider) indicate that gluons —named for their role in binding the up and down quarks inside a proton—play a substantial role in determining the proton spin, a fundamental property which is often overlooked despite its profound influence on the structure of nuclei. The results suggest that the overall contribution from gluons might even be greater than the contribution from valence quarks, which is known to account for only a third of the proton’s spin. By determining the intrinsic contribution from both gluons and quarks, researchers are narrowing in on a final piece of the proton spin puzzle: the contribution from the orbital motion of these elusive constituents. A key factor in recent RHIC runs enabling this landmark progress has been the record luminosity (beam-beam collisions) achieved, which in a single run have exceeded the combined luminosity of all previous RHIC runs combined.

Direct evidence for Nuclei Shaped as a Pear. While most nuclei are either spherical or adopt shapes with symmetric deformations (such as the shape of a football or a doorknob), a few are predicted to have the shape of a pear. These so-called octupole-deformed nuclei come about through the coupling between pairs of nucleons (protons and neutrons) occupying close-lying orbitals within the nucleus, resulting in strong correlations. Now, for the first time, the strength of the octupole, pear-shaped deformation has been quantified in the Barium – Cerium region in Coulomb excitation experiments at ATLAS. Specifically, capability provided by the new Californium Rare Isotope Breeder Upgrade (CARIBU) at ANL allowed the first post acceleration of radioactive ^{144,146}Ba beams. Combined with the enhanced detection capability provided by the upgraded CHICO2 parallel plate avalanche chamber array and the gamma ray tracking provided by the world leading Gamma Ray Energy Tracking In-Beam Nuclear Array detector, these new measurements of the octupole deformation of ^{144}Ba constitute groundbreaking confirmation of the fidelity of nuclear models predicting octupole deformations which can now be extended into other unexplored regions of the nuclear landscape.

Swift Pace of FRIB Construction Allows Early Start of Front-end Commissioning. The FRIB project is the Office of Nuclear Physics' highest priority construction effort. Even though ground breaking of this state-of-the-art, highly complex facility started just back in March 2014, FRIB construction has already surpassed the 70% completion mark as of November 1, 2016. As construction continues, a notable accomplishment has been the production of the first FRIB ion beam with the recently installed Advanced Room Temperature Ion Source (ARTEMIS) electron-cyclotron-resonance (ECR). This ion source was commissioned on the front end of the FRIB linear accelerator (LINAC) 16 months earlier than originally planned by re-sequencing FRIB construction activities, enabling the project to retire associated risk with the front-end ion source and start the installation and commissioning of other front-end components. Over 1,400 scientists eagerly await the physics opportunities that FRIB will provide, and new collaborations to deepen theoretical understanding of FRIB science and develop new detector instrumentation are actively in pursuit.

Building a National Network for Regional Isotope Needs: The DOE Isotope Program has recently established a partnership agreement with the University of Washington (UW) to enable UW to supply astatine-211 (At-211) for pre-clinical research. Operating on a weekly production schedule, the UW processing laboratories and technical staff are able to provide the DOE Isotope Program with regional distribution of highly pure At-211 to western states in the U.S. Addressing a recommendation in the NSAC-Isotope 2015 Long-Range Plan for the DOE Isotope Program, the partnership with UW marks the first of many such potential agreements that could create a network of university-based isotope production centers capable of nationally providing short-lived radionuclides like At-211.

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 which 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. The subprogram has provided support for spin physics research at RHIC, the only collider in the world that can provide polarized proton beams; however, in FY 2018, Medium Energy funding for RHIC is suspended to support other high priority efforts within the program, such as the launching of the 12 GeV CEBAF program. 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 will be completed in 2017, and the highly anticipated science program will be launched in FY 2018. Some of the science goals of the 12 GeV experimental program include the search for exotic new quark anti-quark particles to advance our understanding of the strong force, evidence of new physics from sensitive searches for violations of nature’s fundamental symmetries, and a microscopic understanding in the 12 GeV energy regime of the internal structure of the proton, including the origin of its spin, and how this structure is modified when the proton is inside a nucleus. Research support for CEBAF includes laboratory and university scientific and technical staff needed to conduct high priority data analysis to extract scientific results. No support for capital equipment, Accelerator Improvement Projects, or General Plant Projects is provided to CEBAF in FY 2018. Reduced accelerator R&D efforts at TJNAF focus on high priority activities. Complementary special focus experiments that require different capabilities that have been supported at the High Intensity Gamma Source (HIGS) at Triangle Universities Nuclear Laboratory, Europe, and elsewhere and are paused in FY 2018 to support other high priority efforts within the program. The Research and Engineering Center of the Massachusetts Institute of Technology (MIT) has specialized infrastructure to develop and fabricate advanced instrumentation and accelerator equipment; however, the FY 2018 Request does not include funding to support the Center. The subprogram will instead redirect research efforts to other high priority efforts.

The “SBIR/STTR and Other” category within this subprogram provides funding in accordance with the Small Business Innovation Development Act and subsequent related legislation. The NP funding for the SBIR/STTR Program is technically managed by NP, resulting in commercialization opportunities in markets such as medicine, homeland security, defense, and industry as well as in products and services by U.S. small businesses that benefit NP facilities and researchers. This category also includes funding to meet other NP obligations, such as the annual Lawrence Awards and Fermi Awards for honorees selected by DOE for outstanding contributions to science, and NP contributions to the SC Working Capital Fund.

Research

The Medium Energy Research program, with research groups at TJNAF, BNL, ANL, LANL, and LBNL, and approximately 75 scientists and 60 graduate students at 20 universities, carries out highest priority research programs and conducts experiments at CEBAF; the funding decrease results in an overall reduction in laboratory and university research in the FY 2018 Request. Scientists participate in the development and implementation of advanced instrumentation, including state-of-the-art detectors for experiments that may also have application in areas such as medical imaging instrumentation and homeland security. TJNAF staff research efforts will focus on launching the 12 GeV experimental program, including the implementation of experiments, acquiring data, and performing data analysis at select CEBAF experimental halls (Halls A, B, C, and D). Scientists conduct research to advance knowledge and to identify and develop the science opportunities and goals for next generation instrumentation and facilities. The subprogram also supports an active visiting scientist program at TJNAF and bridge positions with regional universities as a cost-effective approach to augmenting scientific expertise at the laboratory and boosting research experience opportunities.

ANL scientists play a leadership role in many of the new experiments in the 12 GeV scientific program, and are heavily engaged in experiment commissioning, 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. The subprogram will suspend ANL research efforts at Fermilab that were focused on determining the contribution to the proton spin from orbital angular momentum of sea quarks and antiquarks as new research efforts focus on the 12 GeV experimental program. Research groups at BNL and LBNL will play limited roles in the analysis of existing RHIC spin data focused on determining the spin structure of the proton, as this experimental program is ended.

Accelerator R&D research proposals 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 Medium Energy and Heavy Ion subprograms. Limited accelerator R&D funding in Medium Energy and Heavy Ion subprograms supports research on the most significant technical challenges and risk reduction activities associated with concepts for a possible future electron-ion collider.

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 support for the accelerator physicists at TJNAF that operate CEBAF as well as for maintenance and power costs in the first year of operations subsequent to the completion of the 12 GeV CEBAF Upgrade project in 2017. Reductions in facility staff are expected. Investments in accelerator improvements, including the modernization of the accelerator injector components, GPP investments for infrastructure, and capital equipment for research and facility instrumentation, are suspended. Support for developing advances in superconducting radiofrequency (SRF) technology relevant to improving operations of the existing machine are paused as efforts focus on the initiation of the 12 GeV science program. The core competency in SRF technology plays a crucial role in many DOE projects and facilities outside of nuclear physics (such as the Basic Energy Sciences project LCLS II) and has broad applications in medicine, defense, and homeland security. For example, SRF R&D at TJNAF has led to improved land-mine detection techniques and carbon nanotube and nano-structure manufacturing techniques for constructing super-lightweight composites such as aircraft fuselages. TJNAF also has a core competency in cryogenics and has developed award-winning techniques that have led to more cost-effective operations at TJNAF and several other SC facilities; their cryogenics expertise is being applied to the FRIB project and LCLS-II. TJNAF accelerator physicists help train the next generation of accelerator physicists, enabled in part by a close partnership with nearby universities and other institutions with accelerator physics expertise. The subprogram provides Experimental Support for the 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.

Medium Energy Nuclear Physics

Activities and Explanation of Changes

FY 2016 Enacted	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
Medium Energy Nuclear Physics $152,540,000	**$130,167,000**	**-$22,373,000**
Research $34,411,000	**$25,316,000**	**-$9,095,000**
Researchers focused on the 12 GeV experimental program at TJNAF continued to implement and develop experimental instrumentation and prepare for the new Hall D physics capabilities which were demonstrated in FY 2017. Analysis efforts of RHIC polarized proton beam data to learn more about the origin of the proton's spin, and support for short and mid-term accelerator R&D continued.	The 12 GeV experimental program will be launched at CEBAF, with experiments and data taking in select experimental halls. Science goals include the search for exotic new quark/anti-quark particles, sensitive searches for violations of nature's fundamental symmetries, and a detailed microscopic understanding of the internal structure of the proton. Researchers will analyze select data from the RHIC spin run in FY 2017 that focuses on the spin structure of the proton.	The funding decrease requires a reduction in scope. Research efforts at universities and laboratories are reduced, resulting in a reduction of scientific workforce. Terminations include: support for the MIT Research and Engineering Center; Fermilab Nuclear Physics Experimental program; RHIC Spin Research program. Support will be paused for research capital equipment, shifting focus to the enhancement and implementation of existing instrumentation. The program will phase-out efforts focused on analysis and publication of select data sets.
Operations $99,672,000	**$88,598,000**	**-$11,074,000**
Funding supported continued machine development, and its associated incremental power costs, to support the full, future 12 GeV research program, including engineering operations to Hall D and commissioning of newly installed hall equipment for physics running starting in FY 2017. Funding was provided for Other Project Costs (within project TPC), as part of the 12 GeV CEBAF Upgrade project profile. The major milestone in FY 2016 was to establish first beams to Halls B and C for commissioning activities.	Operations of the CEBAF facility will be supported in the highly anticipated first year of operations, following the completion of the project in 2017. Funding will support 1,070 operational hours (about 29% utilization) of running for research, tuning, and beam studies. Experiments in select halls will be operated for data taking.	Funding for both accelerator operations and experimental support are reduced, resulting in a reduction of ~6 weeks of operations. Program will suspend funding for capital equipment and accelerator improvement funding and for General Plant Projects. Funding reductions cannot accommodate the return of facility operations staff from the 12 GeV construction project, which will result in a reduction in the number of scientists at CEBAF. Program will reduce funding for accelerator R&D efforts in SRF technology as the focus is on launching the 12 GeV program.
SBIR/STTR and Other $18,457,000	**$16,253,000**	**-$2,204,000**
Funding was provided in accordance with the Small Business Innovation Development Act and subsequent related legislation, as well as for other DOE and Office of Science obligations.	Funding will be provided in accordance with the Small Business Innovation Development Act and subsequent related legislation, as well as for other DOE and SC obligations.	The decrease reflects the mandated set-aside for SBIR/STTR.

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 LHC at CERN, researchers have seen signs of the same quark-gluon plasma that is believed to have existed shortly after the Big Bang. With careful measurements, scientists are accumulating data that offer insights into the processes early in the creation of the universe, and how protons, neutrons, and other bits of normal matter developed from that plasma. Important avenues of investigation are directed at learning more about the physical characteristics of the quark-gluon plasma including exploring the energy loss mechanism for quarks and gluons traversing the plasma, determining the speed of sound in the plasma, establishing the threshold conditions (minimum nucleus mass and energy) under which the plasma can be formed, and discovering whether a the critical point exists where there is a phase transition between normal nuclear matter and the quark-gluon plasma.

The RHIC facility places heavy ion research at the frontier of discovery in nuclear physics. The RHIC facility is uniquely flexible, providing a full range of colliding nuclei at variable energies spanning the transition to the quark gluon plasma discovered at RHIC. The facility continues to set new records in performance for both integrated Au-Au luminosity at full energy and a number of other beam settings. This flexibility and performance enables a groundbreaking science program extending into the next decade to answer outstanding questions about this exotic form of matter. The FY 2017 run will test the present understanding of QCD as applied to the spin structure of the proton and will further clarify the scientific interpretation of recent heavy ion measurements. In FY 2018, RHIC will accelerate selected isotopes to explore exciting new phenomena that have emerged in quark-gluon plasma formation. In FY 2018, researchers at RHIC will implement significant accelerator improvements developed over the past couple of years to increase luminosity, enabling a campaign to search for a critical point in the phase diagram of nuclear matter the following year. Efforts will continue, within available, existing resources, to enhance the capabilities of the STAR detector, and continue limited advanced engineering and design activities for an upgrade of the PHENIX detector to sPHENIX. The subprogram will also support limited short and mid-term accelerator R&D at RHIC in critical areas that may include the cooling of high-energy hadron beams, high intensity polarized electron sources, and high-energy, high-current energy recovery linear (ERL) accelerators. The RHIC facility has been used by about 1,200 DOE, NSF, and foreign agency-supported researchers annually.

Collaboration in the heavy ion program at the LHC at CERN has provided 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. In FY 2018, NP will suspend U.S. participation in the heavy ion program at the LHC as research efforts will shift focus to the domestic heavy ion program at RHIC.

<u>Research</u>

The subprogram will support heavy ion research groups at BNL, LBNL, LANL, and ORNL to participate in experiments at RHIC. A reduction in laboratory and university research staff is anticipated due to reduced funding in the FY 2018 Request and termination of U.S. participation in the LHC heavy ion program.

The university and national laboratory research groups provide scientific personnel and graduate students for taking data within the RHIC heavy ion program; analyzing data; publishing results; conducting R&D of next-generation detectors; developing and implementing scientific equipment; and planning for future experiments. BNL and LBNL provide computing infrastructure for petabyte-scale data analysis and state-of-the-art facilities for detector and instrument development. At LBNL, a large-scale computational system, the NP-supported Parallel Distributed Systems Facility (PDSF), is a major shared resource used for the analysis of RHIC data in alliance with the National Energy Research Scientific Computing Center (NERSC), which is supported by SC's ASCR program.

Accelerator R&D research proposals for short and mid-term accelerator R&D from universities and laboratories specific to improving operations of current NP facilities or developing new NP facilities are evaluated by peer review through a single competition for funding that is included under the Heavy Ion and Medium Energy subprograms. Limited accelerator R&D funding in Medium Energy and Heavy Ion accelerator R&D supports the most critical pre-conceptual Electron Ion Collider (EIC) accelerator R&D based on the priorities identified by the NP community's EIC R&D review. The focus is on the most significant technical challenges and risk reduction activities required toward the possible realization of a U.S. based EIC.

Operations

The Heavy Ion subprogram provides support for the operations and power costs of the RHIC accelerator complex at BNL. In FY 2018, the subprogram suspends support for capital equipment and accelerator improvement projects and efforts will be focused on operating the machine and enhancing capabilities of existing instrumentation and accelerator components. A reduction in facility operations staff is expected. 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 provides experimental support to the facility, including the development, implementation, and commissioning of scientific equipment associated with the RHIC program. The subprogram will delay support for important improvements to extend STAR capabilities that had been planned for the FY 2019 run and search for the critical point in the phase diagram are delayed, but will continue funding these improvements as funding permits. Within available funding, a small effort will also continue on advanced conceptual engineering and design efforts associated with the planned upgrade of PHENIX to "super PHENIX" or sPHENIX. sPHENIX will enable scientists to study how the strongly interacting QGP liquid arises from the weakly interacting quarks and gluons from which it is formed.

Through operations of the RHIC complex, important core competencies are nurtured in accelerator physics techniques to improve RHIC performance and support the NP mission. These core competencies provide collateral benefits to applications in industry, medicine, homeland security, and other scientific projects outside of NP. Accelerator Improvement Projects have focused on cooling of low energy heavy ion beams with bunched electron beam, which is projected to increase the luminosity by up to another factor of 10. The full system is planned to be implemented in FY 2018, after completion in 2017. RHIC accelerator physicists are providing leadership to the effort to address technical feasibility issues of relevance to a possible next-generation collider, including beam cooling techniques and energy recovery linacs; these activities focus on the highest priority challenges in accelerator R&D as funding is reduced. 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.

Heavy Ion Nuclear Physics

Activities and Explanation of Changes

FY 2016 Enacted	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
Heavy Ion Nuclear Physics $208,124,000	**$185,681,000**	**-$22,443,000**
Research $36,036,000	**$20,943,000**	**-$15,093,000**
Researchers continued to participate in the collection and analysis of new data from RHIC enabled by the completed STAR Heavy Flavor Tracker (HFT) MIE. The FY 2014 run was the commissioning run for the HFT, and provided important first results, but not final precision measurements. The 2015 run generated the baseline data from proton+proton and proton+Au collisions, and the FY 2016 run generated the definitive Au+Au data, which will address unexplained phenomena with charm and bottom quarks to inform our understanding of the perfect liquid discovered at RHIC in 2005. NP also provided scientific leadership to the heavy ion efforts at the international ALICE, CMS, and ATLAS LHC experiments, as well as the required funding to the LHC for U.S. commitments for management and operating costs. Mid- and short-term accelerator R&D relevant to NP programmatic needs was also supported.	Researchers continue to participate in the analysis and collection of data from RHIC to explore new phenomena in quark-gluon plasma formation. Limited efforts will continue in ongoing development of instrumentation aimed at future physics campaigns to probe the properties of the QGP. Limited accelerator R&D relevant to NP programmatic needs will also be supported.	The funding decrease requires a reduction in scope at universities and national laboratories associated with implementing the RHIC and LHC science programs. The overall research support is reduced, resulting in a reduction in workforce. Additional reductions include funding for accelerator R&D directed at addressing feasibility to meet technical requirements for a future EIC. Terminations include participation of U.S. scientists in the LHC heavy ion program, including the small-scale ALICE instrumentation upgrades at the LHC; the program will shift focus on the domestic heavy ion program and will not meet U.S. commitments to the LHC heavy ion program.

FY 2016 Enacted	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
Operations $172,088,000	**$164,738,000**	**-$7,350,000**
RHIC operations provided for 2,697 beam hours, which was approximately 20 weeks and equal to 66% utilization in support of the planned RHIC research program that is taking advantage of dramatic improvements in collider performance and versatility made possible by recent RHIC upgrades. The FY 2016 run (Run-16) was essential to understand results on heavy quark propagation in the quark-gluon plasma discovered at RHIC. The high statistics data completed for Run-16 addresses these phenomena and are required for researchers to interpret the data acquired from the last two years.	RHIC operations of 1,470 hours[a] (about 67% utilization) is focused on a targeted run to confirm the restoration of chiral symmetry - the symmetry of nature responsible for the generation of mass. RHIC staff will continue to develop and install instrumentation, as possible, needed for the upcoming experimental campaigns, including electron cooling. The run in FY 2018 is combined with the run in FY 2019, spanning fiscal year boundaries; the facility operates once over two fiscal years. Accelerator science staff will continue to reduce the highest technical risks associated with operating the complex facility, as well as demonstrating technical feasibility of a possible future electron-ion collider.	Reduction provides support of RHIC operations for 10 weeks. Support for capital equipment and Accelerator Improvement Projects is paused in FY 2018. Reductions in facility operations staff are expected.

[a] Optimal beam hours in FY 2018 available beam time is limited to 2,205 hours to allow for access to install upgrades to the accelerator essential for the FY 2019-20 physics campaign. The run in FY 2018 is combined with the run in FY 2019, spanning fiscal year boundaries; the facility operates once over two fiscal years.

Description

The Low Energy Nuclear Physics subprogram focuses on answering the overarching questions associated with two scientific thrusts, 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?

This subprogram addresses these questions through precision studies using neutron beams and decays of nuclei, including neutrinoless double-beta decay. Beams of cold and ultracold neutrons are used to study fundamental properties of neutrons. 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 only DOE-supported facility providing research opportunities in Nuclear Structure and Nuclear Astrophysics, serving a combined international community of about 400 scientists. ATLAS 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 is the world's premiere facility for stable beams, and it 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 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.

Disposition activities of the ORNL Holifield Radioactive Ion Beam Facility (HRIBF), which ceased operations in FY 2012, are completed in FY 2017.

Two university Centers of Excellence with specific goals and unique physics programs, the Cyclotron Institute at Texas A&M University (TAMU) and accelerator facilities at the Triangle Universities Nuclear Laboratory (TUNL) at Duke University, are supported for data analysis and research efforts, but are not funded for accelerator operations. A third university center, the

Center for Experimental Nuclear Physics and Astrophysics (CENPA) at the University of Washington, is supported to provide unique expertise and capabilities for instrumentation development and leads the Project 8 neutrino mass experiment collaboration. The subprogram will pause funding for operations of the 88-Inch cyclotron at LBNL, which provides beams for a small in-house nuclear science program, which will also, also impact important capabilities in materials irradiation important for external users and other missions.

The Facility for Rare Isotope Beams (FRIB), under construction at Michigan State University (MSU), will advance understanding of rare nuclear isotopes and the evolution of the cosmos by providing beams of rare isotopes with neutron and proton numbers far from those of stable nuclei in order to test the limits of nuclear existence. The project will continue construction activities at a slower rate than originally planned, which will require a rebaseline in FY 2018. The Gamma-Ray Energy Tracking Array (GRETA) MIE, requested as a new start in the FY 2017 Budget Request, is continued in the FY 2018 Request at a slower pace than planned, and is one of the primary tools that the community and NSAC have identified to leverage the capabilities of FRIB. GRETA will have ten times the gamma-ray resolving power of current generation detectors for the vast majority of experiments, and up to a factor of 100 for those requiring multiple gamma-ray correlations. GRETA's unprecedented combination of full coverage with high efficiency, and excellent energy and position resolution, will extend the reach of FRIB's ability to study the nuclear landscape, provide new opportunities to discover and characterize key nuclei for electric dipole moment (EDM) searches, and open new areas of study in nuclear astrophysics.

<u>Research</u>
The subprogram will support Low Energy research groups at ANL, BNL, LBNL, LANL, LLNL, ORNL, and PNNL, with an expected overall reduction in laboratory and university research staff. Historically, about half of the scientists have conducted nuclear structure and astrophysics research primarily using specialized instrumentation at the ATLAS scientific user facility. The GRETA MIE is pursued at a slower pace than had been proposed in the FY 2017 budget, resulting in a delayed completion at a higher cost. Scientists primarily conduct research in fundamental symmetries, including experiments at the Fundamental Neutron Physics Beamline (FNPB) at the Spallation Neutron Source; ongoing double beta-decay experiments such as the Cryogenic Underground Observatory for Rare Events (CUORE) experiment at Gran Sasso Laboratory in Italy, the Majorana Demonstrator R&D effort at the Sanford Underground Research Facility in Lead, South Dakota, and generic R&D for a xenon-based technology for neutrinoless double beta decay experiments; a measurement of the neutrino mass with the Karlsruhe Tritium Neutrino (KATRIN) experiment at the Karlsruhe Institute of Technology in Karlsruhe, Germany; and limited R&D to measure the neutron electric dipole moment. The subprogram continues to provide support, although reduced, to the university Centers of Excellence to maintain their unique capabilities. In FY 2018, the subprogram will suspend funding for competitive R&D efforts, funded in partnership with the NSF, to retire potentially "show-stopping" questions related to detector technologies relevant for a planned down select for a future ton-scale neutrinoless double beta decay experiment are paused.

<u>Operations</u>
ATLAS provides highly reliable and cost-effective stable and selected radioactive beams and specialized instrumentation for scientists to conduct research on nuclear structure and nuclear astrophysics. The subprogram provides support for the operations, power costs and experimental support of ATLAS. The recently installed Electron Beam Ion Source (EBIS) Accelerator Improvement Project enhances the performance of the CARIBU radioactive beam system for accelerated radioactive ion beams. An in-flight radioactive ion separator to increase the intensity of radioactive beams by several orders of magnitude and deliver beams to a larger number of beam lines in the facility comes online in FY 2018 to complement a gas filled analyzer completed the prior year.

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.

Low Energy Nuclear Physics

Activities and Explanation of Changes

FY 2016 Enacted	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
Low Energy Nuclear Physics $81,665,000	**$52,455,000**	**-$29,210,000**
Research $54,263,000	**$33,233,000**	**-$21,030,000**
University and laboratory nuclear structure and nuclear astrophysics efforts continued to focus on research at ATLAS, university-based Centers of Excellence, as well as the highest priority instrumentation development efforts to realize unique scientific opportunities afforded by stopped, slow, and fast beams at FRIB. Efforts continued with the Majorana Demonstrator to demonstrate technical feasibility of a next generation detector in double beta decay. Support continued for maintenance and operations of the GRETINA detector, operations of the KATRIN experiment, and R&D at the FNPB on the feasibility of setting a world leading limit on the electric dipole moment of the neutron (nEDM).	High priority university and laboratory nuclear structure and nuclear astrophysics efforts continue to focus on research at ATLAS. Support will continue on the exploration of the fundamental symmetries of nature through research focused on measuring neutrino masses (KATRIN), the lifetime and decay properties of the neutron, and lepton number violation in neutrinoless double beta decay (CUORE, EXO and the Majorana Demonstrator).	Funding reductions include support for university and national laboratory research, which will result in an anticipated reduction in workforce; MIE funding for GRETA, relative to FY 2017 according to the planned profile, in order to exploit the capabilities of FRIB. The R&D effort aimed at a down-select decision for the next generation neutrinoless double beta decay (0vbb) experiment will be suspended. Operations of the two university Centers of Excellence (HIGS and Texas A&M) accelerator facilities will be paused.
Operations $27,402,000	**$19,222,000**	**-$8,180,000**
Continued operation of ATLAS in a 7 day per week mode was a high priority as demand for ATLAS beam time continues to far exceed availability. FY 2016 funding supported 6,160 hours of beam time, and a program of modest upgrades continued for the only operating DOE-supported scientific user facility in nuclear structure and astrophysics. Support continued for equipment disposition activities at HRIBF.	Operation of ATLAS in a 5 day per week mode will be supported to address the high demand for ATLAS beam time which continues to far exceed availability. ATLAS funding will support 2,620 hours of beam time (~40% of optimal).	Funding will support a reduction of 3,280 operating hours relative to FY 2016. Funding for capital equipment and Accelerator Improvement Projects is not included in FY 2018 Request. Equipment disposition activities at HRIBF are completed in FY 2017.

Nuclear Physics
Nuclear Theory

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. The third year of new five-year topical collaborations within the university and national laboratory communities will be supported in FY 2018 to address only the highest priority topics in nuclear theory that merit a concentrated theoretical effort. The Nuclear Theory subprogram also supports the U.S. Nuclear Data Program (USNDP), which collects, evaluates, and disseminates nuclear physics data for basic nuclear research and for applied nuclear technologies and their development.

Much of the research supported by the Nuclear Theory subprogram requires extensive access to leading-edge supercomputers. One area that has a particularly pressing demand for large, dedicated computational resources is Lattice QCD (LQCD). LQCD calculations are critical for understanding and interpreting many of the experimental results from RHIC, LHC, and CEBAF. A five-year computer hardware project "LQCD-ext II" started in FY 2015 and has been carried out jointly with HEP to ensure effective coordination. It follows the previous joint efforts that address the computational requirements of LQCD research by continuing to provide specialized computing resources for LQCD research. Both HEP and NP require this type of computing capability in order to conduct simulations that address their distinct science programs. The partnering of the two offices ensures effective coordination to maximize the leverage available for this activity from the infrastructure and intellectual capital of both programs and to prevent duplication of effort on resource-intensive calculations inherently central to quantum chromodynamics and particle physics research. In FY 2018, LQCD research focuses on using existing capabilities, and the LQCD-ext II effort will be stretched out with a pause of investment in new hardware.

The Nuclear Theory subprogram also supports SciDAC, a collaborative program with ASCR that partners scientists and computer experts in research teams to address major scientific challenges that require supercomputer facilities performing at current technological limits. The NP SciDAC program operates on a five year cycle, and supports computationally intensive research projects jointly with other SC and DOE offices in areas of mutual interest. SciDAC-3 awards were made in FY 2012 and continued through FY 2016. The new group of SciDAC-4 awards selected in FY 2017 will receive continued support.

<u>Theory Research</u>

The Nuclear Theory subprogram supports the research programs of approximately 105 university scientists and 80 graduate students at 33 universities, as well as nuclear theory groups at seven national laboratories (ANL, BNL, LANL, LBNL, LLNL, ORNL, and TJNAF), for an overall reduction of approximately 27% in laboratory and university research staff. This research has the goals of improving our fundamental understanding of nuclear physics, interpreting the results of experiments carried out under the auspices of the experimental nuclear physics program, and identifying and exploring important new areas of research. Three topical collaborations [JET (QCD in the heavy-ion environment); NuN (neutrinos and nucleosynthesis in hot and dense matter); and TORUS (low-energy nuclear reactions for unstable isotopes)] completed their work in FY 2015. Based on mission need, the success of the initial cohort of topical collaborations, and community support of this program, the subprogram will continue to support the new round of 5-year topical collaborations initiated in FY 2016/FY 2017 to bring together theorists to address specific high-priority theoretical challenges is continued, possibly with reduced scope. The four new collaborations that may receive continued support are: 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 (DBD) 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. DBD is focused on using the most up-to-date methods of nuclear structure theory to calculate nuclear matrix elements for double beta decay cross section and to carry out other fundamental symmetry related calculations. 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. NP will consider how best to optimally support these compelling initiatives within available funding. The subprogram will maintain a new focused effort on FRIB theory initiated in FY 2017, which is critical to theory efforts associated with the planned FRIB scientific program in order to optimize the interpretation of the experimental results.

Nuclear Data

The 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. In FY 2018, two recently established USNDP university efforts will receive continued support, one at Michigan State University, in association with FRIB, and the other at the University of California at Berkeley, in association with the existing Bay Area Nuclear Data groups at LBNL and LLNL. The U.S. Nuclear Data Program recently stood up an Inter-Agency working group including NNSA, DHS, NE, DNDO, and other Federal Agencies to provide evaluated cross-section and decay data relevant to a broad suite of Federal missions and topics. Funding may also support efforts on opportunistic measurements to address serious gaps and uncertainties in existing nuclear data archives.

Nuclear Theory

Activities and Explanation of Changes

FY 2016 Enacted	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
Nuclear Theory $45,638,000	**$33,286,000**	**-$12,352,000**
Theory Research $37,616,000	**$27,749,000**	**-$9,867,000**
Funding continued to support the highest priority theoretical research at universities and national laboratories for the interpretation of experimental results obtained at NP facilities. Theorists concentrated on applying QCD to nucleon structure and hadron spectroscopy, to the force between nucleons, and to the structure of light nuclei. Advanced dynamic calculations to describe relativistic nuclear collisions, nuclear structure and reactions, and topics related to fundamental symmetries focused on activities in preparation for the research program at the upgraded CEBAF 12 GeV facility, the research program at the planned FRIB facility, and ongoing and planned fundamental symmetries experiments. Funding continued to support ongoing SciDAC-3 grants and the LQCD ext-II computing project. Support was provided to initiate the second round of theory topical collaborations.	Funding will continue for high priority theoretical research at universities and national laboratories for the interpretation of experimental results obtained at NP facilities, and the exploration of new ideas and hypotheses that identify potential areas for future experimental investigations. Theorists will continue to 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, nuclear structure and reactions, and topics related to fundamental symmetries 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 fundamental symmetries experiments. Funding will also support the second year of SciDAC-4 grants and the third year of the theory topical collaborations initiated in FY 2016.	The funding decrease requires a reduction in scope. Decreased funding will reduce support for university and national laboratory research and for the FRIB Theory Alliance. Reductions in workforce are anticipated.
Nuclear Data $8,022,000	**$5,537,000**	**-$2,485,000**
Nuclear data evaluation was the prime nuclear data product, combining experiment with theory and linking basic science with applications. The emphasis in FY 2016 was on the compilation and evaluation of nuclear reaction and nuclear structure data which included advanced nuclear reaction modeling and uncertainty quantification; maintaining and developing nuclear data formats and data verification codes; and archiving nuclear physics data and disseminating it using up to date technology.	The primary emphasis in the Nuclear Data Program in FY 2018 will continue to be on the compilation and evaluation of nuclear reaction and nuclear structure data which will include advanced nuclear reaction modeling and uncertainty quantification; maintaining and developing nuclear data formats and data verification codes; and archiving nuclear physics data and disseminating it using up to date technology	Decreased funding reduces the level of effort for the Nuclear Data scientists, compilers and evaluators.

Nuclear Physics
Isotope Development and Production for Research and Applications[a]

Description

The Isotope Development and Production for Research and Applications subprogram (DOE Isotope Program) supports the production, distribution, and development of production techniques for radioactive and stable isotopes in short supply and critical to the Nation. Isotopes are commodities of strategic importance for the Nation that are essential for energy exploration and innovation, medical applications, national security, and basic research. The goal of the program is to make key isotopes more readily available to meet U.S. needs. To achieve this goal, the program incorporates all isotope related R&D and production capabilities, including facilities and technical staff, required for supply chain management of critically important isotopes. The subprogram also supports R&D efforts associated with developing new and more cost-effective and efficient production and processing techniques, and on the production of isotopes needed for research purposes. The R&D activities also provide collateral benefits for training, contributing to workforce development, and helping to ensure a future U.S.-based expertise in the fields of nuclear chemistry and radiochemistry. These disciplines are foundational not only to radioisotope production, but to many other critical aspects of basic and applied nuclear science as well.

All funding from the Isotope Development and Production for Research Applications subprogram is executed through the Isotope Production and Distribution Program revolving fund. The isotope revolving fund maintains its financial viability by utilizing the appropriations from this subprogram along with revenues from the sale of isotopes and services. These resources are used to maintain the staff, facilities, and capabilities at user-ready levels and to support peer-reviewed R&D activities related to the production of isotopes. Isotopes sold to commercial customers are priced to recover the full cost of production, or the market price (whichever is higher). Research isotopes are sold at a reduced price to ensure high priority research requiring them does not become cost prohibitive. Investments in new capabilities are made to meet the growing demands of the Nation and foster future research in applications that will support national security and the health and welfare of the public.

Isotopes are critical national resources used to improve the accuracy and effectiveness of medical diagnoses and therapy, to enhance national security, and to improve the efficiency of industrial processes, and provide precise measurement and investigative tools for materials, biomedical, archeological, and other research. Some examples are:

- strontium-82 for cardiac imaging;
- californium-252 for well logging, homeland security, and energy security;
- germanium-68 for the development of gallium-68 radiopharmaceuticals for cancer imaging;
- berkelium-249, californium-251, and curium-248 for use as targets for discovery of new superheavy elements;
- selenium-75 for industrial radiography;
- actinium-225, bismuth-213, lead-212, astatine-211, copper-67, thorium-227, and radium-223 for cancer and infectious disease therapy research;
- nickel-63 for molecular sensing devices, and lithium-6 and helium-3 for neutron detectors for homeland security applications;
- lithium-7 as a coolant reagent for pressurized water nuclear power plants;
- tungsten-188, lutetium-177, strontium-90, and cobalt-60 for cancer therapy; and
- arsenic-73, iron-52, and zinc-65 as tracers in metabolic studies.

Stable and radioactive isotopes are vital to the missions of many Federal agencies including the National Institutes of Health (NIH), the National Institute of Standards and Technology, the Department of Agriculture, DHS, NNSA, and DOE SC programs. NP continues to work in close collaboration with federal organizations to develop strategic plans for isotope production and to establish effective communication to better forecast isotope needs and leverage resources. Each year, NP conducts an annual workshop, attended by representatives of all Federal agencies that require stable and radioactive isotopes, to provide a comprehensive assessment of national needs for isotope products and services, to inform priorities for investments in research for developing new isotope production and processing techniques, to communicate advances in

[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.

isotope production research and availability, and to communicate concerns about potential constrained supplies of important isotopes to the federal agencies. The Isotope Program participates in a number of federal Working Groups and Interagency groups to promote communication, including the White House Office of Science and Technology Policy (OSTP) working group on molybdenum-99 (Mo-99), the National Science and Technology Committee (NSTC) Subcommittee on Critical and Strategic Mineral Supply Chains, the Interagency Group on Helium-3, which it leads, that reports to the White House National Security Staff, and the OSTP Interagency Working Group on Alternatives to High-Activity Radioactive Sources (whose activities completed in FY 2017). NP participates in the Certified Reference Material Working Group which assures material availability for nuclear forensics applications that support national security missions and also the Nuclear Regulatory Commission Committee on Alternatives to Sealed Sources. As a service, the Isotope Program collects demand and usage information on helium-4 from the federal complex and provides it to the Bureau of Land Management (BLM) so that BLM can optimize their plans for the helium-4 federal reserve.

The DOE Isotope Program also invests in the nation's future biomedical researchers through support for the Nuclear Chemistry Summer School (NCSS) program. The NCSS consists of an intensive six-week program of formal accredited lectures on the fundamentals of nuclear science, radiochemistry, and their applications in related fields, as well as laboratory practicums focusing on state-of-the-art instrumentation and technology used routinely in basic and applied nuclear science.

While the Isotope Program is not responsible for the production of Mo-99, which is the most widely used isotope in diagnostic medical imaging in the Nation, it works closely with NNSA, the lead entity responsible for domestic Mo-99 production, offering technical and management support. Consistent with the National Defense Authorization Act for Fiscal Year 2013, NP also oversees proceedings of the Nuclear Science Advisory Committee in response to a charge to annually assess progress by NNSA toward ensuring a domestic supply of Mo-99. Additionally, NP participates in the international High-Level Group on the Security of Supply of Medical Isotopes lead by the Organisation for Economic Co-operation and Development (OECD).

The mission of the Isotope Program is facilitated by the National Isotope Development Center (NIDC), which is a virtual center that interfaces with the user community and manages the coordination of isotope production across the facilities and business operations involved in the production, sale, and distribution of isotopes. The NIDC includes the Isotope Business Office, which is located at ORNL.

Research

The subprogram supports research to develop new or improved production or separation techniques for high priority isotopes in short supply. Research investments tackle challenges in the efficiency of producing critical isotopes, and develop production methods for isotopes of interest to federal agencies and other stakeholders, when no production route is in existence, enabling new applications and research. The research program has two primary components. One is support of R&D via competitive funding opportunity announcements open to both universities and laboratories. The other is provision of core R&D funding to national laboratories that possess unique facilities and technical expertise that directly support the mission of the DOE Isotope Program. In both components, peer review is used to assess the quality of the research being performed and its relevance for assuring availability of isotopes that are in short supply and needed for research and applications important to the Nation's science and industry. There is also an emphasis in the R&D program on providing training opportunities to students and post-docs to help assure a vibrant work-force essential to the technologies associated with isotope production. Priorities in research isotope production are informed by guidance from NSAC as described in the 2015 Long Range Plan for the DOE-NP Isotope Program published in July 2015 under the title "Meeting Isotope Needs and Capturing Opportunities for the Future." The Isotope Program has also funded research to demonstrate technical feasibility of modern stable isotope enrichment devices to provide the Nation with small-scale enrichment capabilities that have been absent since the DOE calutrons ceased operation in 1998. The U.S. is currently dependent on foreign sources for supplies of stable isotopes; the U.S. inventory has been depleted in the cases of some specific isotopes. The R&D program also develops domestic production capabilities for important radioisotopes for which the U.S. is dependent on foreign sources.

Another high priority is a long-term research effort to produce actinium-225, an isotope that shows great promise in the treatment of diffuse cancers and infections if it can be produced in sufficient quantity and quality. In work performed in FY 2015, production research efforts focused on demonstrating that the accelerator produced isotope functions equivalently to the material derived from the decay of thorium-229 which is presently the only viable source of small quantities of actinium-225. Samples of the isotope produced by the accelerator production approach have been evaluated by several different researchers involved in medical applications research and results indicate that the accelerator produced material works virtually identically to the thorium-229 generated material. The accelerator route of production has the potential to provide quantities sufficient to support both research trials and ultimately clinical applications in the future. Also, in anticipation of the opportunity FRIB will provide as a unique source of many important isotopes for research and applications, scientists are exploring technologies to potentially harvest some of the isotopes that will be produced during physics research experiments. Recent research results have also demonstrated technical feasibility of a potential new production route for lithium-7, an isotope used as a coolant reagent in pressurized water nuclear power plants. Currently, the U.S. is dependent upon foreign supplies of lithium-7 which are not always reliable; this successful research could provide a path for re-establishing domestic production of lithium-7.

Operations

The Isotope Program is the steward of the Isotope Production Facility (IPF) at Los Alamos National Laboratory (LANL) and the Brookhaven Linac Isotope Producer (BLIP) facility at BNL, and provides support for hot cell facilities for processing and handling irradiated materials and purified products at ORNL, BNL, and LANL. Facilities at other sites are used as needed, such as the Idaho National Laboratory reactor for the production of cobalt-60, the Pacific Northwest National Laboratory (PNNL) for processing and packaging strontium-90, the Y-12 National Security Complex for processing and packaging lithium-6 and lithium-7, and the Savannah River Site for the extraction and distribution of helium-3. In addition to isotope production at DOE facilities, the Isotope Program is funding production at universities with capabilities beyond those available in the stewarded facilities, such as an alpha-particle cyclotron at the University of Washington that developed full-scale production of astatine-211 to support research into the use of the isotope in cancer therapy. The establishment of a coordinated network of university based isotope production was a recommendation in the 2015 NSAC Long Range Plan. Still in its infancy, the network is designed to leverage the unique and 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. In this way, both the national laboratories and the universities are able to more efficiently meet domestic isotope production needs.

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. The R&D effort is coming to a close in early FY 2017 and will result in an Enriched Stable Isotope Prototype Plant (ESIPP) 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 developed is completely scalable to produce kilogram quantities of enriched stable isotopes in a cost-effective manner. The FY 2017 appropriation initiates the Stable Isotope Production Facility (SIPF) MIE to help meet the demand for a domestic capability to produce enriched stable isotopes for basic research, medical and industrial applications as recommended by the NSAC Subcommittee on Isotopes in 2015. The FY 2018 Request continues funding for SIPF at a slower pace than originally planned, delaying completion at an increased cost. Examples of discovery research efforts which could benefit from the facility are neutrinoless double beta decay experiments in nuclear physics and dark matter experiments in high-energy physics that are interested in kilogram quantities of enriched stable isotopes, which are not presently available in the U.S. Similarly, the accelerator-production route for Mo-99, a critical medical isotope for cardiac imaging, relies on a feedstock of enriched Mo isotopes, which are also unavailable domestically. Stable isotopic nuclides of heavier elements used for agricultural, nutritional, industrial, ecological, and computing applications could also be produced.

Isotope Development and Production for Research and Applications

Activities and Explanation of Changes

FY 2016 Enacted	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
Isotope Development and Production for Research and Applications $21,633,000	**$21,111,000**	**-$522,000**
Research $6,329,000	**$5,307,000**	**-$1,022,000**
Funding continued to support competitive R&D awards to universities and laboratories, as well as laboratory research groups at LANL, BNL, and ORNL. Development of production techniques for alpha-emitting radionuclides for medical therapy continued to be a priority, and was implemented through a concerted collaborative R&D effort by experts at the national laboratories, particularly at BNL, LANL, and ORNL. Research at universities and national laboratories also lead to new isotope production technologies and effectively engaging and training students and post-docs in nuclear chemistry and radiochemistry.	Funding continues for high priority competitive R&D activities at universities and national laboratories leading to new isotope production technologies. Core support will continue to be provided to national laboratories for the highest priority R&D that enhances isotope production capabilities specifically relevant to the physical resources and expertise available at the laboratories. Arrangements will be made towards the implementation of a university network for short-lived high priority medical isotopes.	Support for national laboratory and university research is reduced.
Operations $15,304,000	**$15,804,000**	**+$500,000**
Support provided for infrastructure and maintenance of facilities, core competencies in isotope production and development, and for the NIDC. The maintenance of aging facilities continued to be a funding priority to maintain isotope production capabilities. Funding for program investments and production of particular isotopes was informed by the Nuclear Science Advisory Committee's updated long-range plan for the Isotope Program (completed in FY 2015) and the Federal workshop held in the fall of 2015.	Funding will provide support for high priority activities needed for mission readiness of the isotope production facilities and the most critical core competencies in isotope production and development. Funding will also support the highest priority activities of the NIDC. Operations of the enriched stable isotope prototype will be initiated to provide the capability to produce small research quantities of enriched stable isotopes, and modest funding continues for the Stable Isotope Production Facility (SIPF) MIE.	Funding is provided for the Stable Isotope Production Facility (SIPF) MIE at a reduced pace than originally planned. Support for the mission readiness of isotope production facilities is reduced relative to current operations by deferring maintenance and enhancements relevant to isotope production. Support for the NIDC is decreased, impacting effective responses to customer inquiries and isotope business operations. Operations of the new stable isotope production prototype is limited.

Description

Consistent with the 2015 NSAC Long-Range Plan's highest priority, the FY 2018 Request includes funding to capitalize on NP's prior scientific facilities investments. Funding in this subprogram provides for design and construction of scientific research facilities needed to meet overall objectives of the Nuclear Physics program. NP currently has two ongoing projects, for which only one will be receiving construction line item funding in FY 2018.

The 12 GeV CEBAF Upgrade at TJNAF will enable scientists to address one of the mysteries of modern physics—the mechanism of quark confinement. The project will be completed in 2017.

The Facility for Rare Isotope Beams (FRIB) at Michigan State University (MSU) continues construction activities in FY 2018 at a slower pace than originally planned, which will require a rebaseline in FY 2018. The completion date will be delayed and the total cost of the project will increase. 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 Michigan State University and was established as a control point in the FY 2014 appropriation. Prior to that time, funding was provided within the Low Energy subprogram.

Construction

Activities and Explanation of Changes

FY 2016 Enacted	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
Construction $107,500,000	**$80,000,000**	**-$27,500,000**
06-SC-01, 12 GeV CEBAF Upgrade, TJNAF $7,500,000	**$0**	**-$7,500,000**
With the scheduled commissioning of the Hall D experimental equipment in FY 2015, the FY 2016 federal funds supported procurements, fabrication, installation, and commissioning of the experimental equipment primarily in Halls B and C; and addressed continuing project risks in order to optimize the successful completion of this project within the current TEC baseline. FY 2016 was the final year of TEC funding for the project as it works towards completion (CD-4B) by the end of FY 2017.	Construction complete. No funding requested in FY 2018.	Construction of the 12 GeV Upgrade to CEBAF will be completed in 2017.
14-SC-50, Facility for Rare Isotope Beams (FRIB) $100,000,000	**$80,000,000**	**-$20,000,000**
Work on conventional facilities continued as well as construction of items such as the linear accelerator (linac) tunnel and the target, linac support, and cryoplant areas. The technical systems were fully underway including efforts such as major procurements, fabrication, and assembly for technical components such as the linac, cryomodules, and experimental systems.	FY 2018 funding will support the construction of the cryogenic plant and distribution system. The funds will also support the procurement, fabrication, assembly, and installation of technical systems within the conventional facilities that are scheduled to be substantially complete in FY 2017. These technical systems include systems such as the linac front end, cryomodules, and experimental systems.	The funding decrease requires the project to re-baseline its profile. The planned completion date will be delayed and the Total Project Cost will increase by approximately $20M.

Nuclear Physics
Performance Measure

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

	FY 2016	FY 2017	FY 2018
Performance Goal (Measure)	**HEP Construction/MIE Cost & Schedule - Cost-weighted mean percentage variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects**		
Target	< 10 %	< 10 %	< 10 %
Result	Met	TBD	TBD
Endpoint Target	Adhering to the cost and schedule baselines for a complex, large scale, science project is critical to meeting the scientific requirements for the project and for being good stewards of the taxpayers' investment in the project.		
Performance Goal (Measure)	**HEP Facility Operations - Average achieved operation time of HEP user facilities as a percentage of total scheduled annual operation time**		
Target	≥ 80 %	≥ 80 %	≥ 80 %
Result	Met	TBD	TBD
Endpoint Target	Many of the research projects that are undertaken at the Office of Science's scientific user facilities take a great deal of time, money, and effort to prepare and regularly have a very short window of opportunity to run. If the facility is not operating as expected the experiment could be ruined or critically setback. In addition, taxpayers have invested millions or even hundreds of millions of dollars in these facilities. The greater the period of reliable operations, the greater the return on the taxpayers' investment.		
Performance Goal (Measure)	**HEP Neutrino Model - Carry out series of experiments to test the standard 3-neutrino model of mixing**		
Target	Physics analyses results from data taking will be presented by the NOvA and MicroBooNE experimental collaborations at the FY 2016 summer conferences.	Fermilab switches operations mode over from neutrino beam to antineutrino beam delivery to the NOvA experiment. NOvA accumulates physics data in antineutrino mode.	MicroBooNE data taking will complete final year of phase-1. NOvA will publish the first muon and electron anti-neutrino oscillation results. ICARUS data taking will begin. SBND physics commissioning will continue.
Result	Met	TBD	TBD
Endpoint Target	Similar to quarks, the mixing between neutrinos is postulated to be described by a unitary matrix. Measuring the independent parameters of this matrix in different ways and with adequate precision will demonstrate whether this model of neutrinos is correct. Such a model is needed to correctly extract evidence for CP violation in the neutrino sector.		
Performance Goal (Measure)	**NP Construction/MIE Cost & Schedule - Cost-weighted mean percentage variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects**		
Target	< 10 %	< 10 %	< 10 %
Result	Met	TBD	TBD
Endpoint Target	Adhering to the cost and schedule baselines for a complex, large scale, science project is critical to meeting the scientific requirements for the project and for being good stewards of the taxpayers' investment in the project.		
Performance Goal (Measure)	**NP Facility Operations - Average achieved operation time of NP user facilities as a percentage of total scheduled annual operation time**		
Target	≥ 80 %	≥ 80 %	≥ 80 %

	FY 2016	FY 2017	FY 2018
Result	Met	TBD	TBD
Endpoint Target	Many of the research projects that are undertaken at the Office of Science's scientific user facilities take a great deal of time, money, and effort to prepare and regularly have a very short window of opportunity to run. If the facility is not operating as expected the experiment could be ruined or critically setback. In addition, taxpayers have invested millions or even hundreds of millions of dollars in these facilities. The greater the period of reliable operations, the greater the return on the taxpayers' investment.		
Performance Goal (Measure)	**NP Nuclear Structure - Conduct fundamental research to discover, explore, and understand all forms of nuclear matter.**		
Target	Perform measurements for identified hadrons with heavy flavor valence quarks to constrain the mechanism for parton energy loss in the quark-gluon plasma at the Relativistic Heavy Ion Collider (RHIC).	Demonstrate the capability to extend the sensitivity of searches for neutrinoless double-beta decay by at least a factor of 5.	Perform measurements in experimental halls with CEBAF to enhance our understanding of the QCD structure of nuclei and hadronic matter.
Result	Met	TBD	TBD
Endpoint Target	Increase the understanding of the existence and properties of nuclear matter under extreme conditions, including that which existed at the beginning of the universe		

Nuclear Physics
Capital Summary ($K)

	Total	Prior Years	FY 2016 Enacted	FY 2017 Annualized CR[a]	FY 2018 Request	FY 2018 vs FY 2016
Capital Operating Expenses Summary						
Capital equipment	n/a	n/a	11,736	—	1,700	-10,036
General plant projects (GPP)	n/a	n/a	2,200	—	0	-2,200
Accelerator improvement projects (AIP)	n/a	n/a	5,552	—	0	-5,552
Total, Capital Operating Expenses	**n/a**	**n/a**	**19,488**	**—**	**1,700**	**-17,788**
Capital Equipment						
Gamma-Ray Energy Tracking Array (GRETA) MIE[b]	52,000–67,000	n/a	0	—	200	+200
Stable Isotope Production Facility (SIPF) MIE[a]	9,500–12,000	n/a	0	—	1,500	+1,500
Total Non-MIE Capital Equipment	n/a	n/a	11,736	—	3,004	-8,732
Total, Capital Equipment	**n/a**	**n/a**	**11,736**	**—**	**4,704**	**-7,032**
General Plant Projects						
General plant projects under $5 million TEC	n/a	n/a	2,200	—	0	-2,200
Accelerator Improvement Projects (AIP)						
RHIC Low Energy Electron Cooling	8,300	5,100	1,900	—	0	-1,900
Other projects under $5 million TEC	n/a	n/a	3,652	—	0	-3,652
Total, Accelerator Improvement Projects	**n/a**	**n/a**	**5,552**	**—**	**0**	**-5,552**

[a] FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above; below that level, a dash (-) is shown.
[b] This is the DOE TPC; MSU's cost share is $94,500,000 bringing the total project cost to $730,000,000. FRIB is funded with operating dollars through a Cooperative Agreement financial assistance award with a work breakdown structure (WBS) that is slightly different from typical federal capital assets. The WBS totals $730,000,000 including MSU's cost share. Because the WBS scope is not pre-assigned to DOE or MSU funds, DOE's baseline of $635,500,000 cannot be broken down between TEC and OPC. The project will be rebaselined to reflect a delayed schedule and increased TPC as a result of FY 2018 funding less than the baseline. The TPC is expected to increase by ~$20M.

Major Items of Equipment Descriptions

Low Energy Nuclear Physics

The ***Gamma-Ray Energy Tracking Array (GRETA) detector*** directly supports the Nuclear Physics mission by addressing the goal to understand the structure of nuclear matter, the processes of nuclear astrophysics, and the nature of the cosmos. A successful implementation of this detector will represent a major advance in gamma-ray tracking detector technology that will impact nuclear science, as well as detection techniques in homeland security and medicine. GRETA will provide unprecedented gains in sensitivity, addressing several high priority scientific topics, including how weak binding and extreme proton-to-neutron asymmetries affect nuclear properties and how the properties of nuclei evolve with changes in excitation energy and angular momentum. GRETA will provide transformational improvements in efficiency, peak-to-total ratio and higher position resolution than the current generation of detector arrays. In particular, the capability of reconstructing the position of the interaction with millimeter resolution is needed to fully exploit the physics opportunities of FRIB. Without GRETA, FRIB will rely on existing instrumentation. In that event, beam-times necessary for the proposed experiments will be expanded significantly, and some proposed experiments will not be feasible at all. CD-0 for GRETA was approved in September 2015 with an estimated Total Project Cost of $52,000,000–$67,000,000. CD-1 is planned for FY 2017. The FY 2018 Request for GRETA of $200,000 is the second year of Total Estimated Cost (TEC) funding. The Total Project Cost Range will be re-evaluated in FY 2018 to consider changes in the planned funding profile.

Isotope Development and Production for Research and Applications

The ***Stable Isotope Production Facility (SIPF).*** The DOE Isotope Program has invested funds since 2009 to develop stable isotope separation technology at ORNL, first identified as a high priority by the NSAC Subcommittee on Isotopes in 2009. NP is completing 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, 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 initiates 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 services, and optimizes the design of centrifuges to isotopes of interest. CD-0 was approved September 2015 with an estimated Total Project Cost of $9,500,000–$10,500,000. CD-1 is planned for 2017. The FY 2018 Request for SIPF of $1,500,000 is the second year of TEC funding. The Total Project Cost Range will be re-evaluated in FY 2018 to consider changes in the planned funding profile.

Nuclear Physics
Construction Projects Summary ($K)

	Total	Prior Years	FY 2016 Enacted	FY 2017 Enacted	FY 2018 Request	FY 2018 vs FY 2016
06-SC-01, 12 GeV CEBAF Upgrade, TJNAF						
TEC	310,500	303,000	7,500	0	0	-7,500
OPC	27,500	22,000	4,500	0	0	-4,500
TPC	338,000	325,000	12,000	0	0	-12,000
14-SC-50, Facility for Rare Isotope Beams						
DOE TPC	635,500[a]	218,000[b]	100,000	100,000	80,000	-20,000
Total, Construction (TPC) All Construction Projects	**n/a**	**n/a**	**112,000**	**100,000**	**80,000**	**-32,000**

Funding Summary ($K)

	FY 2016 Enacted	FY 2017 Annualized CR[c]	FY 2018 Request	FY 2018 vs FY 2016
Research	176,677	—	116,385	-60,292
Scientific User Facilities Operations	289,959	—	269,258	-20,701
Other Facility Operations	24,507	—	19,104	-5,403
Projects				
Major Items of Equipment	0	—	1,700	+1,700
Facility for Rare Isotope Beams	100,000	99,810	80,000	-20,000
12 GeV Upgrade TEC	7,500	7,486	0	-7,500
Total Projects	107,500	—	81,700	-25,800
Other[d]	18,457	—	16,253	-2,204
Total Nuclear Physics	**617,100**	**615,927**	**502,700**	**-114,400**

[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. The project will be rebaselined to reflect a delayed schedule and increased TPC as a result of FY 2018 funding less than the baseline. The TPC is expected to increase by ~$20M.

[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] FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above; below that level, a dash (-) is shown.

[d] Includes SBIR/STTR funding.

Scientific User Facility Operations ($K)

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

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

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

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

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

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

	FY 2016 Enacted	FY 2017 Annualized CR[a]	FY 2018 Request	FY 2018 vs FY 2016
TYPE A FACILITIES				
CEBAF (TJNAF)[b]	**$111,287**	**—**	**$96,318**	**-$14,969**
Number of Users	1,530	—	1,300	-230
Achieved operating hours	N/A	N/A	N/A	N/A
Planned operating hours	0	—	1,070	+1,070

[a] FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above; below that level, a dash (-) is shown.
[b] During FY 2016, there were no research hours to which the CEBAF facility was held accountable while the 12 GeV upgrade was being commissioned. In FY 2016, approximately 16 weeks of machine development were supported. The user community remained active during the shutdown with instrumentation and equipment implementation for the upgraded facility. 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 as operational experience is gained.

	FY 2016 Enacted	FY 2017 Annualized CR[a]	FY 2018 Request	FY 2018 vs FY 2016
TYPE A FACILITIES				
Optimal hours	0	—	3,730	+3,730
Percent optimal hours	N/A	—	28.7%	N/A
Unscheduled downtime hours	N/A	N/A	N/A	N/A
RHIC (BNL)	**$179,152**	**—**	**$169,174**	**-$9,978**
Number of Users	1,200	—	1,020	-180
Achieved operating hours[a]	2,697	N/A	N/A	N/A
Planned operating hours	2,510	—	1,470	-1,040
Optimal hours	4,100	—	2,205[b]	-1,895
Percent optimal hours	65.8%	—	66.7%	+0.9%
Unscheduled downtime hours	0	N/A	N/A	N/A
ATLAS (ANL)	**$22,390**	**—**	**$19,086**	**-$3,304**
Number of Users	320	—	272	-48
Achieved operating hours	6,160	N/A	N/A	N/A
Planned operating hours	5,900	—	2,620	-3,280
Optimal hours[c]	6,200	—	6,600	+400
Percent optimal hours	99.4%	—	39.7%	-59.7%
Unscheduled downtime hours	0	N/A	N/A	N/A
Total Scientific User Facility Operations	**$312,829**	**—**	**$284,578**	**-$28,251**
Number of Users	3,050	—	2,592	-4058
Achieved operating hours	N/A	N/A	N/A	N/A
Planned operating hours	8,410	—	5,160	-3,250
Optimal hours	10,300	—	12,535	+2,235

[a] For achieved operations in FY 2016 RHIC was able to achieve 108% of the planned operating hours in FY 2016 as a result of outstanding performance of the machine. A very effective ramp-up of the luminosity and new techniques to provide increased beam intensity allowed RHIC to exceed the luminosity goal for the highest energy gold-gold setup. Rapid efficient setups enabled deuteron-gold measurements at 4 different energies to meet or exceed all planned goals for the FY 2016 run.
[b] Optimal beam hours in FY 2018 available beam time is limited to 2,205 hours to allow for access to install upgrades to the accelerator essential for the FY 2019-20 physics campaign. The run in FY 2018 is combined with the run in FY 2019, spanning fiscal year boundaries; the facility operates once over two fiscal years.
[c] ATLAS was able to achieve 104% of the planned operating hours in FY 2016 as a result of very high reliability.

	FY 2016 Enacted	FY 2017 Annualized CR[a]	FY 2018 Request	FY 2018 vs FY 2016
TYPE A FACILITIES				
Percent of optimal hours[a]	69.5%	—	52.0%	-17.5%
Unscheduled downtime hours	0	N/A	N/A	N/A

Scientific Employment

	FY 2016 Enacted	FY 2017 Annualized CR[b]	FY 2018 Estimate	FY 2018 vs FY 2016
Number of permanent Ph.D.'s (FTEs)	823	—	586	-237
Number of postdoctoral associates (FTEs)	365	—	244	-121
Number of graduate students (FTEs)	523	—	293	-230
Other[c]	1,089	—	989	-100

[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]FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above; below that level, a dash (-) is shown.

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

14-SC-50, Facility for Rare Isotope Beams (FRIB)
Michigan State University (MSU), East Lansing, MI
Project is for a Cooperative Agreement

1. Significant Changes and Summary

Significant Changes

This Project Data Sheet (PDS) is an update of the FY 2017 PDS and does not include a new start for FY 2018. The FY 2018 requested funding change from the original planned profile will result in an increase to the project's current baseline cost and schedule. SC will conduct a re-baseline effort following an FY 2018 appropriation.

Summary

The most recent approved Critical Decision (CD) for the Facility for Rare Isotope Beams (FRIB) project is CD-3B, Approve Start of Construction of the Accelerator and Experimental Systems, which was approved on August 26, 2014, with a DOE Total Project Cost (TPC) of $635,500,000, and a scheduled CD-4 by 3Q FY 2022. Michigan State University (MSU) is providing an additional cost share of $94,500,000, bringing the total project cost to $730,000,000. Start of civil construction officially began in March 2014, and technical construction began in August 2014. Since the start of the civil and technical construction, multiple independent project assessments have determined the project is proceeding on track within the established project baseline. There are no changes in the project's scope since the establishment of the project's baseline. In FY 2018, the requested project funding decreases by $17,200,000 from the baseline profile. Following an FY 2018 appropriations, the project will evaluate all added risks, costs, and schedule changes resulting from this change and develop a new cost and schedule baseline, which will be reviewed and approved according to DOE guidelines.

FRIB is funded through a cooperative agreement financial assistance award with MSU per 10 CFR 600, and the project is required by this agreement to follow the principles of the DOE Order 413.3B. Funding tables contained in sections 3, 5, and 6 of this PDS differ slightly in how the baseline is presented from a traditional PDS for a federal capital asset construction project in that they include the MSU cost share. The table in section 7, Schedule of Appropriation Requests, displays only DOE funding.

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

2. Critical Milestone History

(fiscal quarter or date)

	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3A	CD-3B	D&D Complete	CD-4
FY 2011	2/9/2004		4Q FY 2010	TBD	TBD	TBD	TBD	N/A	FY 2017–2019
FY 2012	2/9/2004		9/1/2010	4Q FY 2012	TBD	TBD	TBD	N/A	FY 2018–2020
FY 2013	2/9/2004		9/1/2010	TBD	TBD	TBD	TBD	N/A	TBD
FY 2014	2/9/2004		9/1/2010	3Q FY 2013	TBD	3Q FY 2013	TBD	N/A	TBD
FY 2015	2/9/2004		9/1/2010	8/1/2013	4Q FY 2014	8/1/2013	4Q FY 2014	N/A	3Q FY 2022
FY 2016	2/9/2004	9/1/2010	9/1/2010	8/1/2013	8/26/2014[a]	8/1/2013	8/26/2014	N/A	3Q FY 2022
FY 2017	2/9/2004	9/1/2010	9/1/2010	8/1/2013	8/26/2014[a]	8/1/2013	8/26/2014	N/A	3Q FY 2022
FY 2018	2/9/2004	9/1/2010	9/1/2010	8/1/2013	8/26/2014[a]	8/1/2013	8/26/2014	N/A	3Q FY 2022[b]

[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 will continue through 4Q FY 2017.

[b] The requested FY 2018 funding is less than the planned baseline profile. This will result in a re-baselining effort that will likely increase the project's cost, schedule, and risks.

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
CD-4 – Approve Start of Operations or Project Closeout
D&D Complete – Completion Demolition & Decontamination

3. Project Cost History[a]

(dollars in thousands)

	Design/ Construction	R&D/Conceptual Design/NEPA	Pre-Operations	Total TPC	Less MSU Cost Share	DOE TPC
FY 2015	655,700	24,600	49,700	730,000	-94,500	635,500
FY 2016	655,700	24,600	49,700	730,000	-94,500	635,500
FY 2017	655,700	24,600	49,700	730,000	-94,500	635,500
FY 2018	655,700	24,600	49,700	730,000[b]	-94,500	635,500

4. Project Scope and Justification

Scope

FRIB scope includes the design, construction, fabrication, assembly, testing, and commissioning of the civil and technical scope that will enable high intensity primary beams of stable isotopes to be accelerated up to a minimum energy of 200 MeV per nucleon by a superconducting linear accelerator (linac) capable of delivering 400 kW of beam power at full energy. The scope also includes the capability for secondary beams of rare isotopes to be produced "in-flight" and separated from unwanted fragments by magnetic analysis. In support of these capabilities, the civil construction portion includes a structure of approximately 220,000 square feet that will house the linac tunnel, target high bay area, linac support area, and cryoplant area. The technical scope includes a 2K/4.5K cryogenics plant, linac front end, cryomodules, and experimental systems.

CD-4 Key Performance Parameters

System	Parameter	Performance Criteria
Accelerator System	Accelerate heavy-ion beam	Measure FRIB driver linac Argon-36 beam with energy larger than 200 MeV per nucleon and a beam current larger than 20 pico nano amps (pnA).
Experimental Systems	Produce a fast rare isotope beam of Selenium-84	Detect and identify Selenium-84 isotopes in FRIB fragment separator focal plane
	Stop a fast rare isotope beam in gas and reaccelerate a rare isotope beam	Measure reaccelerated rare isotope beam energy larger than 3 MeV per nucleon
Conventional Facilities	Linac tunnel	Beneficial occupancy of subterranean tunnel structure of approximately 500 feet path length (minimum) to house FRIB driver linear accelerator
	Cryogenic helium liquefier plant—building and equipment	Beneficial occupancy of the cryogenic helium liquefier plant building and installation of the helium liquefier plant complete
	Target area	Beneficial occupancy of target area and one beam line installed and ready for commissioning

[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.
[b] The requested FY 2018 funding is less than the planned baseline profile. This will result in a re-baselining effort that will likely increase the project's cost, schedule, and risks.

As contractually required under the financial assistance award agreement, FRIB is being conducted in accordance with the project management principles in DOE O 413.3B, Program and Project Management for the Acquisition of Capital Assets, and all appropriate project management requirements have been met.

Justification

The science which underlies the FRIB mission is a core competency of nuclear physics: understanding how protons and neutrons combine to form various nuclear species; understanding how long chains of different nuclear species survive; and understanding how one nuclear species decays into another and what is emitted when that happens. Forefront knowledge and capability in this competency is essential, both for U.S. leadership in this scientific discipline and to provide the knowledge and workforce needed for numerous activities and applications relevant to national security and economic competitiveness.

FRIB will provide intense beams of rare isotopes for a wide variety of studies in nuclear structure, nuclear astrophysics, and other topics in nuclear physics. This facility will enable the study of the origin of the elements and the evolution of the cosmos, and offers an opportunity for exploring the limits of nuclear existence and identifying new phenomena, with the possibility that a more broadly applicable theory of nuclei will emerge. The facility will offer new glimpses into the origin of the elements, leading to a better understanding of key issues by creating exotic nuclei that, until now, have existed only in nature's most spectacular explosion, the supernova.

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 (ECR) 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.

5. Financial Schedule[a]

	(dollars in thousands)		
	Appropriations	Obligations	Costs[b]
DOE Total Project Cost (TPC)			
FY 2009	7,000	7,000	4,164
FY 2010	12,000	12,000	13,283
FY 2011	10,000	10,000	11,553
FY 2012	22,000	22,000	18,919
FY 2013	22,000	22,000	20,677
FY 2014[c]	55,000	55,000	48,369
FY 2015	90,000	90,000	79,266
FY 2016	100,000	100,000	121,769
FY 2017	100,000	100,000	100,000
FY 2018	80,000	80,000	80,000
FY 2019	75,000	75,000	75,000

[a] The funding profile represents DOE's requested portion, which is less than the current baselined TPC. This will be updated once a re-baseline effort is complete.

[b] Costs through FY 2016 reflect actual costs; costs for FY 2017 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.

	(dollars in thousands)		
	Appropriations	Obligations	Costs[b]
FY 2020	57,200	57,200	47,200
FY 2021	5,300	5,300	10,300
FY 2022	0	0	5,000
Total, DOE TPC	635,500	635,500	635,500[a]

6. Details of Project Cost Estimate[b]

	(dollars in thousands)		
	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Design & Construction			
Management and Support	39,268	40,817	35,400
Conventional Facilities	208,201	191,302	165,300
Accelerator Systems	282,974	258,465	241,400
Experimental Systems	67,175	58,259	55,000
Contingency (DOE Held)	58,132	106,907	158,650
Total, Design & Construction	655,750	655,750	655,750
Other Costs			
Conceptual Design/Tech R&D/NEPA	24,640	24,640	24,600
Pre-ops/Commissioning/Spares	34,658	34,995	35,500
Contingency (DOE Held)	14,952	14,615	14,150
Total, Other Costs	74,250	74,250	74,250
Total, TPC	730,000	730,000	730,000
Less MSU Cost Share	-94,500	-94,500	-94,500
Total, DOE TPC	635,500	635,500	635,500
Total, Contingency (DOE Held)	73,084	121,522	172,800

[a] Due to the reduced project funding request in FY 2018 from the baseline profile, project costs are expected to increase beyond the current TPC estimate. The completion date may also be impacted.

[b] This section shows a breakdown of the total project cost of $730,000,000 as of 02/28/2017, which includes MSU's cost share. The scope of work is not pre-assigned to DOE or MSU funds.

7. Schedule of Appropriation Requests[a]

($K)

		Prior Years	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	Outyears	Total
FY 2011	TPC	29,000	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
FY 2012	TPC	59,000	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
FY 2013	TPC	73,000	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
FY 2014	TPC	128,000	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
FY 2015 PB[b]	TPC	218,000	100,000	100,000	97,200	75,000	40,000	5,300	0	635,500
FY 2016	TPC	218,000	100,000	100,000	97,200	75,000	40,000	5,300	0	635,500
FY 2017	TPC	218,000	100,000	100,000	97,200	75,000	40,000	5,300	0	635,500
FY 2018	TPC	218,000	100,000	100,000	80,000	75,000	57,200	5,300	0	635,500[c]

8. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	3Q FY 2022
Expected Useful Life (number of years)	20
Expected Future Start of D&D of this capital asset	NA[d]

(Related Funding requirements)

(dollars in thousands)

	Annual Costs		Life Cycle Costs	
	Current Total Estimate	Previous Total Estimate	Current Total Estimate	Previous Total Estimate
Operations[e]	90,000	90,000	1,800,000[f]	1,800,000

9. D&D Information

The FRIB project is being constructed at MSU under a cooperative agreement financial assistance award. The one-for-one requirement, which requires the demolition of a square foot of space for every square foot added, is not applicable, since this is not a federal capital acquisition.

10. Acquisition Approach

FRIB project activities will be accomplished following all procurement requirements, which include using fixed-priced competitive contracts with selection based on best value. MSU has contracted for the services of an architect-engineer firm for the design of the conventional facilities. The Driver Linac and Experimental System components will be self-performed by the MSU design staff with assistance from outside vendors and from DOE national laboratories that possess specific areas of

[a] The funding profile represents DOE's portion of the baselined TPC to be provided through federal appropriations.
[b] The Performance Baseline was approved August 1, 2013. The first project data sheet submitted for FRIB was in the FY 2015 Congressional Budget Request. It was established as a control point in the FY 2014 appropriation. Funding for the project prior to that time was provided within the Low Energy subprogram.
[c] Due to the reduced project funding request in FY 2018 from the baseline profile, it is likely that project costs will increase beyond the current TPC estimate.
[d] Per the financial assistance award agreement, MSU is responsible for D&D.
[e] Utilities, maintenance, and repair costs are included within the Operations amounts.
[f] The total operations and maintenance (O&M) is estimated at an average annual cost of approximately $90,000,000 (including escalation) over 20 years.

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.

Workforce Development for Teachers and Scientists

Overview

The Workforce Development for Teachers and Scientists (WDTS) program mission is to help ensure that DOE has a sustained pipeline of science, technology, engineering, and mathematics (STEM) workers. This is accomplished through support of undergraduate internships, and graduate thesis research; administration of the Albert Einstein Distinguished Educator Fellowship for K–12 STEM teachers for federal agencies; and annual, nationwide, middle- and high-school science competitions culminating in the National Science Bowl® in Washington, D.C. These investments support the development of the next generation of scientists and engineers to support the DOE mission, administer programs, and conduct research.

WDTS activities rely significantly on DOE's 17 laboratories and facilities, which employ more than 30,000 workers with STEM backgrounds. The DOE laboratory system provides access to leading scientists; world-class scientific user facilities and instrumentation; and large-scale, multidisciplinary research programs unavailable in universities or industry. WDTS leverages these assets to develop and train post-secondary students and educators in support of the DOE mission. WDTS experience-based STEM learning opportunity programs enable highly qualified applicants to conduct research at DOE laboratories and facilities in support of the workforce mission.

Highlights of the FY 2018 Budget Request

The FY 2018 Budget Request prioritizes funding for programs that place highly qualified applicants in authentic STEM learning and training experience opportunities at DOE laboratories. It also prioritizes support for the DOE National Science Bowl® (NSB), a signature STEM competition testing middle and high school students' knowledge in science and mathematics. By encouraging students to pursue STEM careers, these programs address the DOE's STEM mission critical workforce pipeline needs required to advance national security and promote national competitiveness.

Description

Activities at the DOE Laboratories

WDTS supports activities such as the Science Undergraduate Laboratory Internships program, the Community College Internships program, and the Office of Science (SC) Graduate Student Research Program. One of the primary goals of these programs is to encourage 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 and the strategic objectives of the National Science and Technology Council Committee on STEM Education (CoSTEM) Federal STEM Education 5-Year Strategic Plan.[a]

The **Science Undergraduate Laboratory Internships (SULI)** program places students from 2 and 4 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/sites/whitehouse.gov/files/ostp/Federal_STEM_Strategic_Plan.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.

Albert Einstein Distinguished Educator Fellowship

The Albert Einstein Distinguished Educator Fellowship Act of 1994 charged the Department of Energy (DOE) with administering a fellowship program for elementary and secondary school mathematics and science teachers that focused on bringing teachers' real-world expertise to government to help inform federal STEM education programs. Selected teachers spent eleven months in a Federal agency or a Congressional office. WDTS has managed the Albert Einstein Distinguished Educator Fellowship (AEF) Program for the Federal government. In FY 2018, no funds are requested for the AEF Program as WDTS focuses its efforts on those programs that directly advance DOE and SC workforce training needs. The final cohort of AEF participants, those selected for the 2017 – 2018 Fellowship Year beginning September 1, 2017, is based upon the FY 2017 application and placement process, with this cohort being fully supported by funds obligated in FY 2017. DOE will work with other participating agencies to identify ways in which the original goals of the program can be addressed through other means.

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 275,000 students have participated in the National Science Bowl® throughout its 27-year history, and it is one of the nation's largest science competitions.

The National Science Bowl® regional winning teams receive expenses-paid trips to Washington D.C. to compete at the National Finals in late April. Competing teams are composed of four students, one alternate, and a teacher who serves as an advisor and coach. SC manages the National Science Bowl®, provides central management of 116 regional events, and sponsors the NSB Finals competition.

In FY 2017, more than 5,100 middle school students from 651 schools, and approximately 9,000 high school students from 1,191 schools, participated in the regional competitions, with 48 middle school and 63 high school teams (552 students) participating in the National Finals in Washington, D.C. All 50 U.S. States, 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), featuring a live web-streaming broadcast of the event.

The DOE National Science Bowl® is aligned with the CoSTEM Federal STEM Education 5-Year Strategic Plan priority investment area for STEM engagement.

Technology Development and On-Line Application

This activity modernizes on-line systems used to manage applications and review, data collection, and evaluation for WDTS programs. A project to develop, build, and launch new online application and program support systems is progressing to improve program management, execution, and evaluation by WDTS program staff and by DOE laboratory staff. An important component of the systems is the ability to support regular evidence-based evaluation of program performance and impact. A phased approach is being used to develop and build these systems. The final phase involves the development of an analytics and visualization portal, using a data-dictionary and data warehouse of participant information, with an embedded commercially available business intelligence software tool as its analysis and visualization engine. Using this toolset, a scheduled portfolio of reports will be made available to DOE host laboratories to inform them of their demographic trends and program outcomes. WDTS will use this toolset as part of a data-driven programmatic impact evaluation process, providing means to measure progress and optimize program management.

Evaluation Studies

The Evaluation Studies activity supports work to assess whether WDTS programs meet established goals through the use of collection and analysis of data and other materials, including pre- and post-participation questionnaires, participant deliverables, notable outcomes (publications, presentations, patents, *etc*.), and longitudinal participant tracking. In FY 2014, evaluation plans for each WDTS activity were completed. In FY 2015, a data management and analysis plan was completed, with a set of technical requirements developed. In FY 2016, the technical requirements were used to define a project plan, and begin its execution to develop and implement a data-driven analysis, visualization, and reporting toolset.

In FY 2014, SC completed a study to identify disciplines in which significantly greater emphasis in workforce training at the graduate student or postdoc levels is necessary to address gaps in current and future SC mission needs. In this study, each Office of Science Federal Advisory Committee, each Associate Director, and each Laboratory Director were asked to provide expert assessment on the following: (i) STEM disciplines not well represented in academic curricula; (ii) STEM disciplines in high demand, nationally and/or internationally, resulting in difficulties in recruitment and retention at U.S. universities and at DOE laboratories; (iii) STEM disciplines for which the DOE laboratories may play a role in providing needed workforce development; and (iv) recommendations for programs at the graduate student or postdoc levels that can address discipline-specific workforce development needs. The outcomes of this study now guide prioritization of eligible SCGSR programmatic research areas and inform WDTS strategic planning. More broadly, the outcomes of this study have identified for SC both program-specific workforce development needs and crosscutting workforce development needs in areas such as computing and computational sciences. Based upon the guiding principles, the availability of relevant research areas for SCGSR is reviewed and updated to address emerging mission workforce area needs.

Evaluation Studies is aligned with the GPRA Modernization Act of 2010, which emphasizes the need for federal programs (including STEM education programs) to demonstrate their effectiveness through rigorous evidence-based evaluation. WDTS works cooperatively with SC programs, other DOE programs, and other federal agencies through CoSTEM to share best practices for STEM program evaluation to ensure the implementation of evaluation processes appropriate to the nature and scale of the program effort.

Outreach

WDTS engages in outreach activities, some in cooperation with other DOE program offices and select federal agencies, to widely publicize opportunities for student internships, SC Graduate Student Research program, the Visiting Faculty Program (VFP), and the Albert Einstein Distinguished Educator Program. 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. In FY 2016, a pilot proposal solicitation from DOE host laboratories and facilities was issued to develop and execute outreach activities aimed at recruiting a more diverse spectrum of applicants to WDTS laboratory-based programs. Eligible laboratories and facilities are those that hosted FY 2016 participants in the SULI, CCI, VFP, and/or SCGSR programs.

The Laboratory Equipment Donation Program is consolidated under Outreach, and it continues to provide excess laboratory equipment to faculty at non-profit research institutions and post-secondary educational institutions. Through the Energy Asset Disposal System, DOE sites identify excess equipment and colleges and universities can then search for equipment of interest and apply via the website. The equipment is free, but the receiving institution pays for shipping costs. This consolidation does not alter the scope of this activity.

[a] https://science.energy.gov/wdts

Workforce Development for Teachers and Scientists
Funding ($K)

	FY 2016 Enacted	FY 2017 Annualized CR[a]	FY 2018 Request	FY 2018 vs FY 2016
Activities at the DOE Laboratories				
Science Undergraduate Laboratory Internships	8,300	—	7,900	-400
Community College Internships	1,000	—	1,000	0
Office of Science Graduate Student Research Program	2,500	—	2,000	-500
Visiting Faculty Program	1,700	—	0	-1,700
Total, Activities at the DOE Laboratories	**13,500**	**—**	**10,900**	**-2,600**
Albert Einstein Distinguished Educator Fellowship	**1,200**	**—**	**0**	**-1,200**
National Science Bowl®	**2,900**	**—**	**2,400**	**-500**
Technology Development and On-Line Application	**750**	**—**	**300**	**-450**
Evaluation Studies	**600**	**—**	**200**	**-400**
Outreach	**500**	**—**	**200**	**-300**
Laboratory Equipment Donation Program	**50**	**—**	**0**	**-50**
Total, Workforce Development for Teachers and Scientists	**19,500**	**19,463**	**14,000**	**-5,500**

[a] FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above, below that level, a dash (-) is shown.

Program Accomplishments

Science Undergraduate Laboratory Internships (SULI) - In FY 2016, of the 800 participants, more than 45% worked on SC supported research projects, which is by far the largest DOE program office funded research project representation. While all participants work on DOE mission relevant activities, this outcome supports WDTS SC research mission relevancy, and illustrates willingness of SC principal investigators to serve as mentors.

Community College Internships (CCI) – In FY 2016, semester terms were fully adopted to increase availability of the opportunity, now with an option for a "flex-schedule" where the equivalent of 400 hours spent on-site at a host lab can be spread over a 16 week duration term. This option is available at the discretion of host labs, and is designed to allow participants to stay enrolled in coursework while participating in the program. Under a flex-schedule, weekly stipends are based on a 40 hours per week payment, prorated accordingly, with any housing allowance being based upon a 10-week duration appointment. In FY 2016, 18 participants were from Minority Serving Institutions.

Office of Science Graduate Student Research Program (SCGSR) – In FY 2016, the SCGSR Program supported 110 supplemental awards to graduate students to conduct their thesis research at 13 DOE national laboratories. Over two thirds of the awards support project terms ranging from 6-12 months. The SCGSR Program attracts graduate student applicants at various stages in their graduate education and from a broad range of graduate schools across the U.S. Awards were made to graduate students from 60 different universities who will conduct graduate research in areas that span the research missions of the six Office of Science program offices. A total of 9 new research areas were added, with 4 from the Office of Biological and Environmental Research and 5 from the Office of Basic Energy Sciences.

Visiting Faculty Program (VFP) – In FY 2016, 30 faculty participants were from Minority Serving Institutions (MSIs), with 15 from Hispanic Serving Institutions (HSIs), 13 from Historically Black Colleges and Universities (HBCUs), and 2 from Predominately Black Institutions (PBIs). Additionally, 15 VFP student participants were from MSIs.

Albert Einstein Distinguished Educator Fellowship (AEF) – Two of six WDTS sponsored AEF participants held WDTS office appointments, and in addition to engaging in WDTS programmatic activities, these two participants, as nationally recognized STEM educators, also worked directly with Brookhaven National Laboratory, Idaho National Laboratory, and the National Renewable Energy Laboratory on portions of their STEM education outreach activities. Fellows spent time onsite, with the opportunities being determined by mutual agreement matching interest and opportunity type with expertise.

The National Science Bowl® – The NSB's Science Day is a cornerstone event, opening the finals competition with a tradition of attracting prominent speakers, including outstanding researchers from DOE laboratories, who are able to connect workplace experience and relevancy to these students' science, technology, engineering, and math (STEM) area studies. Having Science Day speakers from across the DOE laboratory complex is particularly relevant from a workforce mission perspective, as this is often the first time that these students become aware of DOE mission research, the its national laboratory complex. In its FY 2016 Science Day, students heard from plenary speaker Dr. Eric Brown, Director of Watson Technologies at the IBM Thomas J. Watson Research Center, as well as from leading researchers at DOE laboratories, who showcased recent developments from the fast-paced fields of high-performance computing and data networks, simulation, modeling, visualization, and data mining.

To enhance the students' learning opportunities, virtual experience kiosks were updated and used at the National 4H Center in Chevy Chase, Maryland, home of the NSB's finals competition, allowing students to self-explore and learn about scientific applications and research at DOE's national laboratories. Also demonstrated at the 4H Center was "Tiny Titan," an interactive educational display computer that visually shows the power of multicore processing and parallel architectures, both of which help form the technological basis for all high-performance computers in use today.

The live attendance at the championship finals was its greatest ever, estimated at 1,100.

Technology Development and On-Line Application – FY 2016 updates to the WDTS Application and Review System (WARS) included an instant SMS-text based user account self-reset feature, as well as improved embedded tooltips and FAQs for client self-help while navigating WARS. WDTS also directed the development and implementation of automated messaging functionalities from within WARS so that SULI, CCI, and VFP program solicitation opening announcements are routinely sent to all eligible College/University Career Placement Offices/Centers. WDTS also initiated a project to develop and implement a data-dictionary/data-warehouse based analytics and visualization toolset supporting data-driven program evaluation. To date, WDTS has directed the development of the relational database and data dictionary, led the evaluation of business intelligence tools, and based upon this evaluation, directed the selection and implementation of a server-side solution using a commercial software package QlikSense (QlikTech Inc., Radnor, PA). WDTS has completed its definition of the technical requirements for development of a related evaluation toolset portal.

Outreach - DOE host laboratories and facilities issued a pilot proposal solicitation to develop and execute outreach activities aimed at recruiting a more diverse applicant pool to WDTS laboratory-based programs. A merit review based selection identified ten outreach proposals for funding in FY 2016, with proposed activities taking place during FY 2017. These proposals all target recruitment of individuals traditionally underrepresented in STEM and address needs to increase the applicant pool diversity for one or more of the WDTS programs currently implemented at DOE host laboratories and facilities. Based upon outcomes, this pilot will be used to establish a baseline for future outreach activity solicitations.

Activities and Explanation of Changes

FY 2016 Enacted	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
Activities at the DOE Laboratories $13,500,000	**$10,900,000**	**$-2,600,000**
Science Undergraduate Laboratory Internships ($8,300,000) SULI supported approximately 800 students, including support for an additional 45 fall and spring semester students.	*Science Undergraduate Laboratory Internships ($7,900,000)* SULI will support approximately 750 students.	*Science Undergraduate Laboratory Internships ($-400,000)* Funding decrease requires a reduction in scope. The number of participants are decreased by 50.
Community College Internships ($1,000,000) CCI supported approximately 100 students.	*Community College Internships ($1,000,000)* CCI will support approximately 100 students.	*Community College Internships ($0)* No change.
Graduate Student Research Program ($2,500,000) The SCGSR program supported approximately 110 graduate students for periods of 3 months to 1 year to conduct a part of their thesis research at DOE laboratories. Targeted priority research areas were informed by SC's workforce training needs studies.	*Graduate Student Research Program ($2,000,000)* The SCGSR program will support approximately 85 graduate students for periods of 3 months to 1 year to conduct a part of their thesis research at DOE laboratories. Targeted priority research areas will be informed by SC's workforce training needs studies.	*Graduate Student Research Program ($-500,000)* Funding decrease requires a reduction in scope. The number of participants are decreased by 25.
Visiting Faculty Program ($1,700,000) VFP supported approximately 65 faculty and 40 students.	*Visiting Faculty Program ($0)* Program ends in FY 2018.	*Visiting Faculty Program ($-1,700,000)* No additional participants will be supported in FY 2018.
Albert Einstein Distinguished Educator Fellowship $1,200,000	**$0**	**$-1,200,000**
The FY 2016 Request supported 6 Fellows.	The participants of the 2017-2018 AEF Fellowship Year are supported by FY 2017 appropriations. No additional participants will be supported in FY 2018.	The AEF Program ends in FY 2018.
National Science Bowl $2,900,000	**$2,400,000**	**$-500,000**
WDTS sponsored the finals competition and provided central management of 116 regional events, involving 14,300 students from all fifty states, the District of Columbia, Puerto Rico, and the U.S. Virgin Islands.	WDTS will sponsor the finals competition and provide central management of 116 regional events, involving 14,300 students from all fifty states, the District of Columbia, Puerto Rico, and the U.S. Virgin Islands.	Funding decreases by $500,000, slowing development and renewal of NSB question sets, decreasing numbers of volunteers able to travel to the NSB finals, and curtailing the scope and number of participant enrichment activities at the NSB finals.

FY 2016 Enacted	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
Technology Development and On-line Application Systems $750,000	**$300,000**	**$-450,000**
Funding continued development and operation of the on-line systems.	Funding will continue development and operation of the on-line systems.	Funding decreases by $450,000, slowing development of some elements while maintaining baseline operations at programmatically required levels of service.
Evaluation $600,000	**$200,000**	**$-400,000**
FY 2016 funding continued support for evaluation activities, including data archiving, curation, and analyses.	Funding will continue support for evaluation activities, including data archiving, curation, and analyses.	Funding decreases by $400,000, slowing development and deployment of some elements while maintaining baseline operations at programmatically required levels of service.
Outreach $500,000	**$200,000**	**$-300,000**
Funding supported a public web portal providing access to the inventory of federally sponsored STEM training and workforce activities and opportunities. Funding supported outreach activities to the scientific community targeting Office of Science mission-driven disciplinary workforce needs in the next 5 to 10 years.	Funding will support outreach activities to the scientific community targeting Office of Science mission-driven disciplinary workforce needs in the next 5 to 10 years, including additional outreach activity proposal solicitations from DOE host labs and facilities. Funding will also support Laboratory Education Equipment Donation Program (LEDP) activities.	Funding decreases by $300,000, curtailing the scope and number of supported WDTS outreach activities at DOE host labs, while maintaining other ongoing on-line/virtual based programmatic outreach activities.
Laboratory Equipment Donation Program $50,000	**$0**	**$-50,000**
Funding supported the ongoing program.	Program is funded in FY 2018 under the Outreach program.	No impact.

Science Laboratories Infrastructure

Overview

The Science Laboratories Infrastructure (SLI) program mission is to support scientific and technological innovation at the Office of Science (SC) laboratories by funding and sustaining general purpose infrastructure and fostering safe and environmentally responsible operations. The main priorities of the SLI program are improving SC's existing physical assets and funding new cutting-edge facilities that enable emerging science opportunities. The SLI program also funds Payments in Lieu of Taxes (PILT) to local communities around the Argonne, Brookhaven, and Oak Ridge National Laboratories.

SC laboratories conduct a rigorous and consistent analysis 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 Campus Strategy identifies activities and infrastructure investments (e.g., Line-Item Construction, General Plant Projects [GPPs]) required to achieve the core capabilities and scientific vision for that laboratory. SC leadership uses these Campus Strategies to establish the corporate facilities and infrastructure priorities and as the basis for SLI Budget Requests.

Thorough analysis of SC's physical assets reveals a continued need to focus on our deferred maintenance backlog as well the number of inadequate facilities and core infrastructure across SC laboratory campuses. In FY 2016, SC invested over $475 million dollars in needed maintenance, repair, and upgrades of general purpose infrastructure. These investments were from a variety of funding sources, including federal appropriations for line-item construction projects and GPPs, as well as overhead-funded investments in institutional GPP work and routine maintenance and repair. The SLI program provides two important pieces of this overall strategy—line-item construction projects and a suite of infrastructure support investments that focus on laboratory core infrastructure and operations.

Highlights of the FY 2018 Budget Request

Ongoing projects that will provide new laboratory buildings, renovated facilities, and upgraded utilities are proceeding towards on-time completion within budget. While significant improvements to SC infrastructure have been made, it is important to maintain a strong level of investment and continue making improvements across the SC national laboratory complex.

The FY 2018 Request includes funding for the Materials Design Laboratory project at Argonne National Laboratory (ANL) and the Integrative Genomics Building project at Lawrence Berkeley National Laboratory (LBNL), both currently in construction. In addition, funding is requested for the Core Facility Revitalization project at Brookhaven National Laboratory (BNL) which will provide the scientific computing infrastructure, power, cooling, and space to support the vast streams of data from the Large Hadron Collider as well as on-site user facilities. The Request also includes funding for the Integrated Engineering Research Center at Fermi National Accelerator Laboratory (FNAL), which will bring together researchers by collocating engineers, scientists and technical staff from old, inadequate, locations across the site to the Central Campus. Lastly, funding is requested for the Energy Sciences Capability project at Pacific Northwest National Laboratory (PNNL), which will provide a science nexus in the central campus with collaborative laboratories, offices, meeting rooms, interaction areas, state-of-the-art data visualization and support facilities.

Science Laboratories Infrastructure
Funding ($K)

	FY 2016 Enacted	FY 2017 Annualized CR[a]	FY 2018 Request	FY 2018 vs FY 2016
Infrastructure Support	**44,690**	**44,605**	**22,900**	**-21,790**
Construction				
Energy Sciences Capability at PNNL (18-SC-71)	---	---	1,000	+1,000
Integrated Engineering Research Center at FNAL (17-SC-71)	---	---	1,500	+1,500
Core Facility Revitalization at BNL (17-SC-73)	---	---	1,500	+1,500
Materials Design Laboratory at ANL (15-SC-76)	23,910	23,865	24,500	+590
Photon Science Laboratory Building at SLAC (15-SC-77)	25,000	24,952	0	-25,000
Integrative Genomics Building at LBNL (15-SC-78)	20,000	19,962	24,800	+4,800
Total, Construction	**68,910**	**68,779**	**53,300**	**-15,610**
Total, Science Laboratories Infrastructure	**113,600**	**113,384**	**76,200**	**-37,400**

[a] The FY 2017 Annualized CR amounts reflect the P.L 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above, below that, a dash (-) is shown. The FY 2017 Annualized Level for SLI is higher than required for the approved project plans for three ongoing projects: the Materials Design Laboratory at ANL, the Photon Science Laboratory Building at SLAC, and the Integrative Genomics Building at LBNL. SC intends to provide only the approved funding profile for each project.

Science Laboratories Infrastructure
Explanation of Major Changes ($K)

	FY 2018 vs FY 2016
Science Laboratories Infrastructure	
Infrastructure Support: Funding continues to support PILT, general facility, and infrastructure support at NBL, as well as landlord responsibilities at the Oak Ridge Reservation. Funding also continues to support nuclear facilities at Oak Ridge National Laboratory (ORNL). Funding to address needs in core general purpose infrastructure at laboratories other than NBL is reduced in FY 2018.	-21,790
Construction: Funding supports line-item projects at Argonne National Laboratory, Lawrence Berkeley National Laboratory, Fermi National Accelerator Laboratory, Brookhaven National Laboratory, and Pacific Northwest National Laboratory in FY 2018. One project received final year funding in FY 2017.	-15,610
Total, Science Laboratories Infrastructure	**-37,400**

Program Accomplishments
Since FY 2006, the SLI program has invested over $770 million in infrastructure and has successfully completed eleven line-item projects while garnering eight DOE Secretary's Achievement Awards. These investments occurred following an FY 2006 SC decision to initiate a major effort to modernize infrastructure across the SC-stewarded laboratory complex. With these investments, the SLI program constructed more than 900,000 gross square feet (gsf) of new space and modernized nearly 400,000 gsf of existing space. As a result, an estimated 2,300 laboratory users and researchers now occupy newly constructed and/or modernized buildings that better support scientific and technological innovation in a collaborative environment.

The *Science and User Support Building project at SLAC National Accelerator Laboratory (SLAC)*. This project, completed in April of 2015, provides SLAC with 62,000 gsf of new office spaces, conference rooms, a cafeteria, and auditorium. During construction, this project provided nearly 100 construction jobs to the greater San Francisco Bay area. This building serves as the main entrance to SLAC bringing together administrative services, visitors and users from across programmatic boundaries in alignment with the Laboratory's multi-program mission.

Removal of Hazard Category 3 Materials from the New Brunswick Laboratory (NBL). The SLI program successfully transferred nuclear material from NBL at the ANL to bring the facility to a state below Hazard Category 3. This reduces risk and achieves a compliant safety posture. The SLI program continues to transfer the remaining nuclear materials from NBL so the building can eventually be renovated and re-purposed.

The *Photon Science Laboratory Building (SLAC).* This project represents a partnership between Stanford University and the Department of Energy to mutually benefit and reduce the capital investment by both parties. In November 2016, Stanford University completed the construction of the building shell and officially turned over the building to DOE. In March 2016, DOE began constructing the fit-out of a portion of the building shell for SLAC use, which will provide a combination of modernized office and laboratory space to enhance science collaboration, productivity, efficiency, and functionality to support simulation, theory and modeling, and materials synthesis and characterization at SLAC.

Utility Infrastructure Upgrades and Modernization at Fermi National Accelerator Laboratory (FNAL) and Thomas Jefferson National Accelerator Facility (TJNAF). The SLI program is upgrading and replacing inadequate core infrastructure critical to mission accomplishment at FNAL and TJNAF. This includes the replacement of 40+ year old industrial cooling water and high voltage electrical systems that reached the end of useful life. In addition, inadequate electrical distribution feeders and cooling tower cells were replaced and communication pathways were upgraded and expanded. These projects are over 90% complete, progressing ahead of schedule and on budget. At peak construction, these projects provided over 100 jobs.

Core General Plant Project upgrades across SC Laboratories. The SLI program funded a suite of investments in core infrastructure whose efficiency and reliability is critical to the success of SC missions. To date, SLI funded the replacement of nine 12kV -480 V substations (K-subs) serving the SLAC linac and upgraded approximately 1.5 miles of high voltage electrical cable and associated substation equipment at ANL. At FNAL, SLI funded renovations to Wilson Hall that will provide for increased collaboration space on 2 of the 15 floors in the lab's largest building and correct deficiencies on the building exterior.

Science Laboratories Infrastructure
Infrastructure Support

Description
This subprogram funds infrastructure support investments that focus on laboratory core infrastructure and operations. Investments in core infrastructure (e.g., utility systems, site-wide services, and general-purpose facilities) are an ongoing need that ensures facilities and utilities are upgraded when they approach end-of-life, systems are improved to increase reliability and performance, and excess space is removed so that it no longer requires operation and maintenance funding. Without this type of investment, SC laboratories would not be able to keep up with the pace of needed upgrades and repairs. Activities include GPP upgrades at various laboratories, general infrastructure support, de-inventory of nuclear material in Building 350 (formerly NBL at ANL), and support for the nuclear facilities at ORNL.

This subprogram also funds PILT to local communities around ANL, BNL, and ORNL, as well as stewardship type needs (e.g., roads and grounds maintenance) across the Oak Ridge Reservation.

Funding ($K)

	FY 2016 Enacted	FY 2017 Annualized CR[a]	FY 2018 Request	FY 2018 vs FY 2016
Infrastructure Support				
Facilities and Infrastructure	24,800	24,753	5,105	-19,695
Nuclear Operations	12,000	11,977	10,000	-2,000
Oak Ridge Landlord	6,177	6,165	6,082	-95
Payments in Lieu of Taxes	1,713	1,710	1,713	0
Total, Infrastructure Support	**44,690**	**44,605**	**22,900**	**-21,790**

Facilities and Infrastructure
This subprogram 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 research programs to review investment needs and select the highest priority activities to be included in the Budget Request.

This subprogram also supports general facilities and infrastructure support, as well as de-inventory, removal, and transfer of nuclear material in the NBL on the site of ANL.

Nuclear Operations
To support critical DOE nuclear operations, this funding is provided 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 ensure the facilities meet mission needs and safety standards.

Oak Ridge Landlord
Funding supports landlord responsibilities, including infrastructure for the 24,000-acre Oak Ridge Reservation and DOE facilities in the city of Oak Ridge, Tennessee. Activities include maintenance of roads, grounds, and other infrastructure; support and improvement of environmental protection, safety, and health; and PILT to Oak Ridge communities.

Payments in Lieu of Taxes
Funding within this activity supports SC stewardship responsibilities for PILT. The Department is authorized to provide discretionary payments to state and local government authorities for real property that is not subject to taxation because it

[a] FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above, below that level, a dash (-) is shown.

is owned by the United States and operated by the Department. Under this authorization, PILT is provided to communities around the ANL and BNL to compensate for lost tax revenues for land removed from local tax rolls. PILT payments are negotiated between the Department and local governments based on land values and tax rates.

Science Laboratories Infrastructure
Infrastructure Support

Activities and Explanation of Changes

FY 2016 Enacted	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
Infrastructure Support $44,690,000	**$22,900,000**	**-$21,790,000**
Facilities and Infrastructure $24,800,000	**$5,105,000**	**-$19,695,000**
FY 2016 funding provided general facility and infrastructure support at NBL, DOE Office of Scientific and Technical Information (OSTI) and the Oak Ridge Institute for Science and Education (ORISE) as well as critical core infrastructure investments for upgrades to facilities and utility systems at SLAC, ANL, and FNAL.	The FY 2018 Request continues to support de-inventory and removal of nuclear material at the NBL Building at ANL.	Funding decreases as a result of completed funding for core infrastructure investments. No funding for OSTI and ORISE. No new investments are funded this year at any SC site.
Nuclear Operations $12,000,000	**$10,000,000**	**-$2,000,000**
FY 2016 funding supported the management of ORNL's nuclear facilities to current expectations, in accordance with federal regulations and DOE Directives.	The FY 2018 Request continues to support critical nuclear operations and provides funding to manage ORNL's nuclear facilities.	Funding to support ORNL's nuclear facilities decreases.
Oak Ridge Landlord $6,177,000	**$6,082,000**	**-$95,000**
FY 2016 funding supported stewardship needs across the Oak Ridge Reservation as well as PILT to Oak Ridge communities.	The FY 2018 Request 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.	Funding decreases slightly as a result of efficiencies.
Payments in Lieu of Taxes $1,713,000	**$1,713,000**	**$0**
FY 2016 funding supported PILT payments to communities around ANL and BNL.	The FY 2018 Request provides funding for PILT payments to communities around ANL and BNL.	Funding to support PILT payments remains the same as prior years.

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 2018 Budget Request includes funding for line-item projects at ANL, Lawrence Berkeley National Laboratory (LBNL), FNAL, BNL, and PNNL.

Energy Sciences Capability at PNNL (18-SC-71)
The Chemical and Molecular Sciences capability forms the basis for PNNL's fundamental science programs in catalysis science, condensed phase and interfacial molecular science, computational and theoretical chemistry, geosciences, and separations and analysis. This core capability also has strong ties to the Condensed Matter Physics and Materials Science, Computational Science, and the Applied Mathematics core capabilities. Exercise of this core capability is hampered by many infrastructure capability gaps, including: insufficient hood space for catalysis synthesis and collaboration; lack of proper environmental controls for state-of-the-art in-situ characterization; limited space to integrate experimental capabilities for visualization supporting research in data analytics, modeling, and simulation, and performance modeling; and limited collaboration space for "point of research work" for collaborators and strategic partners. Closing these gaps will provide for mission-appropriate utility and infrastructure support systems for PNNL research. It will also significantly improve collaboration among researchers, both on-site and remotely.

The most recent DOE O 413.3B Critical Decision (CD) is CD-0, *Approve Mission Need,* approved on December 12, 2016. This project has a total project cost range of $73,000,000 to $99,000,000. This cost range encompasses the most feasible preliminary alternatives. The preliminary total project cost is estimated to be $93,000,000. The cost, scope, and schedule for executing the project will be determined at CD-2.

FY 2018 funds support Project Engineering and Design activities.

Preliminary Schedule

CD-0	CD-1	CD-2	CD-3	CD-4
12/12/2016	4Q FY 2018	4Q FY 2019	4Q FY 2020	4Q FY 2025

Preliminary Cost Estimates
(Dollars in Thousands)

	FY 2018 Appropriations	Total Appropriations
Design	$1,000	$9,000
Construction	0	$81,000
Other Project Costs	0	$3,000
Preliminary Total Project Cost	$1,000	$93,000

Integrated Engineering Research Center FNAL (17-SC-71)
The Integrated Engineering Research Center project will construct a scientific user support facility to accommodate increased collaboration and interactions among staff at FNAL, who will in turn be working with scientific collaborators and international partners in the design, construction, and operation of physics experiments.

In May 2014, the Particle Physics Project Prioritization Panel (P5) issued a report that included recommendations to "…develop a coherent short- and long-baseline neutrino program hosted at Fermilab…" and to "…reformulate the long-baseline neutrino program as an internationally designed, coordinated, and funded program with [FNAL] as host." SC and the High Energy Physics (HEP) program accepted the recommendations in the P5 report and are committed to implementing a successful program based on this 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, staff and their associated manufacturing, assembly, engineering, and technical facilities are scattered among three parts of the campus—the Silicon Detector Complex, the Village, and Wilson Hall. As a result, they are unable to efficiently collaborate on ongoing and planned projects in support of the mission of the laboratory. The Integrated Engineering Research Center will provide FNAL with a collaborative, multi-divisional and interdisciplinary research center. This research center will close existing capability and infrastructure gaps by reducing the overall footprint of outdated facilities, and collocating engineering and associated research staff in a new or renovated facility near the central campus. This approach will complement the ongoing and planned renovations of Wilson Hall by establishing the main campus as the anchor point of the site. It will improve operational efficiency and collaboration because groups working on key projects would be in close proximity 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 most recent DOE O 413.3B approved Critical Decision (CD) is CD-1, *Approve Alternative Selection and Cost Range*, which was approved on April 18, 2017. The estimated preliminary total project cost range for this project is $74,000,000 to $99,000,000. This range encompasses the most feasible preliminary alternatives. The preliminary total project cost is estimated to be $86,000,000. The cost, scope, and schedule for executing the project will be determined at Critical Decision (CD)-2.

FY 2018 funding will support Project Engineering and Design activities.

Preliminary Schedule

CD-0	CD-1	CD-2	CD-3	CD-4
07/17/2015	04/18/2017	3Q FY 2019	3Q FY 2020	2Q FY 2024

Preliminary Cost Estimates

(Dollars in Thousands)

	FY 2018 Appropriations	Total Appropriations
Design	$1,500	$10,000
Construction	0	$75,000
Other Project Costs	0	$1,000
Preliminary Total Project Cost	$1,500	$86,000

Core Facility Revitalization at BNL (17-SC-73)

A significant amount of computation and data storage is currently conducted within the Relativistic Heavy Ion Collider (RHIC) ATLAS Computing Facility (RACF) that is located on the BNL campus. The RACF directly supports RHIC research operations funded by Nuclear Physics (NP) and the US-ATLAS research operations funded by High Energy Physics (HEP). The RACF also provides mid-scale computing support to other research programs funded by SC, research efforts funded by strategic partners, and computationally-intensive research that indirectly supports the broader SC mission.

The data volume generated by the RHIC experiments and ATLAS is expected to increase three to six times over the next ten years and will require proportional increases in computation and data storage capacities. Almost half of the current RACF computing and data storage facility is expected become functionally obsolete and unable to accommodate future generations of computation and data storage technologies over the next five to ten years. Therefore, the projected capability gaps in computing infrastructure are due to a combination of decreases due to degrading capacities and increases in future requirements of mid-scale computing performed by RACF. Increases in computation and data storage will drive increased requirements for space, power, and cooling of computing facilities. A mission need therefore exists to provide sufficient mid-range computation and data storage capabilities to support to current and planned experiments using RHIC and the ATLAS detectors, and potentially other programs.

The most recent DOE O 413.3B Critical Decision (CD) is CD-1, *Approve Alternative Selection and Cost Range,* was approved on April 18, 2017. This project has a total project cost range of $68,500,000 to $84,500,000. This cost range encompasses the most feasible preliminary alternatives. The preliminary total project cost is estimated to be $74,850,000. The cost, scope, and schedule for executing the project will be determined at CD-2.

FY 2018 funds support Project Engineering and Design activities.

Preliminary Schedule

CD-0	CD-1	CD-2	CD-3	CD-4
09/10/2015	04/18/2017	3Q FY 2018	1Q FY 2019	4Q FY 2023

Preliminary Cost Estimates
(Dollars in Thousands)

	FY 2018 Appropriations	Total Appropriations
Design	$1,500	$7,000
Construction	0	$67,000
Other Project Costs	0	$850
Preliminary Total Project Cost	$1,500	$74,850

<u>Materials Design Laboratory at ANL (15-SC-76)</u>
The Materials Design Laboratory will support research in materials science in energy and a range of other fields. It will entail constructing a new laboratory office building of approximately 100,000 gross square feet (gsf) in size and located adjacent to the recently completed Energy Sciences Building. The existing research buildings at Argonne dedicated to this SC research mission are all more than 40 years old, some as old as 55 years. These structures require frequent repair, resulting in interruptions to research activities, and they are unable to meet modern standards for instruments requiring vibration, electromagnetic, and/or thermal stability.

The most recent DOE O 413.3B approved Critical Decision (CD) is CD-3, Approve Start of Construction, on August 12, 2016. The Total Project Cost (TPC) for this project is $96,000,000.

The FY 2018 Request for the Materials Design Laboratory Project is $24,500,000, which is $590,000 more than the FY 2016 Enacted level and consistent with the baseline funding profile. FY 2018 funds will be used for construction and project management and support activities.

FY 2017 Milestones	FY 2018 Milestones	FY 2019–2022 Key Milestones
Construction Continues	Construction Continues	CD-4 – Approve Project Completion

<u>Integrative Genomics Building at LBNL (15-SC-78)</u>
The Integrative Genomics Building will allow the laboratory to relocate a significant fraction of the research and operations currently located in commercially leased space onto the main LBNL campus. Portions of the biosciences program at LBNL are located off-site, away from the main laboratory, and dispersed across multiple locations up to 20 miles apart. Collocation of these programs will increase the synergy and efficiency of biosciences and other research at LBNL and will provide a state-of-the-art facility for biosciences research in a collaborative environment close to other key LBNL facilities and programs.

The most recent DOE O 413.3B approved Critical Decision (CD) is CD-3, Approve Start of Construction, which was approved on October 7, 2016. The TPC for this project is $91,500,000.

FY 2018 Request for the Integrative Genomics Building is $24,800,000, which is $4,800,000 more than the FY 2016 Enacted level. FY 2018 funds will be used for construction, project management, and support activities.

FY 2017 Milestones	FY 2018 Milestones	FY 2019–2022 Key Milestones
CD-3 – Approve Start of Construction	Construction Continues	CD-4 – Approve Project Completion

Activities and Explanation of Changes

FY 2016 Enacted	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
Construction $68,910,000	**$53,300,000**	**-$15,610,000**
Energy Sciences Capability at PNNL (18-SC-71) $0	**$1,000,000**	**+$1,000,000**
	Funding in FY 2018 Request supports Project Engineering and Design activities.	Funding will support PED activities.
Integrated Engineering Research Center at FNAL (17-SC-71) $0	**$1,500,000**	**+$1,500,000**
	Funding in FY 2018 Request supports Project Engineering and Design activities.	Funding will support PED activities.
Core Facility Revitalization at BNL (17-SC-73) $0	**$1,500,000** Funding in FY 2018 Request supports Project Engineering and Design activities.	**+$1,500,000** Funding will support PED activities.
Materials Design Laboratory at ANL (15-SC-76) $23,910,000	**$24,500,000**	**+$590,000**
FY 2016 funding initiated construction of the project.	Funding in FY 2018 Request supports on-going construction of the project.	Additional funding needed to support on-going construction.
Photon Sciences Laboratory Building at SLAC (15-SC-77) $25,000,000	**$0**	**-$25,000,000**
FY 2016 funding supported ongoing construction of the project.	No new funding is requested. Project funding was completed in FY 2017.	Project funding completed in FY 2017
Integrative Genomics Building at LBNL (15-SC-78) $20,000,000	**$24,800,000**	**+$4,800,000**
FY 2016 funding supported construction of the project.	Funding in FY 2018 Request supports completion of construction of the project.	Additional funding needed to support on-going construction.

Science Laboratories Infrastructure
Capital Summary ($K)

	Total	Prior Years	FY 2016 Enacted	FY 2017 Annualized CR[a]	FY 2018 Request	FY 2018 vs FY 2016
Capital Operating Expense Summary						
General Plants Projects						
ALS HVAC System Upgrade at LBNL (TEC $9.0M)	9,000	0	0	–	0	0
Electrical Distribution Upgrades at SLAC (TEC $10.0M)	10,000	0	0	–	0	0
Linac K-sub Remediation at SLAC (TEC $9.8M)	9,800	0	9,800	–	0	-9,800
Wilson Hall Renovations at FNAL (TEC $9.0M)	9,000	0	9,000	–	0	-9,000
Other GPP (TEC <$5M)	n/a	n/a	4,500	–	0	-4,500
Total, Capital Operating Expenses	**n/a**	**n/a**	**23,300**	**–**	**0**	**-23,300**

Construction Projects Summary ($K)

	Total Project Cost (TPC)	Prior Years	FY 2016 Enacted	FY 2017 Enacted	FY 2018 Request	FY 2018 vs FY 2016
Energy Sciences Capability at PNNL (18-SC-71)						
TEC	90,000[b]	0	0	0	1,000	+1,000
OPC[c]	3,000	0	0	0	1,000	+1,000
TPC	93,000[b]	0	0	0	2,000	+2,000
Integrated Engineering Research Center at FNAL (17-SC-71)						
TEC	85,000[b]	0	0	2,500	1,500	+1,500
OPC[c]	2,000	500	500	0	0	-500
TPC	87,000[b]	500	500	2,500	1,500	+1,000
Core Facility Revitalization at BNL (17-SC-73)						
TEC	74,000[b]	0	0	1,800	1,500	+1,500
OPC[c]	850	0	850	0	0	-850
TPC	74,850[b]	0	850	1,800	1,500	+650

[a] FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above, below that level, a dash (-) is shown.
[b] This project has not received CD-2 approval; therefore, preliminary cost estimates are shown for TEC and TPC.
[c] Other Project Costs shown are funded through laboratory overhead.

	Total Project Cost (TPC)	Prior Years	FY 2016 Enacted	FY 2017 Enacted	FY 2018 Request	FY 2018 vs FY 2016
Materials Design Laboratory at ANL (15-SC-76)						
TEC	95,000	7,000	23,910	19,590	24,500	+590
OPC[c]	1,000	1,000	0	0	0	0
TPC	96,000	8,000	23,910	19,590	24,500	+590

	Total Project Cost(TPC)	Prior Years	FY 2016 Enacted	FY 2017 Enacted	FY 2018 Request	FY 2018 vs FY 2016
Photon Sciences Laboratory Building at SLAC (15-SC-77)						
TEC	55,000	10,000	25,000	20,000	0	-25,000
OPC[a]	2,000	472	0	459	0	0
TPC	57,000	10,472	25,000	20,459	0	-25,000
Integrative Genomics Building at LBNL (15-SC-78)						
TEC	90,000	12,090	20,000	19,561	24,800	+4,800
OPC[b]	1,500	1,500	0	0	0	0
TPC	91,500	13,590	20,000	19,561	24,000	+4,800
Total, Construction						
TEC	n/a	n/a	68,910	63,451	53,300	-15,610
OPC[b]	n/a	n/a	1,350	459	1,000	-350
TPC	n/a	n/a	70,260	63,910	54,300	-15,960

[a] Other Project Costs shown are funded through laboratory overhead.

15-SC-76 Materials Design Laboratory
Argonne National Laboratory (ANL), Argonne, IL
Project is for Construction

1. Significant Changes and Summary

Significant Changes

This Construction Project Data Sheet (CPDS) is an update of the FY 2017 CPDS and does not include a new start for FY 2018.

Summary

The most recent DOE O 413.3B approved Critical Decision (CD) is CD-3, Approve Start of Construction, which was approved on August 12, 2016. The Total Estimated Cost (TEC) is $95,000,000. The Total Project Cost (TPC) for this project is $96,000,000.

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

This project will provide new laboratory and office space to support basic energy-related materials science and engineering research. Final Design was completed in May 2016 and the construction general contractor was issued a notice to proceed in December 2016.

FY 2018 funds will be used for construction and associated activities.

2. Critical Milestone History

(fiscal quarter or date)

	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2015	08/27/2010	N/A	4QFY 2014	4QFY 2015	4QFY 2016	3QFY 2016	N/A	2QFY 2020
FY 2016	08/27/2010	1QFY 2015	2QFY 2015	2QFY 2016	3QFY 2017	1QFY 2017	N/A	3QFY 2020
FY 2017	08/27/2010	11/12/2014	01/30/2015	2QFY 2016	3QFY 2017	1QFY 2017	N/A	3QFY 2020
FY 2018PB	08/27/2010	11/12/2014	01/30/2015	03/18/2016	05/09/2016	08/12/2016	N/A	3Q FY 2021

CD-0 – Approve Mission Need
Conceptual Design Complete – Actual date the conceptual design was completed
CD-1 – Approve Alternative Selection and Cost Range
CD-2 – Approve Performance Baseline
Final Design Complete – Actual date the final design was completed
CD-3 – Approve Start of Construction
D&D Complete – Completion of D&D Work (see section 9)
CD-4 – Approve Project Completion
PB – Indicates the Performance Baseline

	Performance Baseline Validation
FY 2015	N/A
FY 2016	1QFY 2017
FY 2017	3QFY 2016
FY 2018	03/18/2016

3. Project Cost History

(dollars in thousands)

	TEC, Design	TEC, Construction	TEC, Total	OPC[a] Except D&D	OPC, D&D	OPC, Total	TPC
FY 2015	7,000	88,000	95,000	1,000	N/A	1,000	96,000
FY 2016	7,000	88,000	95,000	1,000	N/A	1,000	96,000
FY 2017	7,000	88,000	95,000	1,000	N/A	1,000	96,000
FY 2018	7,000	88,000	95,000	1,000	N/A	1,000	96,000

4. Project Scope and Justification

Scope

The scope of this project includes the design and construction of a Materials Design Laboratory building at least 97,000 gross square feet in size and located adjacent to the recently completed Energy Sciences Building.

The table below outlines the KPPs.

Key Performance Parameters

Description	Threshold Value (Minimum)	Objective Value (Maximum)
Multi-story laboratory building	97,000 gross square feet	130,000 gross square feet

Justification

The mission need of this project is to provide flexible and sustainable laboratory and office space needed to support scientific theory/simulation, materials discovery, characterization, and application of new energy-related materials and processes. The Materials Design Laboratory project will provide the modern collaborative scientific environment critical for this initiative to thrive and will focus on four themes central to implementing the Materials for Energy strategy:

- Frontiers of materials and molecular synthesis, and fabrication of devices;
- Interfacial engineering for energy applications;
- Materials under extreme conditions; and
- *In situ* characterization and modeling.

The project is being conducted in accordance with the project management requirements in DOE O 413.3B, and all appropriate project management requirements have been met.

5. Financial Schedule

(dollars in thousands)

	Appropriations	Obligations	Costs[b]
Total Estimated Cost (TEC)			
Design			
FY 2015	7,000	7,000	2,773
FY 2016	0	0	3,998
FY 2017	0	0	229
Total, Design	7,000	7,000	7,000
Construction			

[a] OPC are funded through laboratory overhead.

[b] Costs through 2016 reflect actual Costs; costs for FY 2017 and the outyears are estimates.

	(dollars in thousands)		
	Appropriations	Obligations	Costs[b]
FY 2016	23,910	23,910	0
FY 2017	19,590	19,590	10,000
FY 2018	24,500	24,500	44,000
FY 2019	20,000	20,000	23,800
FY 2020	0	0	10,200
Total, Construction	88,000	88,000	88,000
TEC			
FY 2015	7,000	7,000	2,773
FY 2016	23,910	23,910	3,998
FY 2017	19,590	19,590	10,229
FY 2018	24,500	24,500	44,000
FY 2019	20,000	20,000	23,800
FY 2020	0	0	10,200
Total, TEC	95,000	95,000	95,000
Other Project Cost (OPC)[a]			
OPC except D&D			
FY 2010	412	412	412
FY 2011	-30[b]	-30[d]	-30[d]
FY 2014	328	328	328
FY 2015	290	290	290
Total, OPC except D&D	1,000	1,000	1,000
Total Project Cost (TPC)			
FY 2010	412	412	412
FY 2011	-30[c]	-30[b]	-30[b]
FY 2014	328	328	328
FY 2015	7,290	7,290	3,063
FY 2016	23,910	23,910	3,998
FY 2017	19,590	19,590	10,229
FY 2018	24,500	24,500	44,000
FY 2019	20,000	20,000	23,800
FY 2020	0	0	10,200
Total, TPC	96,000	96,000	96,000

[a] OPC are funded through laboratory overhead.

[b] OPC Funding was adjusted in FY 2011 to reflect FY 2010 actuals ($382,000 for OPC funding in FY 2010).

[c] OPC Funding was adjusted in FY 2011 to reflect FY 2010 actuals ($382,000 for OPC funding in FY 2010).

6. Details of Project Cost Estimate

	(dollars in thousands)		
	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	6,647	6,000	6,647
Contingency	353	1,000	353
Total, Design	7,000	7,000	7,000
Construction			
Construction	76,004	73,000	76,362
Contingency	11,996	15,000	11,638
Total, Construction	88,000	88,000	88,000
Total, TEC	95,000	95,000	95,000
Contingency, TEC	12,349	16,000	11,991
Other Project Cost (OPC)[a]			
OPC except D&D			
Conceptual Planning	382	382	382
Conceptual Design	618	500	618
Contingency	0	118	0
Total, OPC	1,000	1,000	1,000
Contingency, OPC	0	118	0
Total, TPC	96,000	96,000	96,000
Total, Contingency	12,349	16,118	11,991

7. Schedule of Appropriation Requests

(dollars in thousands)

Request Year		Prior Years	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	Total
FY 2015	TEC	0	0	7,000	24,003	36,466	27,531	0	95,000
	OPC[a]	382	500	0	0	0	118	0	1,000
	TPC	382	500	7,000	24,003	36,466	27,649	0	96,000
FY 2016	TEC	0	0	7,000	23,910	25,090	39,000	0	95,000
	OPC[a]	382	300	0	0	0	318	0	1,000
	TPC	382	300	7,000	23,910	25,090	39,318	0	96,000
FY 2017	TEC	0	0	7,000	23,910	25,090	39,000	0	95,000
	OPC[a]	382	300	0	0	0	318	0	1,000
	TPC	382	300	7,000	23,910	25,090	39,318	0	96,000
FY 2018	TEC	0	0	7,000	23,910	19,590	24,500	20,000	95,000
	OPC[a]	382	328	290	0	0	0	0	1,000
	TPC	382	328	7,290	23,910	19,590	24,500	20,000	96,000

[a] OPC are funded through laboratory overhead.

8. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy Expected……	2QFY 2021
Useful Life……	50 years
Expected Future Start of D&D of this capital asset……	2QFY 2071

(Related Funding Requirements)

(dollars in thousands)

	Annual Costs		Life-Cycle Costs	
	Current Total Estimates	Previous Total Estimates	Current Total Estimates	Previous Total Estimates
Operations	376	376	18,800	18,800
Utilities	429	429	21,450	21,450
Maintenance and Repair	958	958	47,900	47,900
Total – Operations and Maintenance	1,763	1,763	88,150	88,150

9. D&D Information

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

	Square Feet
New area being constructed by this project at *Argonne National Laboratory*……	97,000 to 130,000
Area of D&D in this project at *Argonne National Laboratory*……	None
Area at *Argonne National Laboratory* to be transferred, sold, and/or D&D outside the project including area previously banked"……	None
Area of D&D in this project at other sites……	None
Area at other sites to be transferred, sold, and/or D&D outside the project including area previously "banked"……	None[a]
Total area eliminated……	None

10. Acquisition Approach

Acquisition for this project will be performed by the Management and Operating (M&O) Contractor, UChicago Argonne, LLC, and will be overseen by the Argonne Site Office. Various acquisition approaches and project delivery methods were evaluated prior to achieving CD-1. A tailored Design-Bid-Build approach was selected as the overall best project delivery method with the lowest risk to DOE. The M&O Contractor is responsible for awarding and administering all subcontracts related to this project. Project performance metrics are included in the M&O Contractor's annual performance evaluation and measurement plan.

[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.

15-SC-78, Integrative Genomics Building
Lawrence Berkeley National Laboratory (LBNL), Berkeley, California
Project is for Construction

1. Significant Changes and Summary

Significant Changes

This Construction Project Data Sheet (CPDS) is an update of the FY 2017 CPDS and does not include a new start for FY 2018.

The project funding profile has changed since the last submitted CPDS. Construction funding has extended by one year to FY 2019. Total project cost has not changed.

Summary

The most recent DOE O 413.3B Critical Decision (CD) is CD-3, Approve Start of Construction, was approved on October 7, 2016. The approved Total Estimated Cost (TEC) for this project is $90,000,000. The approved Total Project Cost (TPC) for this project is $91,500,000.

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

This project will provide new space necessary to relocate a significant fraction of biosciences research currently occupying leased commercial space onto the main LBNL campus. Final Design was completed in May 2016. Construction began in December 2016.

FY 2018 funds will be used for construction and associated tasks.

2. Critical Milestone History

(fiscal quarter to date)

	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2015	9/17/2013	N/A	1QFY 2015	3QFY 2016	4QFY 2016	3Q FY 2016	N/A	1QFY 2021
FY 2016	9/17/2013	1QFY 2015	2QFY 2015	2QFY 2016	3QFY 2016	4Q FY 2016	N/A	1QFY 2021
FY 2017	9/17/2013	10/28/2014	02/20/2015	2QFY 2016	3QFY 2016	1Q FY 2017	N/A	1QFY 2021
FY 2018	9/17/2013	10/28/2014	02/20/2015	3/18/2016	5/2/2016	10/7/2016	N/A	1QFY 2021

CD-0 – Approve Mission Need
Conceptual Design Complete – Actual date the conceptual design was completed
CD-1 – Approve Alternative Selection and Cost Range
CD-2 – Approve Performance Baseline
Final Design Complete – Estimated date the project design will be completed
CD-3– Approve Start of Construction
D&D Complete – Completion of D&D work (see Section 9)
CD-4 – Approve Project Completion

	Performance Baseline Validation
FY 2015	N/A
FY 2016	N/A
FY 2017	2QFY 2016
FY 2018PB	3/18/2016

3. Project Cost History

(dollars in thousands)

	TEC, Design	TEC, Construction	TEC, Total	OPC[a] Except D&D	OPC, D&D	OPC, Total	TPC
FY 2015	12,090	77,910	90,000	1,500	0	1,500	91,500
FY 2016	9,590	80,410	90,000	1,500	0	1,500	91,500
FY 2017	6,500	83,500	90,000	1,500	0	1,500	91,500
FY 2018	6,900	83,100	90,000	1,500	0	1,500	91,500

4. Project Scope and Justification

Scope

The scope of this project includes the design and construction of a new state-of-the-art facility for bioscience research at least 80,800 gross square feet in size and located on the main LBNL campus in Berkeley, California. The facility will be physically located on the former site of the demolished Bevatron particle accelerator.

The table below outlines the KPPs.

Key Performance Parameters

Description	Threshold Value (Minimum)	Objective Value (Maximum)
Biosciences and other research space	79,000 gross square feet	95,000 gross square feet

Justification

The mission need of this project is to increase the synergy and efficiency of biosciences and other research at Lawrence Berkeley National Laboratory (LBNL). LBNL has grown from a pioneering particle and nuclear physics laboratory into a multidisciplinary research facility with broad capabilities in physical, chemical, computational, biological, and environmental systems research in support of the Department of Energy (DOE) mission. Portions of the biosciences program at LBNL are located off-site, away from the main laboratory, and dispersed across several locations approximately twenty miles apart. This arrangement has produced research and operational capability gaps that limit scientific progress, in genomics-based biology related to energy and the environment. This project will close the present capability gaps by providing a state-of-the-art facility that will collocate biosciences research and other programs.

FY 2018 funds will be used for construction and project management and support activities.

The project is being conducted in accordance with the project management requirements in DOE O 413.3B, and all appropriate project management requirements have been met.

[a] Other project costs (OPC) are funded through laboratory overhead.

5. Financial Schedule

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
Total Estimated Cost (TEC)			
Design			
FY 2015	6,900	6,900	2,086
FY 2016	0	0	4,541
FY 2017	0	0	273
Total, Design	6,900	6,900	6,900
Construction			
FY 2015	5,190	5,190	0
FY 2016	20,000	20,000	0
FY 2017	19,561	19,561	18,000
FY 2018	24,800	24,800	41,000
FY 2019	13,549	13,549	24,100
Total, Construction	83,100	83,100	83,100
TEC			
FY 2015	12,090	12,090	2,086
FY 2016	20,000	20,000	4,541
FY 2017	19,561	19,561	18,273
FY 2018	24,800	24,800	41,000
FY 2019	13,549	13,549	24,100
Total, TEC	90,000	90,000	90,000
Other Project Cost (OPC)[b]			
OPC except D&D			
FY 2014	1,145	1,145	1,145
FY 2015	355	355	355
Total, OPC	1,500	1,500	1,500
Total Project Cost (TPC)			
FY 2014	1,145	1,145	1,145
FY 2015	12,445	12,445	2,441
FY 2016	20,000	20,000	4,541
FY 2017	19,561	19,561	18,273
FY 2018	24,800	24,800	41,000
FY 2019	13,549	13,549	24,100
Total, TPC	91,500	91,500	91,500

[a] Costs through FY 2016 reflect actual costs; costs for FY 2017and the outyears are estimates.

[b] Other Project Costs (OPC) are funded through laboratory overhead.

6. Details of Project Cost Estimate

	(dollars in thousands)		
	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	6,900	5,964	6,216
Contingency	0	536	684
Total, Design	6,900	6,500	6,900
Construction			
Construction	73,950	71,265	71,495
Contingency	9,150	12,235	11,605
Total, Construction	83,100	83,500	83,100
Total, TEC	90,000	90,000	90,000
Contingency, TEC	9,150	12,771	12,289
Other Project Cost (OPC)[a]			
OPC except D&D			
Conceptual Planning	400	355	355
Conceptual Design	1,000	1,145	1,145
Contingency	100	0	0
Total, OPC	1,500	1,500	1,500
Contingency, OPC	100	0	0
Total, TPC	91,500	91,500	91,500
Total, Contingency	9,250	12,771	12,289

7. Schedule of Appropriation Requests

Request Year		FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	Total
		(dollars in thousands)						
FY 2015	TEC	0	12,090	17,299	30,148	30,463	0	90,000
	OPC[a]	1,300	0	0	0	0	200	1,500
	TPC	1,300	12,090	17,299	30,148	30,463	200	91,500
FY 2016	TEC	0	12,090	20,000	25,064	32,846	0	90,000
	OPC[a]	1,500	0	0	0	0	0	1,500
	TPC	1,500	12,090	20,000	25,064	32,846	0	91,500
FY 2017	TEC	0	12,090	20,000	19,561	38,349	0	90,000
	OPC[a]	1,145	355	0	0	0	0	1,500
	TPC	1,145	12,445	20,000	19,561	38,349	0	91,500
FY 2018	TEC	0	12,090	20,000	19,561	24,800	13,549	90,000
	OPC[a]	1,500	0	0	0	0	0	1,500
	TPC	1,500	12,090	20,000	19,561	24,800	13,549	91,500

[a] Other Project Costs (OPC) are funded through laboratory overhead.

8. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	1QFY 2020
Expected Useful Life	50 years
Expected Future Start of D&D of this capital asset	1QFY 2070

(Related Funding requirements)

(dollars in thousands)

	Annual Costs		Life Cycle Costs	
	Current Total Estimate	Previous Total Estimate	Current Total Estimate	Previous Total Estimate
Operations	179	179	5,735	5,735
Utilities	324	324	11,919	11,919
Maintenance and Repair	644	644	20,662	20,662
Total, Operations & Maintenance	1,147	1,147	38,316	38,316

9. D&D Information

The new area that will be constructed in this project will not replace existing facilities.

	Square Feet
New area being constructed by this project at *Lawrence Berkeley National Laboratory*……………………………………………………………………………………………………..	79,000 to 95,000
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

10. Acquisition Approach

Acquisition for this project will be performed by the Management and Operating (M&O) Contractor, University of California, and overseen by the Berkeley Site Office. Various acquisition approaches and project delivery methods were evaluated prior to achieving CD-1. A tailored Design-Bid-Build approach with a Construction Manager as General Contractor was selected as the overall best project delivery method with the lowest risk to DOE. The M&O contractor is responsible for awarding and administering all subcontracts related to this project. Project performance metrics are included in the M&O contractor's annual performance evaluation and measurement plan.

[a] 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, Illinois
Preliminary Information for Design

1. Summary

This document contains preliminary information for a design and construction project requested in FY 2018 and is an update from the FY 2017 Project Data Sheet (PDS).

The FY 2018 Request for this project is $1,500,000. The most recent DOE O 413.3B Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range, which was approved on April 18, 2017.

This project has a Total Estimated Cost (TEC) range of $73,000,000 to $98,000,000 and a Total Project Cost (TPC) range of $74,000,000 to $99,000,000. These cost ranges encompass the most feasible preliminary alternatives. This preliminary information reflects funding for a project to design and construct new space to accommodate increased collaboration and interactions among FNAL staff. The project is intended improve the infrastructure to support 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).

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

FY 2018 funds will support Project Engineering and Design activities.

2. Critical Milestone History

(fiscal quarter or date)

	CD-0	CD-1	CD-2/3A	CD-3	CD-4
FY 2017	07/17/2015	1Q FY 2017[a]	3Q FY 2018[a]	3Q FY 2019[a]	4Q FY 2023[a]
FY 2018	07/17/2015	4/18/2017	3Q FY 2019[a]	3Q FY 2020[a]	4Q FY 2024[a]

CD-0 – Approve Mission Need
CD-1 – Approve Alternative Selection and Cost Range
CD-2 – Approve Performance Baseline/Start of Construction – Site Prep
CD-3 – Approve Start of Construction - Building Construction
CD-4 – Approve Project Completion

3. Current Preliminary Project Cost Estimates

(dollars in thousands)

	TEC, Design	TEC, Construction	TEC, Total	OPC[b]	TPC
FY 2017	10,000	75,000	85,000[a]	2,000	87,000[a]
FY 2018	10,000	75,000	85,000[a]	1,000	86,000[a]

[a] This project is pre-CD-2; schedule and funding estimates are preliminary.
[b] Other project costs (OPC) are funded through laboratory overhead.

4. Project Scope and Justification

Scope

The Integrated Engineering Research Center project will construct a scientific user support facility to accommodate increased collaboration and interactions among staff at Fermilab (FNAL), who will in turn be working with scientific collaborators and international partners in the design, construction, and operation of physics experiments.

This project has not yet received CD-2 approval; therefore the Key Performance Parameters (KPPs) are not yet established. The table below outlines preliminary KPPs.

Key Performance Parameters (Preliminary)

Description	Threshold Value (Minimum)	Objective Value (Maximum)
Multistory Laboratory/Office Building	67,000 gross square feet	134,000 gross square feet

Justification

In May 2014, the Particle Physics Project Prioritization Panel (P5) issued a report that included recommendations to "…develop a coherent short- and long-baseline neutrino program hosted at Fermilab," and to "Reformulate the long-baseline neutrino program as an internationally designed, coordinated, and funded program with [Fermi National Accelerator Laboratory, FNAL or Fermilab] as host." SC and the High Energy Physics (HEP) program accepted the recommendations in the P5 report and are committed to implementing a successful program based on this new vision.

Implementing these recommendations will require significantly increased collaboration and interactions among FNAL staff, who will in turn be working with scientific collaborators and international partners in the design, construction, and operation of physics experiments. Currently, these staff and their associated manufacturing, assembly, engineering, and technical facilities are scattered among three parts of the campus – the Silicon Detector Complex, the Village, and Wilson Hall. As a result, they are unable to efficiently collaborate on ongoing and planned projects in support of the laboratory's mission.

Co-location of these staff will improve collaboration because it will increase interactions among the various groups and reduce down-time spent traveling across the site. From an infrastructure standpoint, however, FNAL currently lacks sufficient space to do this. Continuing the previous example, groups from the three Divisions noted above total approximately 300 staff occupying more than 170,000 square feet of laboratories, technical areas, and offices in 15 buildings and trailers. In addition, many of these spaces are inadequate to accommodate current and planned scientific programs because they are obsolete (e.g., leaking roofs, inadequate HVAC systems) and do not support the configuration or specification needs of current and future technical programs.

The Integrated Engineering Research Center will provide FNAL with a collaborative, multi-divisional and interdisciplinary research center. This research center will close existing capability and infrastructure gaps by reducing the overall footprint of outdated facilities, and collocating engineering and associated research staff in a new or renovated facility near the central campus. This approach will complement the ongoing and planned renovations of Wilson Hall by establishing the main campus as the anchor point of the site. It will improve operational efficiency and collaboration because groups working on key projects would be in close proximity to one another. Such a facility will provide technical and engineering staff the necessary environment for interdisciplinary collaboration necessary to establish an international neutrino program and support other HEP science opportunities described in the P5 report.

The project is being conducted in accordance with the project management requirements in DOE O 413.3B, and all appropriate project management requirements have been met.

5. Details of Preliminary Project Cost Estimate

	(dollars in thousands)		
	Total Preliminary Cost Range: Minimum Estimate	Total Preliminary Cost: Current Point Estimate	Total Preliminary Cost Range: Maximum Estimate
Total Estimated Cost (TEC)			
Design			
Design	6,500	8,000	9,000
Contingency	1,500	2,000	2,000
Total, Design	8,000	10,000	11,000
Construction			
Construction	52,000	61,000	70,000
Contingency	13,000	14,000	17,000
Total, Construction	65,000	75,000	87,000
Total, TEC[a]	73,000	85,000	98,000
Contingency, TEC	14,500	16,000	19,000
Other Project Cost (OPC)[b]			
OPC except D&D			
Conceptual Planning	250	250	250
Conceptual Design	450	450	450
Start-up	150	150	150
Contingency	150	150	150
Total, OPC	1,000	1,000	1,000
Contingency, OPC	150	150	150
Total, TPC[a]	74,000	86,000	99,000
Total, Contingency	14,650	16,150	19,150

6. Preliminary Acquisition Approach

Acquisition for this project will be performed by the Management and Operating (M&O) contractor, Fermi Research Alliance, LLC and overseen by the Fermi Site Office. Various acquisition approaches and project delivery methods were evaluated prior to achieving CD-1. A Construction Manager/General Contractor (CM/GC) project delivery with best value procurement approach was selected as the overall best delivery method with the lowest risk to DOE. The M&O contractor is responsible for awarding and administering all subcontracts related to this project. Project performance metrics are included in the M&O contractor's annual performance evaluation and measurement plan.

[a] This project is pre-CD-2; schedule and funding estimates are preliminary.
[b] Other project costs (OPC) are funded through laboratory overhead.

17-SC-73 Core Facility Revitalization
Brookhaven National Laboratory (BNL), Upton, New York
Preliminary Information for Design

1. Summary

This document contains preliminary information for a design and construction project requested in FY 2018 and is an update from the FY 2017 Project Data Sheet (PDS).

The FY 2018 Request for this project is $1,500,000. The most recent DOE O 413.3B Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range*,* which was approved on April 18, 2017.

This project has a Total Estimated Cost (TEC) range of $67,650,000 to $83,650,000 and a Total Project Cost (TPC) range of $68,500,000 to $84,500,000. These cost ranges encompass the most feasible preliminary alternatives. This preliminary information reflects funding for a project to provide the most urgent computation and data storage capabilities in time to support BNL's expanding core mission computing requirements, such as the computationally-intensive research associated with the Relativistic Heavy Ion Collider (RHIC) and the US-A Toroidal Large Hadron Collider Apparatus (US-ATLAS) at CERN.

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

FY 2018 funds will support Project Engineering and Design activities.

2. Critical Milestone History

(fiscal quarter or date)

	CD-0	CD-1	CD-2	CD-3	CD-4
FY 2017	09/10/2015	3Q FY 2017[a]	3Q FY 2019[a]	3Q FY 2020[a]	4Q FY 2024[a]
FY 2018	09/10/2015	04/18/2017	3Q FY 2019[a]	1Q FY 2020[a]	4Q FY 2024[a]

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

3. Current Preliminary Project Cost Estimates

(dollars in thousands)

	TEC, Design	TEC, Construction	TEC, Total	OPC[b]	TPC
FY 2017	6,400	57,000	63,400[a]	1,100	64,500[a]
FY 2018	7,000	67,000	74,000[a]	850	74,850[a]

4. Project Scope and Justification

Scope
The Core Facility Revitalization project will provide facilities and infrastructure to enable the computational requirements of the Office of Science's (SC) Nuclear Physics (NP) program, High Energy Physics (HEP) program, and other research programs physically conducted at Brookhaven National Laboratory (BNL) and other locations.

[a] This project is pre-CD-2; schedule and funding estimates are preliminary.
[b] Other project costs (OPC) are funded through laboratory overhead.

This project has not yet received CD-2 approval; therefore the Key Performance Parameters (KPPs) are not yet established. The table below outlines preliminary KPPs.

Key Performance Parameters (Preliminary)

Description	Threshold Value (Minimum)	Objective Value (Maximum)
Deliver identified Computing Facility IT power and emergency back-up power/cooling capabilities	3.6 MW IT power, 1.2 MW emergency back-up capabilities	3.6 MW IT power, 2.4 MW emergency back-up capabilities
Renovation of space to support the computing equipment and associated infrastructure	40,400 GSF	60,600 GSF

Justification

BNL is a multi-purpose research institution funded primarily by SC that operates facilities for studies in physics, chemistry, biology, medicine, applied science, and a wide range of advanced technologies. Among BNL's core capabilities are: nuclear physics, particle physics, large-scale user facilities for advanced instrumentation and programmatic strengths in data-centric and high-throughput "mid-scale" computational science.

A significant amount of computation and data storage is currently conducted within RHIC ATLAS Computing Facility (RACF) that is located on the BNL campus. The RACF directly supports RHIC research operations funded by SC's NP and US-ATLAS research operations funded by SC's HEP. The RACF also provides mid-scale computing support to other research programs funded by SC, research efforts funded by strategic partners, and computationally-intensive research that indirectly supports the broader SC mission. In addition, other SC program offices may conduction core mission computing that is enabled by the infrastructure upgrades considered within this project.

The data volume generated by the RHIC experiments and ATLAS is expected to increase three to six times over the next ten years and will require proportional increases in computation and data storage capacities. Almost half of the current RACF computing and data storage facility is expected become functionally obsolete and unable to accommodate future generations of computation and data storage technologies over the next five to ten years. Therefore, the projected capability gaps in computing infrastructure are due to a combination of decreases due to degrading capacities and increases in future requirements of mid-scale computing performed by RACF. Increases in computation and data storage will drive increased requirements for space, power, and cooling of computing facilities. Similarly, as research experiments are fully developed that utilize the beamlines at BNL's National Synchrotron Light Source-II, which is funded by SC's Basic Energy Science Program Office, additional core mission computing will be required. A mission need therefore exists to provide sufficient, mid-range computation and data storage capabilities to support to current and planned experiments at BNL.

FY 2018 funds will be used for preliminary and final design and project management and support activities.

The project is being conducted in accordance with the project management requirements in DOE O 413.3B, and all appropriate project management requirements have been met.

5. Details of Preliminary Project Cost Estimate

	(dollars in thousands)		
	Total Preliminary Cost Range: Minimum Estimate	Total Preliminary Cost: Current Point Estimate	Total Preliminary Cost Range: Maximum Estimate
Total Estimated Cost (TEC)			
Design			
Design	4,700	5,600	6,412
Contingency	940	1,400	1,924
Total, Design	5,640	7,000	8,336
Construction			
Construction	51,670	53,600	57,941
Contingency	10,340	13,400	17,373
Total, Construction	62,010	67,000	75,314
Total, TEC[a]	67,650	74,000	83,650
Contingency, TEC	11,280	14,800	19,297
Other Project Cost (OPC)[b]			
OPC except D&D			
Conceptual Planning	229	229	229
Conceptual Design	451	451	451
Contingency	170	170	170
Total, OPC	850	850	850
Contingency, OPC	170	170	170
Total, TPC[a]	68,500	74,850	84,500
Total, Contingency	11,450	14,970	19,467

6. Preliminary Acquisition Approach

Acquisition for this project will be performed by the Management and Operating (M&O) Contractor, Brookhaven Science Associates and overseen by the Brookhaven Site Office. Various acquisition and project delivery methods were evaluated prior to achieving CD-1. A Construction Manager/General Contractor (CM/GC) project delivery with best value procurement approach was selected as the overall best delivery method with the lowest risk to DOE. The M&O Contractor is responsible for awarding and administering all subcontracts related to this project. Project performance metrics are included in the M&O Contractor's annual performance and evaluation measurement plan.

[a] This project is pre-CD-2; schedule and funding estimates are preliminary.
[b] Other project costs (OPC) are funded through laboratory overhead.

18-SC-71 Energy Sciences Capability
Pacific Northwest National Laboratory (PNNL), Richland, Washington
Preliminary Information for Design

1. Significant Changes and Summary

Significant Changes
This project is a proposed new start for FY 2018.

Summary
The FY 2018 Request for this project is $1,000,000. The most recent DOE O 413.3B Critical Decision (CD) is CD-0, Approve Mission Need*,* which was approved on December 12, 2016.

This project has a Total Estimated Cost (TEC) range of $70,000,000 to $96,000,000 and a Total Project Cost (TPC) range of $73,000,000 to $99,000,000. These cost ranges encompass the most feasible preliminary alternatives. This preliminary information reflects funding for a project that 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.

A Federal Project Director with the appropriate certification level will be assigned to this project prior to CD-1 approval.

FY 2018 funds will support Project Engineering and Design activities.

2. Critical Milestone History

(fiscal quarter or date)

	CD-0	CD-1	CD-2	CD-3	CD-4
FY 2018	12/12/2016	4Q FY 2018	4Q FY 2019[a]	4Q FY 2020[a]	4Q FY 2025[a]

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

3. Current Preliminary Project Cost Estimates

(dollars in thousands)

	TEC, Design	TEC, Construction	TEC, Total	OPC[b]	TPC
FY 2018	9,000	81,000	90,000[a]	3,000	93,000[a]

4. Project Scope and Justification

Scope
The objective of the Energy Sciences Capability (ESC) project is to increase the impact of chemical conversions research and development at PNNL, and expand the reach of user programs in EMSL. To accomplish these goals 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 80,000 to 120,000 net square feet of wet chemistry, instrumentation, and computational space in 40 to 45 laboratory modules along with offices for 150 to 200 research and support staff.

[a] This project is pre-CD-2; schedule and funding estimates are preliminary.
[b] Other project costs (OPC) are funded through laboratory overhead.

This project has not yet received CD-2 approval; therefore the Key Performance Parameters (KPPs) are not yet established. The table below outlines preliminary KPPs.

Key Performance Parameters (Preliminary)

Description	Threshold Value (Minimum)	Objective Value (Maximum)
Multi-story Laboratory Building	80,000 net square feet (NSF)	120,000 NSF

Justification

Pacific Northwest National Laboratory (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 Energy Sciences Capability project at PNNL is to enable the transformation of catalysis science and how catalysts are designed, synthesized, and engineered. 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 EMSL and ARM 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 Energy Sciences Capability 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 Energy Sciences Capability 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.

FY 2018 funds will be used for preliminary and final design and project management and support activities.

The project is being conducted in accordance with the project management requirements in DOE O 413.3B, and all appropriate project management requirements have been met.

5. Details of Preliminary Project Cost Estimate

	(dollars in thousands)		
	Total Preliminary Cost Range: Minimum Estimate	Total Preliminary Cost: Current Point Estimate	Total Preliminary Cost Range: Maximum Estimate
Total Estimated Cost (TEC)			
Design			
Design	6,000	7,500	8,000
Contingency	1,000	1,500	2,000
Total, Design	7,000	9,000	10,000
Construction			
Construction	54,000	70,000	73,000
Contingency	9,000	11,000	13,000
Total, Construction	63,000	81,000	86,000
Total, TEC[a]	70,000	90,000	96,000
Contingency, TEC	10,000	12,500	15,000
Other Project Cost (OPC)[b]			
OPC except D&D	1,650	1,650	1,650
Conceptual Planning	100	100	100
Conceptual Design	1,000	1,000	1,000
Contingency	250	250	250
Total, OPC	3,000	3,000	3,000
Contingency, OPC	250	250	250
Total, TPC[a]	73,000	93,000	99,000
Total, Contingency	10,250	12,750	15,250

6. Preliminary Acquisition Approach

Acquisition for this project will be performed by the Management and Operating (M&O) contractor, Battelle Memorial Institute and overseen by the Pacific Northwest Site Office. Various acquisition approaches and project delivery methods will be considered prior to achieving CD-1. The M&O contractor will be responsible for awarding and administering all subcontracts related to this project. Project performance metrics are included in the M&O contractor's annual performance evaluation and measurement plan.

[a] This project is pre-CD-2; schedule and funding estimates are preliminary.
[b] Other project costs (OPC) are funded through laboratory overhead.

Safeguards and Security

Overview
The Office of Science (SC) Safeguards and Security (S&S) program is designed to ensure appropriate security measures are in place to support the SC mission requirement of open scientific research and to protect critical assets within SC laboratories. This is accomplished by 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 2018 Budget Request
The FY 2018 Request supports sustained levels of operations in S&S program elements, including Protective Forces, Security Systems, Information Security, Personnel Security, Material Control and Accountability, and Program Management.

The highest priority in the S&S program is to ensure adequate security for the special nuclear material housed in Building 3019 at the Oak Ridge National Laboratory (ORNL). SC is proactive in evaluating and improving security at that facility and includes funding to do so.

As another key priority, the FY 2018 Request ensures that the Cyber Security element maintains the ability to detect, mitigate, and recover from cyber intrusions and attacks against protected information.

Within the S&S FY 2018 Request, SC supports the Cybersecurity Departmental Crosscut. This includes the Department's CyberOne strategy for managing enterprise-wide cyber security and identity authentication for Department of Energy (DOE) information technology (IT) systems. The CyberOne strategy provides improved Department-wide capabilities for incident management and logical access to federal IT systems.

FY 2018 Crosscuts ($K)

	Cybersecurity
Safeguards and Security	33,619[a]

Description
The S&S program is organized into seven program elements: Protective Forces, Security Systems, Information Security, Cyber Security, Personnel Security, Material Control and Accountability, and Program Management.

Protective Forces

The Protective Forces program element supports security officers, access control officers, and security policy officers assigned to protect S&S interests, along with their related equipment and training. Activities within this program element include access control and security response operations as well as physical protection of the Department's critical assets and SC facilities. The Protective Forces mission includes providing effective response to emergency situations, random prohibited article inspections, security alarm monitoring, and performance testing of the protective force response to various event scenarios.

Security Systems

The Security Systems program element provides physical protection of Departmental personnel, material, equipment, property, and facilities, and includes fences, barriers, lighting, sensors, surveillance devices, entry control devices, access control systems, and power systems operated and used to support the protection of DOE property, classified information, and other interests of national security.

[a] The Cyber Security amount includes $6,309,000 for CyberOne funded through the Working Capital Fund (WCF).

Information Security

The Information Security program element provides support to ensure that sensitive and classified information is accurately, appropriately, and consistently identified, reviewed, marked, protected, transmitted, stored, and ultimately destroyed. Specific activities within this element include management, planning, training, and oversight for maintaining security containers and combinations, marking documents, and administration of control systems, operations security, special access programs, technical surveillance countermeasures, and classification and declassification determinations.

Cyber Security

DOE is engaged in two categories of cyber-related activities: protecting the DOE enterprise from a range of cyber threats that can adversely impact mission capabilities and improving cybersecurity in the electric power subsector and the oil and natural gas subsector. The cybersecurity crosscut supports central coordination of the strategic and operational aspects of cybersecurity and facilitates cooperative efforts such as the Joint Cybersecurity Coordination Center (JC3) for incident response and the implementation of Department-wide Identity, Credentials, and Access Management (ICAM).

Personnel Security

The Personnel Security program element encompasses the processes for employee suitability and security clearance determinations at each site to ensure that individuals are trustworthy and eligible for access to classified information or matter. This element also includes the management of security clearance programs, adjudications, security education, awareness programs for Federal and contractor employees, and processing and hosting approved foreign visitors.

Material Control and Accountability (MC&A)

The MC&A program element provides assurance that Departmental materials are properly controlled and accounted for at all times. This element supports administration, including testing performance and assessing the levels of protection, control, and accountability required for the types and quantities of materials at each facility; documenting facility plans for materials control and accountability; assigning authorities and responsibilities for MC&A functions; and establishing programs to detect and report occurrences such as material theft, the loss of control or inability to account for materials, or evidence of malevolent acts.

Program Management

The Program Management program element coordinates the management of Protective Forces, Security Systems, Information Security, Personnel Security, Cyber Security, and MC&A to achieve and ensure appropriate levels of protections are in place.

Safeguards and Security
Funding ($K)

	FY 2016 Enacted	FY 2017 Annualized CR[a]	FY 2018 Request	FY 2018 vs FY 2016
Protective Forces	37,899	–	40,545	+2,646
Security Systems	10,097	–	10,097	0
Information Security	7,647	–	4,356	-3,291
Cyber Security[b]	32,974	–	33,619	+645
Personnel Security	5,334	–	5,334	0
Material Control and Accountability	2,431	–	2,431	0
Program Management	6,618	–	6,618	0
Total, Safeguards and Security	**103,000**	**102,805**	**103,000**	0

[a] FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above; below that level, a dash (-) is shown.

[b] The Cyber Security amount includes $7,093,000 in FY 2016, $4,525,000 in FY 2017, and $6,309,000 in FY 2018 for CyberOne through the Working Capital Fund (WCF). In FY 2016, $1,514,000 was forward funded to address the estimated FY 2017 CyberOne charges of $6,039,000.

Safeguards and Security

Activities and Explanation of Changes

FY 2016 Enacted	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
Protective Forces $37,899,000	**$40,545,000**	**+$2,646,000**
Funding provided for this program element maintained protection levels, equipment, and training needed to ensure proper protection and effective performance at all SC laboratories.	Provides funding to maintain proper protection levels, equipment, and technical training needed to ensure effective performance at all SC laboratories.	The increase will ensure adequate protection of the special nuclear material housed in Building 3019 at ORNL, addresses contractual Cost of Living adjustments and supports sustained levels of operations across at all SC laboratories.
Security Systems $10,097,000	**$10,097,000**	**$0**
Funding provided maintained the security systems in place and supported investments in SC laboratory physical security systems.	Provides funding to maintain the security systems currently in place.	Protection of physical security systems remains at the same level as prior years.
Information Security $7,647,000	**$4,356,000**	**-$3,291,000**
Funding provided for personnel, equipment, and systems necessary to ensure that sensitive and classified information was properly safeguarded at SC laboratories.	Provides funding to maintain personnel, equipment, and systems necessary to ensure sensitive and classified information is safeguarded at SC laboratories.	The decrease reflects the completion of Multi-Factor Authentication implementation for privileged user accounts.
Cyber Security $32,974,000	**$33,619,000**	**+$645,000**
Provided funding to properly protect SC laboratories' computer resources and sensitive data, and to continue support of the Department's CyberOne strategy.	Provides funding to maintain protection of laboratory computers, networks and data from unauthorized access. The Request also continues support of the Department's CyberOne strategy.	The increase will provide funding to ensure the Cyber Security program element is properly funded to detect, mitigate, and recover from cyber intrusions and attacks against protected information. The increase also supports the Department's CyberOne strategy.
Personnel Security $5,334,000	**$5,334,000**	**$0**
Maintained Personnel Security efforts at SC laboratories.	Provides funding to maintain Personnel Security efforts at SC laboratories.	Personnel Security remains the same level as prior years.
Material Control and Accountability $2,431,000	**$2,431,000**	**$0**
Maintained proper protection of material at SC laboratories.	Provides funding to maintain protection of material at SC laboratories.	Material Control and Accountability remains the same level as prior years.
Program Management $6,618,000	**$6,618,000**	**$0**
Provided funding for oversight, administration, and planning for security programs at SC laboratories and ensured security procedures and policy support for SC research missions.	Provides funding to maintain oversight, administration, and planning for security programs at SC laboratories and will support security procedures and policy support SC Research missions.	Program Management remains the same level as prior years.

Estimates of Cost Recovered for Safeguards and Security Activities ($K)

In addition to the direct funding received from S&S, sites recover Safeguards and Security costs related to Strategic Partnerships Projects (SPP) activities from SPP customers, including the cost of any unique security needs directly attributable to the customer. Estimates of those costs are shown below.

	FY 2016 Current Costs	FY 2017 Planned Costs	FY 2018 Planned Costs
Ames National Laboratory	80	40	40
Argonne National Laboratory	1,100	1,100	1,100
Brookhaven National Laboratory	1,218	1,218	1,218
Lawrence Berkeley National Laboratory	733	1,010	1,007
Oak Ridge Institute for Science and Education	595	677	700
Oak Ridge National Laboratory	4,500	4,710	4,710
Pacific Northwest National Laboratory	5,000	4,781	5,001
Princeton Plasma Physics Laboratory	40	50	55
SLAC National Accelerator Laboratory	120	135	158
Total, Security Cost Recovered	**13,386**	**13,721**	**13,989**

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 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 grants and contracts supporting about 19,000 researchers located at over 300 institutions and 17 national laboratories, spanning all fifty states and the District of Columbia.

Headquarters (HQ)
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 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 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 and other construction projects.
- Provide oversight and management of the maintenance and operational integrity of the ten SC national laboratories.
- Provide policy, strategy, and resource management in the areas of laboratory oversight, information technology, grants and contracts, budget, and human capital.

Site Offices
SC Site Office federal staff provide contract management and critical support for the scientific mission 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.
- Provides federal program managers to oversee the New Brunswick Laboratory located at Argonne Site Office.

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; human capital shared services; financial management; grant and contract processing; safety, security, and health management; labor relations, intellectual property and patent management; environmental compliance; facility infrastructure operations and maintenance; and information systems development and support. As part of this, the ISC:

- Monitors the multi-appropriation, multi-program allotments for all SC national laboratories through administration of laboratory Management and Operating (M&O) contracts and is responsible for over 3,000 grants per year to university-based researchers.
- Provides support to SC and other DOE programs for solicitations and funding opportunity announcements, as well as the negotiation, award, administration, and closeout of contracts and financial assistance awards using certified contracting officers and professional acquisition staff.

<u>Office of Scientific and Technical Information (OSTI):</u>
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 being made available to the public within 12 months of publication in a journal.

Highlights of the FY 2018 Budget Request

The FY 2018 Request of $168,516,000 is a decrease of $16,484,000, or 8.9 percent, from the FY 2016 Enacted level and supports a total level of 785 FTEs, 133 FTEs less than the FY 2016 Enacted level. SC will achieve these savings and FTE reductions through a restriction in hiring and an ongoing review of functions that can either be eliminated or restructured to cut costs and improve efficiency. Through workforce analysis/restructuring, SC will continue to review, analyze and prioritize mission requirements and identify those organizations and functions most in line with Administration and Department program objectives and SC strategic goals. Using available human capital workforce reshaping tools, SC will focus on functional consolidation, elimination of positions, and hiring limitations to achieve necessary results.

The FY 2018 Request includes:

- Four (4) FTEs in the Office of Planning and Management Oversight to support the Office of the Under Secretary for Science and Energy. The FY 2016 Request included funding for these FTEs in the Departmental Administration appropriation.
- Twenty-four (24) FTEs in the Office of the Chief Human Capital Officer operating the Science & Energy Shared Service Center (S&E SSC) and supporting HR Advisory Offices. In FY 2016, SC moved to a shared service center model for HR delivery with all human resources services involving SC personnel obtained through the Office of the Chief Human Capital Officer.
- Two-hundred and eighty-three (283) Headquarters (HQ) federal staff, a reduction that saves roughly $5.0M, or 9 percent, compared to the FY 2016 Enacted level.
- Forty (40) OSTI federal staff, a reduction that saves roughly $100k, or 1 percent, compared to the FY 2016 Enacted level.
- Four-hundred and thirty-four (434) Integrated Service Center (ISC) and Site Office federal staff, a reduction that saves roughly $8.7M, or 12 percent.
- A decrease in Working Capital Fund (WCF) costs, which are projected to decrease in FY 2018 due to a reduced federal and contractor workforce. Additionally, SC will reduce its space utilization and make other changes to eliminate WCF charges and offset inflation in costs for items such as building occupancy and telecommunications.
- A decrease in travel funding. In FY 2017, SC implemented a three-month travel moratorium and funded travel at reduced levels for the remainder of the fiscal year. The FY 2018 Request continues this reduced level of travel, resulting in annual savings of over $1.5M.

Science Program Direction
Funding ($K)

	FY 2016 Enacted[a]	FY 2017 Annualized CR[b]	FY 2018 Request	FY 2018 vs FY 2016
Headquarters				
Science HQ				
Salaries and Benefits	56,508	–	51,529	-4,979
Travel	1,891	–	1,100	-791
Support Services	16,344	–	15,572	-772
Other Related Expenses	3,697	–	3,772	+75
Working Capital Fund	10,000	–	8,250	-1,750
Total, Science HQ	**88,440**	–	**80,223**	**-8,217**
Under Secretary for Science and Energy				
Salaries and Benefits	566	–	880	+314
Travel	2	–	0	-2
Support Services	375	–	0	-375
Other Related Expenses	0	–	400	+400
Total, Under Secretary for Science and Energy	**943**	–	**1,280**	**+337**
Human Capital S&E Shared Service Center				
Salaries and Benefits	N/A	–	2,952	+2,952
Other Related Expenses	N/A	–	400	+400
Total, Human Capital S&E Shared Service Center	N/A	–	**3,352**	**+3,352**
Total Headquarters				
Salaries and Benefits	57,074	–	55,361	-1,713
Travel	1,893	–	1,100	-793
Support Services	16,719	–	15,572	-1,147
Other Related Expenses	3,697	–	4,572	+875
Working Capital Fund	10,000	–	8,250	-1,750
Total, Headquarters	**89,383**	–	**84,855**	**-4,528**

[a] The FY 2016 Enacted level reflects updates through the end of the fiscal year.

[b] FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the congressional control level and above; below that level, a dash (-) is shown

	FY 2016 Enacted[a]	FY 2017 Annualized CR[b]	FY 2018 Request	FY 2018 vs FY 2016
Office of Scientific and Technical Information				
Salaries and Benefits	5,673	–	5,600	-73
Travel	92	–	70	-22
Support Services	1,791	–	1,553	-238
Other Related Expenses	1,382	–	861	-521
Total, Office of Scientific and Technical Information	**8,938**	**–**	**8,084**	**-854**
Field Offices				
Chicago Office				
Salaries and Benefits	21,805	–	18,648	-3,157
Travel	320	–	190	-130
Support Services	736	–	614	-122
Other Related Expenses	2,379	–	1,613	-766
Total, Chicago Office	**25,240**	**–**	**21,065**	**-4,175**
Oak Ridge Office				
Salaries and Benefits	21,787	–	16,625	-5,162
Travel	430	–	190	-240
Support Services	1,772	–	931	-841
Other Related Expenses	3,649	–	3,592	-57
Total, Oak Ridge Office	**27,638**	**–**	**21,338**	**-6,300**
Ames Site Office				
Salaries and Benefits	500	–	310	-190
Travel	34	–	10	-24
Support Services	0	–	2	+2
Other Related Expenses	2	–	0	-2
Total, Ames Site Office	**536**	**–**	**322**	**-214**
Argonne Site Office				
Salaries and Benefits	3,649	–	4,125	+476
Travel	100	–	45	-55
Support Services	88	–	108	+20
Other Related Expenses	15	–	36	+21
Total, Argonne Site Office	**3,852**	**–**	**4,314**	**+462**

	FY 2016 Enacted[a]	FY 2017 Annualized CR[b]	FY 2018 Request	FY 2018 vs FY 2016
Berkeley Site Office				
Salaries and Benefits	2,674	–	2,992	+318
Travel	58	–	30	-28
Support Services	228	–	150	-78
Other Related Expenses	10	–	126	+116
Total, Berkeley Site Office	**2,970**	**–**	**3,298**	**+328**
Brookhaven Site Office				
Salaries and Benefits	3,616	–	3,806	+190
Travel	101	–	60	-41
Support Services	449	–	404	-45
Other Related Expenses	96	–	215	+119
Total, Brookhaven Site Office	**4,262**	**–**	**4,485**	**+223**
Fermi Site Office				
Salaries and Benefits	2,213	–	2,338	+125
Travel	52	–	45	-7
Support Services	82	–	42	-40
Other Related Expenses	12	–	38	+26
Total, Fermi Site Office	**2,359**	**–**	**2,463**	**+104**
New Brunswick Laboratory Program Office[c]				
Salaries and Benefits	2,151	–	1,134	-1,017
Travel	43	–	40	-3
Support Services	430	–	533	+103
Other Related Expenses	969	–	901	-68
Total, New Brunswick Laboratory Program Office	**3,593**	**–**	**2,608**	**-985**
Oak Ridge National Laboratory Site Office				
Salaries and Benefits	4,883	–	4,896	+13
Travel	75	–	60	-15
Support Services	376	–	384	+8
Other Related Expenses	132	–	25	-107
Total, Oak Ridge National Laboratory Site Office	**5,466**	**–**	**5,365**	**-101**

[c]Laboratory was closed and functions have been distributed across multinational laboratories with program office within the Argonne Site Office overseeing operations.

	FY 2016 Enacted[a]	FY 2017 Annualized CR[b]	FY 2018 Request	FY 2018 vs FY 2016
Pacific Northwest Site Office				
Salaries and Benefits	4,546	–	4,448	-98
Travel	133	–	70	-63
Support Services	70	–	34	-36
Other Related Expenses	106	–	99	-7
Total, Pacific Northwest Site Office	**4,855**	–	**4,651**	**-204**
Princeton Site Office				
Salaries and Benefits	1,671	–	1,503	-168
Travel	35	–	20	-15
Support Services	22	–	10	-12
Other Related Expenses	36	–	69	+33
Total, Princeton Site Office	**1,764**	–	**1,602**	**-162**
SLAC Site Office				
Salaries and Benefits	2,095	–	2,134	+39
Travel	67	–	30	-37
Support Services	147	–	111	-36
Other Related Expenses	0	–	52	+52
Total, SLAC Site Office	**2,309**	–	**2,327**	**+18**
Thomas Jefferson Site Office				
Salaries and Benefits	1,757	–	1,660	-97
Travel	49	–	40	-9
Support Services	25	–	8	-17
Other Related Expenses	4	–	31	+27
Total, Thomas Jefferson Site Office	**1,835**	–	**1,739**	**-96**
Total Field Offices				
Salaries and Benefits	73,347	–	64,619	-8,728
Travel	1,497	–	830	-667
Support Services	4,425	–	3,331	-1,094
Other Related Expenses	7,410	–	6,797	-613
Total, Field Offices	**86,679**	–	**75,577**	**-11,102**

	FY 2016 Enacted[a]	FY 2017 Annualized CR[b]	FY 2018 Request	FY 2018 vs FY 2016
Total Program Direction				
Salaries and Benefits	136,094	–	125,580	-10,514
Travel	3,482	–	2,000	-1,482
Support Services	22,935	–	20,456	-2,479
Other Related Expenses	12,489	–	12,230	-259
Working Capital Fund	10,000	–	8,250	-1,750
Total, Program Direction	**185,000**	**184,648**	**168,516**	**-16,484**
Federal FTEs	**918**	–	**785**	**-133**
Technical Support				
Development of specifications	137	–	0	-137
System review and reliability analyses	1,609	–	949	-660
Surveys or reviews of technical operations	72	–	469	+397
Total, Technical Support	**1,818**	–	**1,418**	**-400**
Management Support				
Automated data processing	9,067	–	9,097	+30
Training and education	898	–	596	-302
Reports and analyses, management, and general administrative services	11,152	–	9,345	-1,807
Total, Management Support	**21,117**	–	**19,038**	**-2,079**
Total, Support Services	**22,935**	–	**20,456**	**-2,479**
Other Related Expenses				
Rent to GSA	1,041	–	989	-52
Rent to others	2,348	–	1,208	-1,140
Communications, utilities, and miscellaneous	2,551	–	2,721	+170
Printing and reproduction	12	–	0	-12
Other services	425	–	1,990	+1,565
Operation and maintenance of equipment	305	–	142	-163
Operation and maintenance of facilities	1,650	–	1,313	-337
Supplies and materials	1,064	–	744	-320
Equipment	3,093	–	3,123	+30
Total, Other Related Expenses	**12,489**	–	**12,230**	**-259**
Working Capital Fund	**10,000**	–	**8,250**	**-1,750**

Program Direction

Activities and Explanation of Changes

FY 2016 Enacted	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
Program Direction $185,000,000	**$168,516,000**	**-$16,484,000**
Salaries and Benefits $136,094,000	**$125,580,000**	**-$10,514,000**
The FY 2016 Enacted level supported 918 FTEs to perform scientific oversight, project management, essential operations support associated with science program portfolio management, support for the Under Secretary for Science and Energy, and administration of PCAST. This funding also included support for expenses such as increases in general schedule pay rates, health insurance costs and retirement allocations in the Federal Employees Retirement System.	The FY 2018 Request will support 785 FTEs to perform scientific oversight, project management, essential operations support associated with science program portfolio management, and support for the Office of the Chief Human Capital Officer operating the Science & Energy Shared Service Center (S&E SSC) and supporting HR Advisory Offices. This funding also includes support for expenses such as increases in general schedule pay rates, health insurance costs and retirement allocations in the Federal Employees Retirement System.	Reduced salaries and benefits is the result of a planned reduction in federal staff, which will be achieved through a continued hiring freeze and ongoing organizational review and analysis to identify areas where we can gain maximum efficiency through functional consolidation and position reductions.
Travel $3,482,000	**$2,000,000**	**-$1,482,000**
Ensuring scientific management, compliance, safety oversight, and external review of research funding across all SC programs required staff to travel, since SC senior program managers are not co-located with grantees or at national laboratories. Travel was also required for facility visits where the use of electronic telecommunications was not practical for mandated on-site inspections and 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. Travel is also required for facility visits where the use of electronic telecommunications is not practical for mandated on-site inspections and operations reviews.	The decrease is a result of increased use of telecommunications and video conference technologies and support of only essential travel for a reduced federal workforce.
Travel was included to support travel requirements in the Office of the Under Secretary for Science and Energy.	No travel is included for the Office of the Under Secretary for Science and Energy. If travel requirements arise, it would be funded from the overall SC travel budget.	Travel requirements for this office are expected to be minimal.

FY 2016 Enacted	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
Travel was included to support meetings of the PCAST, scheduled for six times per year with additional meetings called at the discretion of the President. PCAST is an advisory group to the President and Executive Office of the President.	No travel is included for PCAST, as no meetings are currently scheduled or expected.	The PCAST advisory committee has dissolved and SC is not aware of any plans to reform this committee in FY 2018.
Travel was included for the SC Federal Advisory Committee travel, which includes over 170 representatives from universities, national laboratories, and industry, representing a diverse balance of disciplines, professional experience, and geography. Each of the six advisory committees provides valuable, independent advice to the Department regarding the complex scientific and technical issues that arise in the planning, management, and implementation of SC programs.	The Request will continue to support travel for the SC Federal Advisory Committees.	No change for SC Federal Advisory Committee travel.
Support Services $22,935,000	**$20,456,000**	**-$2,479,000**
Technical expertise and business services sustained the following: maintenance, operation, and cyber security management of SC mission-specific information technology systems and infrastructure as well as SC-corporate Enterprise Architecture and Capital Planning Investment Control management; administration of 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; operations and maintenance of the Searchable Field Work Proposal system to provide HQ and Field organizations a tool to search and monitor field work proposals; selected routine administrative services including travel processing and Federal staff training	Request funds will continue to support activities at a slightly reduced level.	SC plans to conduct a review of all PD-funded support contracts and identify functions or tasks which could be eliminated or scaled back to achieve savings. Planned consolidation of functions and offices will also result in a corresponding reduction in contractor staff.

FY 2016 Enacted	FY 2018 Request	Explanation of Changes FY 2018 vs FY 2016
and education to maintain appropriate certification and update skills; select reports or analyses directed toward improving the effectiveness, efficiency, and economy of services and processes; and safeguards and security oversight functions.		
The FY 2016 Enacted level funded essential information technology infrastructure, ongoing operations and maintenance of IT systems and safety management support, training for the SC workforce, and continued to support the IT Modernization Plan.	The FY 2018 Request will fund only essential information technology infrastructure, ongoing operations and maintenance of IT systems and safety management support, as well as training for the SC workforce.	
Other Related Expenses $12,489,000	**$12,230,000**	**-$259,000**
The FY 2016 Enacted included funding for fixed requirements in the Field Offices associated with rent, utilities, and telecommunications, building and grounds maintenance, computer/video maintenance and support, equipment leases, purchases, maintenance, and site-wide health care units. It also included SC-wide assessments for payroll processing and the Corporate Human Resource Information System.	The FY 2018 Request includes funding to support ongoing activities at a slightly reduced rate.	The requirement for other related expenses such as rent and utilities is reduced as the federal and contractor workforce being supported is reduced.
Working Capital Fund $10,000,000	**$8,250,000**	**-$1,750,000**
The FY 2016 Enacted provided the SC contribution to the WCF. The WCF provides for common administrative services at HQ including PD-funded items such as rent and building occupancy, corporate business systems, corporate training services, health services, printing and graphics, and supplies.	The FY 2018 Request includes $8,250,000 to support the SC contribution to the WCF.	The reduction reflects reductions in business lines such as rent and telecommunications as the federal and contractor workforce being supported is reduced.

Science
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 goals and objectives.

Costs for Direct-Funded Maintenance and Repair (including Deferred Maintenance Reduction) ($K)

	FY 2016 Planned Cost	FY 2016 Actual Cost	FY 2017 Planned Cost	FY 2018 Planned Cost
Argonne National Laboratory	0	0	0	11,900
Brookhaven National Laboratory	5,228	4,194	5,791	5,908
Fermi National Accelerator Laboratory	0	15	0	0
Lawrence Berkeley National Laboratory	0	0	9,000	18,500
Notre Dame Radiation Laboratory	175	123	175	175
Oak Ridge National Laboratory	14,420	13,965	14,853	15,298
Oak Ridge Office	4,075	3,388	9,079	6,324
Office of Scientific and Technical Information	392	387	402	412
SLAC National Accelerator Laboratory	3,667	3,338	3,740	4,878
Thomas Jefferson National Accelerator Facility	71	344	73	75
Total, Direct-Funded Maintenance and Repair	**28,028**	**25,754**	**43,113**	**63,470**

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 SC laboratories have over 1,400 operational buildings and real property trailers, with nearly 20 million gross square feet of space.
Generally, facilities maintenance and repair expenses are funded through an indirect overhead charge. In some cases, however, a laboratory may charge maintenance directly to a specific program. One example would be when maintenance is performed in a building used only by a single program. Such direct-funded charges are not directly budgeted.

Costs for Indirect-Funded Maintenance and Repair (including Deferred Maintenance Reduction) ($K)

	FY 2016 Planned Cost	FY 2016 Actual Cost	FY 2017 Planned Cost	FY 2018 Planned Cost
Ames Laboratory	2,300	2,347	2,600	2,900
Argonne National Laboratory	48,100	56,902	57,200	59,500
Brookhaven National Laboratory	39,388	38,296	44,971	45,918
Fermi National Accelerator Laboratory	18,383	15,505	19,126	19,238
Lawrence Berkeley National Laboratory	27,450	28,288	27,860	28,103
Lawrence Livermore National Laboratory	2,869	2,869	2,926	2,984
Los Alamos National Laboratory	611	611	623	635
Oak Ridge Institute for Science and Education	443	509	489	490
Oak Ridge National Laboratory and Y-12	59,103	70,032	62,376	64,202
Pacific Northwest National Laboratory	7,608	8,813	6,805	8,137
Princeton Plasma Physics Laboratory	7,000	7,731	8,000	8,200
Sandia National Laboratories	2,940	2,940	2,998	3,058
SLAC National Accelerator Laboratory	9,240	10,572	10,120	10,835
Thomas Jefferson National Accelerator Facility	5,900	6,498	6,360	6,550
Total, Indirect-Funded Maintenance and Repair	**231,335**	**251,913**	**252,454**	**260,750**

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 2016 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 2016 to the amount planned for FY 2016, including Congressionally directed changes.

Science
Total Costs for Maintenance and Repair ($K)

	FY 2016 Planned Costs	FY 2016 Actual Costs
Ames Laboratory	2,300	2,347
Argonne National Laboratory	48,100	56,902
Brookhaven National Laboratory	44,616	42,490
Fermi National Accelerator Laboratory	18,383	15,520
Lawrence Berkeley National Laboratory	27,450	28,288
Lawrence Livermore National Laboratory	2,869	2,869
Los Alamos National Laboratory	611	611
Notre Dame Radiation Laboratory	175	123
Oak Ridge Institute for Science and Education	443	509
Oak Ridge National Laboratory and Y-12	73,523	83,997
Oak Ridge Office	4,075	3,388
Office of Scientific and Technical Information	392	387
Pacific Northwest National Laboratory	7,608	8,813
Princeton Plasma Physics Laboratory	7,000	7,731
Sandia National Laboratories	2,940	2,940
SLAC National Accelerator Laboratory	12,907	13,910
Thomas Jefferson National Accelerator Facility	5,971	6,842
Total, Maintenance and Repair	**259,363**	**277,667**

Science
Research and Development ($K)

	FY 2016 Enacted	FY 2017 Annualized CR	FY 2018 Request	FY 2018 vs. FY 2016
Basic	4,452,419	4,513,985	3,829,898	-622,521
Applied	0	0	0	0
Subtotal, R&D	4,452,419	4,513,985	3,829,898	-622,521
Equipment	222,135	177,298	96,804	-125,331
Construction	630,842	603,478	506,010	-124,832
Total, R&D	**5,305,396**	**5,294,761**	**4,432,712**	**-872,684**

Science
Small Business Innovative Research/Small Business Technology Transfer (SBIR/STTR) ($K)

	FY 2016 Enacted	FY 2017 Annualized CR	FY 2018 Request	FY 2018 vs. FY 2016
Office of Science				
Advanced Scientific Computing Research				
SBIR	18,450	—	22,785	+4,335
STTR	2,768	—	3,204	+436
Basic Energy Sciences				
SBIR	47,468	—	42,444	-5,024
STTR	7,120	—	5,969	-1,151
Biological and Environmental Research				
SBIR	18,135	—	11,076	-7,059
STTR	2,720	—	1,558	-1162
Fusion Energy Sciences				
SBIR	9,333	—	7,902	-1,431
STTR	1,400	—	1,111	-289
High Energy Physics				
SBIR	18,128	—	16,377	-1,751
STTR	2,719	—	2,303	-416
Nuclear Physics				
SBIR	14,040	—	12,941	-1,099
STTR	2,106	—	1,820	-286
Total, Office of Science SBIR	**125,554**	—	**113,525**	**-12,029**
Total, Office of Science STTR	**18,833**	—	**15,965**	**-2,868**
Other DOE				
Nuclear Energy				
SBIR	TBD	TBD	TBD	TBD
STTR	TBD	TBD	TBD	TBD
Electricity Delivery & Energy Reliability				
SBIR	TBD	TBD	TBD	TBD
STTR	TBD	TBD	TBD	TBD
Energy Efficiency & Renewable Energy				
SBIR	TBD	TBD	TBD	TBD
STTR	TBD	TBD	TBD	TBD
Environmental Management				
SBIR	TBD	TBD	TBD	TBD
STTR	TBD	TBD	TBD	TBD

	FY 2016 Enacted	FY 2017 Annualized CR	FY 2018 Request	FY 2018 vs. FY 2016
Defense Nuclear Nonproliferation				
SBIR	TBD	TBD	TBD	TBD
STTR	TBD	TBD	TBD	TBD
Fossil Energy				
SBIR	TBD	TBD	TBD	TBD
STTR	TBD	TBD	TBD	TBD
Total, Other DOE SBIR	**TBD**	**TBD**	**TBD**	**TBD**
Total, Other DOE STTR	**TBD**[a]	**TBD**[a]	**TBD**[a]	**TBD**[a]
Total, DOE SBIR	**125,554**	**—**	**113,525**	**-12,029**
Total, DOE STTR	**18,833**	**—**	**15,965**	**-2,868**

[a] The DOE SBIR/STTR amounts are listed in the other DOE program budget volumes.

Science
Safeguards and Security Crosscut ($K)

	FY 2016 Enacted	FY 2017 Annualized CR[a]	FY 2018 Request	FY 2018 vs. FY 2016
Protective Forces	37,899	–	40,545	+2,646
Physical Security Systems	10,097	–	10,097	0
Information Security	7,647	–	4,356	-3,291
Cyber Security	32,974	–	33,619	+645
Personnel Security	5,334	–	5,334	0
Material Control and Accountability	2,431	–	2,431	0
Program Management	6,618	–	6,618	0
Total, Safeguards and Security Crosscut	**103,000**	**102,805**	**103,000**	0

[a] FY 2017 Annualized CR amounts reflect the P.L. 114-254 continuing resolution level annualized to a full year. These amounts are shown only at the "congressional control" level and above; below that level, a dash (-) is shown.

Isotope Production and Distribution Program Fund

Overview

The Department of Energy's Isotope Program produces and sells radioactive and stable isotopes, byproducts, surplus materials, and related isotope services world-wide. It operates under a revolving fund, the Isotope Production and Distribution Program Fund, established by the 1990 Energy and Water Development Appropriations Act (Public Law 101-101), as amended by the 1995 Energy and Water Development Appropriations Act (Public Law 103-316). Funding for the Isotope Production and Distribution Program Fund is provided by the combination of an annual appropriation 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.

The annual appropriation in NP funds a payment into the revolving fund to maintain mission-readiness of facilities by supporting the 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 now 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 climate-related research. For example, radioisotopes are used in the diagnosis or treatment of about one-third of all patients admitted to hospitals.[a] Nearly 18 million Americans undergo nuclear medicine procedures each year for a variety of conditions, including cancer, cardiovascular disease, neurological conditions, and other physiological problems.[b] Such nuclear procedures are among the safest and most effective diagnostic tests available and enhance patient care by avoiding exploratory surgery and other invasive procedures. The Isotope Program continuously assesses isotope needs to inform program direction; for example, in November 2016, the Isotope Program organized the fifth annual Federal workshop to assess stakeholder requirements in order to optimize the utilization of resources and assure the greatest availability of isotopes.

Isotopes are primarily produced and processed at three facilities stewarded by the Isotope Program: the Brookhaven Linac Isotope Producer (BLIP) and associated processing labs at Brookhaven National Laboratory (BNL), the Isotope Production Facility (IPF) and associated processing labs at Los Alamos National Laboratory (LANL), and processing facilities at Oak Ridge National Laboratory (ORNL). In addition, production and distribution activities are supported at the Advanced Test Reactor (ATR) at Idaho National Laboratory, the High Flux Isotope Reactor (HFIR) at ORNL, Pacific Northwest National Laboratory, the Y-12 National Security Complex, and the Savannah River Site. IPF and BLIP provide accelerator production capabilities, while HFIR and ATR provide reactor production capability. HFIR has the highest neutron flux available for isotope production in the United States. The Isotope Program is broadening capability by including university-supported accelerator and reactor facilities used for research, education, and isotope production that can provide cost-effective and unique production capabilities, including facilities at the University of Washington, Duke University, Washington University, Texas A&M

[a] http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/med-use-radioactive-materials.html
[b] http://interactive.snm.org/docs/whatisnucmed2.pdf

University, the University of California at Davis, and the Missouri University Research Reactor. Most of these facilities reside in university medical departments.

In FY 2016, a total of $69.12 million was deposited in the revolving fund. This consisted of the FY 2016 appropriation of $21.63 million paid into the revolving fund from the Nuclear Physics program, plus collections of $47.49 million to recover costs related to isotope production and isotope services. Collections in FY 2016 included sales of californium-252, helium-3, selenium-75, cobalt-60, nickel-63, germanium-68, actinium-225, and strontium-82. Californium-252 has a variety of industrial applications; helium-3 is used in neutron detectors for national security; selenium-75 is used as a radiography source; cobalt-60 is used in gamma-ray cancer surgery; nickel-63 enhances national security through its use in detectors for explosives and illicit material; germanium-68 supports development of gallium-68 diagnostic imaging pharmaceuticals; actinium-225 is used in pharmaceuticals being developed to more effectively treat cancer and other diseases; and strontium-82 has gained world-wide acceptance for use in heart imaging. In FY 2016, the Isotope Program served 130 customers including major pharmaceutical companies, industrial users, and researchers at hospitals, national laboratories, other Federal agencies, universities, and private companies, with the sale of 140 different radioactive and stable isotopes. Among the isotopes produced, eight are high-volume, moderately priced isotopes; the remaining are low-volume research isotopes, which are more expensive to produce. Commercial isotopes are priced to recover full cost or the market price, whichever is higher.

Program Accomplishments

An Enriching Experience with Stable Isotopes. To re-establish a general capability for stable isotope enrichment in the U.S. that has not existed since 1998, the DOE Isotope Program has made investments in R&D and prototype capabilities to develop a Federal stable isotope enrichment capability, as recommended by the Nuclear Science Advisory Committee. This prototype facility, which uses state-of-the art electromagnetic and gas centrifuge enrichment devices at ORNL, commenced operation at the ending of FY 2016. U.S. inventories of important enriched stable isotopes can now start to be replenished, and research quantities of enriched stable isotopes will be fabricated to support a broad range of U.S. research in fields such as medicine, biology, chemistry, physics, and national security. The prototype facility is planned to be upgraded over the next few years to enable production of kg-quantities of high priority isotopes (Stable Isotope Production Facility) and the reduction of U.S. dependency on foreign supply.

Raising the Bar Using Proton Beam Rastering and Higher Current to Dramatically Increase Isotope Production at BLIP. The growth in utilization of two important medical imaging isotopes, strontium-82 (Sr-82) and germanium-68 (Ge-68), produced by the DOE Isotope Program at the Brookhaven Linac Isotope Producer (BLIP) and the Isotope Production Facility (IPF) at LANL, led to demand that exceeds production capabilities. To address this need, the DOE Isotope Program approved the BLIP Raster and Linac Intensity Upgrade accelerator improvement projects. The goal of these modest upgrades was to design and install a proton beam raster system to more evenly distribute the beam on isotope production targets by manipulating its position on the target surface in a series of circular patterns, and to increase the proton beam pulse width to effectively increase the current produced by the BNL linac. The rastered beam decreases the power density across targets (reduces the development of thermal “hot spots” on targets that can lead to target failures) which enables use of the greater proton beam current provided by the linac intensity upgrade. The combination of beam rastering and increased beam current has resulted in a 40% increase in isotope production while also reducing the risk of target failures.

Highlights of the FY 2018 Budget Request

For FY 2018, the Department foresees moderate growth in isotope demand, with particular interest in alpha-emitters for cancer therapy and stable isotopes to exploit the newly established domestic production capabilities. The portfolio of the isotope program continues to grow as isotope availability is increased by the program. Revolving fund resources will be used to support efforts to produce isotopes, increase radioisotope production capabilities and availability to meet demand, and upgrade proton beamline equipment at IPF to enhance the reliability of facility operations and increase isotope production yields. SC is requesting funding in the FY 2018 Nuclear Physics budget for the Stable Isotope Production Facility (SIPF) MIE, at a reduced pace relative to original plans. Originally proposed as a new start in the FY 2017 President’s Request, SIPF will provide increased domestic capability for cost-effective production of critically needed enriched stable isotopes and reduce the nation’s dependence on foreign suppliers. NP will make investments in aging isotope production infrastructure to maintain productivity and to provide enhanced facility infrastructure for increased production of Ac-225, a promising cancer therapeutic.

($K)

Science	FY 2016 Enacted	FY 2017 Annualized CR	FY 2018 Request
Ames Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	98	0	0
Basic Energy Sciences			
Basic Energy Sciences	21,332	19,245	16,611
Biological and Environmental Research			
Biological and Environmental Research	1,200	1,200	1,000
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	445	410	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	0	2,000	0
Safeguards and Security			
Safeguards and Security	1,293	1,231	1,229
Total, Ames Laboratory	**24,368**	**24,086**	**18,840**
Ames Site Office			
Program Direction			
Program Direction	536	633	322
Total, Ames Site Office	**536**	**633**	**322**
Argonne National Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	96,615	83,956	103,472
Basic Energy Sciences			
Basic Energy Sciences	247,813	236,609	214,738
Biological and Environmental Research			
Biological and Environmental Research	32,206	30,518	19,598
High Energy Physics			
High Energy Physics	17,347	15,973	12,700
Nuclear Physics			
Nuclear Physics	29,506	28,530	23,975
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	1,231	1,180	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	27,510	26,418	29,605
Safeguards and Security			
Safeguards and Security	9,022	9,245	9,166
Total, Argonne National Laboratory	**461,250**	**432,429**	**413,254**
Argonne Site Office			
Program Direction			
Program Direction	3,852	4,449	4,314
Total, Argonne Site Office	**3,852**	**4,449**	**4,314**

Science	FY 2016 Enacted	FY 2017 Annualized CR	FY 2018 Request
Berkeley Site Office			
Program Direction			
Program Direction	2,970	3,377	3,298
Total, Berkeley Site Office	**2,970**	**3,377**	**3,298**
Brookhaven National Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	971	1,180	0
Basic Energy Sciences			
Basic Energy Sciences	193,047	173,628	134,626
Biological and Environmental Research			
Biological and Environmental Research	11,938	9,814	7,200
High Energy Physics			
High Energy Physics	74,291	68,619	46,440
Nuclear Physics			
Nuclear Physics	191,339	189,280	176,245
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	1,964	1,310	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	0	0	1,500
Safeguards and Security			
Safeguards and Security	13,416	12,369	12,413
Total, Brookhaven National Laboratory	**486,966**	**456,200**	**378,424**
Brookhaven Site Office			
Program Direction			
Program Direction	4,262	4,814	4,485
Total, Brookhaven Site Office	**4,262**	**4,814**	**4,485**

($K)

Science	FY 2016 Enacted	FY 2017 Annualized CR	FY 2018 Request
Chicago Operations Office			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	38,507	31,158	11,929
Basic Energy Sciences			
Basic Energy Sciences	302,252	286,394	277,466
Biological and Environmental Research			
Biological and Environmental Research	130,050	97,066	41,159
Fusion Energy Sciences			
Fusion Energy Sciences	167,025	111,775	100,974
High Energy Physics			
High Energy Physics	117,581	105,432	58,140
Nuclear Physics			
Nuclear Physics	180,973	179,680	123,713
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	1,149	1,710	1,713
Safeguards and Security			
Safeguards and Security	45	45	50
Program Direction			
Program Direction	25,240	23,567	21,065
Total, Chicago Operations Office	**962,822**	**836,827**	**636,209**
Fermi National Accelerator Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	355	530	0
Basic Energy Sciences			
Basic Energy Sciences	1,496	1,424	995
Fusion Energy Sciences			
Fusion Energy Sciences	20	0	0
High Energy Physics			
High Energy Physics	367,505	367,387	376,699
Nuclear Physics			
Nuclear Physics	45	25	30
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	274	210	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	9,000	0	1,500
Safeguards and Security			
Safeguards and Security	5,610	5,297	5,341
Total, Fermi National Accelerator Laboratory	**384,305**	**374,873**	**384,565**

($K)

Science	FY 2016 Enacted	FY 2017 Annualized CR	FY 2018 Request
Fermi Site Office			
Program Direction			
Program Direction	2,359	2,613	2,463
Total, Fermi Site Office	**2,359**	**2,613**	**2,463**
Idaho National Laboratory			
Basic Energy Sciences			
Basic Energy Sciences	800	900	900
Fusion Energy Sciences			
Fusion Energy Sciences	2,690	2,690	2,450
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	486	240	0
Total, Idaho National Laboratory	**3,976**	**3,830**	**3,350**
Lawrence Berkeley National Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	153,596	146,644	127,513
Basic Energy Sciences			
Basic Energy Sciences	168,425	154,736	135,147
Biological and Environmental Research			
Biological and Environmental Research	147,554	149,795	88,534
Fusion Energy Sciences			
Fusion Energy Sciences	3,466	2,466	0
High Energy Physics			
High Energy Physics	89,442	65,570	51,595
Nuclear Physics			
Nuclear Physics	21,684	18,742	13,535
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	1,302	740	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	20,000	28,962	24,800
Safeguards and Security			
Safeguards and Security	7,796	7,169	7,240
Total, Lawrence Berkeley National Laboratory	**613,265**	**574,824**	**448,364**

($K)

Science	FY 2016 Enacted	FY 2017 Annualized CR	FY 2018 Request
Lawrence Livermore National Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	7,187	3,171	1,321
Basic Energy Sciences			
Basic Energy Sciences	2,883	2,321	1,309
Biological and Environmental Research			
Biological and Environmental Research	23,357	23,424	15,033
Fusion Energy Sciences			
Fusion Energy Sciences	6,500	8,208	6,224
High Energy Physics			
High Energy Physics	4,605	2,825	825
Nuclear Physics			
Nuclear Physics	848	1,000	904
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	290	300	0
Total, Lawrence Livermore National Laboratory	**45,670**	**41,249**	**25,616**
Los Alamos National Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	8,028	1,620	127
Basic Energy Sciences			
Basic Energy Sciences	26,309	25,120	8,206
Biological and Environmental Research			
Biological and Environmental Research	23,437	24,391	10,900
Fusion Energy Sciences			
Fusion Energy Sciences	3,138	1,780	3,150
High Energy Physics			
High Energy Physics	2,085	2,107	1,705
Nuclear Physics			
Nuclear Physics	10,519	7,927	6,823
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	500	270	0
Total, Los Alamos National Laboratory	**74,016**	**63,215**	**30,911**
National Energy Technology Lab			
Basic Energy Sciences			
Basic Energy Sciences	200	200	181
Total, National Energy Technology Lab	**200**	**200**	**181**

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Science	FY 2016 Enacted	FY 2017 Annualized CR	FY 2018 Request
National Renewable Energy Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	173	0	0
Basic Energy Sciences			
Basic Energy Sciences	14,416	11,419	10,700
Biological and Environmental Research			
Biological and Environmental Research	886	500	500
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	1,306	710	0
Total, National Renewable Energy Laboratory	**16,781**	**12,629**	**11,200**
Nevada Operations Office			
Basic Energy Sciences			
Basic Energy Sciences	365	300	0
Total, Nevada Operations Office	**365**	**300**	**0**
New Brunswick Laboratory Program Office			
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	1,200	0	0
Program Direction			
Program Direction	3,593	2,465	2,608
Total, New Brunswick Laboratory Program Office	**4,793**	**2,465**	**2,608**
Oak Ridge Institute for Science & Education			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	2,719	0	1,000
Basic Energy Sciences			
Basic Energy Sciences	4,279	1,925	850
Biological and Environmental Research			
Biological and Environmental Research	3,016	2,148	1,030
Fusion Energy Sciences			
Fusion Energy Sciences	1,816	544	494
High Energy Physics			
High Energy Physics	1,024	251	0
Nuclear Physics			
Nuclear Physics	572	467	353
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	9,426	4,170	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	1,000	1,000	0
Safeguards and Security			
Safeguards and Security	1,997	1,925	1,929
Total, Oak Ridge Institute for Science & Education	**25,849**	**12,430**	**5,656**

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Science	FY 2016 Enacted	FY 2017 Annualized CR	FY 2018 Request
Oak Ridge National Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	266,564	265,220	348,503
Basic Energy Sciences			
Basic Energy Sciences	326,929	318,344	285,357
Biological and Environmental Research			
Biological and Environmental Research	79,677	74,904	26,041
Fusion Energy Sciences			
Fusion Energy Sciences	134,790	133,465	78,021
High Energy Physics			
High Energy Physics	125	550	450
Nuclear Physics			
Nuclear Physics	20,726	13,013	10,981
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	12,000	11,977	10,000
Safeguards and Security			
Safeguards and Security	12,060	12,374	12,215
Total, Oak Ridge National Laboratory	**852,871**	**829,847**	**771,568**
Oak Ridge National Laboratory Site Office			
Program Direction			
Program Direction	5,466	6,134	5,365
Total, Oak Ridge National Laboratory Site Office	**5,466**	**6,134**	**5,365**
Oak Ridge Office			
Basic Energy Sciences			
Basic Energy Sciences	85	85	0
Nuclear Physics			
Nuclear Physics	0	86	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	6,177	6,165	6,082
Safeguards and Security			
Safeguards and Security	20,577	21,794	22,074
Program Direction			
Program Direction	27,638	23,725	21,338
Total, Oak Ridge Office	**54,477**	**51,855**	**49,494**

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Science	FY 2016 Enacted	FY 2017 Annualized CR	FY 2018 Request
Office of Scientific & Technical Information			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	236	214	145
Basic Energy Sciences			
Basic Energy Sciences	557	0	0
Biological and Environmental Research			
Biological and Environmental Research	257	76	152
Fusion Energy Sciences			
Fusion Energy Sciences	221	145	0
High Energy Physics			
High Energy Physics	277	230	0
Nuclear Physics			
Nuclear Physics	246	211	108
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	50	0	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	200	200	0
Safeguards and Security			
Safeguards and Security	682	784	783
Program Direction			
Program Direction	8,938	8,620	8,084
Total, Office of Scientific & Technical Information	**11,664**	**10,480**	**9,272**
Pacific Northwest National Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	8,842	1,519	1,779
Basic Energy Sciences			
Basic Energy Sciences	31,185	29,718	25,577
Biological and Environmental Research			
Biological and Environmental Research	117,392	105,685	54,967
Fusion Energy Sciences			
Fusion Energy Sciences	1,913	1,763	1,150
High Energy Physics			
High Energy Physics	3,256	3,425	2,600
Nuclear Physics			
Nuclear Physics	500	0	0
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	1,029	760	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	0	0	1,000
Safeguards and Security			
Safeguards and Security	13,383	12,839	12,654
Total, Pacific Northwest National Laboratory	**177,500**	**155,709**	**99,727**

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Science	FY 2016 Enacted	FY 2017 Annualized CR	FY 2018 Request
Pacific Northwest Site Office			
Program Direction			
Program Direction	4,855	4,969	4,651
Total, Pacific Northwest Site Office	**4,855**	**4,969**	**4,651**
Princeton Plasma Physics Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	295	0	0
Basic Energy Sciences			
Basic Energy Sciences	1,300	1,300	1,000
Fusion Energy Sciences			
Fusion Energy Sciences	92,378	76,899	62,965
High Energy Physics			
High Energy Physics	200	0	0
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	487	250	0
Safeguards and Security			
Safeguards and Security	2,771	2,535	2,684
Total, Princeton Plasma Physics Laboratory	**97,431**	**80,984**	**66,649**
Princeton Site Office			
Program Direction			
Program Direction	1,764	1,607	1,602
Total, Princeton Site Office	**1,764**	**1,607**	**1,602**
Sandia National Laboratories			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	11,768	2,829	2,257
Basic Energy Sciences			
Basic Energy Sciences	34,791	28,326	12,646
Biological and Environmental Research			
Biological and Environmental Research	10,413	13,389	5,950
Fusion Energy Sciences			
Fusion Energy Sciences	2,774	2,543	2,170
High Energy Physics			
High Energy Physics	35	100	0
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	130	100	0
Total, Sandia National Laboratories	**59,911**	**47,287**	**23,023**

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Science	FY 2016 Enacted	FY 2017 Annualized CR	FY 2018 Request
Savannah River National Laboratory			
Basic Energy Sciences			
Basic Energy Sciences	737	737	292
Fusion Energy Sciences			
Fusion Energy Sciences	425	425	0
Total, Savannah River National Laboratory	**1,162**	**1,162**	**292**
SLAC National Accelerator Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	852	125	0
Basic Energy Sciences			
Basic Energy Sciences	408,437	403,064	362,200
Biological and Environmental Research			
Biological and Environmental Research	3,940	4,011	800
Fusion Energy Sciences			
Fusion Energy Sciences	8,014	7,948	5,300
High Energy Physics			
High Energy Physics	91,520	95,636	54,059
Nuclear Physics			
Nuclear Physics	269	789	506
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	400	350	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	34,800	34,952	0
Safeguards and Security			
Safeguards and Security	4,257	4,247	4,251
Total, SLAC National Accelerator Laboratory	**552,489**	**551,122**	**427,116**
Stanford Site Office			
Program Direction			
Program Direction	2,309	2,404	2,327
Total, Stanford Site Office	**2,309**	**2,404**	**2,327**

Science	FY 2016 Enacted	FY 2017 Annualized CR	FY 2018 Request
Thomas Jefferson National Accelerator Facility			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	284	0	0
High Energy Physics			
High Energy Physics	1,040	140	0
Nuclear Physics			
Nuclear Physics	119,587	112,804	96,818
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	180	150	0
Safeguards and Security			
Safeguards and Security	2,687	2,709	2,717
Total, Thomas Jefferson National Accelerator Facility	**123,778**	**115,803**	**99,535**
Thomas Jefferson Site Office			
Program Direction			
Program Direction	1,835	1,861	1,739
Total, Thomas Jefferson Site Office	**1,835**	**1,861**	**1,739**
Washington Headquarters			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	23,910	81,653	123,964
Basic Energy Sciences			
Basic Energy Sciences	61,362	149,690	65,699
Biological and Environmental Research			
Biological and Environmental Research	23,677	70,921	76,086
Fusion Energy Sciences			
Fusion Energy Sciences	12,830	86,516	47,042
High Energy Physics			
High Energy Physics	24,667	65,244	67,487
Nuclear Physics			
Nuclear Physics	40,286	63,373	48,709
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	0	8,313	14,000
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	564	0	0
Safeguards and Security			
Safeguards and Security	7,404	8,242	8,254
Program Direction			
Program Direction	89,383	93,410	84,855
Total, Washington Headquarters	**284,083**	**627,362**	**536,096**
Total, Science	**5,350,200**	**5,340,029**	**4,472,516**

GENERAL PROVISIONS – DEPARTMENT OF ENRGY
(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 "Final Bill" column in the "Department of Energy" table included under the heading "Title III—Department of Energy" in the explanatory statement accompanying this Act.

(e) The amounts made available by this title may be reprogrammed for any program, project, or activity, and the Department shall notify the Committees on Appropriations of both Houses of Congress at least 30 days prior to the use of any proposed reprogramming that would cause any program, project, or activity funding level to increase or decrease by more than $5,000,000 or 10 percent, whichever is less, during the time period covered by this Act.

(f) None of the funds provided in this title shall be available for obligation or expenditure through a reprogramming of funds that—

(1) creates, initiates, or eliminates a program, project, or activity;

(2) increases funds or personnel for any program, project, or activity for which funds are denied or restricted by this Act; or

(3) reduces funds that are directed to be used for a specific program, project, or activity by this Act.

(g) (1) The Secretary of Energy may waive any requirement or restriction in this section that applies to the use of funds made available for the Department of Energy if compliance with such requirement or restriction would pose a substantial risk to human health, the environment, welfare, or national security.

(2) The Secretary of Energy shall notify the Committees on Appropriations of both Houses of Congress of any waiver under paragraph (1) as soon as practicable, but not later than 3 days after the date of the activity to which a requirement or restriction would otherwise have applied. Such notice shall include an explanation of the substantial risk under paragraph (1) that permitted such waiver.

SEC. 302. The unexpended balances of prior appropriations provided for activities in this Act may be available to the same appropriation accounts for such activities established pursuant to this title. Available balances may be merged with funds in the applicable established accounts and thereafter may be accounted for as one fund for the same time period as originally enacted.

SEC. 303. Funds appropriated by this or any other Act, or made available by the transfer of funds in this Act, for intelligence activities are deemed to be specifically authorized by the Congress for purposes of section 504 of the National Security Act of 1947 (50 U.S.C. 3094) during fiscal year 2018 until the enactment of the Intelligence Authorization Act for fiscal year 2018.

SEC. 304. None of the funds made available in this title shall be used for the construction of facilities classified as high-hazard nuclear facilities under 10 CFR Part 830 unless independent oversight is conducted by the Office of Enterprise Assessments to ensure the project is in compliance with nuclear safety requirements.

SEC. 305. None of the funds made available in this title may be used to approve critical decision–2 or critical decision–3 under Department of Energy Order 413.3B, or any successive departmental guidance, for construction projects where the total project cost exceeds $100,000,000, until a separate independent cost estimate has been developed for the project for that critical decision.

SEC. 306. Notwithstanding section 301(c) of this Act, none of the funds made available under the heading "Department of Energy—Energy Programs—Science" in this or any subsequent Energy and Water Development and Related Agencies appropriations Act for any fiscal year may be used for a multiyear contract, grant, cooperative agreement, or Other Transaction Agreement of $1,000,000 or less unless the contract, grant, cooperative agreement, or Other Transaction Agreement is funded for the full period of performance as anticipated at the time of award.

SEC. 307. (a) NEW REGIONAL RESERVES.—The Secretary of Energy may not establish any new regional petroleum product reserve unless funding for the proposed regional petroleum product reserve is explicitly requested in advance in an annual budget submission and approved by the Congress in an appropriations Act.

(b) The budget request or notification shall include—

(1) the justification for the new reserve;

(2) a cost estimate for the establishment, operation, and maintenance of the reserve, including funding sources;

(3) a detailed plan for operation of the reserve, including the conditions upon which the products may be released;

(4) the location of the reserve; and

(5) the estimate of the total inventory of the reserve.

SEC. 308. Uranium Lease and Take-Back Revolving Fund.—There is hereby established in the Treasury of the United States a fund to be known as the "Uranium Lease and Take-Back Revolving Fund" (the Fund), which shall be available without fiscal year limitation, for Department of Energy expenses, including the purchase, construction, and acquisition of plant and capital equipment and other expenses necessary in carrying out section 3173 of the National Defense Authorization Act for Fiscal Year 2013. For initial capitalization, there is appropriated $1,000,000 to the Fund. Notwithstanding 31 U.S.C. 3302, revenues received under section 3173 of such Act in this and subsequent fiscal years shall be credited to the Fund to be available for carrying out the purposes of the Fund without further appropriation. Funds collected in fiscal year 2018 shall be credited as offsetting collections to the Fund, so as to result in a final fiscal year 2018 appropriation from the general fund estimated at not more than $0.

SEC. 309. Treatment of Lobbying and Political Activity Costs as Allowable Costs under Department of Energy Contracts.

(a) Allowable Costs.—

(1) Section 4801(b) of the Atomic Energy Defense Act (50 U.S.C. 2781(b)) is amended—

(A) by striking "(1)" and all that follows through "the Secretary" and inserting "The Secretary"; and

(B) by striking paragraph (2).

(2) Section 305 of the Energy and Water Development Appropriation Act, 1988, as contained in section 101(d) of Public Law 100–202 (101 Stat. 1329–125), is repealed.

(b) Regulations Revised.—The Secretary of Energy shall revise existing regulations consistent with the repeal of 50 U.S.C. 2781(b)(2) and section 305 of Public Law 100–202 and shall issue regulations to implement 50 U.S.C. 2781(b), as amended by subsection (a), no later than 150 days after the date of the enactment of this Act. Such regulations shall be consistent with the Federal Acquisition Regulation 48 C.F.R. 31.205–22.

SEC. 310. 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. 311. Notwithstanding section 161 of the Energy Policy and Conservation Act (42 U.S.C. 6241), the Secretary of Energy shall draw down and sell one million barrels of refined petroleum product from the Strategic Petroleum Reserve during fiscal year 2018. Proceeds from sales under this section shall be deposited into the general fund of the Treasury during fiscal year 2018.

Title V – General Provisions

SEC. 501. None of the funds appropriated by this Act may be used in any way, directly or indirectly, to influence congressional action on any legislation or appropriation matters pending before Congress, other than to communicate to Members of Congress as described in 18 U.S.C. 1913.

SEC. 502. None of the funds made available by this Act may be used in contravention of Executive Order No. 12898 of February 11, 1994 (Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations).