DOE/CF-0122
Volume 4

Department of Energy
FY 2017 Congressional Budget Request

Science

Advanced Research Projects Agency−Energy

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Funding by Appropriation

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request[1]	FY 2017 vs. FY 2016 $	FY 2017 vs. FY 2016 %
	($K)					
Department of Energy Budget by Appropriation						
Energy and Water Development, and Related Agencies						
Energy Programs						
Energy Efficiency and Renewable Energy	1,914,195	1,840,847	2,069,194	2,898,400	+829,206	+40.1%
Electricity Delivery and Energy Reliability	146,975	143,901	206,000	262,300	+56,300	+27.3%
Nuclear Energy	833,379	821,883	986,161	993,896	+7,735	+0.8%
Office of Technology Transitions	0	0	0	8,400	+8,400	N/A
21st Century Clean Transportation Plan Investments	0	0	0	1,335,000	+1,335,000	N/A
Fossil Energy Programs						
Clean Coal Technology	-6,600	-2,876	0	0	0	N/A
Fossil Energy Research and Development	560,587	548,885	632,000	600,000	-32,000	-5.1%
Use of Prior Year Balances	0	0	0	-240,000	0	N/A
Naval Petroleum and Oil Shale Reserves	19,950	20,640	17,500	14,950	-2,550	-14.6%
Elk Hills School Lands Fund	15,580	15,580	0	0	0	N/A
Strategic Petroleum Reserve	200,000	200,000	212,000	257,000	+45,000	+21.2%
Northeast Home Heating Oil Reserve	1,600	1,600	7,600	6,500	-1,100	-14.5%
Total, Fossil Energy Programs	**791,117**	**783,829**	**869,100**	**638,450**	**-230,650**	**-26.5%**
Uranium Enrichment Decontamination and Decommissioning (UED&D) Fund	625,000	625,000	673,749	673,749	0	N/A
Energy Information Administration	117,000	117,000	122,000	131,125	+9,125	+7.5%
Non-Defense Environmental Cleanup	246,000	246,030	255,000	218,400	-36,600	-14.4%
Science	5,067,738	5,132,813	5,347,000	5,672,069	+325,069	+6.1%
Advanced Research Projects Agency - Energy (ARPA-E)	279,982	279,982	291,000	500,000	+209,000	+71.8%
Departmental Administration	125,043	135,686	130,971	144,866	+13,895	+10.6%
Office of Indian Energy	0	0	0	22,930	+22,930	N/A
Office of the Inspector General	40,500	40,500	46,424	44,424	-2,000	-4.3%
Title 17 - Innovative Technology Loan Guarantee Program	17,000	17,000	17,000	10,000	-7,000	-41.2%
Advanced Technology Vehicles Manufacturing Loan Program	4,000	4,000	6,000	5,000	-1,000	-16.7%
Total, Energy Programs	**10,207,929**	**10,188,471**	**11,019,599**	**13,559,009**	**+2,539,410**	**+23.0%**
Atomic Energy Defense Activities						
National Nuclear Security Administration						
Weapons Activities	8,180,359	8,180,609	8,846,948	9,243,147	+396,199	+4.5%
Defense Nuclear Nonproliferation	1,615,248	1,612,651	1,940,302	1,807,916	-132,386	-6.8%
Naval Reactors	1,233,840	1,233,840	1,375,496	1,420,120	+44,624	+3.2%
Office of the Administrator	-413	-413	0	0	0	N/A
Federal Salaries and Expenses	370,000	370,000	363,766	412,817	+49,051	+13.5%
Total, National Nuclear Security Administration	**11,399,034**	**11,396,687**	**12,526,512**	**12,884,000**	**+357,488**	**+2.9%**
Environmental and Other Defense Activities						
Defense Environmental Cleanup	4,990,017	4,989,555	5,289,742	5,226,950	-62,792	-1.2%
Other Defense Activities	753,449	753,449	776,425	791,552	+15,127	+1.9%
Total, Environmental and Other Defense Activities	**5,743,466**	**5,743,004**	**6,066,167**	**6,018,502**	**-47,665**	**-0.8%**
Total, Atomic Energy Defense Activities	**17,142,500**	**17,139,691**	**18,592,679**	**18,902,502**	**+309,823**	**+1.7%**
Power Marketing Administrations						
Southeastern Power Administration	0	0	0	0	0	N/A
Southwestern Power Administration	11,400	11,400	11,400	11,057	-343	-3.0%
Western Area Power Administration	91,740	91,740	93,372	95,581	+2,209	+2.4%
Falcon and Amistad Operating and Maintenance Fund	228	228	228	232	+4	+1.8%
Colorado River Basins Power Marketing Fund	-23,000	-23,000	-23,000	-23,000	0	N/A
Total, Power Marketing Administrations	**80,368**	**80,368**	**82,000**	**83,870**	**+1,870**	**+2.3%**
Federal Energy Regulatory Commission (FERC)	0	0	0	0	0	N/A
Subtotal, Energy and Water Development and Related Agencies	**27,430,797**	**27,408,530**	**29,694,278**	**32,545,381**	**+2,851,103**	**+9.6%**
Uranium Enrichment Decontamination and Decommissioning Fund Discretionary Payments	-463,000	-463,000	0	-155,100	-155,100	N/A
Uranium Enrichment Decontamination and Decommissioning Fund Contribution	463,000	463,000	0	155,100	+155,100	N/A
Excess Fees and Recoveries, FERC	-28,485	-17,325	-23,587	-9,426	+14,161	+60.0%
Title XVII Loan Guarantee Program Section 1703 Negative Credit Subsidy Receipt	0	0	-68,000	-37,000	+31,000	+45.6%
Total, Funding by Appropriation	**27,402,312**	**27,391,205**	**29,602,691**	**32,498,955**	**+2,896,264**	**+9.8%**

[1] FY 2017 Request includes mandatory spending: $1.335B for Clean Transportation Plan, $674M for UED&D Fund, $150M for ARPA-E, and $100M for Science.

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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 [17] *15* passenger motor vehicles for replacement only, [including one ambulance] and one bus, [$5,350,200,000,] *$5,572,069,000,* to remain available until expended: *Provided*, That of such amount, [$185,000,000] *$204,481,000,* shall be available until September 30, [2017] *2018*, for program direction[: *Provided further*, That of such amount, not more than $115,000,000 shall be made available for the in-kind contributions and related support activities of ITER: Provided further, That not later than May 2, 2016, the Secretary of Energy shall submit to the Committees on Appropriations of both Houses of Congress a report recommending either that the United States remain a partner in the ITER project after October 2017 or terminate participation, which shall include, as applicable, an estimate of either the full cost, by fiscal year, of all future Federal funding requirements for construction, operation, and maintenance of ITER or the cost of termination].

Explanation of Change

Proposed appropriation language updates reflect the funding and replacement of passenger motor vehicle levels requested in FY 2017. In addition, the fiscal year 2016 restrictions on the obligation of funding for in-kind contributions and related support activities and reporting requirements for ITER are proposed for elimination.

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 2015 Enacted	FY 2015 Current[a]	FY 2016 Enacted	FY 2017 Request
5,067,738	5,132,813	5,347,000	5,672,069

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*—discovering 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 the 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*—advancing a clean energy agenda through fundamental research on energy production, conversion, storage, transmission, and use by advancing our understanding of the earth and its climate. Targeted investments include three DOE Bioenergy Research Centers (BRCs), the Energy Frontier Research Centers (EFRCs), two Energy Innovation Hubs, and atmospheric process and climate modeling research.

SC is an established leader of the U.S. scientific discovery and innovation enterprise. Over the decades, SC investments and accomplishments in basic research have provided the foundations for new technologies, businesses, and industries, making significant contributions to our Nation's economy and quality of life. Select scientific accomplishments in FY 2015 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 2017 Budget Request

The FY 2017 Budget Request for SC is $5.572 billion, an increase of $222 million or 4.1 percent, relative to the FY 2016 Enacted level. The FY 2017 Request supports a balanced research portfolio invested in discovery science research probing the most fundamental questions: in high energy, nuclear, and plasma physics; materials and chemistry; biological systems; the complex interactions between earth system components; mathematics; crosscutting high-performance computing and simulation; and basic research that produces advances in clean energy. The Request supports over 24,000 investigators at over 300 U.S. institutions and the DOE laboratories. SC user facilities continue to provide unmatched tools and capabilities for more than 31,000 researchers from universities, national laboratories, industry, and international partners. The FY 2017 Request supports the construction of new user facilities, and the operation, maintenance, and enhancement of the existing network of user facilities, which provide world class research capabilities in the United States. The FY 2017 Request also invests significantly in targeted research and development (R&D), such as accelerator R&D, necessary for future facilities and facility upgrades to deliver desired capabilities and maximize scientific potential.

In addition to the FY 2017 Request, an authorization proposal for $100 million of mandatory funding for University Grants (Mandatory) will be transmitted to Congress, for a total FY 2017 Budget of $5.672 billion. SC will make the funds available through a competitive, merit-based review of proposals solicited from and provided by the university community. The

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[a] Includes funding for Small Business Innovation Research (SBIR) and Small Business Technology Transfer Research (STTR) transferred to SC by other Department of Energy components.

solicitation will be designed to leverage past accomplishments and accelerate ongoing activities, as well as open new paths for future SC basic research endeavors in the mission areas of Advanced Scientific Computing Research, Basic Energy Sciences, Biological and Environmental Research, Fusion Energy Sciences, High Energy Physics and Nuclear Physics.

Highlights of the FY 2017 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 United States. The ASCR Budget Request of $663.2 million is an increase of $42.2 million, or 6.8 percent, relative to the FY 2016 Enacted level. The increase supports research on the linked challenges of capable exascale and data-intensive science, and computational partnerships under the Scientific Discovery through Advanced Computing (SciDAC) program to support clean energy. In FY 2017, the ASCR portion of the SC component of the Department's Exascale Computing Initiative (ECI) is contained in a new line item, the Office of Science Exascale Computing Project (SC-ECP), which includes only the activities required for the delivery of exascale computers. 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. With the creation of the new line item, funds are incorporated within SC-ECP research activities from existing applied mathematics, computer science, computational partnerships, and research and evaluation prototypes subprograms of the ASCR budget. The FY 2017 Request supports preparations at the two Leadership Computing Facilities for 75–200 petaflop upgrades at each facility in the 2018–2019 timeframe. The National Energy Research Scientific Computing Center (NERSC) will take delivery of the NERSC-8 supercomputer, which will expand the capacity of the facility to 10–40 petaflops to address growing demand.

- *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 $1,936.7 million is an increase of $87.7 million or 4.7 percent from the FY 2016 Enacted level. The FY 2017 Request includes increases for core research and the Energy Frontier Research Centers (EFRCs) in key areas related to Departmental priorities, such as the Subsurface Technology and Engineering RD&D and the Advanced Materials crosscutting initiatives. A new activity is initiated in Computational Chemical Sciences to advance U.S. leadership in computational chemistry codes in preparation for exascale computing and supports the ECI. The Request continues to support the Fuels from Sunlight and the Batteries and Energy Storage DOE Energy Innovation Hubs. The FY 2017 Request also provides for the operations of five synchrotron light sources, five nanoscale research centers, and two neutron scattering centers. The Request continues to support construction of the Linac Coherent Light Source-II (LCLS-II), and it continues funding the Advanced Photon Source (APS) Upgrade Major Item of Equipment (MIE) request.

- *Biological and Environmental Research (BER)* supports fundamental research and scientific user facilities to achieve a predictive understanding of complex biological, climatic, and environmental systems for a secure and sustainable energy future. The BER Budget Request of $661.9million is an increase of $52.9 million or 8.7 percent above the FY 2016 Enacted level. The FY 2017 Request continues to support for core research in Genomic Science and the three DOE Bioenergy Research Centers (BRC), and it increases support for research to understand microbiome interactions in diverse environments. The Request also continues to support core research to understand climate-relevant atmospheric and ecosystem processes, and requests increased support for field research and modeling to understand the dynamic physical, biogeochemical, microbial, and plant processes interactions involved in the energy-water nexus. The Request supports the operations of BER's three scientific user facilities: the DOE Joint Genome Institute (JGI), the Environmental Molecular Sciences Laboratory (EMSL), and the Atmospheric Radiation Measurement Climate Research Facility (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 2017 Request of $398.18 million decreases by $39.8 million or 9.1 percent from the FY 2016 Enacted level. The FES Budget Request supports continued progress on the U.S. Contributions to ITER Project and core research in burning plasma science. It requests increased funding for the operation of the National Spherical Torus Experiment Upgrade (NSTX-U) to support 16 weeks of run time and to conduct high priority plasma-materials interaction research. DIII-D operations funding supports 560 hours of operation and the Request includes an increase to provide for targeted enhancements to the facility. Increased funding for research at both DIII-D and NSTX-U will support research in areas identified as priorities by the research community and for enhanced collaborations with MIT research staff.

- *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 2017 Request of $817.9 million increases by $22.9 million or 2.9 percent above the FY 2016 Enacted level. The Request continues to implement the recommendations of the 2014 High Energy Physics Advisory Panel (HEPAP) Particle Physics Project Prioritization Panel (P5) Report. The FY 2017 Request supports full operation of existing major HEP facilities and experiments, including optimal operations for the upgraded Neutrinos at the Main Injector (NuMI) beamline of NuMI Off-axis ν_e Appearance (NOvA) Experiment, construction of the Muon to Electron Conversion Experiment (Mu2e), consistent with the planned construction funding profile, and the MIEs for the Large Hadron Collider (LHC) upgrades the ATLAS (A Large Toroidal LHC Apparatus) and Compact Muon Solenoid (CMS) detectors. Consistent with the P5 Report recommendations, the FY 2017 Request enhances support for technical design and construction associated with the Long Baseline Neutrino Facility (LBNF)/Deep Underground Neutrino Experiment (DUNE) project, and continued construction of three MIEs for next-generation dark-energy and dark-matter experiments. The Request includes funding for one new MIE, the Facility for Advanced Accelerator Experimental Tests II (FACET-II), and for research and conceptual design of the Proton Improvement Plan II (PIP-II) construction project. Funding increases for the fabrication of the Large Synoptic Survey Telescope MIE according to the planned profile. Core research increases slightly to provide support for high priority efforts.

- *Nuclear Physics (NP)* supports experimental and theoretical research to discover, explore, and understand all forms of nuclear matter. The FY 2017 Budget Request of $635.7 million increases $18.6 million or 3.0 percent relative to the FY 2016 Enacted level. The Request provides for modest increases in core research at universities and DOE national laboratories to support high priority research of the nuclear physics community, as well as the development of cutting-edge approaches for producing isotopes critical to the nation. It also supports the continued construction of the Facility for Rare Isotope Beams (FRIB), which will provide world-leading capabilities for nuclear structure and astrophysics research. The 12 GeV Upgrade for the Continuous Electron Beam Accelerator Facility (CEBAF) will be completed in FY 2017 and the full 12 GeV scientific program initiated, enabling groundbreaking searches for exotic particles and new physics. The FY 2017 Request also provides for increased operations of the Relativistic Heavy Ion Collider (RHIC) for explorations of spin physics and intriguing new phenomena observed in quark gluon plasma formation, and for operations of the Argonne Tandem Linac Accelerator System (ATLAS) utilizing newly completed instrumentation. Two new MIEs are initiated in FY 2017 the Gamma-Ray Energy Tracking Array (GRETA) detector to exploit the world-leading science capabilities of FRIB, and the Stable Isotope Production Facility (SIPF) to establish a domestic capability for the production of a broad range of enriched stable isotopes for research and applications.

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 "tech teams" and 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. 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]

The Office of Science 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,

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

high-reward basic research elements in its research portfolios to drive innovation and challenge current thinking, using a variety of mechanisms to develop topics: Federal advisory committees, triennial Committees of Visitors, program and topical workshops, interagency working groups, National Academies studies, and special SC program solicitations. Many of these topics are captured in formal reports, e.g., *Building for Discovery: Strategic Plan for U.S. Particle Physics in the Global* Context, by the High Energy Physics Advisory Panel (HEPAP-P5) (2014) [a]; *Top Ten Exascale Research Challenges*, by the Advanced Scientific Computing Advisory Committee (ASCAC) (2014) [b]; *Report of the BESAC Subcommittee on Future X-ray Light Sources,* by the Basic Energy Sciences Advisory Committee (BESAC) (2013) [c]; *Challenges at the Frontiers of Matter and Energy: Transformative Opportunities for Discovery Science*, by BESAC (2015)[d]; *Synergistic Challenges in Data-Intensive Science and Exascale*, ASCR workshop report (2012) [e]; *Molecular Science Challenges*, BER workshop report (2014)[f]; *Building Virtual Ecosystems: Computational Challenges for Mechanistic Modeling of Terrestrial Environments*, BER workshop report (2014)[g]; *Isotope Research and Production Opportunities and Priorities*, by the Nuclear Science Advisory Committee (NSAC) (2015)[h];and *Nuclear Physics Long Range Plan*, by the NSAC (2015) [i].

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, graduate-level experimental training in areas associated with scientific user facilities, such as particle and accelerator physics, neutron and x-ray scattering, 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 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.

Crosscutting Initiatives

The FY 2017 Budget Request for SC includes investments that serve as the first step in implementing the President's commitment to double Federal funding for clean energy research over the next five years. Through the government-wide Mission Innovation initiative, SC and DOE will join other Federal entities in commitment to accelerate the pace of innovation and the research and development of affordable clean energy technologies to ensure a secure and clean energy future for the United States. The FY 2017 Budget Request for SC's ASCR, BES, BER, and FES programs will support a new generation of scientists and engineers conducting fundamental research aimed at addressing complex scientific questions and accelerating the transformation of that research into clean energy technology solutions. Specific proposed activities in this area are discussed in greater detail in the respective program's budgets.

The Department is organized into three Under Secretariats—Science and Energy, Nuclear Security, and Management and Performance—which recognize the complex interrelationship between the DOE Program Offices. The Budget Request continues crosscutting programs coordinated across the Department and seek to tap DOE's full capability to effectively and efficiently address the United States' energy, environmental, and national security challenges. These crosscutting initiatives are discussed further within the Programs in which the crosscuts are funded. SC participates in the following crosscuts:

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[a] http://science.energy.gov/~/media/hep/hepap/pdf/May%202014/FINAL_P5_Report_Interactive_060214.pdf
[b] http://science.energy.gov/~/media/ascr/ascac/pdf/meetings/20140210/Top10reportFEB14.pdf
[c] http://science.energy.gov/~/media/bes/besac/pdf/Reports/Future_Light_Sources_report_BESAC_approved_72513.pdf
[d] http://science.energy.gov/~/media/bes/besac/pdf/Reports/CFME_rpt_print.pdf
[e] http://science.energy.gov/~/media/ascr/ascac/pdf/reports/2013/ASCAC_Data_Intensive_Computing_report_final.pdf
[f] http://genomicscience.energy.gov/biosystemsdesign/index.shtml
[g] http://science.energy.gov/~/media/ber/pdf/workshop%20reports/VirtualEcosystems.pdf
[h] http://science.energy.gov/~/media/np/nsac/pdf/docs/2015/2015_NSACI_Report_to_NSAC_Final.pdf
[i] Working title, to be released in Fall 2015, link TBD

Advanced Materials (Adv Mat): Affordable, reliable, and high-performance materials are critical for clean energy applications and for global manufacturing competitiveness in the 21st century. The new Advanced Materials crosscut, identified as a priority in both the 2015 Quadrennial Technology Review and Quadrennial Energy Review, will employ advanced synthesis, modeling, and characterization to accelerate and reduce the cost of materials qualification in a wide variety of clean energy applications, from discovery through deployment. While materials RD&D underpins much of DOE's historic and current portfolio across both basic science and applied offices, this newly formed crosscut focuses on a subset of materials R&D that will involve close coordination among the participating offices in forming a cohesive network with the following capabilities: (1) materials design and synthesis, (2) functional (applied) design, (3) process scale-up, (4) qualification, and (5) digital data and informatics.

Exascale Computing Initiative (ECI): Exascale systems are needed to support areas of research that are critical to national security objectives as well as applied research advances in areas such as earth-systems models, combustion systems, and nuclear reactor design that are not within the capacities of today's systems. Exascale systems' computational power is needed for increasing capable data-analytic and data-intense applications across the entire Federal complex. Exascale is a component of long-term collaboration between the Office of Science's Advanced Scientific Computing Research program and the National Nuclear Security Administration's Advanced Simulation and Computing Campaign (ASC) program.

Subsurface Technology and Engineering RD&D (Subsurface): Over 80 percent of our total energy supply comes from the subsurface, and this importance is magnified by the ability to also use the subsurface to store and sequester fluids and waste products. The subsurface crosscut, Subsurface, will address identified grand challenges in the subsurface through highly focused and coordinated research in Wellbore Integrity, Stress State and Induced Seismicity, Permeability Manipulation, and New Subsurface Signals and Risk Assessment Tools to ensure enhanced energy security, material impact on climate change via CO_2 sequestration, and significantly mitigated environmental impacts from energy-related activities and operations.

Energy-Water Nexus (EWN): There is increasing urgency to address the energy-water nexus in an integrated way due to changing precipitation and temperature patterns, accelerated drawdown of critical water supplies, population growth and regional migration trends, and the introduction of new technologies that could shift water and energy demands. The energy-water nexus crosscut is an integrated set of cross-program collaborations designed to accelerate the Nation's transition to more resilient energy and coupled energy-water systems. The crosscut supports: (1) an advanced, integrated data, modeling, and analysis platform to improve understanding and inform decision-making for a broad range of users and at multiple scales; (2) investments in targeted technology research opportunities within the system of water-energy flows that offer the greatest potential for positive impact; and (3) policy analysis and stakeholder engagement designed to build from and strengthen the two preceding areas while motivating more rapid community involvement and response.

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 Credential and Access Management (ICAM).

FY 2017 Crosscuts ($K)

	Adv Mat	ECI	Subsurface	EWN	Cyber security	Total
Advanced Scientific Computing Research	0	154,000	0	0	0	154,000
Basic Energy Sciences	17,600[a]	26,000	41,300	0	0	84,900
Biological and Environmental Research	0	10,000	0	24,300	0	34,300
Safeguards and Security	0	0	0	0	27,197[b]	27,197
Total, Crosscuts	17,600	190,000	41,300	24,300	27,197	300,397

[a] The $17,600K supports the Department's Advanced Materials Crosscut. An additional $11,500K in BES for Quantum Materials is also included in SC's total investment, as described in the advanced materials crosscut narrative.
[b] The $27,197K supports the Department's Cybersecurity Crosscut. An additional $6,039K for CyberOne in the Safeguards and Security program is also included in SC's total investment to support cybersecurity. CyberOne is funded through the Working Capital Fund (WCF).

Science
Funding by Congressional Control ($K)

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016 Enacted
Advanced Scientific Computing Research					
Research	541,000	523,411	621,000	509,180	-111,820
17-SC-20 Office of Science Exascale Computing Project (SC-ECP)	0	0	0	154,000	+154,000
Total, Advanced Scientific Computing Research	**541,000**	**523,411**	**621,000**	**663,180**	**+42,180**
Basic Energy Sciences					
Research	1,594,500	1,544,224	1,648,700	1,746,730	+98,030
Construction					
13-SC-10 Linac Coherent Light Source-II, SLAC	138,700	138,700	200,300	190,000	-10,300
Total, Basic Energy Sciences	**1,733,200**	**1,682,924**	**1,849,000**	**1,936,730**	**+87,730**
Biological and Environmental Research	**592,000**	**572,618**	**609,000**	**661,920**	**+52,920**
Fusion Energy Sciences					
Research	317,500	307,366	323,000	273,178	-49,822
Construction					
14-SC-60 ITER	150,000	150,000	115,000	125,000	+10,000
Total, Fusion Energy Sciences	**467,500**	**457,366**	**438,000**	**398,178**	**-39,822**
High Energy Physics					
Research	729,000	708,232	728,900	729,476	+576
Construction					
11-SC-40 Long Baseline Neutrino Facility/Deep Underground Neutrino Facility, FNAL	12,000	12,000	26,000	45,021	+19,021
11-SC-41 Muon to Electron Conversion Experiment, FNAL	25,000	25,000	40,100	43,500	+3,400
Total, Construction	**37,000**	**37,000**	**66,100**	**88,521**	**+22,421**
Total, High Energy Physics	**766,000**	**745,232**	**795,000**	**817,997**	**+22,997**
Nuclear Physics					
Operation and Maintenance	489,000	474,244	509,600	535,658	+26,058
Construction					
14-SC-50 Facility for Rare Isotope Beams, Michigan State University	90,000	90,000	100,000	100,000	0
06-SC-01 12 GeV CEBAF Upgrade, TJNAF	16,500	16,500	7,500	0	-7,500
Total, Construction	**106,500**	**106,500**	**107,500**	**100,000**	**-7,500**
Total, Nuclear Physics	**595,500**	**580,744**	**617,100**	**635,658**	**+18,558**
Workforce Development for Teachers and Scientists	**19,500**	**19,500**	**19,500**	**20,925**	**+1,425**

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016 Enacted
Science Laboratories Infrastructure					
Infrastructure Support					
Payment in Lieu of Taxes	1,713	1,713	1,713	1,764	+51
Oak Ridge Landlord	5,777	5,777	6,177	6,182	+5
Facilities and Infrastructure	6,100	6,100	24,800	32,603	+7,803
Oak Ridge Nuclear Operations	0.	0	12,000	26,000	+14,000
Total, Infrastructure Support	**13,590**	**13,590**	**44,690**	**66,549**	**+21,859**
Construction					
17-SC-71 Integrated Engineering Research Center, FNAL	0	0	0	2,500	+2,500
17-SC-73 Core Facility Revitalization at BNL	0	0	0	1,800	+1,800
15-SC-75 Infrastructure and Operational Improvements at PPPL	25,000	25,000	0	0	0
15-SC-76 Materials Design Laboratory at ANL	7,000	7,000	23,910	19,590	-4,320
15-SC-77 Photon Science Laboratory Building at SLAC	10,000	10,000	25,000	20,000	-5,000
15-SC-78 Integrative Genomics Building at LBNL	12,090	12,090	20,000	19,561	-439
12-SC-70 Science and User Support Building, SLAC	11,920	11,920	0	0	0
Total, Construction	**66,010**	**66,010**	**68,910**	**63,451**	**-5,459**
Total, Science Laboratories Infrastructure	**79,600**	**79,600**	**113,600**	**130,000**	**+16,400**
Safeguards and Security	**93,000**	**93,000**	**103,000**	**103,000**	**0**
Program Direction	**183,700**	**183,700**	**185,000**	**204,481**	**+19,481**
University Grants (Mandatory)	**0**	**0**	**0**	**100,000**	**+100,000**
Small Business Innovation/Technology Transfer Research (SC portion)	**0**	**132,905**	**0**	**0**	**0**
Subtotal, Science	**5,071,000**	**5,071,000**	**5,350,200**	**5,672,069**	**+321,869**
Small Business Innovation/Technology Transfer Research (DOE transfer)	**0**	**65,075**	**0**	**0**	**0**
Rescission of prior year balances	**-3,262**	**-3,262**	**-3,200**	**0**	**+3,200**
Total, Science	**5,067,738**	**5,132,813**	**5,347,000**	**5,672,069**[a]	**+325,069**
Federal FTEs	**940**	**902**	**905**	**930**	**+25**

SBIR/STTR:

- FY 2015 Transferred: SBIR: $116,796,000 was reprogrammed within SC and $57,381,000 was transferred from other DOE programs; STTR: $16,109,000 was reprogrammed within SC and $7,694,000 was transferred from other DOE programs.
- FY 2016 projected: SBIR: $125,763,000 and STTR: $18,865,000 (SC only).
- FY 2017 Request: SBIR: $140,541,000; STTR: $19,764,000 (SC Only).

[a] In the FY 2017 Budget Request, most funding for the Working Capital Fund (WCF) is transferred to Program Direction to establish a consolidated source of funding for goods and services provided by the WCF. CyberOne is still funded through program dollars. In FY 2016 and prior years, WCF costs were shared by SC research programs and Program Direction.

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, in partnership with the research community, including U.S. industry. The strategy to accomplish this has two thrusts: developing and maintaining world-class computing and network facilities for science; and advancing research in applied mathematics, computer science and advanced networking.

During the past six decades, U.S. computing capabilities have been maintained through sustained research and the development and deployment of new computing systems with rapidly increasing performance on applications of major significance to government, industry, and academia. The Department of Energy (DOE) and its predecessor organizations have played a key role in that process–advancing national security, science, and industrial competitiveness. To maximize the benefits of high performance computing (HPC) in the coming decades, DOE will sustain and enhance its scientific, technological, and economic leadership position in 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 collaboration, 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 collaborating with industry and academia.
- Develop a comprehensive technical and scientific approach to transition HPC research on hardware, system software, development tools, and applications efficiently into development and, ultimately, operations.

On July 29, 2015, an executive order established the National Strategic Computing Initiative (NSCI) to ensure a coordinated Federal strategy in HPC research, development, and deployment. DOE, along with the Department of Defense and the National Science Foundation, have been selected to co-lead the NSCI. Specifically, the DOE Office of Science (SC) and the DOE National Nuclear Security Administration (NNSA) are responsible for the execution of a joint program focused on advanced simulation through a capable exascale 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.

DOE will meet its NSCI assignment through the Exascale Computing Initiative (ECI), which began in FY 2016. The ECI, which is a partnership between SC and NNSA, will accelerate the research and development (R&D) to overcome key exascale challenges in parallelism, energy efficiency, and reliability, leading to deployment of exascale systems in the mid-2020s. The acceleration or advancement is defined as a hundred-fold increase in sustained performance over today's computing capabilities, enabling applications to address next-generation science, engineering, and data problems. The plan for the ECI has been reviewed by the interagency community and the Advanced Scientific Computing Advisory Committee (ASCAC).

In addition to underpinning DOE's mission in science, capabilities developed in the ECI will also support DOE's applied energy technology developments. ECI is critical to advancing energy technologies. The DOE's Quadrennial Technology Review (QTR), released in September 2015, identifies R&D opportunities across the six energy technology areas and documents a cross-cutting need for modeling, simulation, and analytics. ECI is a critical tool in support of advancing energy technologies.

In FY 2017, the ASCR portion of the Office of Science component of the ECI is contained in the Office of Science Exascale Computing Project (SC-ECP), which includes only the activities required for the delivery of exascale computers.

The scope of the SC-ECP has four 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;
- *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; and
- *Exascale Systems:* The Exascale Systems focus area supports advanced system engineering development by the vendors needed to produce capable exascale systems. System procurement activities will be executed in coordination with each DOE HPC facility's existing system acquisition timelines. It also includes acquisition and support of prototypes and testbeds for the application, software, and hardware testing activities.

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 the Office of Science for the planning, design, and construction of all of its major projects, including the Leadership Computing Facilities at Argonne and Oak Ridge National Laboratories (ORNL) and NERSC at Lawrence Berkeley National Laboratory (LBNL). Computer acquisitions use a tailored version of Order 413.3B. The first four years of SC-ECP will focus on research in software (new algorithms and methods to support application and system software development) and hardware (node and system design). During the last six years of the SC-ECP, activities will focus on delivering application software, the system software stack, and hardware technologies that will be deployed in the exascale systems.

Overall project management for SC-ECP will be conducted via a Project Office that has been established at 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 collaboration among six DOE national laboratories with a TPC of $1.4 billion. The Project Office is now initiating coordination among partners and developing the bases for pending Critical Decisions for the SC-ECP.

Highlights of the FY 2017 Budget Request

The FY 2017 Budget Request for ASCR continues support for the basic and applied research activities that support the broad scientific objectives of the Office of Science. The ASCR budget also implements the DOE responsibilities defined in the Administration's National Strategic Computing Initiative and supports the Department's Agency Priority Goal on high performance computing, by accelerating the delivery of a capable exascale computing system. A capable exascale computing system integrates hardware and software capability to deliver approximately 100 times the performance of current 10 petaflop systems across a range of applications representing government needs, including data-intensive science. In the FY 2017 Budget Request, most funding for the Working Capital Fund (WCF) is transferred to Science Program Direction to establish a consolidated source of funding for goods and services provided by the WCF. CyberOne is still funded through program dollars in the Office of Science Safeguards and Security program. In FY 2016 and prior years, WCF costs were shared by SC research programs and Program Direction.

<u>Mathematical, Computational, and Computer Sciences Research</u>
With the initiation of the SC-ECP, research efforts that are on the critical path for the ECI have been shifted from the Mathematical, Computational, and Computer Sciences Research subprogram to the Exascale Computing subprogram.

As noted in the NSCI, the era of silicon-based microchips advancing in accordance with Moore's Law (feature sizes reducing by a factor of two approximately every two years) is nearing an end due to limits imposed by fundamental physics. ASCR will invest $12 million across research and facilities to understand the impacts these technologies may have on our applications. Beginning in FY 2017, the computer science and computational partnerships activities will invest $7 million to initiate new research efforts on technologies "Beyond Moore's Law," responding to the NSCI and recommendations made by the Secretary of Energy Advisory Board, to understand the challenges that these dramatically different 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 developing technologies.

The NSCI also drew attention to the need to increase the capacity and capability of an enduring national HPC ecosystem by employing a holistic approach that addresses relevant factors such as networking technology, workflow, downward scaling, foundational algorithms and software, accessibility, and workforce development. Activities in applied mathematics, computer science, and next generation networking for science that are not included in the ECI provide the foundation for increasing the capability of the national HPC ecosystem. In FY 2017, these activities will continue to develop the methods, software, and tools to ensure DOE applications can fully exploit the most advanced computing systems available 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. This allows the other scientific programs in the Office of Science to more effectively use the current and immediate next generation high performance computing facilities. In FY 2017, the SciDAC activity will be re-competed and expanded. The focus of the new SciDAC portfolio will be on developing the mission critical applications of the other Office of Science programs. These efforts will be informed by the research results emerging from the exascale computing initiative and will, whenever possible, incorporate the software, methods, and tools developed by that initiative. The increase in Computational Partnerships also initiates: a partnership with BES and BER to develop new tools and technologies for the BRAIN initiative, a partnership with NNSA on seismic simulation, and partnerships supporting the Administration's Clean Energy Initiatives.

<u>High Performance Computing and Network Facilities</u>
With the initiation of the SC-ECP, research efforts that are on the critical path for the ECI have been shifted from the High Performance Computing and Network Facilities subprogram to the Exascale Computing Subprogram.

In FY 2017, the Leadership Computing Facilities (LCFs) will continue preparations for planned 75-200 petaflops (pf) upgrades at each site to be completed in the 2018-2019 timeframe. The Argonne LCF (ALCF) will also deploy an interim system in FY 2017 to transition ALCF users to the new many-core architecture being introduced by computer vendors in that time frame. Because these upgrades represent technological advances in both hardware and software, funds are included in Research and Evaluation Prototypes (REP) to continue supporting non-recurring engineering efforts for the ASCR facilities that incorporate custom features to meet the Department's mission requirements.
The National Energy Research Scientific Computing Center (NERSC) will begin operation of the NERSC-8 supercomputer, named Cori, which will expand the capacity of the facility to approximately 30pf to address the continued increase in demand from Office of Science researchers. To keep pace with the growing demand for capacity computing to meet mission needs, the Department has begun planning for deployment of 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 objectives of the NSCI, the REP activity will continue to support the Computational Sciences Graduate Fellowship at $10,000,000 in FY 2017. 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, support also continues for a post-doctoral training program for high end computational science and engineering. In addition, the three ASCR HPC user facilities will continue coordinating efforts to quantify scientist's computational requirements and to prepare their users for future architectures.

To support the new research effort within the computer science and computational partnerships activities, REP will support a small-scale testbed for technologies that are "Beyond Moore's Law." Given the increasing threat from cyber-attacks on federal resources and the expertise within the ASCR research community, the research and evaluation prototypes activity will also initiate a modest research effort in cybersecurity in FY 2017 with an emphasis on the unique challenges of the Department's HPC facilities, which are not currently addressed by ongoing cyber-security R&D.

In FY 2017, the Energy Science Network (ESnet) will provide increases in bandwidth to address the growing data requirements of SC facilities, such as the Department's light sources, neutron sources, and particle accelerators at CERN.

This includes upgrading high-traffic links to 400 gigabits per second (gbps). ESnet will also continue to extend science engagement efforts to solve the end-to-end network issues between DOE facilities and universities.

Exascale Computing

With the initiation of the SC-ECP, activities that are on the critical path for the ECI have been shifted to this new subprogram.

The primary goal of the ECI in SC is to provide the forefront computing resources needed to meet and 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. Because DOE partners with HPC vendors to accelerate 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. The FY 2017 Request includes $154,000,000 for the SC-ECP.

The investment strategy for the ECI has five components:

- Conduct research, development, and design efforts in hardware, software, and mathematical technologies leading toward capable exascale systems.
- Prepare today's scientific and data-intensive computing applications to exploit fully the capabilities of exascale systems by coordinating their development with the emerging technologies from the research, development, and design efforts.
- Partner with HPC vendors to accelerate the pace of implementation of technologies required for capable exascale computing.
- Acquire and operate increasingly capable computing systems, starting with hundred-plus petaflop machines that incorporate emerging technologies from research investments.
- Collaborate with other Federal agencies to ensure broad applicability and use of capable exascale computing across the US Government.

Within the FY 2017 Budget Request, ASCR supports the Department's ECI goal to significantly accelerate the development of capable exascale computing systems to meet national needs through the 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, climate and energy modeling, genomics and systems biology, as well as to support national security objectives and applied-energy research advances in DOE. Exascale systems' computational power is also needed for increasing data-analytic and data-intense applications across the set of DOE science programs and other Federal organizations that rely on large-scale simulations, e.g., the National Oceanographic and Atmospheric Administration and the National Institutes of Health. The importance of exascale computing to the DOE science programs is documented in previous and ongoing individual requirements reviews for each SC program office. Exascale computing is a central component of long-term collaboration between the SC's Advanced Scientific Computing Research (ASCR) program and the National Nuclear Security Administration's (NNSA) Advanced Simulation and Computing Campaign (ASC) program.

FY 2017 Crosscuts ($K)

	ECI
Advanced Scientific Computing Research	154,000

Advanced Scientific Computing Research
Funding ($K)

	FY 2015 Enacted	FY 2015 Current[a]	FY 2016 Enacted	FY 2017 Request[b]	FY 2017 vs FY 2016
Mathematical, Computational, and Computer Sciences Research					
Applied Mathematics	49,155	49,454	49,229	39,229	-10,000
Computer Science	55,767	55,259	56,848	39,296	-17,552
Computational Partnerships	46,918	43,996	47,918	45,596	-2,322
Next Generation Networking for Science	19,000	19,011	19,000	19,000	0
SBIR/STTR	5,830	0	6,181	7,733	+1,552
Total, Mathematical, Computational, and Computer Sciences Research	**176,670**	**167,720**	**179,176**	**150,854**	**-28,322**
High Performance Computing and Network Facilities					
High Performance Production Computing	75,605	75,905	86,000	92,145	+6,145
Leadership Computing Facilities	184,637	190,698	181,317	187,000	+5,683
Research and Evaluation Prototypes	57,329	53,298	121,471	17,890	-103,581
High Performance Network Facilities and Testbeds	35,000	35,790	38,000	45,000	+7,000
SBIR/STTR	11,759	0	15,036	16,291	+1,255
Total, High Performance Computing and Network Facilities	**364,330**	**355,691**	**441,824**	**358,326**	**-83,498**
Exascale Computing					
17-SC-20 Office of Science Exascale Computing Project (SC-ECP)	0	0	0	154,000	+154,000
Total, Advanced Scientific Computing Research	**541,000**	**523,411**	**621,000**	**663,180**	**+42,180**

SBIR/STTR funding:

- FY 2015 Enacted: SBIR $15,457,000 and STTR $2,132,000
- FY 2016 Request: SBIR $18,450,000 and STTR $2,767,000
- FY 2017 Request: SBIR $21,062,000 and STTR $2,962,000

[a] Reflects the transfer of Small Business Innovation/Technology Transfer Research (SBIR/STTR) funds within the Office of Science.
[b] A transfer of $1,364,000 to Science Program Direction is to consolidate all Working Capital Funds in one program.

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

	FY 2017 vs FY 2016
Mathematical, Computational, and Computer Sciences Research: With the initiation of the SC-ECP, $46,106,000 in research efforts that are on the critical path for the exascale computing initiative have been shifted to the Exascale Computing Subprogram. The computer science and computational partnerships activities will initiate efforts to investigate the impact of technologies "Beyond Moore's Law;" the SciDAC portfolio will be recompeted and expanded to initiate a partnership with BES and BER to develop new tools and technologies for the BRAIN initiative, a partnership with NNSA on seismic simulation, and partnerships supporting the Administration's Clean Energy Initiatives.	**-28,322**
High Performance Computing and Network Facilities: With the initiation of the SC-ECP, $107,894,000 of Research and Evaluation Prototypes efforts that are on the critical path for the exascale computing initiative have been shifted to the Exascale Computing Subprogram. Increased facilities funding supports: operations, including increased power costs at the facilities; initial site preparation activities for NERSC-9; LCF completion of site preparations for planned upgrades in FY 2018–19—including support for OLCF to exercise the option to take delivery of a 200pf system, which is 50pf larger than planned for in FY 2016; ALCF deployment of an interim system to help ALCF users transition to the new many-core architecture in their planned upgrade; Research and Evaluation Prototypes, which will support the Computational Sciences Graduate Fellowship at $10,000,000 and initiate testbeds for exploring computer technologies "Beyond Moore's Law" and a modest new effort in cybersecurity for HPC systems; and ESnet efforts to provide increases in bandwidth for the growing data requirements of SC facilities, such as upgrading high-traffic links to 400gbps.	**-83,498**
Exascale Computing: With the initiation of the SC-ECP, research efforts that are on the critical path for the exascale computing initiative have been shifted to the Exascale Computing subprogram.	**+154,000**
Total, Advanced Scientific Computing Research	**+42,180**

Basic and Applied R&D Coordination
Coordination across disciplines and programs is a cornerstone of the ASCR program. Partnerships within the Office of Science are mature and continue to advance the use of high performance computing 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. Areas of mutual interest between ASCR and the DOE technology programs, particularly the Office of Electricity Delivery and Energy Reliability (OE) and the Office of Nuclear Energy (NE), are applied mathematics for the optimization of complex systems, control theory, and risk assessment. 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 2016, cross-agency interactions and collaborations will continue, fostered by the NSCI, in coordination with OSTP.

Program Accomplishments
Advances in Materials Science to Reduce Friction in Energy Systems. Advances in materials science and nanotechnology often underpin technological improvements in energy delivery. For example, it is estimated that 1/3 of the energy consumed in passenger cars is to overcome mechanical friction.[a] In a collaboration at Argonne, involving materials scientists at the Argonne Center for Nanoscale Materials, computational scientists, and an applied-energy program laboratory fellow, the Mira supercomputer was used to identify and improve a new mechanism for reducing friction, which is feeding into the development of a hybrid material that exhibits superlubricity at the macroscale for the first time. Computer simulations revealed that when the lubricant materials—graphene and diamond-like carbon (DLC)—slid against each other, the graphene began rolling up to form hollow cylindrical "scrolls" that helped to practically eliminate friction. These so-called nanoscrolls represent a completely new mechanism for superlubricity, a state in which friction essentially disappears. Superlubricity is a highly desirable property in a host of mechanical systems. Considering that nearly one-third of every tank of fuel is spent overcoming friction in automobiles, a material that can achieve superlubricity would provide a significant economic advantage and would benefit industry and consumers alike. The research team is in the process of seeking a patent for the hybrid material, which could potentially be used for applications in dry environments, such as computer hard drives, wind turbine gears, and mechanical rotating seals for microelectromechanical and nanoelectromechanical systems. The team's groundbreaking nanoscroll discovery would not have been possible without a supercomputer like Mira. Replicating the experimental setup required simulating up to 1.2 million atoms for dry environments and up to 10 million atoms for humid environments. This work was published in Science Magazine in June 2015.

Harnessing Large Scale Turbulence to Improve Clean Coal Combustion. Fundamental understanding in chemistry and turbulence often holds the keys for improving the efficiency of large-scale combustion devices, such as those used in coal-fired power plants. Researchers at the University of Utah and its NNSA–funded Carbon Capture Multi-Disciplinary Simulation Center (CCMSC) are using the Oak Ridge LCF (OLCF) to improve modeling capabilities to enable petascale simulations to guide the design of next-generation oxy-coal boilers for clean electric energy. The scale of these boilers (up to 300 feet tall), their cost (hundreds of millions of dollars), and their ability to provide electricity for up to a million people underscore the importance of optimizing the design. The computational models developed by CCMSC use large-eddy simulation, derived from long-term investments by ASCR and Basic Energy Sciences (BES) to model turbulence in the boilers and to include ray-tracing approaches to model thermal radiation, which is the dominant mode of heat transfer. In order to show that these models are capable of being used to model a complete boiler, the team used the OLCF to develop, implement, and test Reverse Monte Carlo Ray Tracing (RMCRT), a unique technique for modeling radiative heat transfer in clean coal boilers, at large scale on both CPUs and GPUs. The OLCF GPUs reduced the team's time to solution by a factor of two and enabled simulations previously too computationally expensive to perform. These achievements lay the groundwork for full-architectural utilization—CPU and GPU—of OLCF to perform multi-physics simulation for oxy-coal boiler modeling, including combustion, fluid flow and radiative heating, necessary to achieve CCMSC's goal of simulating during the next five years clean coal boiler of between a 350MWe and 1000MWe. This technology was recently acquired by GE Power Systems.

[a] http://www.stle.org/resources/lubelearn/friction/

Basic Science of Converting CO_2 Into Fuel and Useful Chemicals. BES-funded basic research in the functional role of pyridinium during aqueous electrochemical reduction of CO_2 on platinum, coupled with simulations run on NERSC's Hopper supercomputer explain why submerging a platinum semiconductor into an acidic solution of pyridine and CO_2 and charging it with just 600 millivolts of electricity, the CO_2 can be transformed into formic acid, formaldehyde and methanol. Simulations reveal that, unexpectedly, the CO_2 conversion process is initiated by a reaction with hydrogen atoms bound to a platinum surface. Other mechanisms had been proposed before these simulations settled the issue. Although platinum catalysts would be too expensive to use at scale, this research opens the door to systematic exploration of catalysts that are more affordable. The findings are expected to be useful in the design and development of new technologies that can generate fuels that are consumed without producing CO_2, a long held goal in reducing the carbon footprint of chemical manufacturing and energy production.

Advancing Next Generation Nuclear Energy. Although nuclear fission of uranium has been used in commercial power plants for decades across the U.S. and generates about 20 percent of the nation's electricity in a carbon-free manner, significant fundamental intricacies of the process remain unknown. Basic research in nuclear physics, coupled with ASCR simulation capabilities are allowing scientists to delve into these questions in the study of the model system of fission of fermium-264 as it splits into two symmetric nuclei of tin-132. They combined sophisticated calculations and techniques that considered the variations in the shape of a single fermium-264 atom as it breaks apart and found that the optimal fission path is strongly impacted by nucleonic pairing, also known as superfluidity. The coupling between shape and pairing can lead to a dramatic departure from the standard picture of fission. For the first time, researchers are able to study spontaneous fission microscopically with a computational model that considers factors which were previously estimated. When extended to the more complex case of uranium fission, this research could open doors for improving the performance and safety of nuclear reactors, as well as for national security applications. The research team from the Michigan State University, funded by NNSA and using the OLCF supercomputer, is working to develop a predictive framework to describe nuclear fission.

ESnet Support of High-Energy Physics Experiments and Secretarial Recognition. In 2015, ESnet transatlantic circuit capacity was expanded to 340 gigabits/second, to support resumption of experiments at the Large-Hadron Collider at the CERN (*Organisation Européenne pour la Recherche Nucléaire*) in Geneva, Switzerland. The capacity expansion was designed and implemented on time to support the start of LHC Run2, which began in June 2015. ESnet staff received a Secretarial Honor Award—DOE's highest non-monetary recognition—for developing the On-demand Secure Circuits and Reservation System (OSCARS), a widely-used software application that creates dedicated bandwidth 'highways' for scientists to transfer massive, time-critical data sets over long distances.

Delivering on Exascale technologies. As part of the ASCR Fast Forward computer-science research activity, NVIDIA developed a signaling technology called GRS (ground-referenced signaling) that ultimately led to the development of the NV Link technology, which is a key technology in their Pascal and Volta generation GPUs. GRS is a high-speed (20 gigabits/second) low-energy (0.5-picojoule/bit) signaling technology. During the development of GRS, NVIDIA sketched a number of application scenarios including using the technology to provide a high-bandwidth channel between the CPU and GPU—and hence enabling full-bandwidth GPU access to CPU memory via NV Link. NVLink 1.0 will be available on the Pascal GP100 GPU and on the IBM Power 8+ CPU (and several other yet unannounced CPUs). It provides high-bandwidth, low-latency communication between the CPU and the GPU in a heterogeneous system, which will be critical in exascale systems. This link enables the GPU to use the full memory bandwidth of the CPU memory, which will greatly simplify the programmability of scientific and engineering algorithms on heterogeneous HPCs.

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

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 middleware to efficiently and effectively harness the potential of today's high performance computing systems and advanced networks for science and engineering applications;
- operating systems, data management, analyses, 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;
- networking 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, energy efficiency, and reliability.

Deriving scientific insights and knowledge from vast amounts of data flowing from Office of Science user facilities will require a focused research effort to develop the necessary theories, software tools, and technologies to manage the full data lifecycle from generation or collection through integration, transformation, analysis, and visualization, to capturing the historic record of the data and archiving, and sharing them.

With the initiation of the SC-ECP, research efforts that are on the critical path for the exascale computing initiative have been shifted to the Exascale Computing Subprogram.

<u>Applied Mathematics</u>
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 physical and energy-related biological 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 next generation HPC systems. High-fidelity modeling and simulation require a number of new algorithmic techniques and strategies supported by this activity, including 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.

<u>Computer Science</u>
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 within 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 run-time data management and analysis.

Significant innovation in computer science is needed to realize the computational and data-analytic potential of next-generation HPC systems and other scientific user facilities in a timeframe consistent with their anticipated availability. There will be continued emphasis on data-intensive science challenges with particular attention to the intersection with exascale computing challenges and the unique needs of DOE scientific user facilities including data management. 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.

Computational Partnerships

The Computational Partnerships activity supports the SciDAC program, which accelerates progress in scientific computing through partnerships among applied mathematicians, computer scientists, and scientists in other disciplines. These 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. Current SciDAC applications include climate science, fusion research, high energy physics, nuclear physics, astrophysics, materials science, chemistry, and accelerator physics.

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 high performance computing, 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, multi-core and many-core architectures.

Next Generation Networking for Science

ASCR has played a leading role in the development of the high-bandwidth networks connecting researchers to facilities, data, and to one another. ASCR-supported researchers helped establish critical protocols on which the internet is based. Next Generation Networking for Science research provides underpinning technologies used in international collaborations such as the Large Hadron Collider, including virtual meeting and other commercial collaboration tools. These research efforts build upon results from Computer Science and Applied Mathematics to develop integrated software tools and advanced network services to use new capabilities in ESnet to advance DOE missions.

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs FY 2016
Mathematical, Computational, and Computer Sciences Research $179,176,000	**$150,854,000**	**-$28,322,000**
Applied Mathematics $49,229,000	**$39,229,000**	**-$10,000,000**
Applied Mathematics continues efforts to develop new algorithmic techniques and strategies that extract scientific advances and engineering insights from massive data for DOE missions. Applied Mathematics addresses many of the challenges of exascale including: advanced solvers, uncertainty quantification, algorithmic resilience, and strategies for reducing global communications.	Applied Mathematics will continue efforts to develop new algorithmic techniques and strategies that extract scientific advances and engineering insights from massive data for DOE missions including: uncertainty quantification, algorithmic resilience, and strategies for reducing global communications.	$10,000,000 of Applied Mathematics efforts have been moved to the Exascale Computing subprogram.
Computer Science $56,848,000	**$39,296,000**	**-$17,552,000**
Computer Science continues efforts to develop software, new programming models and metrics for evaluating system status. This activity is primarily focused on addressing the challenges of exascale and data-intensive science. Emphasis remains on efforts to promote ease of use; increase parallelism, energy efficiency, and reliability, and ensures 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. As Moore's law reaches its final phase, impacts will be seen in several technology areas, including HPC and knowledge extraction from large datasets resulting from next-generation scientific experiments. Given the Department's significant investment in these areas, it is essential that our research community understands and is ready to mitigate these impacts to our mission applications.	$20,106,000 of Computer Science efforts have been moved to the Exascale Computing subprogram. The computer science activity will initiate new efforts to begin to investigate the impact of technologies "Beyond Moore's Law."

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs FY 2016
Computational Partnerships $47,918,000	**$45,596,000**	**-$2,322,000**
The SciDAC Institutes are 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 Leadership Computing Facilities, the National Energy Research Scientific Computing Center, and similar world-class computing facilities over the following five years. In addition, the exascale Co-design centers will undergo a comprehensive external peer review in FY 2015 to document progress and impact, and to inform the recompetition of these efforts in FY 2016.	The SciDAC institutes continue to play a key role in assisting DOE mission critical applications to effectively use the ASCR production and leadership computing facilities. The science application partnerships, with the other Office of Science programs, will be recompeted and expanded in FY 2017 to address the challenges in moving toward larger data sets and more complex computing systems on the path to exascale. FY 2017 marks the beginning of the fourth iteration of the SciDAC portfolio. This highly successful program has never been more important to bridge the gap between core research efforts in computer science and applied math and the applications supported by the other Office of Science programs. The focus on SciDAC over the next four years will be on readying Office of Science applications to harness the potential of the upgraded ASCR leadership and production computing facilities with priority emphasis on efforts that are needed to advance the science goals in partnerships with the Offices of Basic Energy Sciences (BES), Biological and Environmental Research (BER), High Energy Physics, Nuclear Physics, and Fusion Energy Sciences (FES). ASCR will continue to work with the DOE Applied Energy programs and other Federal agencies, in support of the whole-of-government objective of the NSCI. As part of ASCR efforts to understand the impacts of technologies "Beyond Moore's Law," this activity will initiate partnerships within the Office of Science for application specific efforts to begin to explore these technologies.	$16,000,000 of co-design efforts have been moved to the Exascale Computing subprogram. Funding supports recompetition and expansion of the SciDAC partnerships including new efforts with BES, BER and FES supporting the Administration's Clean Energy Initiatives. Funding also initiates a partnership with BES and BER to develop new tools and technologies for the BRAIN initiative, a partnership with NNSA on seismic simulation, and partnerships within the Office of Science to begin to explore technologies "Beyond Moore's Law."

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs FY 2016
Next Generation Networking for Science $19,000,000	**$19,000,000**	**$0**
The Next Generation Networking for Science activity continues 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 allows 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 continue 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.	No change
SBIR/STTR $6,181,000	**$7,733,000**	**+$1,552,000**
In FY 2016, SBIR/STTR funding is set at 3.45% of non-capital funding.	In FY 2017, 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 the National Energy Research Scientific Computing Center (NERSC) at LBNL and Leadership Computing Facilities (LCFs) at ORNL and ANL. These computers, and the other Office of Science 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 Energy Science Network (ESnet). Finally, the 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 activity addresses the challenges of next generation computing systems. By actively partnering with the research community, including industry, on the development of technologies that enables next-generation machines, ASCR ensures that commercially available architectures serve the needs of the scientific community. The Research and Evaluation Prototypes activity also prepares researchers to effectively use the next generation of scientific computers and seeks to reduce risk for future major procurements.

Allocation of computer time at ASCR facilities follows the peer-reviewed, 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, climate modeling, materials, high energy and nuclear physics, fusion, and biology. NERSC users come from nearly every state in the U.S., with about 65% based in universities, 25% in DOE laboratories, and 10% in other government laboratories and industry. NERSC's large and diverse user base requires an agile support staff to aid users entering the high performance computing arena for the first time, as well as those preparing codes to run on the largest machines available at NERSC and other Office of Science computing facilities. In FY 2015, NERSC moved into the new Computational Research and Theory building located on the Lawrence Berkeley National Laboratory campus.

NERSC is a vital resource for the Office of Science 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 Office of Science 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 is one of the most powerful computers in the world for scientific research, and is ranked number two on the June 2015 Top 500 list.[a] Through allocations at the OLCF, many applications, including the water cycle and cryosphere systems in advanced climate simulations, developing models of astrophysical explosions, direct-numerical simulation of turbulent combustion flexible-fuel gas turbines, dynamical simulations of magnetic fields in high-energy-density plasmas, first-principles based statistical physics of alloys and functional materials, simulations of high-temperature superconductors, molecular design of next-generation nanostructured polymer electrolytes, simulation of fundamental energy conversion processes in cells, simulations of neutron transport in fast-fission reactor cores, and earthquake simulations, are running at the multi-petaflop scale. 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.

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 Research and Evaluation Prototypes activity. This HPC system achieves high performance with relatively lower electrical power consumption than other current petascale computers. The ALCF will also begin operations of an 8.5 pf Intel-based machine to prepare their users for the ALCF-3 upgrade in 2019.

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.

The demand for 2015 INCITE allocations at the LCFs outpaced the available resources by a factor of three.

Research and Evaluation Prototypes

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 technologies "Beyond Moore's Law." This activity also supports some near-term research efforts needed by the ASCR facilities and focused on their unique needs—such as cybersecurity efforts focused on the unique challenges of open HPC systems.

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

With the initiation of the SC-ECP, research and evaluation prototype efforts that are on the critical path for the exascale computing initiative and activities, such as the vendor partnerships on critical technologies, nodes and system integration, have been shifted to the Exascale Computing Subprogram.

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. 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. Additional funds are used to support the growth in science data traffic and for testing and evaluation of 400-gbps technologies and software-defined networking services that will be required to keep pace with the expected data volume.

[a] http://www.top500.org/lists/2014/11/

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs FY 2016
High Performance Computing and Network Facilities $441,824,000	**$358,326,000**	**-$83,498,000**
High Performance Production Computing $86,000,000	**$92,145,000**	**+$6,145,000**
Supports 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.	In January 2017, NERSC will begin production operations of the NERSC-8 system. Named “Cori” after Nobel Laureate Gerty Cori, this system is an approximately 30-pf Cray XC supercomputer with Intel Xeon Phi processors. The full production system will provide roughly four times the CY 2016 NERSC capacity. Demand for production computing for the Office of Science continues to grow along with system capability and the rapid increase in data from experiments. To help NERSC keep pace, the Department approved the NERSC-9 Mission Need Statement in August 2015. An RFP was issued in FY 2016 and the vendor will be selected in FY 2017 to deliver a pre-exascale system, with three to five times the capacity of NERSC-8, in 2020.	Increase supports production operations of NERSC-8, including increased power costs, lease payments, and user support, and the start of site preparations for NERSC-9 .
Leadership Computing Facilities $181,317,000	**$187,000,000**	**+$5,683,000**
Support 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 includes lease payments, power, and user support. Also supports 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.	Site preparations for planned upgrades at both LCF facilities will be completed in 2017. The OLCF will begin to install cabinets for the new 200-pf IBM Power9 heterogeneous supercomputer with NVIDIA Volta GPUs at the end of FY 2017. Installation, testing, early science access and transition to operations for the system, named Summit, are all planned for FY 2018. This upgrade will provide approximately five times the capability of Titan.	Increase supports completion of site preparations for planned upgrades at both LCF facilities. These include finalizing power and cooling capacity, as well as space and weight requirements because the final specification of the machines is now known for both facilities. Increase also supports installation and operations of an interim Intel-Cray computing system at the ALCF to transition users to the new many-core architecture

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs FY 2016
	The ALCF will complete site preparations in early FY 2018 for its planned upgrade in FY 2019 to an Intel-Cray supercomputer, called Aurora, to be built with 3rd Generation Intel Xeon Phi many-core processors. This system is a dramatic change from the Current Mira system, which is an IBM BlueGene Q supercomputer. Therefore, the ALCF will install and operate an 8.5-pf interim system, called Theta, in early FY 2017 based on Intel's second-generation Xeon Phi processor. This system will serve as an early production system to transition ALCF users to the new architecture. The LCF upgrades will advance energy and manufacturing technologies, as well as our fundamental understanding of the universe, while maintaining the United States' global leadership in HPC on the path to exascale computing.	and exercise the option to acquire a 200-pf machine at the OLCF expanding the current plan of record by 50 pf.
Leadership Computing Facility at ANL: $77,000,000	$80,000,000	+$3,000,000
Leadership Computing Facility at ORNL: $104,317,000	$107,000,000	+$2,683,000
Research and Evaluation Prototypes $121,471,000	**$17,890,000**	**-$103,581,000**
REP supports efforts to improve the energy efficiency and reliability of critical technologies such as memory, processors, network interfaces and interconnects. The compute node is the basic building block of a high performance computer and all of these technologies come together in the node. Therefore, REP will competitively select R&D partnerships with U.S. vendors to initiate the design and development of node and system designs suitable for exascale systems. These efforts will influence the development of prototypes that advance DOE goals and are based on the results of the *Fast Forward and Design Forward* investments. This is an essential component of the Department's exascale computing plan and a key step in the vendor's productization efforts.	Availability of experienced and knowledgeable workforce issues continues to be of vital importance to the ASCR facilities and to the NSCI exascale goals. The CSGF program plays an important role in providing future DOE leaders in HPC and computational science. Therefore, Research and Evaluation Prototypes will continue support for the program at $10,000,000 in FY 2017. This activity will also support a modest effort in cybersecurity research that is focused on the unique challenges of open-science HPC systems and a small scale testbed for researchers explore technologies "Beyond Moore's Law".	With the initiation of the SC-ECP, REP funding of $107,894,000 (a reduction of $3,577,000 from the FY 2016 level for these efforts) has been shifted to the newly established Exascale Computing subprogram. Increase is for a new effort in cybersecurity and a testbed for "Beyond Moore's Law" research efforts.

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs FY 2016
Support is provided for non-recurring engineering efforts in support of ASCR facilities. To emphasize the vital importance of the CSGF program to the ASCR facilities and to our exascale goals, Research and Evaluation Prototypes supports the program at $10,000,000.		
High Performance Network Facilities and Testbeds $38,000,000	**$45,000,000**	**+$7,000,000**
ESnet operates 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.	ESnet has become a critical enabler of 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. This request provides bandwidth increases to support data requirements of all Office of Science facilities; upgrades selected high-traffic links to 400-gbps technology; supports transatlantic access to LHC data; and extends direct science engagement efforts to improve end-to-end network performance between DOE facilities and U.S. universities. The request also continues ongoing enhancement of network architectures and 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 R&D 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.	Increase supports operations and staff for the ESnet, including upgrading high-traffic links to 400 gbps; transatlantic access to LHC data; expansion of science engagement efforts; and research and tool development.
SBIR/STTR $15,036,000	**$16,291,000**	**+$1,255,000**
In FY 2016, SBIR/STTR funding is set at 3.45% of non-capital funding.	In FY 2017, 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 ASCR's participation in the U. S. Department of Energy's ECI, to ensure the hardware and software R&D, including applications software, for a capable exascale system is completed in time to meet the scientific and national security mission needs of the mid-2020s.

On July 29, 2015 President Obama established, by Executive Order, the National Strategic Computing Initiative (NSCI) to maximize the benefits of High Performance Computing (HPC) for U.S. economic competitiveness and scientific discovery. DOE is one of the three lead agencies for the NSCI and is specifically assigned the responsibility for executing a program, joint between Office of Science and NNSA, to develop a capable exascale computing program with an emphasis on sustained performance on relevant applications and analytic computing to support DOE missions.

The SC-ECP comprises R&D and delivery 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*, which has been used by the Office of Science 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 will use a tailored version of Order 413.3B. The first four years of SC-ECP will focus on research in software (new algorithms and methods to support application and system software development) and hardware (node and system design). During the last six years of the SC-ECP, activities will focus on delivering application software, the system software stack, and hardware technologies that will be deployed in the exascale systems.

FY 2017 funding will support codesign activities with a representative subset of mission applications; efforts to develop an exascale software stack, new programming models and efforts to promote ease of use; increase parallelism, energy efficiency, and reliability; and the initiation of vendor partnerships to design and develop scalable prototypes of exascale systems.

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs FY 2016
17-SC-20 Office of Science Exascale Computing Project (SC-ECP) $0	**$154,000,000**	**+$154,000,000**
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 2017 funding will support codesign activities with a representative subset of mission applications; efforts to develop an exascale software stack, new programming models and efforts to promote ease of use; increase parallelism, energy efficiency, and reliability and the initiation of vendor partnerships to design and develop scalable prototypes of exascale systems.	Increase reflects the transfer of exascale research efforts previously funded within Applied Mathematics, Computer Sciences, Computational Partnerships, and Research and Evaluation Prototypes activities.

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. The following table shows the targets for FY 2015 through 2017. Details on the Annual Performance Report can be found at http://energy.gov/cfo/reports/annual-performance-reports.

	FY 2015	FY 2016	FY 2017
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.		
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	Conduct an external peer review of the three original co-design centers to document progress, impact, and lessons learned.	Fund two teams to develop exascale node designs.	Fund two teams to develop programming environments for exascale computing systems.
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 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
Capital operating expenses							
Capital equipment	n/a	n/a	8,000	13,100	6,000	5,000	-1,000

Funding Summary ($K)

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
Research	228,169	221,018	294,466	315,011	+20,545
Scientific user facility operations	295,242	302,393	305,317	324,145	+18,828
Other	17,589	0	21,217	24,024	+2,807
Total, Advanced Scientific Computing Research	**541,000**	**523,411**	**621,000**	**663,180**	**+42,180**

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

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

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

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

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

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

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

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
TYPE A FACILITIES					
NERSC	**$75,605**	**$75,905**	**$86,000**	**$92,145**	**+6,145**
Number of Users	5,608	5,608	5,608	6,000	+392
Achieved operating hours	N/A	N/A	N/A	N/A	N/A
Planned operating hours	8,585	8,585	8,585	8,322[a]	-263
Optimal hours	8,585	8,585	8,585	8,322	-263
Percent optimal hours	N/A	N/A	N/A	N/A	N/A
Unscheduled downtime hours	N/A	N/A	N/A	N/A	N/A

[a] Due to the planned upgrade NERSC will schedule less hours for FY 2017. However, the significant increase in the capacity of this upgrade system will allow NERSC to deliver an increase in computing time for users despite the reduced schedule.

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
OLCF	**$104,317**	**$108,902**	**$104,317**	**$107,000**	**+$2,683**
Number of Users	1,064	1,064	1,064	1,064	-
Achieved operating hours	N/A	N/A	N/A	N/A	N/A
Planned operating hours	7,008	7,008	7,008	7,008	-
Optimal hours	7,008	7,008	7,008	7,008	-
Percent optimal hours	N/A	N/A	N/A	N/A	N/A
Unscheduled downtime hours	N/A	N/A	N/A	N/A	N/A
ALCF	**$80,320**	**$81,796**	**$77,000**	**$80,000**	**+$3,000**
Number of Users	1,434	1,434	1,434	1,434	-
Achieved operating hours	N/A	N/A	N/A	N/A	N/A
Planned operating hours	7,008	7,008	7,008	7,008	-
Optimal hours	7,008	7,008	7,008	7,008	-
Percent optimal hours	N/A	N/A	N/A	N/A	N/A
Unscheduled downtime hours	N/A	N/A	N/A	N/A	N/A
ESnet	**$35,000**	**$35,790**	**$38,000**	**$45,000**	**+$7,000**
Number of users[a]	N/A	N/A	N/A	N/A	N/A
Achieved operating hours	N/A	N/A	N/A	N/A	N/A
Planned operating hours	8,760	8,760	8,760	8,760	-
Optimal hours	8,760	8,760	8,760	8,760	-
Percent optimal hours	N/A	N/A	N/A	N/A	N/A
Unscheduled downtime hours	N/A	N/A	N/A	N/A	N/A

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

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
Total Facilities	**$295,242**	**$302,393**	**$305,317**	**$324,145**	**+$18,828**
Number of Users[a]	8,106	8,106	8,106	8,498	+392
Achieved operating hours	N/A	N/A	N/A	N/A	N/A
Planned operating hours	31,361	31,361	31,361	31,098	-263
Optimal hours	31,361	31,361	31,361	31,098	-263
Percent of optimal hours[b]	N/A	N/A	N/A	N/A	N/A
Unscheduled downtime hours	N/A	N/A	N/A	N/A	N/A

Scientific Employment

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Estimate	FY 2017 vs FY 2016
Number of permanent Ph.D.'s (FTEs)	548	548	584	636	+52
Number of postdoctoral associates (FTEs)	137	137	146	165	+19
Number of graduate students (FTEs)	428	428	460	486	+26
Other scientific employment (FTEs)[c]	234	234	247	257	+10

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

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

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

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

1. Significant Changes and Summary

Significant Changes

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 in partnership with the National Nuclear Security Administration (NNSA) and addresses DOE's science and national security mission requirements. In FY 2016, an Exascale Crosscut aggregated Office of Science programs (specifically the Advanced Scientific Computing Research (ASCR), Basic Energy Sciences (BES), and Biological and Environmental Research (BER) programs) and NNSA exascale activities.

In FY 2017, the Office of Science 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 activities required for the delivery of exascale computers. The FY 2017 Request for this project is $154,000,000, which represents only those activities, and is a decrease of $3,894,000 below the FY 2016 Enacted level of $157,894,000[a]. Other activities related to the ECI but outside of the scope of the delivery of exascale computers are not within the SC-ECP, though they do remain in the scope of the ECI and are funded through the Exascale Computing subprogram in ASCR, and through subprograms within BES and BER. This Project Data Sheet is for the SC-ECP only; prior-year activities related to the SC-ECP are also included.

Summary

On July 29, 2015, President Obama established by Executive Order the National Strategic Computing Initiative (NSCI) to maximize the benefits of High Performance Computing (HPC) for U.S. economic competitiveness, scientific discovery, and national security. DOE is one of three lead federal agencies for the NSCI, and it is specifically assigned the responsibility for executing the ECI. As a lead agency, DOE will work with other agencies identified in the NSCI to implement the objectives of the NSCI and to address the wide variety of needs across the Federal Government.

In FY 2017, SC-ECP funding will support project management; development of project documentation; conduct of co-design activities with a representative subset of mission applications; research and development of exascale systems software and tools needed for exascale programming; and vendor partnerships. The estimated Total Project cost range of the SC-ECP is $1.7 billion to $2.7 billion.

2. Critical Milestone History

(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

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 $1.7 billion and $2.7 billion. The cost range will be updated at CD-0 and CD-1, and a project baseline (scope, schedule, and cost) will be established at CD-2.

[a] In FY 2016, ASCR's ECI activities were not partitioned into a separate program/project.

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 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 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 four focus areas:

1. *Hardware Technology:* The Hardware Technology focus area supports vendor-based research and development 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.
2. *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.
3. *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.
4. *Exascale Systems:* The Exascale Systems focus area supports advanced system engineering development by the vendors needed to produce capable exascale systems. System procurement activities will be executed in coordination with each DOE HPC facility's existing system acquisition timelines. It also includes acquisition and support of prototypes and testbeds for the application, software, and hardware testing activities. No civil construction is within the scope of the SC-ECP.

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 the Office of Science for the planning, design, and construction of all of its major projects, including the Leadership Computing Facilities 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 five years of the project, project activities will focus on delivering application software, the system software stack, and hardware technologies that will be deployed in the exascale systems 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. Preliminary Financial Schedule

	(dollars in thousands)		
	Appropriations	Obligations	Costs
Total Estimated Cost (TEC) (Delivery of Applications Development, System Software Technology Hardware Technology and Exascale Systems)			
FY 2016[a]	0	0	0
FY 2017	0	0	0
FY 2018[b] – FY 2025	TBD	TBD	TBD
Subtotal	TBD	TBD	TBD
Total, TEC	TBD	TBD	TBD
Other project costs (OPC) (Research for Application Development , System Software Technology and Hardware Technology)			
FY 2016[a]	157,894	157,894	87,370
FY 2017	154,000	154,000	156,000
FY 2018	TBD	TBD	68,524
FY 2019 – FY 2026	TBD	TBD	TBD
Subtotal	TBD	TBD	TBD
Total, OPC	TBD	TBD	TBD
Total Project Costs (TPC)			
FY 2016[a]	157,894	157,894	87,370
FY 2017	154,000	154,000	156,000
FY 2018[b]	TBD	TBD	68,524
FY 2019 – FY 2026	TBD	TBD	TBD
Subtotal	TBD	TBD	TBD
Total, TPC	TBD	TBD	TBD

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

[b] The project is currently pre-CD-0 so yearly planning numbers are not available.

6. Details of the 2017 Project Cost Estimate

The SC-ECP will be baselined at CD-2. The current cost estimate is based on pre-CD-0 information. 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)			
Production Ready Software	TBD	N/A	N/A
Hardware Build	TBD	N/A	N/A
Total, TEC	TBD	N/A	N/A
Other Project Costs (OPC) (Research)			
Planning/Project Mgmt	8,000	N/A	N/A
Application Development	85,000	N/A	N/A
Software Research	87,000	N/A	N/A
Hardware Research	131,894	N/A	N/A
Total OPC	TBD	N/A	N/A
Total, TPC	TBD	N/A	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

8. Related Operations and Maintenance Funding Requirements

System procurement activities for the capable exascale computers are not part of the SC-ECP. The exascale computers will become part of existing facilities and operations and maintenance funds and will be included in the ASCR facilities' operations budget.

Start of Operation	2024
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.

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

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 five years duration will support finalizing applications and system software, the procurement of an exascale computer system, and start of operations.

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 DOE missions in energy, environment, and national security.

The research disciplines that BES supports—condensed matter and materials physics, chemistry, geosciences, and aspects of physical 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. BES facilities probe materials 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 and computational models can predict the behavior of materials before they exist.

As history has shown, breakthroughs in clean energy technologies will likely be built on a foundation of basic research advances. Key to exploiting such discoveries is the ability to create new materials using sophisticated synthesis and processing techniques, precisely define the atomic arrangements in matter, and control physical and chemical transformations. The energy systems of the future—whether they tap sunlight, store electricity, or make fuel by splitting water or reducing carbon dioxide—will revolve around materials and chemical changes that convert energy from one form to another. Such materials will need to be more functional than today's energy materials. To control chemical reactions or to convert a solar photon to an electron requires coordination of multiple steps, each carried out by customized materials with designed nanoscale structures. Such advanced materials are not found in nature; they must be designed and fabricated to exacting standards using principles revealed by basic science.

Highlights of the FY 2017 Budget Request

The BES FY 2017 Request includes increases for core research and the Energy Frontier Research Centers (EFRCs) in key areas related to Departmental priorities, such as topics in support of the 2015 Quadrennial Energy and Technology Reviews, the Departmental crosscuts, and priorities outlined in the 2015 Basic Energy Sciences Advisory Committee Report, "Challenges at the Frontiers of Matter and Energy: Transformative Opportunities for Discovery Science." A new activity is initiated in Computational Chemical Sciences to leverage U.S. leadership in computational chemistry codes in preparation for exascale computing; this systematic effort to modify or replace existing computational chemistry codes with codes that are well-adapted to anticipated exascale architectures is essential to maintain U.S. leadership in this high impact competitive area. The Request also continues support for the Batteries and Energy Storage Energy Innovation Hub, the Fuels from Sunlight Energy Innovation Hub, and Computational Materials Sciences at the FY 2016 Enacted level.

Toward enabling advancement of clean energy technologies, the BES FY 2017 Request increases support for applicable fundamental research directions. Among these investments, studies of materials and chemistry in extreme environments will analyze key dynamics of phenomena that are central to sustainable clean energy technologies, such as non-equilibrium material response and degradation and the decay and separation of heavy elements and their isotopes in nuclear waste. Research on chemistry and materials for energy efficiency will target a wide range of processes for clean energy utilization and conversion, such as photocatalysis, solar energy conversion, biomimetic catalysis, and thermal conversion materials.

In FY 2017, BES will support optimal operations at all of its scientific user facilities, including support for clean energy research. The Linac Coherent Light Source-II project will continue construction activities, and the Advanced Photon Source-Upgrade Major Item of Equipment (MIE) project is flat funded. FY 2016 is the last year of funding for the NSLS-II Experimental Tools (NEXT) MIE project; no funds are requested in FY 2017. As part of the Presidential BRAIN Initiative and in close coordination with the National Institutes of Health, BES will develop next generation tools and technologies at DOE X-ray Light Sources and Nanoscale Science Research Centers to enable advances in brain imaging and sensing.

In the FY 2017 Request, most funding for the DOE Working Capital Fund (WCF) is transferred to Science Program Direction to establish a consolidated source of funding for goods and services provided by the WCF. The Department's CyberOne project is still funded through program dollars in the Office of Science (SC) Safeguards and Security program. In FY 2016 and prior years, SC WCF costs were shared by SC research programs and Science Program Direction.

The BES FY 2017 Budget Request includes increases for research related to three Department-wide crosscutting activities: Subsurface Science, Technology and Engineering R&D (Subsurface), the Exascale Computing Initiative (ECI), and Advanced Materials for Energy Innovation as described below.

- *Advanced Materials (Adv Mat)* – As part of the Advanced Materials for Energy Innovation crosscut, BES will initiate new research activities to understand materials challenges in the areas of lightweight structural materials, corrosion-resistant materials in extreme environments, and quantum materials. The expanded research will emphasize interfaces in lightweight materials and corrosion, development of new characterization tools and predictive capabilities to design improved chemistries and structures, and discovery of new quantum materials with unprecedented properties. These priorities were identified in the 2015 Quadrennial Technology Review, with research directions supported by BES basic research needs reports and the 2015 BES Advisory Committee report "Challenges at the Frontiers of Matter and Energy: Transformative Opportunities for Discovery Science."

- *Exascale Computing Initiative (ECI)* – As part of the ECI, BES will be responsible for the Computational Materials Sciences activity and will initiate a new Computational Chemical Sciences activity in FY 2017. Collectively, Computational Materials and Chemical Sciences will support basic research resulting in codes to predictively design functional materials and chemical processes, including codes that take full advantage of the future generation of exascale leadership computing capabilities. The report from the foundational workshop for this activity, Computational Materials Science and Chemistry (2010), and the follow-on community-based workshops that occurred in 2011–2015 identified a number of applications that would take full advantage of future exascale computing resources, including: 1) new catalysts to improve the efficiency of industrial processes, make effective use of bioenergy, drive energy conversion processes, and mitigate environmental impact; 2) better models of photovoltaic processes and improved efficiency of photovoltaic devices; 3) natural and artificial photosynthesis to unlock the potential of solar driven energy conversion and storage; 4) next generation electronic and magnetic materials whose properties are governed by the strong interactions of electrons and have totally new functionalities; 5) membranes and molecular complexes composed of solid-gas/liquid interfaces, which are critical for separation technologies for energy and water applications.

- *Subsurface Science, Technology and Engineering R&D (Subsurface)* – In FY 2015, BES organized and participated in two strategic planning activities that identified a grand challenge for subsurface science: "Advanced imaging of geophysical and geochemical signals in the subsurface." BES will initiate new Energy Frontier Research Centers in FY 2017 to support multidisciplinary teams to address this grand challenge. The scientific focus will be on fracture networks, associated fluid flow and reaction, and the gaps in fidelity, resolution, and conceptual understanding of subsurface imaging in hard-to-access environments. In addition, BES will support single investigator research on fundamental geochemistry and geophysics with an emphasis on subsurface fluid flow and complex chemistry on widely varying timescales from microseconds to millennia. This research is anticipated to have high relevance for oil and gas production, geothermal energy applications, carbon capture and storage, and nuclear waste disposal.

FY 2017 Crosscuts ($K)

	Subsurface	ECI	Adv Mat	Total
Basic Energy Sciences	41,300	26,000	17,600[a]	84,900

[a] This $17,600K supports the Department's Advanced Materials Crosscut. An additional $11,500K in BES for Quantum Materials is also included in SC's total investment, as described in the advanced materials crosscut narrative.

Basic Energy Sciences
Funding ($K)

	FY 2015 Enacted	FY 2015 Current[a]	FY 2016 Enacted	FY 2017 Request[b]	FY 2017 vs FY 2016
Materials Sciences and Engineering					
Scattering and Instrumentation Sciences Research	64,407	67,788	62,260	70,318	+8,058
Condensed Matter and Materials Physics Research	122,120	120,539	118,049	133,800	+15,751
Materials Discovery, Design, and Synthesis Research	72,424	70,882	70,010	76,871	+6,861
Experimental Program to Stimulate Competitive Research (EPSCoR)	9,951	9,951	14,776	8,520	-6,256
Energy Frontier Research Centers (EFRCs)	50,800	50,800	55,800	55,800	0
Energy Innovation Hubs—Batteries and Energy Storage	24,175	24,175	24,137	24,088	-49
Computational Materials Sciences	8,000	8,000	12,000	12,000	0
SBIR/STTR	12,008	0	12,758	14,448	+1,690
Total, Materials Sciences and Engineering	**363,885**	**352,135**	**369,790**	**395,845**	**+26,055**
Chemical Sciences, Geosciences, and Biosciences					
Fundamental Interactions Research	76,796	73,429	74,599	79,233	+4,634
Chemical Transformations Research	93,493	91,000	92,341	106,423	+14,082
Photochemistry and Biochemistry Research	68,797	73,735	64,189	71,197	+7,008
Energy Frontier Research Centers (EFRCs)	49,200	49,200	54,200	86,766	+32,566
Energy Innovation Hubs—Fuels from Sunlight	15,000	15,000	15,000	15,000	0
Computational Chemical Sciences	0	0	0	13,635	+13,635
General Plant Projects (GPP)	600	1,000	1,000	1,000	0
SBIR/STTR	10,350	0	10,732	14,102	+3,370
Total, Chemical Sciences, Geosciences, and Biosciences	**314,236**	**303,364**	**312,061**	**387,356**	**+75,295**
Scientific User Facilities					
Synchrotron Radiation Light Sources	447,186	450,103	481,906	489,059	+7,153
High-Flux Neutron Sources	244,113	245,050	264,645	261,177	-3,468
Nanoscale Science Research Centers (NSRCs)	113,649	114,925	118,763	122,272	+3,509
Other Project Costs	9,300	9,300	0	0	0
Major Items of Equipment	42,500	42,500	35,500	20,000	-15,500
Research	31,713	26,847	34,853	37,537	+2,684
SBIR/STTR	27,918	0	31,182	33,484	+2,302
Total, Scientific User Facilities	**916,379**	**888,725**	**966,849**	**963,529**	**-3,320**
Subtotal, Basic Energy Sciences	**1,594,500**	**1,544,224**	**1,648,700**	**1,746,730**	**+98,030**

[a] Reflects the transfer of Small Business Innovation/Technology Transfer Research (SBIR/STTR) funds within the Office of Science.
[b] A transfer of $3,867,000 to Science Program Direction is to consolidate all Working Capital Funds in one program.

	FY 2015 Enacted	FY 2015 Current[a]	FY 2016 Enacted	FY 2017 Request[b]	FY 2017 vs FY 2016
Construction					
Linac Coherent Light Source-II (LCLS-II), SLAC	138,700	138,700	200,300	190,000	-10,300
Total, Construction	**138,700**	**138,700**	**200,300**	**190,000**	**-10,300**
Total, Basic Energy Sciences	**1,733,200**	**1,682,924**	**1,849,000**	**1,936,730**	**+87,730**

SBIR/STTR Funding:

- FY 2015 Transferred: SBIR $44,182,000 and STTR $6,094,000
- FY 2016 Projected: SBIR $47,540,000 and STTR $7,132,000
- FY 2017 Request: SBIR $54,385,000 and STTR $7,649,000

Basic Energy Sciences
Explanation of Major Changes ($K)

	FY 2017 vs FY 2016 Enacted
Materials Sciences and Engineering: Additional funds are requested to support research in areas identified as high priorities in the Quadrennial Technology Review, the Departmental crosscuts, and the 2015 BES Advisory Committee report "Challenges at the Frontiers of Matter and Energy: Transformative Opportunities for Discovery Science." A major emphasis is an increase in materials research under extremes of temperature, pressure, stress, photon and radiation flux, electromagnetic fields, and electrochemical environments often encountered in clean energy technologies. Additional research will support novel materials for enhanced efficiency in energy conversion and utilization. Topical areas cover light-weight composites, thermoelectric and thermocaloric materials for efficient heat conversion, and quantum materials for next generation electronics. There will be an increase in synthesis science underpinning these enhanced activities. Specifically, the research will target the development of the understanding required for predictive design of interfaces in lightweight polymer composite materials that are relevant to efficient energy systems and transportation; to determine the mechanisms of corrosion in radiative and other extreme chemical/temperature environments relevant to improved energy generation systems; to investigate quantum materials as a foundation for next generation electronics and computing; to study thermal transport in materials to make efficient use of heat; to advance new characterization tools to understand how materials respond and evolve during actual use; and to develop models of materials synthesis that enable understanding of how to control and configure atoms to achieve a desired structure and function.	**+26,055**
Chemical Sciences, Geosciences, and Biosciences: A new initiative in Computational Chemical Sciences will leverage U.S. leadership in computational chemistry codes in preparation for the path to exascale computing. A systematic effort to modify or replace existing computational chemistry codes with codes that are well-adapted to anticipated exascale architectures is critically needed to enable high-fidelity simulations to inform models that improve and accelerate the research, design, demonstration, and deployment phases of the energy innovation cycle. Additional funds are requested to support single investigator and team research related to the Subsurface crosscut. Through the Energy Frontier Research Center (EFRC) program, BES will support multidisciplinary teams to address the grand challenge of "advanced imaging of geophysical and geochemical signals in the subsurface," with a focus on fracture networks, associated fluid flow and reaction, and the gaps in fidelity, resolution, and conceptual understanding of subsurface imaging in hard-to-access environments. In addition, BES will support single investigator research on fundamental geochemistry and geophysics with an emphasis on subsurface fluid flow and complex chemistry on widely varying timescales from microseconds to millennia. Among efforts to enable advances in clean energy technologies, chemistry research will target the areas of energy efficiency and chemistry in extreme environments. Investments in energy efficiency will target the discovery of catalysts with higher activity and selectivity, leading to lower energy consumption for chemical conversions and less demand for the purification of products. BES will support small groups of multidisciplinary investigators to draw on biomimetic and computational expertise, including synergistic approaches such as electro- and photo (electro) catalysis. Chemistry under extreme conditions will focus on the radiative environments generated by energetic photons, electrons and intense x-rays, for example, to understand nuclear waste mixtures. Targeted research will elucidate the nature, dynamics, and kinetics of complex chemical processes ranging from fundamental research on elements with f-electrons to highly selective removal of specific radioactive species.	**+75,295**

	FY 2017 vs FY 2016 Enacted
Scientific User Facilities: BES will support optimal operations at all of the scientific user facilities—five light sources, five Nanoscale Science Research Centers, and two neutron sources—to enable research including clean energy research. FY 2016 is the last year of funding for the NEXT MIE project. In FY 2017, no funds are requested for NEXT or for Other Project Costs for the Linac Coherent Light Source-II (LCLS-II) construction project per the project plan. The Advanced Photon Source-Upgrade MIE project is flat funded. As part of the Presidential BRAIN Initiative and in close coordination with the National Institutes of Health, BES will develop next generation tools and technologies at DOE X-ray Light Sources and Nanoscale Science Research Centers to enable advances in brain imaging and sensing.	**-3,320**
Construction: Funding for the LCLS-II construction project will decrease slightly in FY 2017 per the project plan.	**-10,300**
Total, Basic Energy Sciences	**+87,730**

Basic and Applied R&D Coordination

As a program that supports fundamental scientific research relevant to many Department of Energy 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. For example, the DOE Energy Innovation Hubs Working Group meets regularly to coordinate programmatic oversight and promote commonality across the Hubs. BES also coordinates with DOE technology offices on 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 have also established formal technical coordination working groups that meet on a regular basis to discuss R&D programs with wide applications for basic and applied programs including the Office of Environmental Management. Additionally, DOE technology office personnel participate in reviews of BES research, and BES personnel participate in reviews of research funded by the technology offices and the Advanced Research Projects Agency-Energy (ARPA-E).

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

National Synchrotron Light Source-II. The NSLS-II construction project has been completed on time and within budget.

- Construction of the most advanced storage-ring-based light source facility in the world, the National Synchrotron Light Source-II (NSLS-II) at Brookhaven National Laboratory, was completed in March 2015, about 3 months ahead of schedule. The planning, design, and construction of this 627,000-square-foot facility spanned 10 years at a total project cost of $912 million. The project benefited from $150 million of American Recovery and Reinvestment Act funding, which allowed the project to accelerate civil construction and to reduce overall project risks. This premier BES scientific user facility produces extremely bright beams of x-rays, providing unprecedented capabilities to accelerate advances in chemistry, biology, energy, geology, physics, and materials science. NSLS-II has been officially designated as a user facility and started serving general users in July 2015.

Chemistry by Design. Coupling predictive theory and computation with advanced synthesis has led to the discovery of molecular assemblies with novel functions.

- Complementary computational and experimental analyses revealed the interplay of electronic and geometric effects that are responsible for the formation of a new class of nanoscale cage clusters of uranium peroxide. These clusters could be produced under chemically simple conditions and be tailored to selectively bind to toxic or undesirable chemical species, enabling their use in chemical purification and separation for nuclear fuel reprocessing or environmental decontamination.
- In a feat of computational chemistry, researchers bypassed potentially decades of experiments with the results from one day's worth of computing time on the Argonne Leadership Computing Facility supercomputer, Mira. Rather than synthesize hundreds of thousands of catalytic porous zeolites and test each one for their ability to purify ethanol and enhance fuel production, the researchers utilized a hierarchical predictive chemical simulation to predict the most effective zeolitic structure. Synthesis and experimental testing of the predicted zeolitic

framework proved that the simulation produced the "right answer": a new catalyst that is highly effective, with potential to streamline industrial-scale ethanol purification from a multi-step to single-step process.

- Experiments and computation were used to demonstrate that a new compound based on a metal-organic framework (MOF) was effective in degrading soman—one of the most toxic chemical agents—in minutes. The new MOF structure contains nodes of zirconium atoms that selectively break the bond in the nerve agent, rendering it innocuous. While the structural design was inspired by a natural enzyme in bacteria, the new MOF compound is thermally and chemically robust and functions in wide temperature ranges and humid environments.

Cooperative interactions drive new molecular behavior. Complex interactions and correlations of the atomic and molecular constituents in matter have resulted in new chemical properties, expanding the frontiers of energy applications.

- Conversion of nitrogen to ammonia, as in the synthetic Haber-Bosch process, also occurs in natural systems, following a far less energy-intensive pathway. Computational analysis of this pathway in the nitrogenase enzyme of algae and plants revealed that a small iron-based protein "rocks" across the surface of the larger nitrogenase unit during the conversion. The rocking motion pushes the two molecular units into close contact, facilitating the key transfer of electrons. This insight may lead to innovative design principles for a more energy-efficient synthetic process.
- X-ray crystallography showed how the orange carotenoid protein in cyanobacteria may protect plants from photodamage when exposed to sunlight. Researchers observed that under illumination, a carotenoid pigment molecule within the protein moved 12 Ångstroms (approximately 4 atom widths)—an extremely large movement whose scale is unprecedented in observations of this kind. Researchers hypothesized that the movement couples the pigment to the light absorbers in plants, allowing excess light energy to be converted to heat and preventing photodamage. Understanding such interactions that are central to light harvesting and photoprotection can help guide design of stable and efficient artificial photosynthetic systems.
- Experiments and computation have uncovered a novel cooperative mechanism for CO_2 adsorption in porous MOF materials. Insertion of one CO_2 molecule into the MOF facilitates the insertion of another CO_2 at a neighboring site, resulting in a "domino effect" of carbon adsorption along the cylindrical pores of the MOF. This efficient and tunable class of adsorbents may allow for drastic reductions in the capital cost of carbon capture from power plant flue gas or from the atmosphere.

Predictive Materials Science. The Materials Genome Initiative supports the integration of theory and experimental research to accelerate materials discovery. New computer codes and extensive databases for predictive materials science research are now available to the public.

- By harnessing high performance computing and state-of-the-art theoretical tools, computed properties of new and predicted materials have been gathered into a publicly available database for over 60,000 compounds, 70,000 electrochemical phase diagrams, 28,000 electronic band structures, and 1,300 full elastic tensors (for mechanical behavior). These data are being used by over 16,000 scientists and engineers, including over 2,000 from industry, to identify new electrolytes and electrode materials for batteries, thermoelectric materials, and photocatalysts for chemical conversions.
- Through a combination of theory and advanced characterization techniques, the roles of specific element additions to magnesium alloys have been predicted, and then demonstrated via experiments, to promote development of precipitates that optimally control the mechanical properties of the lightweight materials. The results led to new mechanistic understanding on how to make lightweight materials stronger.
- Improved algorithms have been developed for the quantum Monte Carlo method, a computational technique that can predict the quantum state and geometric structure of complex materials for which standard methods fail. The new codes are publicly available and have predicted experimentally-validated binding energies and diffusivities for lithium ion batteries, surface energies for catalysts, volumes and bulk moduli for metals and ionic materials, and melting temperatures of hydrogen under pressure.

Going beyond post-mortem analysis – materials characterization in real time and under real operating conditions. "In situ" or "in operando" characterization investigates materials evolution, leading to more efficient synthesis and discovery of new and improved materials.

- During charging and discharging of a commercial lithium ion battery, a novel, lensless x-ray diffraction technique imaged the structure of a nanoparticle in an electrode and the migration of defects. During extreme charging, phase changes were localized to the material near the defects, providing new understanding that could lead to defect engineering for optimized battery performance.
- Catalysts drive efficient industrial processes for energy production and pollution control. During high-energy x-ray experiments, specific surface characteristics of palladium and nickel nanoparticles were observed to accelerate the conversion of carbon monoxide to CO_2. Analysis of the experiments, combined with theoretical calculations, showed that the number of atomic neighbors at surface sites and the distances between atoms can tune catalytic activity.
- For the first time, nanoparticles rotating freely in a liquid solution have been "seen" in three dimensions (3D) with near-atomic resolution. Images from world-leading electron microscopes, equipped with a graphene-based liquid cell and direct electron detectors, were reconstructed into high-resolution 3D movies of the interactions and growth of platinum nanoparticles. Results confirmed that individual, and surprisingly asymmetric, particles from the same synthesis solution followed different growth pathways, providing a new approach to understand and control growth of nanoparticle structures.

BES user facilities enable U.S. industries to advance frontiers in information and semiconductor technologies.

- An original laser zone annealing apparatus has been constructed at the Center for Functional Nanomaterials that can quickly form self-assembled polymer nanostructures over an 8-inch-diameter semiconductor wafer. The new process reduces the ordering time of the block-copolymer self-assembly by more than 1,000-fold, from hours to less than a second, making this tool extremely attractive for industrial-scale, rapid manufacture of ordered nanoscale arrays for terabyte magnetic memories, nanoelectronics, and nanophotonics.
- The IBM Research Alliance worked with researchers at Argonne National Laboratory to develop a new method for quantitatively mapping the detailed structures of microprocessors at nanoscale spatial resolution. The ability to noninvasively detect and control subtle perturbations of the atomic crystal lattice planes in operating devices is critical to improving the performance and reliability of computer processors. This technique can also be applied to other nanoscale systems such as photovoltaics, power electronics, and batteries.
- Researchers at the Center for Nanoscale Materials transferred their innovative low-temperature diamond deposition technology to the U.S. semiconductor industry. The method deposits nanocrystalline diamond on a variety of wafer substrate materials at temperatures as low as 400°C, enabling for the first time the integration of high-power diamond electronics with conventional silicon integrated circuits.

Neutron scattering enables basic discoveries in magnetism, solving a decades-old conundrum, and facilitates advances critical to performance of fuel injectors and catalytic converters.

- Researchers have discovered time-fluctuating magnetism in the radioactive element plutonium (Pu) using inelastic neutron scattering techniques at the Spallation Neutron Source. The surprising result that the magnetism is not of a conventional static character, but instead rapidly fluctuates in time, resolves a 50-year-old controversy between theory and experiment over the existence of magnetism in Pu.
- Using time-resolved neutron imaging, scientists have observed local fuel flow dynamics of a gasoline injector nozzle. Measurements reveal cavitation and local pressure-drop effects during one-millisecond-long injection events. These first direct observations are critical in developing advanced computational models and in understanding fluid flow processes to improve vehicle fuel efficiency and lower emissions.
- Neutron imaging has been used to measure the distribution of water inside an entire catalytic converter for vehicles. The presence of water can seriously degrade the performance of these converters, and neutron imaging provides a unique insight into how such engineered water-management systems perform in practical operations.

Basic Energy Sciences
Materials Sciences and Engineering

Description

The 2015 Quadrennial Energy and Technology Reviews confirm the continued critical role of materials to nearly every aspect of energy generation and end-use, especially as these challenges relate to clean energy and energy efficiency. Materials limitations are often the barrier to improved energy efficiencies, longer lifetimes of infrastructure and devices, or the introduction of new or cleaner energy technologies. The latest BES Advisory Committee report, "Challenges at the Frontiers of Matter and Energy: Transformative Opportunities for Discovery Science," provided 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 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 – 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. Finally, the research includes investigation of the interfaces between physical and biological sciences to explore new approaches to novel materials design. This subprogram is also the home of the DOE Experimental Program to Stimulate Competitive Research (EPSCoR) that supports research spanning the broad range of DOE's science and technology programs in states that have historically received relatively less Federal research funding in the university sector.

Among its efforts toward enabling advancement of clean energy technologies, the subprogram stresses fundamental research related to materials behavior under extreme environments and on materials phenomena that will promote more efficient use and conversion of energy. New materials and their responses under extremes in temperature, pressure, stress, photon and radiation flux, electromagnetic fields, and electrochemical environments are important to future improvements in energy efficiency and for clean generation and use. Advanced characterization tools and instruments across a wide range of space and time scales, especially in combination and under dynamic "in operando" conditions that can analyze non-equilibrium materials and excited-state phenomena, are essential to this work. For thermal energy efficiency, new thermocaloric materials can improve efficiency in cooling and in microelectronic devices, and new thermoelectric materials can convert wasted heat into electricity. New fundamental understanding of heat transport and energy conversion in materials and of the behavior of thermoelectric properties is necessary for these advances. Additional research will target lightweight materials such as polymers and polymer composites, and new families of porous materials of importance for carbon capture technologies.

In addition to single-investigator and small-group research, the subprogram supports Energy Frontier Research Centers (EFRCs), the Batteries and Energy Storage Energy Innovation Hub, and Computational Materials Sciences activities. These research modalities support multi-investigator, multidisciplinary research and focus on forefront energy technology challenges. The EFRCs support teams of investigators to perform basic research to accelerate transformative solutions for a wide range of energy technologies. The Batteries and Energy Storage Hub supports a large, tightly integrated team and research that spans basic and applied regimes with the goal of providing the scientific understanding that will enable the next generation of electrochemical energy storage for vehicles and the electrical grid. 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.

Scattering and Instrumentation Sciences Research

Advanced characterization tools with very high precision in space and time are essential to understand, predict, and ultimately control matter and energy at the electronic, atomic, and molecular levels. These capabilities provide the foundation for research central to DOE missions in energy, environment, and national security. Research in Scattering and Instrumentation Science supports innovative science, techniques, and instrumentation for scattering, spectroscopy, and imaging using electrons, neutrons, and x-rays. These tools provide precise information on the atomic structure and dynamics in materials. The use of DOE's world-leading electron, neutron, and synchrotron x-ray scattering facilities in major advances in materials science, and by large materials science user communities, is continuing evidence of the importance of this research field. The BES Advisory Committee report, "Challenges at the Frontiers of Matter and Energy: Transformative Opportunities for Discovery Science," identified imaging as one of the pillars for transformational advances for the future.

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 several orders of magnitude. A distinct aspect of this activity is the development of innovative instrumentation concepts and techniques for neutron scattering 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 techniques.

Understanding how extreme environments (temperature, pressure, stress, photon and radiation flux, electromagnetic fields, and electrochemicals) impact materials at the atomic and molecular 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.

Condensed Matter and Materials Physics Research

Understanding the foundations of how to control and change the properties of materials is critical to improving their functionality on every level and is 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, the materials that 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 strong 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. Emphasis is placed on investigating 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 is relevant to energy technologies and 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 electrical and thermal conduction in a wide range of material systems. 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. Theoretical research also includes development of computational and data-oriented techniques for materials discovery.

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.

The Quadrennial Technology Review identified materials research in this area as critical for additional investments and coordination with the DOE technology programs, especially related to more efficient and cleaner energy generation and use. Three key areas with high potential for accelerated development were identified and are proposed for additional research support: lightweight structural materials, corrosion-resistance for materials use in extreme environments, and quantum materials. A basic research challenge for lightweight materials such as polymer composites is improved understanding of how to design the interfaces between the matrix and the reinforcements, including new tools to characterize these interfaces and predictive capabilities to design improved chemistries and structures. The need for corrosion resistant materials is clear—energy technologies continue to place increasing demands on materials performance with respect to extremes in stress, strain, temperature, chemical reactivity and radiation flux as lifetimes are extended and operating conditions are optimized for maximal efficiency and minimal environmental impact. These operating conditions demand materials that can be used reliably in these extreme environments, requiring a comprehensive understanding of the impact of the degradation that results from exposures to these conditions. Additional research is proposed to assess the evolution of material structure and properties in multiple extreme environments, including multiscale modeling (nano to meso to macro) with emphasis on the interfaces in the materials, often a region with enhanced susceptibility to corrosion and degradation. Many energy-relevant technological advances, ranging from magnetism to superconductivity, are enabled by quantum materials. Due to recent advances in the ability to manipulate and exploit coherence in light and matter, additional research is proposed to take advantage of these phenomena to discover new materials with unprecedented properties. Research would include predictive modeling, evaluation of phenomena that occur at ultrafast timescales (beyond-equilibrium phenomena), and controlled synthesis and design of materials to enable high quality, tailored interfaces, controlled heterogeneity, and coherent manipulation of charge, spin and lattice dynamics that result in entirely new material properties.

In addition, new research will focus on developing a fundamental understanding of materials phenomena related to heat management and use of excess heat for improved thermal efficiency. Important to this research area is improved theoretical understanding of heat transport and energy conversion in materials. Fundamental theory to advance novel materials for high temperature environments, such as high-entropy alloys, will also be emphasized.

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 BES Advisory Committee 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. Research supported in this portfolio underpins many energy-related technologies such as batteries and fuel cells, catalysis and electrocatalysis, solar energy conversion and storage, friction and lubrication, and filtration membranes and porous architectures for advanced separations, efficient ion transport, and highly selective gas separation and storage. For example, for lighter weight materials, research on polymers and polymer composites generates new insights into the design of idealized matrix-additive interfaces, new chemistries, and exploiting the structural hierarchies to engineer a material's strength and other mechanical properties.

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.

Related to improved energy efficiency and expansion of the knowledge base for cleaner energy generation and use, thermocaloric and thermoelectric materials is a prominent area that will see significant growth. Another topic of increasing importance is carbon capture technologies, especially the development of new families of porous materials. This research will require a concerted effort in manipulating the pore sizes, gas-solid binding interactions and properties ranging from the mechanical stability to kinetic selectivity.

Experimental Program to Stimulate Competitive Research (EPSCoR)

DOE's Experimental Program to Stimulate Competitive Research (EPSCoR) is a Federal-State partnership program designed to enhance the capabilities and research infrastructure of designated states and territories to conduct sustainable and nationally competitive research. This activity supports basic research spanning the broad range of science and technology related to DOE mission areas in states and territories that have historically received relatively less Federal research funding than other states. EPSCoR supports research in these states that will develop their scientific capabilities and advance their ability to successfully compete for research funding through open research solicitations. The EPSCoR program supports materials sciences, chemical sciences, physics, energy-relevant biological sciences, geological and environmental sciences, high energy physics, nuclear physics, fusion energy sciences, advanced computing, and the basic sciences underpinning fossil energy, electricity delivery and reliability, nuclear energy, and energy efficiency and renewable energy.

EPSCoR promotes strong research collaboration between scientists/engineers in the designated states/territories and the world-class national laboratories, leveraging national user facilities and taking advantage of opportunities for intellectual collaboration across the DOE system. DOE EPSCoR supports Implementation Grants (large grants that promote development of infrastructure and research teams) and State-Laboratory partnership grants (individual university-based principal investigators teaming with national laboratories). EPSCoR also supports early career researchers in the designated states and territories. EPSCoR is science-driven and supports the most meritorious proposals based on peer review and programmatic priorities.

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 that possible in standard single-investigator or small-group awards. These multi-investigator, multi-disciplinary centers foster, encourage, and accelerate basic research to provide the basis for transformative energy technologies. The EFRCs supported in this subprogram are focused on: the design, discovery, synthesis, and characterization of novel, solid-state materials that improve the conversion of solar energy and heat into electricity and that enhance the conversion of electricity to light; the development of the understanding of materials and processes required to enable improved electrical energy storage, efficient separation of gases for carbon capture, and control of defect evolution in radiation environments; and the exploration of phenomena such as superconductivity and spintronics that can optimize energy flow and boost the efficiency of energy transmission. After five years of research activity, the original cohort of 46 EFRCs produced an impressive breadth of accomplishments, including over 5,950 peer-reviewed journal papers, over 275 patent applications and an additional 100 patent/invention disclosures. The current 32 centers (22 of which were renewed from the initial group, and 10 of which are new centers initiated in FY 2014) continue to expand upon these accomplishments. These EFRCs are 4-year awards with funding for the final two years contingent upon successful outcome of a mid-term review.

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 program and progress compared to its scientific goals. To facilitate communication of results to other EFRCs and interactions with DOE technology programs, meetings of the EFRC principal investigators are held on an approximately biennial frequency.

Energy Innovation Hubs—Batteries and Energy Storage

Advanced energy storage solutions have become increasingly critical to the Nation with the expanded deployment of renewable energy sources coupled with growth in the numbers of hybrid and electric vehicles. For the electric grid, new approaches to electrochemical energy storage can provide enhanced grid stability and enable intermittent renewable energy sources to meet continuous electricity demand. For vehicles, new batteries with improved lifetimes, safety, and storage capacity are needed to expand the range of electric vehicles from a single charge while simultaneously decreasing the volume, manufacturing cost and weight. Today's electrical energy storage approaches suffer from limited energy and power capacities, lower-than-desired rates of charge and discharge, life-cycle limitations, low abuse tolerance, high cost, and decreased performance at high or low temperatures.

The Batteries and Energy Storage Hub, established in December 2012, focuses on understanding the fundamental performance limitations for electrochemical energy storage to launch the next generation, beyond lithium-ion energy storage technologies relevant to both the electric grid and transportation. The Hub, the Joint Center for Energy Storage Research (JCESR), is led by Argonne National Laboratory joined by four other national laboratories, five universities, and four industrial partners. JCESR's core task is basic research—using a new generation of nanoscience tools that enable observation, characterization, and control of matter down to the atomic and molecular scales to understand materials and chemical processes that are at the core of battery performance. The participation of industrial partners will facilitate efforts to ensure that the outcome of basic research leads toward practical solutions that are competitive in the marketplace.

JCESR focuses on systems beyond lithium-ion and discovery of new energy storage chemistries through the development of an atomic-level understanding of reaction pathways and development of universal design rules for electrolyte function. The overarching goals driving the scientific and engineering research towards next-generation energy storage technologies are summarized by JCESR as 5/5/5—five times the energy density of current systems at one-fifth the cost within five years, the award period for the Hub. As part of their internal evaluation of progress and potential for each research direction to meet the Hub goals, in consultation with BES, JCESR continues to evolve their research thrusts to maximize the impact of resources used in pursuit of these goals. JCESR will also deliver two additional legacies to the broader energy storage community: creation of a library of fundamental scientific knowledge of the phenomena and materials of energy storage at the atomic and molecular level and demonstration of a new paradigm for battery R&D—integrating discovery science, battery design and computation, and research prototyping in a single highly interactive organization. Success in achieving these legacies will be measured by the rate, quality, and impact of JCESR's scientific publications, patents, and interactions across its discovery science, battery design and computation, and research prototyping functions. Progress against milestones is evaluated by quarterly/annual reports and annual performance reviews by external panels of science and management experts to verify and validate performance. JCESR underwent a management and early operations review in October 2013, and science-focused reviews in July 2014 and in July 2015. The review panels provided positive input and recommendations for furthering the JCESR research goals. The July 2015 review reported significant progress towards the project goals. BES continues to monitor progress closely. FY 2017 is the last year of the first award period for JCESR. The fifth year of research ends in December 2017. Evaluations of research progress in FY 2016 and FY 2017 will be used to determine if renewal of JCESR will be considered, including assessment of the funding level and technical focus for a renewal award.

Computational Materials Sciences

Recent major strides in materials synthesis, processing, and characterization, combined with concurrent advances in computational science—enabled by improvements in high performance computing capabilities—have opened an unprecedented opportunity to design new materials with specific function and properties. The opportunity 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 is a critical area in which the United States needs to be competitive.

This paradigm shift will accelerate the design of revolutionary materials to meet the Nation's energy goals and enhance economic competitiveness. Development of fundamentally new design principles could enable stand-alone research codes and software packages to address multiple length and time scales for prediction of the total functionality of materials over a lifetime of use. Scientific workshops and National Research Council studies have identified enticing scientific challenges that would advance these goals.[a] 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 research and development with the goal of creating experimentally validated, robust community codes that will enable functional materials innovation.

Research awards to perform computational materials research were launched in FY 2015 (3 teams) and additional awards (up to 2 additional teams) will be supported in FY 2016. The 4-year awards focus on 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. Research uses the unique world leading tools and instruments at DOE's user facilities, from ultrafast free electron lasers to aberration-corrected electron microscopes and 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 future exascale leadership class computers. The ideal end products for this research are 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.

FY 2017 funding will continue support of the teams that received multi-year awards in FY 2015 and those awarded in FY 2016 to perform the basic research and develop/deliver codes and associated experimental/computational data for the design of functional materials. Computational materials science research activities are managed using the approaches developed by BES for similar large team funded modalities. Management reviews by a peer review panel are held in the first year of the award, followed by a mid-term peer review to assess scientific progress, with monthly teleconferences, quarterly and annual progress reports, and active management by BES throughout the performance period.

[a] U.S. DOE. *Computational Materials Science and Chemistry for Innovation*. U.S. Department of Energy Office of Science, 2010. National Research Council. Integrated Computational Materials Engineering: A Transformational Discipline for Improved Competitiveness and National Security. Washington, DC: The National Academies Press, 2008.

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs FY 2016
Materials Sciences and Engineering $369,790,000	**$395,845,000**	**+$26,055,000**
Scattering and Instrumentation Sciences Research $62,260,000	**$70,318,000**	**+$8,058,000**
Research continues to emphasize use of advanced characterization techniques to tackle forefront science on energy-relevant materials science phenomena. Ultrafast science continues to be a priority research area. Investments will emphasize 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 stress 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 are pursued. Research that uses traditional diffraction, imaging, and spectroscopy techniques continues at a reduced level.	Research into ultrafast science, including development of electron optics and sources, sample environments, and enhanced detectors will continue to better understand critical dynamic processes at sub-angstrom spatial resolution and nanosecond temporal resolution. The program will stress hypothesis -driven research with existing ultrafast science capabilities. Based on the important role that in operando characterization can play in improving materials for energy-related environments and the BES advisory committee report on transformative challenges for materials discovery, the program will emphasize research that advances imaging with x-rays, neutrons, and electrons to form spatially and temporally resolved maps of dynamics that allow quantitative predictions of time-dependent material properties and chemical processes. 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 will be pursued.	The FY 2017 program will enhance research understanding of imaging with x-rays, neutrons, and electrons to form spatially and temporally resolved maps of dynamics regarding evolution of chemical composition, crystal orientation, structural phases, magnetic and electric domains, cracks, and defects in materials, including evolution in the atomic structure caused by exposure to heat, stress, chemicals, current flow, and other environmental factors associated with materials use, especially as these relate to improving efficient use of energy. Support for materials characterization research that does not elucidate functionality or interrogate phenomena spanning multiple length and time scales will be reduced. Topical areas specifically targeted for reduction include conventional superconductivity, organic photovoltaics, confined nanofluids, and mature use of high pressure scattering, spectroscopy, and imaging. Research involving well-established neutron and x-ray scattering and imaging techniques, and conventional microscopy and scanning probe imaging for studies of materials behavior will be deemphasized.
Condensed Matter and Materials Physics Research $118,049,000	**$133,800,000**	**+$15,751,000**
The program continues to support fundamental experimental and theoretical research on the properties of materials. It focuses on structural, optical, and electrical properties and control of material functionality in response to external stimuli	The program will continue to support experimental and theoretical research that advances our fundamental understanding of known materials and will lead to the discovery of new materials and new phenomena. The program will initiate research	For structural materials, additional research will focus on lightweight polymer composites, emphasizing design of the matrix-reinforcement interfaces, including new characterization tools and predictive capabilities to design improved chemistries and

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs FY 2016
including temperature, pressure, magnetic and electric fields, and radiation. Phenomena in materials are investigated from atomistic through nanoscale to mesoscale length scales. The research supported continues to address defect structures in materials and how these influence materials properties, especially in energy relevant materials. There is 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, are continued. Research involving theory and computational data coupled to experimental characterization of material properties continues to grow. Research on superconducting vortex matter, isolated nanoparticles, quantum Hall behavior, and low dimensional phenomena in carbon nanotubes and graphene continues at a reduced level.	activities related to more efficient and cleaner energy as identified in the Quadrennial Energy and Technology Reviews. Also, it will initiate research with a focus on lightweight structural materials, corrosion, and quantum materials—materials whose properties result from strong and coherent interactions of the constituent electrons with each other, the atomic lattice, or light. Research on lightweight structural materials and corrosion resistant materials, especially those exposed to extreme stress, strain, temperature, reactive chemicals and radiation flux, will focus on development of understanding of interfacial phenomena and on predictive design capabilities. Research will expand on thermal transport in materials, including caloric, high entropy, and high temperature materials and non-dissipative transport in novel topological materials.	structures. For materials in extreme environments, additional research will emphasize the development of a fundamental understanding of corrosion and degradation processes including the role of interfaces, linking nano/microscale and mesoscale phenomena, and development of quantitative prediction capabilities for materials performance in multiple extreme conditions. In the area of quantum materials, research will focus on predictive modeling, evaluation of ultrafast regimes (non-equilibrium phenomena), and controlled synthesis and design of materials to enable high quality, tailored interfaces, controlled heterogeneity, and coherent manipulation of charge, spin and lattice dynamics. The program will continue to deemphasize research on granular materials, conventional superconductivity, high strain rate, high dose radiation effects, and cold atom physics. It will continue to reduce research on superconducting vortex matter and heavy fermion phenomena; isolated nanoparticles and quantum dots; quantum wells; and quantum Hall behavior. Studies on low dimensional phenomena in carbon nanotubes and single-layer graphene will continue to be reduced in favor of research that involves interactions of nano and low dimensional systems that can potentially produce new phenomena with properties related to advanced energy technologies.
Materials Discovery, Design, and Synthesis Research **$70,010,000**	**$76,871,000**	**+$6,861,000**
Research continues 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, are developed. Additionally,	Research on "Synthesis Science", i.e., predictive materials design and synthesis, will expand to accelerate the pace of discovery of new materials as well as to provide a foundation for next generation energy technologies. In addition, the program will increase focus on fundamental materials synthesis and materials chemistry related to improved energy	The increase will support research related to energy-efficient use of heat, such as thermocaloric and thermoelectric materials, improved polymer chemistries to control interfaces related to light weight polymer composites, and discovery of new classes of porous materials and improved catalysts. Additional research will exploit advances in characterization of

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs FY 2016
synthesis pathways are 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, is strengthened to take advantage of the 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 continues at a reduced level.	efficiency, including light weight polymers and interfacial chemistry, discovery of new classes of porous materials, and improved catalysts. Mastering nature's design rules such as hierarchical architecture and beyond-equilibrium matter to enable entirely new classes of functional materials will be a key challenge, as identified in the BES Advisory Committee report on transformative challenges for materials discovery. Research will include predictive models, including the incorporation of metastability, to guide the creation of beyond-equilibrium matter; synthesis and assembly of hierarchical structures for multi-dimensional hybrid matter; and in situ characterization of spatial and temporal evolution during synthesis and assembly. This effort will include harnessing coherence in light and matter, together with improving our understanding of the critical roles played by heterogeneity, interfaces and disorder.	materials during synthesis, in combination with computation and theory, to develop new predictive models of synthesis for targeted functionality that incorporate metastability and focus on non-equilibrium matter and assembly of hierarchical inorganic-organic hybrid materials. Other cross-cutting opportunities include exploring materials phenomena that transcend the nano-micro-meso scales, and underpin the processes at interfaces which are ubiquitous in nearly all energy technologies. The program will continue to deemphasize research on developing synthesis methods for nanomaterials, e.g., nanoparticles, nanorods, as well as maturing areas such as nanomaterial synthesis (not assembly), traditional semiconductors for solid-state lighting, thin film transistors, liquid crystals, and hydrogen storage materials for automotive applications.
Experimental Program to Stimulate Competitive Research (EPSCoR) $14,776,000	**$8,520,000**	**-$6,256,000**
Efforts continue 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 is emphasized.	Efforts will continue 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 will be sustained.	Research support is reduced compared to the FY 2016 Enacted level, returning the program to the requested funding levels. The FY 2017 program will focus on research topics identified by the Quadrennial Technology Review, the Department crosscuts, and the BES advisory committee report on transformative challenges for materials discovery.

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs FY 2016
Energy Frontier Research Centers (EFRCs) $55,800,000	**$55,800,000**	**$0**
The EFRCs continue to perform fundamental multi-disciplinary research aimed at accelerating scientific innovation. All EFRCs undergo a mid-term review in FY 2016 to assess progress toward meeting scientific research goals. DOE issues a Funding Opportunity Announcement for up to five new EFRC awards in FY 2016.	FY 2017 funds will provide the fourth year of funding for awards made in FY 2014, as well as the second year of funding for new awards made in FY 2016.	Research support is flat with the FY 2016 Enacted level.
Energy Innovation Hubs—Batteries and Energy Storage $24,137,000	**$24,088,000**	**-$49,000**
The Hub, in its fourth year, continues to follow its project plan with an increasing focus on developing lab-scale prototypes to supplement the ongoing fundamental research science underpinning batteries for transportation and the grid, as well as cross-cutting research on materials characterization, theory, and modeling. JCESR completes 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.	In FY 2017, the last year of the first award period, the Hub will focus on developing energy storage research prototypes (components and cells) for transportation and grid applications that are based on beyond lithium ion concepts (e.g., multivalent ions, chemical transformation, non-aqueous redox flow), identified through JCESR research on materials discovery and techno-economic modeling. These prototypes will demonstrate the potential to scale-up to manufacturing prototype batteries that will meet the JCESR goal of delivering five times the energy density of 2011 battery systems at one-fifth the cost. Crosscutting fundamental research on materials characterization, theory, and modeling will continue to provide alternates for prototype development and to support JCESR's goals in creation of a library of fundamental scientific knowledge of the phenomena and materials of energy storage at the atomic and molecular level and demonstration of a new paradigm for battery R&D.	The funding is approximately flat with the FY 2016 Enacted level, following the planned funding profile.
Computational Materials Sciences $12,000,000	**$12,000,000**	**$0**
Computational Materials Sciences advances U.S. leadership in the development of computational codes for materials sciences and engineering. The research	Basic research will continue to support the development of computational codes and the associated experimental and computational data to	The funding is flat compared to the FY 2016 Enacted level.

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs FY 2016
activities involve teams of theorists, computational experts, and experimentalists with expertise in synthesis, characterization, and processing/fabrication of materials. The computational materials sciences teams that started in FY 2015 perform the first year of research as outlined in their proposals. This research focuses 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 will utilize current and future leadership class computers. Funding supports 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.	provide predictive capability for design of functional materials. The research uses DOE user facilities to generate experimental data and synthesize materials to validate the predictions and DOE's leadership class computational capabilities in development of new software tools for materials discovery. In FY 2017, a mid-term peer review of the FY 2015 awards will assess the scientific progress of the individual activities, including progress towards the goal of providing open-source, community codes and publicly accessible databases.	

Basic Energy Sciences
Chemical Sciences, Geosciences, and Biosciences

Description

The transformation of energy between types (optical, electrical, chemical, heat, etc.) and the rearrangement of matter at the atomic, molecular, and nano-scales are critically important in every energy technology. The *Chemical Sciences, Geosciences, and Biosciences* subprogram supports research that explores fundamental aspects of chemical reactivity and energy transduction to develop a broad spectrum of new chemical processes, such as catalysis, that can contribute significantly to the advancement of new or cleaner energy technologies. Research addresses the challenge of understanding physical and chemical phenomena over a tremendous range of spatial and temporal scales, from molecular through nanoscale and on to mesoscale, and at multiple levels of complexity, including the transition from quantum to classical behavior.

At the heart of this research lies the quest to understand and control chemical processes and the transformation of energy at the molecular scale in systems spanning simple atoms and molecules, active catalysts, and larger biochemical or geochemical systems. At the most fundamental level, the 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 results in meso- and macro-scale energy conversion systems.

This subprogram seeks to extend this 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 assembly and manipulation of larger, more 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**—Structural and dynamical studies of atoms, molecules, and nanostructures with the aim of providing a complete understanding of atomic and molecular interactions in the gas phase, condensed phase, and at interfaces.

- **Chemical Transformations**—Design, synthesis, characterization, and optimization of chemical processes that underpin advanced energy technologies, including catalytic production of fuels, nuclear energy, and geological storage of carbon dioxide or waste products related to the energy sector.

- **Photochemistry and Biochemistry**—Research on the molecular mechanisms involved in the capture of light energy and its conversion into chemical and electrical energy through biological and chemical pathways, with the goal of providing foundational knowledge of fundamental processes for energy capture, conversion, and storage.

The portfolio includes several unique efforts that enable these overall research themes. Novel sources of photons, electrons, and ions are developed to probe and control atomic, molecular, nanoscale, and mesoscale systems, particularly ultrafast optical and x-ray techniques to study and direct molecular dynamics and chemical reactions. This subprogram supports the nation's largest Federal effort in catalysis science and synthesis for the design of new catalytic methods and materials for clean and efficient production of fuels and chemicals. It also contains a unique effort in the fundamental chemistry of heavy elements, with complementary research on chemical separations and analysis. Crosscutting research of interfaces underpins a fundamental understanding of processes in catalysis, natural and artificial membranes, as well as geological systems. Research in geosciences emphasizes analytical and physical geochemistry especially in the subsurface, rock-fluid interactions, and flow/transport phenomena that are critical to a scientific understanding of geological storage of waste products such as carbon dioxide, produced water, or radioactive materials. Natural photosynthetic systems are studied to create robust artificial and bio-hybrid systems that exhibit the biological traits of self-assembly, regulation, and self-repair. Complementary research on artificial systems includes organic and inorganic photo- and electrochemistry, photo-induced electron and energy transfer, and molecular assemblies for artificial photosynthesis. The subprogram also emphasizes the co-development of experimental and computational tools to continuously expand the complexity of research problems that can be investigated.

Among its efforts toward enabling advancement of clean energy technologies, the subprogram stresses research on efficient energy use and conversion and on chemistry in extreme environments. Highly efficient catalysts enable reduced energy use in industrial production and manufacturing, and photocatalysis can drive clean electricity generation and fuel production. New concepts, such as biomimetic approaches, are needed for design of efficient low-temperature catalysts and photocatalysts to enable clean energy conversion technologies. In extreme radiative environments, such as the natural decay of isotopes in nuclear waste, understanding of the complex dynamics and kinetics of heavy-element chemical processes is necessary for the design of remediating agents.

In addition to single-investigator and small-group research, the subprogram supports EFRCs and the Fuels from Sunlight Energy Innovation Hub. These research modalities support multi-investigator, multidisciplinary research and focus on forefront energy technology challenges. The Hub supports a large, tightly integrated team and research that spans basic and applied regimes with the goal of providing the scientific understanding that will enable the next generation of technologies for the direct conversion of sunlight to chemical fuels.

Fundamental Interactions Research

This activity builds the fundamental science basis essential for technological advances in a diverse range of energy processes. Research encompasses structural and dynamical studies of atoms, molecules, and nanostructures, and the description of their interactions in full quantum detail. The ultimate objective, often gained through studies of model systems, is a complete understanding of reactive chemistry in the gas phase, condensed phase, and at interfaces. This activity also supports development of novel experimental and theoretical tools. New sources of photons, electrons, and ions are used to probe and control atomic, molecular, nanoscale, and mesoscale matter and processes on ultrafast time scales. New algorithms for computational chemistry are developed and applied in close coordination with experiment. Use-inspired areas of research are emphasized with relevance, for example, to combustion and catalysis. The knowledge and techniques produced by this 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 (AMO) sciences and chemical physics. AMO research emphasizes the interactions of atoms, molecules, and nanostructures with photons, particularly x-ray light, to characterize and control their behavior. AMO research examines energy transfer within isolated molecules that provides the foundation for understanding the making and breaking of chemical bonds. The goal is to develop accurate quantum mechanical descriptions of dynamical processes such as chemical bond breaking and forming, interactions in strong fields, and electron correlation.

Chemical physics research builds from the AMO foundation by examining the reactive chemistry of molecules whose chemistry is profoundly affected by the environment. The transition from molecular-scale chemistry to collective phenomena is explored in complex systems, such as the effects of solvation or interfaces on chemical structure and reactivity. Understanding such collective behavior is critical in a wide range of energy and environmental applications, from solar energy conversion to improved methods for including radiolytic effects in the context of advanced nuclear fuel or waste remediation. Gas-phase chemical physics emphasizes the rich and surprisingly complex chemistry of combustion—burning diesel fuel involves thousands of chemical reactions and hundreds of distinct species. Combustion simulation and diagnostic studies address the subtle interplay between combustion chemistry and the turbulent flow that characterizes all real combustion devices where accurate simulation of fundamental in-cylinder combustion/emission-formation processes and the effects of fuel composition will enable increased engine efficiency. This activity includes support for the Combustion Research Facility, a multi-investigator research laboratory at the Sandia National Laboratories campus in Livermore, California, for the study of combustion science. Computational and theoretical research supports the development and integration of new and existing theoretical and computational approaches for accurate and efficient descriptions of processes relevant to energy systems. Of special interest is foundational research on computational design of molecular- to meso-scale materials, and on next-generation simulation of complex dynamic processes.

Chemical Transformations Research

Chemical Transformation Research emphasizes the design, synthesis, characterization, and optimization of chemical processes that underpin advanced energy technologies including the catalytic production of fuels, the efficient separation of reaction products and reacting phases, the chemistry of actinides important to nuclear energy, and the geological sequestration of waste products. A tremendous breadth of novel chemistry is covered: inorganic, organic, and hybrid molecular complexes; nanostructured surfaces; electrochemistry; nanoscale membranes; bio-inspired chemistry; and analytical and physical geochemistry. This activity develops unique tools for chemical analysis, using laser-based and ionization techniques for molecular detection, and lab and synchrotron techniques for in-situ characterization ranging from electrode surfaces to catalytic processes, with an emphasis on imaging chemically distinct species. This activity also supports training in radiochemistry and nuclear chemistry.

Theoretical and computational approaches are being developed to achieve a deeper understanding of reaction and separation processes, design new catalysts and membranes, and predict subsurface transport and reaction. This activity has a leadership role in the application of basic science to unravel the principles that define how catalysts work—how they accelerate and direct chemistry. Such knowledge enables the rational synthesis of novel catalysts, designed at the nanoscale but operating at the mesoscale, which will lead to increased energy efficiency and chemical selectivity. Because so many processes for the production of fuels and chemicals rely on catalysts, improving catalytic efficiency and selectivity is likely to have broad impact in reducing manufacturing costs and energy consumption on a global scale.

This activity supports several research areas with potential impact on energy production, storage, and use. Advanced separation schemes for the removal of carbon dioxide from post-combustion streams are explored—these are essential to making carbon capture economical. Fundamental studies of the structure and reactivity of actinide-containing molecules provide the basis for their potential use in advanced nuclear energy systems. The extreme radiation environment involving radionuclides and the presence of elements containing f-electrons create complicated chemical systems exhibiting unique dynamic and kinetic behavior. The challenges are further compounded by the evolving chemical mixtures with time that must be understood to develop viable waste treatment options for the storage of nuclear waste and for the generation of clean nuclear energy. Geosciences improves understanding of the consequences of deliberate storage, or accidental discharge, of energy related products such as carbon dioxide, produced water or radioactive waste materials which requires ever more refined knowledge of how such species react and move in the subsurface environment. Subsurface fluid flow and complex chemistry occurring on a wide range of time scales are relevant not only for the efficient production of oil, gas, and geothermal energy but also for carbon sequestration and disposal of nuclear waste.

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. The work is of critical importance for the effective use of our most abundant and durable energy source—the sun. 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 are developed and used to investigate the structural and chemical dynamics of energy absorption, transfer, conversion and storage across spatial and temporal scales. The fundamental chemical and physical concepts from the study of both natural systems (e.g. photosynthetic and affiliated downstream biological processes) and man-made chemical systems provide crucial foundational knowledge for using solar energy and photocatalysis to drive clean electricity generation and fuel production and for developing efficient, environmentally benign, sustainable catalysts that can help enable next generation clean energy conversion technologies.

Natural photosynthesis is studied to understand the dynamic mechanisms of solar energy capture and conversion in biological systems and to provide roadmaps for the creation of robust artificial and bio-hybrid systems that exhibit biological traits of self-assembly, regulation, and self-repair and that span from the atomic scale through the mesoscale. Physical science tools are extensively used to elucidate the molecular and chemical mechanisms of biological energy transduction, including 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 chemical and artificial systems encompasses organic and inorganic photochemistry, electrochemistry, light-driven energy and electron transfer processes, and molecular assemblies for electricity generation and artificial photosynthetic fuel production. Fundamental knowledge resulting from these studies of complex chemical processes and electron dynamics under changing environmental conditions can provide an important foundation for the development of efficient solar energy technologies.

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 that possible in standard single-investigator or small-group awards. These multi-investigator, multi-disciplinary centers foster, encourage, and accelerate basic research to provide the basis for transformative energy technologies. The EFRCs supported in this subprogram are focused on the following topics: the design, discovery, control, and characterization of the chemical, biochemical, and geological moieties and processes for the advanced conversion of solar energy into chemical fuels; for improved electrochemical storage of energy; for the creation of next-generation biofuels via catalytic chemistry and biochemistry; and for science-based carbon capture and geological sequestration. After five years of research activity, the original cohort of 46 EFRCs produced an impressive breadth of accomplishments, including over 5,950 peer-reviewed journal papers, over 275 patent applications, and an additional 100 patent/invention disclosures. The current 32 centers (22 of which were renewed from the initial group, and 10 of which are new centers initiated in FY 2014) continue to expand upon these accomplishments. These EFRCs are 4-year awards with funding for the final two years contingent upon the successful outcome of a mid-term review.

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 program and progress compared to its scientific goals. To facilitate communication of results to other EFRCs and interactions with DOE technology programs, meetings of the EFRC principal investigators are held on an approximately biennial frequency.

In response to two strategic planning activities related to the Subsurface crosscut, additional funds are requested in FY 2017 to fully support up to five new EFRC awards to address the grand challenge of "Advanced imaging of geophysical and geochemical signals in the subsurface." The scientific focus will be on fracture networks, associated fluid flow and reaction, and the gaps in fidelity, resolution, and conceptual understanding of subsurface imaging in hard-to-access environments. Current limitations to fully exploiting our subsurface energy resources in an environmentally responsible manner lie in the inadequate resolution attainable in seismic imaging, in traditional sampling techniques before and after injection that provide insufficient insight into fluid elements and isotopic composition over extended length and time scales, and in the effect of physical changes and concurrent geochemical processes in rock-fluid systems associated with subsurface and geological engineering.

The EFRC model has proven effective in promoting partnerships and addressing grand challenge science requiring multidisciplinary teams focused on discrete problems with novel approaches. Efforts will build on cross-cutting themes such as advanced, predictive computational methods to describe heterogeneous time-dependent studies of geologic systems; new laboratory studies on both natural and geo-architected subsurface materials that deploy advanced high-resolution 3D imaging; and chemical analysis methods to determine the rates and mechanisms of fluid-rock processes. The EFRC R&D platforms will be closely coupled with field-based approaches to enable the translation of scientific knowledge to practical solutions in subsurface engineering. A key deliverable will be the development of experimental imaging tools and computational approaches broadly applicable to the field of subsurface science.

Energy Innovation Hubs—Fuels from Sunlight

Solar energy is a significant yet largely untapped clean energy resource. More energy from the sun strikes the earth in one hour than is consumed by all humans on the planet in a year. Through the process of photosynthesis, plants can effectively convert energy from the sun into energy-rich chemical fuels using the abundant feedstocks of water and carbon dioxide. If a human-made artificial photosynthesis system can be developed that can generate usable fuels directly from sunlight, carbon dioxide, and water, the potential energy benefits for the Nation would be substantial, reducing dependence on fossil fuels and eliminating waste streams from fossil fuel production, such as produced water, and from fossil fuel use, such as CO_2.

Due to the significant scientific and engineering challenges associated with developing such a system, however, there are no commercially-available fuels generated via artificial photosynthesis. For this reason, the Basic Energy Sciences Advisory

Committee report, New Science for Secure and Sustainable Energy Future,[a] listed the production of fuels directly from sunlight as one of three strategic goals for which transformational science breakthroughs are most urgently needed.

Established in September 2010, the Fuels from Sunlight Hub, called the Joint Center for Artificial Photosynthesis (JCAP), is a multi-disciplinary, multi-investigator, multi-institutional effort to create critical transformative advances in the development of artificial photosynthetic systems for converting sunlight, water, and carbon dioxide into a range of commercially useful fuels. The Hub is targeted towards understanding and designing catalytic complexes or solids that generate chemical fuel from carbon dioxide and/or water; integrating all essential elements, from light capture to fuel formation components, into an effective solar fuel generation system. 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 several University of California institutions. JCAP is composed of internationally renowned scientists and engineers who seek to integrate decades of research community efforts and address critical research and development gaps; its visionary goal is the construction of an artificial photosynthetic system for robustly producing fuel from the sun.

JCAP's efforts are synergistically split between JCAP-South on the campus of Caltech and JCAP-North located at LBNL, with the exception of the benchmarking and high-throughput experimentation projects that are consolidated at JCAP-South. JCAP makes use of state-of-the-art facilities at LBNL and SLAC as part of its efforts to examine, understand, and manipulate matter at the nanoscale. Despite the different geographic locations, JCAP operates as a single scientific entity. Its efforts consist of discovery research to identify robust, Earth-abundant light absorbers, catalysts, linkers, and membranes that are required components of a complete system and scale-up science for design and development of prototypes. By studying the science of scale-up and by benchmarking both components (catalysts) and systems (device prototypes), JCAP seeks to move bench-top discovery to proof-of-concept prototyping and thus accelerate the transition from laboratory discovery to industrial use.

The initial award for the Fuels from Sunlight Hub ended on September 29, 2015. During this award period, research at JCAP centered primarily on the production of hydrogen fuel with smaller efforts addressing the considerably more challenging area of carbon-based fuels. Selected accomplishments during the first award term include discovery of new mechanisms and materials for electrocatalytically splitting water, identification of a novel oxygen evolution reaction catalyst, establishment of objective standardized procedures for evaluation of the efficacy and stability of electrocatalysts, and development of a semiconductor protection method capable of expanding the range of materials that can be used in solar fuel generators. Most importantly, JCAP reached its five-year goal to design and develop a photocatalytic prototype capable of generating fuel, specifically hydrogen, from sunlight. In December 2014, BES solicited a renewal proposal from JCAP for a final award term with a maximum duration of five years and directed JCAP to focus on the fundamental science of carbon dioxide reduction, a critical need for efficient solar-driven production of carbon-based liquid transportation fuels.

Based on the outcome of external peer review, the Fuels from Sunlight Hub was renewed by BES for a final five-year award term starting on September 30, 2015, at an annual funding level of $15M. The renewal leverages accomplishments and infrastructure from the initial award and maintains the unified operation led by Caltech in primary partnership with LBNL. SLAC National Accelerator Laboratory, the University of California, Irvine, and the University of California, San Diego, also remain as partners in the Hub. The objectives of the renewal project include the discovery and understanding of highly selective catalytic mechanisms for carbon dioxide reduction and oxygen evolution operating under defined conditions; accelerated discovery of electrocatalytic and photoelectrocatalytic materials and light-absorber photoelectrodes for selective and efficient carbon dioxide reduction into hydrocarbon fuels; and, using JCAP prototypes, demonstration of highly efficient and selective artificial photosynthetic carbon dioxide reduction and oxygen evolution components.

Computational Chemical Sciences

Computational Chemical Sciences is a new activity in FY 2017 to develop open-source modular software tools that can be reused as plug-and-compute tools for the basic energy sciences community in preparation for the arrival of exascale computing facilities and for the optimized usage of existing petascale computers, leveraging the U.S.' leadership in the development of computational chemistry codes.

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[a] U.S. DOE Basic Energy Sciences Advisory Committee. *New Science for a Secure and Sustainable Energy Future*. U.S. Department of Energy Office of Science, 2008.

Software solutions and infrastructure as enabling tools are necessary components of an effective scientific strategy to address the nation's energy challenges. Codes such as GAUSSIAN, GAMESS and NWChem have established U.S. dominance in computational chemistry; that leadership is now being challenged with the transition to predominantly massively-parallel high performance computing platforms. Today's best chemical simulation codes are currently unable to efficiently use more than one percent of the processors available on existing leadership-class supercomputers. A systematic effort to modify or replace existing computational chemistry codes with codes that are well-adapted to anticipated exascale architectures is critically needed.

Recent breakthroughs in computational chemistry provide a strong foundation for future success in this activity. For example, researchers developed a density-functional based predictive method with unprecedented accuracy for gas phase thermochemistry. This method is based upon a new and systematically improvable genomic framework and, for the first time, delivers energetics that rival those of the most-accurate wavefunction-based computational chemistry codes. Unlike the latter, the new predictive paradigm can in principle be extended to methods that are amenable to atoms in the lower half of the periodic table, and to structures composed of a solid-gas/liquid interface which are particularly important to the chemistry-based energy sciences. Such systems form the molecular building blocks for catalysts, gas-separation technologies, and natural and artificial photosynthesis.

In this activity, computational chemists will deploy these capabilities in all major open-source chemical simulation-software used by the community, rewrite software and algorithms to fully realize the current and future gains in efficiency offered by massively parallel computing platforms and systematically alleviate the need to employ semi-empirical case-by-case corrections. Tackling these enormously complex challenges will require multi-investigator teams to combine theoretical, computational and algorithmic advances to jointly increase by at least 1,000 times the accuracy and speed of molecular and chemical design.

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 2017 Request	Explanation of Changes FY 2017 vs FY 2016
Chemical Sciences, Geosciences, and Biosciences $312,061,000	**$387,356,000**	**+$75,295,000**
Fundamental Interactions Research $74,599,000	**$79,233,000**	**+$4,634,000**
Research continues 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 continues to develop advanced theoretical methods to guide and interpret ultrafast measurements and to design new experiments. It also continues to emphasize time-resolved electron and x-ray probes of matter at unprecedented short time scales and in systems of increasing complexity. Computational efforts stress the development of improved methods to calculate electronically excited states in molecules and extended mesoscale systems. Work continues on advanced combustion research to accelerate the predictive simulation of highly efficient and clean internal combustion engines. Increased emphasis is on investigating properties of combustion in high-pressure or multiphase systems. The program deemphasizes research at the interface of nanoscience with molecular physics.	Research will continue to develop and apply forefront ultrafast x-ray and optical probes of matter using 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 will continue to develop advanced theoretical methods to guide and interpret ultrafast measurements and to design new experiments. It will also continue to emphasize the development of novel instrumentation for time-resolved electron and x-ray probes of matter at ultrafast time scales and in systems of increasing complexity. Computational efforts will stress the development of improved methods to calculate electronically excited states in molecules and to characterize and model chemical systems. Work will continue on advanced combustion research to accelerate the predictive simulation of highly efficient and clean internal combustion engines. The program will place Increased emphasis on investigating properties of combustion in high-pressure or multiphase systems.	Research support increases compared to the FY 2016 Enacted level to include a new multidisciplinary effort in energy efficiency with the goal to develop operating conditions compatible with new catalysts and renewable fuels in combustion engines. To maintain support for forefront research in ultrafast science, the FY 2017 program deemphasizes research on ultra-cold molecules and molecular and particle spectroscopy. The program also supports investments in predictive theory and modeling to guide and interpret increasingly complex measurements of chemical processes in preparation for the arrival of exascale computing capabilities through the proposed Computational Chemical Sciences program.
Chemical Transformations Research $92,341,000	**$106,423,000**	**+$14,082,000**
Synthesis, guided by theory and computation, continues 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 emphasizes catalytic conversion of biomass to fuels and other energy related chemical products as well as the search	Guided by theory and computation, the research will continue to design and synthesize novel catalytic materials at the nano- and mesoscale for the efficient conversion of traditional and new feedstocks into higher-value fuels and other chemicals, with a new emphasis on energy efficiency. The program will continue to emphasize the catalytic conversion of	The funding increase will enhance this program's contribution to the Subsurface crosscut with an emphasis on fundamental geochemistry and geophysics, specifically subsurface fluid flow and complex chemistry on timescales of microseconds to millennia with importance for oil and gas production, geothermal energy, carbon capture and storage, and

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs FY 2016
for catalysts for new ammonia production routes that avoid the generation of greenhouse gases. To support these new emphases, the program will deemphasize the development of mass spectrometric techniques. Likewise, coupled predictive theory and synthesis of designer mesoporous membranes and filter materials seek more efficient separation of carbon dioxide from power plant effluents or of oxygen from air relevant to oxycombustion approaches. Subsurface geochemistry and geophysics seek 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 continues 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 continues in parallel with efforts in other offices as coordinated by the Subsurface Science, Technology and Engineering R&D (Subsurface) crosscut.	biomass and light alkanes to fuels and other energy related chemical products. Likewise, coupled predictive theory and synthesis of designer mesoporous membranes and filter materials will continue to seek more efficient separation of carbon dioxide and environmentally malign products of combustion from conventional or advanced power plants. Subsurface geochemistry and geophysics will seek to provide data and mechanistic interpretation for models of reactive flow and transport important for waste sequestration and extraction of tight gas and oil. Actinide research will continue to emphasize new insights in actinides chemical bonding enabling new chemistry for separation and related nuclear fuel and waste processes, particularly using ionic liquids. Fundamental research activities in geochemistry and geophysics of the subsurface will continue in FY 2017 in parallel with efforts in other offices as coordinated by the Subsurface crosscut.	nuclear waste disposal. In addition, the increase will support new directions in energy efficiency and chemistry in extreme environments. The program will target new catalysts capable of operating at low temperatures and inspired by natural systems, as well as synergistic approaches such as electro- and photoelectrocatalysis. This research is a cross disciplinary effort between the Chemical Transformations and the Photochemistry and Biochemistry Research areas. Chemistry research in extreme environments focuses on elucidating the nature, dynamics, and kinetics of complex chemical processes in the highly radiative nuclear waste environment. Understanding such processes is further complicated by the involvement of f-electrons for heavy elements. Research in this area will focus on the bonding, chemical reactivity, and the design of selective agents to extract unwanted species from the waste mixture. Investments in mass spectrometric tools will be deemphasized since it has reached a high level of technical maturity.
Photochemistry and Biochemistry Research $64,189,000	**$71,197,000**	**+$7,008,000**
Research continues to emphasize a fundamental understanding of light energy capture and conversion in non-biological and biological (photosynthetic) systems. These studies will establish a foundation for direct conversion of solar energy to electricity, fuels, and high value chemicals. The program continues 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 continues to emphasize research to	Research will continue to emphasize a fundamental understanding of light energy capture and conversion in non-biological and biological (photosynthetic) systems. These studies will establish a foundation for direct conversion of solar energy to electricity, fuels, and high value chemicals. The program will continue 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. Continued work in electrochemistry and	Research support is increased compared to the FY 2016 Enacted level to include a new multidisciplinary effort in energy efficiency and chemistry in extreme environments. This research is part of a synergistic cross-disciplinary effort between the Photochemistry and Biochemistry Research and Chemical Transformations Research areas to establish energy efficient catalysts and understand chemical dynamics during energy conversion and in radiative environments, building on the expertise in radiation chemistry, photo(electro) catalysis, and enzyme-mediated (biological) catalysis. Such research can span

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs FY 2016
understand the fundamental mechanisms of water-splitting, redox, cell wall biosynthesis, and other energy-relevant biological (enzymatic) reactions, from the nano- to the mesoscale. These studies provide 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 deemphasizes research on fundamental mechanisms of carbon capture.	photocatalysis will seek to advance development of solar energy conversion for generation of electricity and chemical fuels, as will research to identify and characterize potential new mechanisms, such as perovskites, to increase efficiency of solar energy conversion and use. The program will continue to emphasize research to understand the fundamental mechanisms of water-splitting, redox, dynamical complex assembly, electron and other energy-relevant biological (enzymatic) reactions, from the nano- to the mesoscale. These studies will provide 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.	different time and spatial scales, for instance from understanding electron dynamics to determining mechanisms important for efficient complex assembly and function. The program will deemphasize efforts in the study of plant hormones, biotic stress and on the development of genetic systems to allow investments in the basic research of dye-sensitized solar cells and the analysis of the structure, function, and mechanism of enzymes that mediate the flow of electrons in biological systems.
Energy Frontier Research Centers (EFRCs) $54,200,000	**$86,766,000**	**+$32,566,000**
The EFRCs continue to perform fundamental multi-disciplinary research aimed at accelerating scientific innovation. All EFRCs undergo a mid-term review in FY 2016 to assess progress toward meeting scientific research goals. DOE issues a Funding Opportunity Announcement for up to five new EFRC awards in FY 2016.	FY 2017 funds will provide the fourth year of funding for awards made in FY 2014 as well as the second year of funding for new awards made in FY 2016. New funds in FY 2017 will fully support up to five new EFRCs related to the Subsurface crosscut to develop experimental imaging tools and computational approaches broadly applicable to the field of subsurface science.	The funding increase will enhance the BES contribution to the Subsurface crosscut by addressing the grand challenge "Advanced imaging of geophysical and geochemical signals in the subsurface," with a focus on fracture networks, associated fluid flow and reaction, and the gaps in fidelity, resolution, and conceptual understanding of subsurface imaging in hard-to-access environments. Funds are requested to enable up to five new awards for multidisciplinary teams from DOE laboratories, industry, and academia to work closely with field-based projects to address the grand challenge identified in the 2015 Subsurface strategic planning workshops.
Energy Innovation Hubs—Fuels From Sunlight $15,000,000	**$15,000,000**	**$0**
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,	The Fuels from Sunlight Hub will continue to perform research on the fundamental science of carbon dioxide reduction needed to enable efficient, sustainable solar-driven production of liquid transportation fuels.	Research support is flat with the FY 2016 Enacted level.

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs FY 2016
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. JCAP undergoes a scientific and merit review in FY 2016 to assess progress toward meeting project milestones and goals.	JCAP will undergo a scientific and merit review in FY 2017 to assess progress toward meeting project milestones and goals.	
Computational Chemical Sciences $0	**$13,635,000**	**+$13,635,000**
N/A	A new investment in Computational Chemical Sciences will develop open-source modular software tools that can be reused and tailored for the specific needs of the basic research community, essentially acting as "plug-and-compute" tools. While the U.S. is a leader in the development of computational chemistry codes such as GAUSSIAN, GAMESS, and NWChem, U.S. leadership is being challenged with the transition to predominantly massively-parallel computer platforms. The best chemical simulation codes are currently unable to efficiently use more than one percent of the processors available on existing leadership computers. A systematic effort to modify or replace existing computational chemistry codes with codes that are well-adapted to anticipated exascale architectures is critically needed. This investment will build on current quantum chemistry software, seeking to create new codes that fully leverage massively-parallel high performance computing platforms.	This new activity readies the computational chemistry community for the arrival of exascale computer systems and optimizes the use of current petascale capabilities of DOE's Leadership Computing Facilities as an enabling tool for the development of new quantum chemical codes to predict, model and solve complex chemical problems. BES will start extending the quantum chemistry codes to other systems, including processes in molecular complexes composed of atoms in the lower two-thirds of the periodic table (i.e., belonging to the d- and f-block elements). Topical areas of emphasis will also include membranes and structures composed of a solid-gas/liquid interface. Advances in these areas are particularly important to the chemistry-based energy sciences, as such systems form the molecular building blocks for catalysts, gas-separation technologies, and natural and artificial photosynthesis.
General Plant Projects $1,000,000	**$1,000,000**	**$0**
Funding supports minor facility improvements at Ames Laboratory.	Funding will support 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 2015, the BES scientific facilities were used by more than 14,000 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 for clean energy production 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.

Synchrotron Radiation 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 synchrotron 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, synchrotron radiation has transformed the role of x-rays as a mainline 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, synchrotron radiation has vastly enhanced the utility of pre-existing and contemporary techniques, such as x-ray diffraction, x-ray spectroscopy, and imaging and has 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 synchrotron radiation the x-ray source of choice 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 National Accelerator Laboratory (SLAC) and four storage ring based light sources—the Advanced Light Source (ALS) at Lawrence Berkeley National Laboratory (LBNL), Advanced Photon Source (APS) at Argonne National Laboratory (ANL), Stanford Synchrotron Radiation Lightsource (SSRL) at SLAC, and the newly constructed National Synchrotron Light Source-II (NSLS-II) at Brookhaven National Laboratory (BNL). Funds are provided to support facility operations, enable cutting-edge research and technical support, and to administer a robust 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 Oak Ridge National Laboratory (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 are DOE's premier user facilities for 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 are provided to enable cutting-edge research and technical support and to administer a robust 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.

<u>Other Project Costs</u>

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 research and development, startup, and commissioning. OPC is always funded via operating funds.

<u>Major Items of Equipment</u>

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 development stages of a project. Additional reviews may be required depending on the complexity and needs of the projects in question.

<u>Research</u>

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 supports long term surveillance and maintenance (LTS&M) responsibilities and legacy cleanup work at Brookhaven National Laboratory and SLAC National Accelerator Laboratory.

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs FY 2016
Scientific User Facilities $966,849,000	**$963,529,000**	**-$3,320,000**
Synchrotron Radiation Light Sources $481,906,000	**$489,059,000**	**+$7,153,000**
Funding supports near optimal operations of the five BES light sources, including the first full year of operations for the newly constructed NSLS-II. No funding is provided for NSLS as it ceased operations in FY 2015. $5M is for R&D in support of the Advanced Light Source Upgrade.	The FY 2017 Request includes funding for optimal operations of the five BES light sources to fully support research, including clean energy research. These five operating facilities together are responsible for almost 75% of the total users of BES national user facilities. It is essential that these facilities be fully staffed and that funding be provided for high-priority upgrades of beam lines and other equipment essential for the users' research. The request also includes funds to expand the beamline capabilities for the newly constructed NSLS-II and to enhance the ability of users to perform cutting-edge research at the only free electron laser x-ray source in the U.S.	The funding increase will support optimal operations and allow the facilities to proceed with necessary maintenance, routine accelerator and instrumentation improvements, and crucial staff hires or replacements. The request will support the development of beamlines for the newly constructed NSLS-II based on reconfigured equipment from NSLS that will make use of the high brightness available at NSLS-II.
High-Flux Neutron Sources $264,645,000	**$261,177,000**	**-$3,468,000**
Funding supports 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 2017 Request includes funding for optimal operation of HFIR and SNS at Oak Ridge National Laboratory (ORNL) to fully support research, including clean energy research. Part of this funding supports selected strategic hires at the neutron facilities to enhance the overall scientific impact and breadth of the facility research program and to increase collaborative programs with the ORNL Center for Nanophase Materials Science. The funding will allow purchase and installation of additional detectors on selected instruments at the SNS to increase their overall productivity and will also fund other critically needed high priority instrument enhancements. At HFIR, the FY 2017 Request also funds critical upgrades to older triple axis spectrometers to improve resolution and data collection efficiency. The request	The funding increase will support optimal operations and necessary maintenance of the neutron sources, high priority upgrades to instruments, and crucial staff hires or replacements.

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs FY 2016
	also includes funds for planning and initial disposition of unused equipment at the Lujan Center.	
Nanoscale Science Research Centers $118,763,000	**$122,272,000**	**+$3,509,000**
Funding supports operations at the NSRCs at near optimal levels. Program emphasis continues to cultivate and expand the user base from universities, national laboratories, and industry. Planning efforts continue 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 includes funding for optimal operations of the five Nanoscale Science Research Centers to fully support research, including clean energy research. Funding will be used to exploit synergies between the NSRCs and major co-located x-ray, neutron, computation and fabrication facilities including developing new beamlines. These efforts build tools and capabilities to address challenges in characterizing ultrafast chemical and physical nanoscale phenomena in real environments. Joint activities involving all NSRCs such as workshops will be continued.	The funding increase will support optimal operations and instrument repairs, and replacement. Some NSRCs will begin developing joint capabilities with their co-located facilities.
Other Project Costs $0	**$0**	**$0**
No funds are requested for Other Project Costs.	No funds are requested for Other Project Costs.	No funds are requested.
Major Items of Equipment $35,500,000	**$20,000,000**	**-$15,500,000**
The Advanced Photon Source-Upgrade (APS-U) project continues with planning and facility design, magnet prototyping, and research and development related to implementation of the multi-bend achromat lattice during FY 2016.	APS-U will continue activity associated with R&D, engineering design, equipment prototyping and equipment fabrication in preparation for long lead procurements in FY 2017.	The FY 2017 Request for APS-U is flat compared to the FY 2016 Enacted level.
The NSLS-II Experimental Tools (NEXT) project continues with the design, procurements, construction/fabrication, installation, testing and commissioning of equipment during FY 2016.	No funds are requested for NEXT in FY 2017. NEXT will continue with the remaining design, procurements, construction/fabrication, installation, testing and commissioning of equipment during FY 2017. The project will complete by the end of FY 2017.	FY 2016 is the last year of funding for NEXT per the project plan.

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs FY 2016
Research $34,853,000	**$37,537,000**	**+$2,684,000**
The research funding for the scientific user facilities continues to support selected, high-priority research activities. This funding supports 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 to continue the long term surveillance and maintenance responsibilities at BNL and SLAC is included.	The FY 2017 Request will allow concerted efforts in innovative concepts in beam acceleration techniques and expanded development of advanced instrumentation for beam characterization, measurement, and control to enable the full utilization of the high flux, brilliance, and ultra-short pulses provided by the new light sources, and increased intensity at the neutron sources. As part of the Presidential BRAIN Initiative and in close coordination with the National Institutes of Health (NIH), BES will develop next generation tools and technologies at DOE X-ray Light Sources and Nanoscale Science Research Centers to enable advances in brain imaging and sensing. The research will focus on developing novel tools and bio-compatible nano-materials to improve the sensitivity and the spatial and temporal resolution of imaging and sensing of neural transmission, and on developing bio-compatible nanomaterials for studying these systems with potential for use in medicine. Funding to continue the long term surveillance and maintenance responsibilities at BNL and SLAC is included.	The increase supports development of tools and technologies related to the Presidential BRAIN Initiative as well as novel methods of beam acceleration and additional development of instruments and techniques to measure and control particle and photon beams. Funding for long term surveillance and maintenance is reduced according to project needs.

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.

Taking the findings and recommendations of the July 25, 2013 BES Advisory Committee report into account, the Linac Coherent Light Source-II (LCLS-II) project was modified to include the addition of a superconducting linear accelerator and additional undulators to generate an unprecedented high-repetition-rate free-electron laser. This new, world-leading, high-repetition-rate x-ray source will solidify the LCLS complex as the world leader in ultrafast x-ray science for decades to come.

In April 2015, the Office of Science conducted an external Independent Project Review (IPR) to assess the project's readiness for Critical Decision-3B (CD-3B), Approve Long Lead Procurements. Based on the positive IPR review outcome, the CD-3B was approved on May 28, 2015 which authorized long lead and advanced procurements for key components of the cryoplant and the superconducting linac which are on the critical path for the project. The IPR committee also recommended increasing the cryoplant refrigeration capacity to mitigate technical risks. The recommendation was accepted by BES and the project and led to an increase of the preliminary total project cost (TPC) point estimate from $965,000,000 to $1,045,000,000.

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, and which are reproduced in the construction project data sheet.

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs FY 2016
Construction $200,300,000	**$190,000,000**	**-$10,300,000**
Linac Coherent Light Source-II (LCLS-II) $200,300,000	**$190,000,000**	**-$10,300,000**
The project continues with facility design, initiates critical long-lead procurements of technical materials and cryogenic systems, continues research and development and prototyping activities, and fabricates technical equipment during FY 2016.	The FY 2017 Request supports the continuation of the construction effort according to the project plan.	The FY 2017 Request decreases compared to the FY 2016 Enacted level.

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. The following table shows the targets for FY 2015 through FY 2017. Details on the Annual Performance Report can be found at http://energy.gov/cfo/reports/annual-performance-reports.

	FY 2015	FY 2016	FY 2017
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 set back. 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 Facility Construction/MIE Cost & Schedule—Cost-weighted mean percent 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	Through the "electrolyte genome," demonstrate a framework for designing new electrolytes using structure-chemical trends extracted from >10,000 first-principles calculated molecular motifs, modifications and mutations.	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.
Result	Met	TBD	TBD
Endpoint Target	Deliver two high-performance research 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. The performance goal will be achieved by the *Batteries and Energy Storage* Energy Innovation Hub.		

Basic Energy Science
Capital Summary ($K)

	Total	Prior Years	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
Capital Operating Expenses Summary							
Capital Equipment	n/a	n/a	48,100	67,105	41,000	29,500	-11,500
General Plant Projects (GPP)	n/a	n/a	600	1,800	1,000	1,000	0
Accelerator Improvement Projects (AIP)	n/a	n/a	9,925	5,150	9,425	13,000	+3,575
Total, Capital Operating Expenses	**n/a**	**n/a**	**58,625**	**74,055**	**51,425**	**43,500**	**-7,925**
Capital Equipment							
Major Items of Equipment							
Advanced Photon Source Upgrade (APS-U), ANL (TPC TBD)[a]	TBD	68,500	20,000	20,000	20,000	20,000	0
Linac Coherent Light Source-II (LCLS-II), SLAC[b,c]	—	85,600	0	0	0	0	0
NSLS-II Experimental Tools (NEXT), BNL (TPC $90,000)	90,000	52,000	22,500	22,500	15,500	0	-15,500
Total, Major Items of Equipment	n/a	n/a	42,500	42,500	35,500	20,000	-15,500
Total, Non-MIE Capital Equipment	n/a	n/a	5,600	24,605	5,500	9,500	+4,000
Total, Capital equipment	**n/a**	**n/a**	**48,100**	**67,105**	**41,000**	**29,500**	**-11,500**
General Plant Projects (GPP)							
Other general plant projects under $5 million TEC	n/a	n/a	600	1,800	1,000	1,000	0
Accelerator Improvement Projects (AIP)							
Accelerator improvement projects under $5 million TEC	n/a	n/a	9,925	5,150	9,425	13,000	+3,575

[a] Following the July 2013 BESAC report on Future X-Ray Light Sources, the APS-U project has been rescoped to upgrade to a fourth generation storage ring and beamlines.

[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.

Major Items of Equipment Descriptions

Advanced Photon Source Upgrade (APS-U)

The Advanced Photon Source Upgrade (APS-U) MIE supports activities to develop, design, build, install, and test the equipment necessary to upgrade an existing third-generation synchrotron light source facility, the Advanced Photon Source (APS). The FY 2017 Request for the APS-U is $20,000,000, which is flat compared to the FY 2016 Enacted level. The APS is one of the Nation's most productive x-ray light source facilities, serving over 5,000 users annually and providing key capabilities to enable forefront scientific research in a broad range of fields of physical and biological sciences. The APS is the only hard x-ray 7 GeV source in the U.S. and one of only four in the world, along with the European Synchrotron Radiation Facility (ESRF) in France, PETRA-III in Germany, and SPring-8 in Japan. In 2015 China announced its intention to construct a fourth generation 6 GeV hard x-ray synchrotron light source. High-energy penetrating x-rays are critical for probing materials under real working environments, such as a battery or fuel cell under load conditions. All three foreign facilities are well into campaigns of major upgrades of beamlines and are also incorporating technological advancements in accelerator science to enhance performance. With the ever increasing demand for higher penetration power for probing real-world materials and applications, the higher energy hard x-rays (20 keV and above) produced at APS provide unique capabilities in the U.S. x-ray arsenal that are a pre-requisite for tackling the grand science and energy challenges of the 21st Century. In response to the findings and recommendations of the July 25, 2013 BES Advisory Committee report, 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 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. The APS-U will ensure that the APS remains a world leader in hard x-ray science. 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 managed by Argonne National Laboratory.

The National Synchrotron Light Source-II (NSLS-II) Experimental Tools (NEXT)

The NSLS-II Experimental Tools (NEXT) MIE supports activities to add beamlines to the National Synchrotron Light Source-II (NSLS-II) Project. FY 2016 is the last year of construction funding for NEXT; no funding is requested in FY 2017. The NEXT Project will provide NSLS-II with complementary best-in-class beamlines that support the identified needs of the U.S. research community and the DOE energy mission. Implementation of this state-of-the-art instrumentation will significantly increase the scientific quality and productivity of NSLS-II. In addition, the NEXT project will enable and enhance more efficient operation of NSLS-II. The project is managed by Brookhaven National Laboratory.

Construction Projects Summary ($K)

	Total	Prior Years	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
13-SC-10, Linac Coherent Light Source-II (LCLS-II), SLAC							
TEC	993,100	142,700	138,700	138,700	200,300	190,000	-10,300
OPC	51,900	28,600	9,300	9,300	0	0	0
TPC	**1,045,000**	**171,300**[a]	**148,000**	**148,000**	**200,300**	**190,000**	**-10,300**
Total, Construction							
TEC	n/a	n/a	138,700	138,700	200,300	190,000	-10,300
OPC	n/a	n/a	9,300	9,300	0	0	0
TPC	**n/a**	**n/a**	**148,000**	**148,000**	**200,300**	**190,000**	**-10,300**

Funding Summary ($K)

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
Research	686,876	681,346	692,214	791,188	+98,974
Scientific User Facilities Operations	804,948	810,078	865,314	872,508	+7,194
Major Items of Equipment	42,500	42,500	35,500	20,000	-15,500
Construction Projects (includes OPC)	148,000	148,000	200,300	190,000	-10,300
Other[b]	50,876	1,000	55,672	63,034	+7,362
Total, Basic Energy Sciences	**1,733,200**	**1,682,924**	**1,849,000**	**1,936,730**	**+87,730**

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

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

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 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
TYPE A FACILITIES					
Advanced Light Source	**$60,500**	**$61,250**	**$68,050**	**$64,950**	**-$3,100**
Number of Users	2,400	2,560	2,450	2,400	-50
Achieved operating hours	N/A	5,770	N/A	N/A	N/A
Planned operating hours	5,000	5,000	5,200	5,000	-200
Optimal hours	5,300	5,300	5,300	5,000[a]	-300
Percent optimal hours	94.3%	108.9%	98.1%	100%	N/A
Unscheduled downtime hours	<10%	<10%	<10%	<10%	N/A

[a] Optimal hours decreased for scheduled maintenance.

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
Advanced Photon Source	**$124,815**	**$125,540**	**$130,432**	**$133,995**	**+$3,563**
Number of Users	5,000	5,331	5,100	5,000	-100
Achieved operating hours	N/A	4,944	N/A	N/A	N/A
Planned operating hours	5,000	5,000	5,000	5,000	0
Optimal hours	5,000	5,000	5,000	5,000	0
Percent optimal hours	100%	98.9%	100%	100%	N/A
Unscheduled downtime hours	<10%	<10%	<10%	<10%	N/A
National Synchrotron Light Source, BNL	**$5,500**	**$7,000**	**$0**	**$0**	**$0**
Achieved operating hours	N/A	N/A	N/A	N/A	N/A
Planned operating hours	0	0	0	0	0
Optimal hours	0	0	0	0	0
Percent optimal hours	N/A	N/A	N/A	N/A	N/A
Unscheduled downtime hours	N/A	N/A	N/A	N/A	N/A
National Synchrotron Light Source-II, BNL	**$90,415**	**$90,715**	**$110,000**	**$111,834**	**+$1,834**
Number of Users	200	110	700	900	+200
Achieved operating hours	N/A	1,965	N/A	N/A	N/A
Planned operating hours	2,100	2,100	3,250	3,500	+250
Optimal hours	2,300	2,300	3,300	3,500	+200
Percent optimal hours	91.3%	85.4%	98.5%	100%	N/A
Unscheduled downtime hours	<10%	<10%	N/A	<10%	N/A
Stanford Synchrotron Radiation Lightsource	**$39,000**	**$39,798**	**$40,755**	**$41,986**	**+$1,231**
Number of Users	1,500	1,626	1,550	1,500	-50
Achieved operating hours	N/A	4,925	N/A	N/A	N/A
Planned operating hours	5,200	5,200	5,300	5,200	-100
Optimal hours	5,400	5,400	5,400	5,200[a]	-200
Percent optimal hours	96.3%	91.2%	98.1%	100%	N/A
Unscheduled downtime hours	<10%	<10%	<10%	<10%	N/A

[a] Optimal hours decreased for scheduled maintenance.

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
Linac Coherent Light Source	**$126,956**	**$125,800**	**$132,669**	**$136,294**	**+$3,625**
Number of Users	580	837	580	380	-200
Achieved operating hours	N/A	4,555	N/A	N/A	N/A
Planned operating hours	4,700	4,700	4,600	3,000	-1,600
Optimal hours	4,700	4,700	4,700	3,000[a]	-1,700
Percent optimal hours	100%	96.9%	97.9%	100%	N/A
Unscheduled downtime hours	<10%	<10%	<10%	<10%	N/A
High Flux Isotope Reactor	**$60,688**	**$61,625**	**$63,419**	**$64,968**	**+$1,549**
Number of Users	450	491	450	450	0
Achieved operating hours	N/A	3,658	N/A	N/A	N/A
Planned operating hours	3,400	3,400	3,450	3,500	+50
Optimal hours	3,500	3,500	3,500	3,500	0
Percent optimal hours	97.1%	104.5%	98.6%	100%	N/A
Unscheduled downtime hours	<10%	<10%	<10%	<10%	N/A
Lujan Neutron Scattering Center	**$2,000**	**$2,000**	**$3,000**	**$3,000**	**$0**
Achieved operating hours	N/A	N/A	N/A	N/A	N/A
Planned operating hours	0	0	0	0	0
Optimal hours	0	0	0	0	0
Percent optimal hours	N/A	N/A	N/A	N/A	N/A
Unscheduled downtime hours	N/A	N/A	N/A	N/A	N/A
Spallation Neutron Source	**$181,425**	**$181,425**	**$198,226**	**$193,209**	**-$5,017**
Number of Users	800	845	850	850	0
Achieved operating hours	N/A	4,441	N/A	N/A	N/A
Planned operating hours	4,700	4,700	4,650	4,700	+50
Optimal hours	4,700	4,700	4,700	4,700	0
Percent optimal hours	100%	94.5%	98.9%	100%	N/A
Unscheduled downtime hours	<10%	<10%	<10%	<10%	N/A

[a] Optimal hours for LCLS are adjusted from 4,700 to 3,000 hours in FY 2017 to allow the facility to conduct transition activities required for LCLS-II.

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
TYPE B FACILITIES					
Center for Nanoscale Materials	**$23,427**	**$23,852**	**$24,481**	**$25,205**	**+724**
Number of users	470	529	500	500	0
Center for Functional Nanomaterials	**$19,908**	**$19,908**	**$20,804**	**$21,418**	**+$614**
Number of users	400	493	420	450	+30
Molecular Foundry	**$26,403**	**$26,403**	**$27,591**	**$28,406**	**+$815**
Number of users	470	677	500	500	0
Center for Nanophase Materials Sciences	**$22,901**	**$23,752**	**$23,932**	**$24,638**	**+$706**
Number of users	440	575	450	500	+50
Center for Integrated Nanotechnologies	**$21,010**	**$21,010**	**$21,955**	**$22,605**	**+650**
Number of users	400	513	420	450	+30
Total, All Facilities	**$804,948**	**$810,078**	**$865,314**	**$872,508**	**+$7,194**
Number of Users	13,110	14,587	13,970	13,880	-90
Achieved operating hours	N/A	30,258	N/A	N/A	N/A
Planned operating hours	30,100	30,100	31,450	29,900	-1,550
Optimal hours	30,900	30,900	31,900	29,900	-2,000
Percent of optimal hours	97.9%	96.5%	98.7%	100%	N/A
Unscheduled downtime hours	<10%	<10%	<10%	<10%	N/A

Scientific Employment

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Estimate	FY 2017 vs FY 2016
Number of permanent Ph.D.'s (FTEs)	4,300	4,300	4,340	4,830	+490
Number of postdoctoral associates (FTEs)	1,110	1,110	1,120	1,320	+200
Number of graduate students (FTEs)	1,670	1,670	1,670	2,030	+360
Other[a]	2,840	2,840	2,900	3,060	+160

[a] 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 2016 CPDS and does not include a new start for FY 2017.

The FY 2017 Request for the Linac Coherent Light Source-II (LCLS-II) is $190,000,000, $10,300,000 less than the FY 2016 Enacted level of $200,300,000. In April 2015, the Office of Science (SC) conducted an external Independent Project Review (IPR) to assess the project's readiness for CD-3B, Approve Long Lead Procurements. The IPR committee found that the project was making good progress overall, but needed to increase the cryoplant refrigeration capacity to address technical risks. In response to this recommendation, the project team proposed increasing the scope of the project by increasing the cryoplant cooling capacity to mitigate the highest technical risk. The Basic Energy Sciences (BES) program accepted the proposal. This change in scope, which includes additional commissioning costs and a larger building to house the additional cryogenic equipment, increased the preliminary total project cost (TPC) point estimate from $965,000,000 to $1,045,000,000. CD-4 is estimated for the third quarter of FY 2022. CD-3B was approved on May 28, 2015, which authorized long lead and advanced procurements for key components of the cryoplant and the superconducting linac which are on the critical path for the project.

Summary

The most recent DOE 413.3B approved Critical Decision (CD) is a revised CD-3B, Approve Long Lead Procurements, that was approved on May 28, 2015. The TPC range of $750,000,000-$1,200,000,000 has not changed.

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.

FY 2015 activities included design, long lead and advance procurements (LLP/APs) of critical systems, R&D, prototyping, fabrication, and installation activities. FY 2016 funding will continue activities for design, LLP/APs, R&D, prototyping, site preparation activities (which includes the removal of original linac equipment), fabrication, installation, and initiate construction activities after CD2/CD3 approval is received. FY 2017 funding will be 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 will also continue in FY 2017.

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

(fiscal quarter or date)

	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2017[a]	4/22/2010	1/21/2014	8/22/2014	2Q FY 2016	4Q FY 2017	2Q FY 2016	N/A	3Q FY 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 Design Scope and Project Costs 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
D&D Complete – Completion of D&D work
CD-4 – Approve Start of Operations or Project Closeout

	Performance Baseline Validation	CD-3A[b]	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	3/14/2014	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[a,c]	47,000	946,100	993,100	51,900	N/A	51,900	1,045,000

4. Project Scope and Justification

Scope

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

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

[b] 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.

[c] 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.

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.

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, which will define the official performance baseline at CD-2, 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. The KPPs presented here are preliminary, pre-baseline values. The final key parameters will be established as part of CD-2, Performance Baseline.

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	3,500
FY 2015	21,000	21,000	20,000
FY 2016	15,000	15,000	14,500
FY 2017	0	0	2,000
Total, Line item construction funding	40,000	40,000	40,000
Total, Design phase	47,000	47,000	47,000
Construction phase			
MIE funding			
FY 2012	42,500[c]	20,000	13,862
FY 2013[b]	17,500	40,000	33,423
FY 2014	0	0	12,256
FY 2015	0	0	455
FY 2016	0	0	4
Total, MIE funding	60,000	60,000	60,000
Line item construction funding			
FY 2014	71,700	71,700	15,213
FY 2015	117,700	117,700	54,531
FY 2016	185,300	185,300	240,300
FY 2017	190,000	190,000	235,000
FY 2018	192,100	192,100	200,000
FY 2019	129,300	129,300	129,300
FY 2020	0	0	11,756
Total, Line item construction funding	886,100	886,100	886,100
Total, Construction phase	946,100	946,100	946,100
TEC			
MIE funding			
FY 2012	44,500[c]	22,000	15,862
FY 2013[b]	22,500	45,000	38,423
FY 2014	0	0	12,256
FY 2015	0	0	455
FY2016	0	0	4
Total, MIE funding	67,000	67,000	67,000

[a] Costs through FY 2015 reflect actual costs; costs for FY 2016 and the outyears are estimates.
[b] FY 2013 funding was requested as a line item, but due to a Continuing Resolution, FY 2013 funds were executed as an MIE.
[c] FY 2012 funding shown includes $22,500,000 of prior year balances from FY 2012 that was reallocated to the LCLS-II project during FY 2013.

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
Line item construction funding			
FY 2014	75,700	75,700	18,713
FY 2015	138,700	138,700	74,531
FY 2016	200,300	200,300	254,800
FY 2017	190,000	190,000	237,000
FY 2018	192,100	192,100	200,000
FY 2019	129,300	129,300	129,300
FY 2020	0	0	11,756
Total, Line item construction funding	926,100	926,100	926,100
Total, TEC[b]	993,100	993,100	993,100
Other Project Cost (OPC)			
OPC except D&D			
MIE funding			
FY 2010	1,126	1,126	938
FY 2011	9,474	9,474	8,033
FY 2012	8,000	8,000	8,893
FY 2013[c]	0	0	116
FY 2014	0	0	439
FY 2015	0	0	10
FY 2016	0	0	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	4,000
FY 2017	0	0	4,508
FY 2018	7,900	7,900	6,700
FY 2019	6,100	6,100	6,600
FY 2020	0	0	700
Total, Line item construction funding	33,300	33,300	33,300
Total, OPC[b]	51,900	51,900	51,900
Total Project Cost (TPC)			
MIE funding			
FY 2010	1,126	1,126	938
FY 2011	9,474	9,474	8,033
FY 2012	52,500[d]	30,000	24,755
FY 2013[c]	22,500	45,000	38,539
FY 2014	0	0	12,695
FY 2015	0	0	465
FY 2016	0	0	175
Total, MIE funding	85,600	85,600	85,600

[a] Costs through FY 2015 reflect actual costs; costs for FY 2016 and the outyears are estimates.

[b] This project has not yet received CD-2 approval; funding and cost estimates are preliminary. Amounts shown include MIE funding of $67,000,000 in the TEC, $18,600,000 in the OPC, and $85,600,000 in the TPC.

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

[d] 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.

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
Line item construction funding			
FY 2014	85,700	85,700	26,855
FY 2015	148,000	148,000	77,181
FY 2016	200,300	200,300	258,800
FY 2017	190,000	190,000	241,508
FY 2018	200,000	200,000	206,700
FY 2019	135,400	135,400	135,900
FY 2020	0	0	12,456
Total, Line item construction funding	959,400	959,400	959,400
Total, TPC[b]	1,045,000	1,045,000	1,045,000

6. Details of Project Cost Estimate

	(dollars in thousands)		
	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	40,750	37,770	N/A
Contingency	6,250	9,230	N/A
Total, Design	47,000	47,000	N/A
Construction			
Site Preparation	24,700	24,700	N/A
Equipment	672,900	564,800	N/A
Other Construction	58,500	58,500	N/A
Contingency	190,000	221,400	N/A
Total, Construction	946,100	869,400	N/A
Total, TEC[b]	993,100	916,400	N/A
Contingency, TEC	196,250	230,630	N/A
Other Project Cost (OPC)			
OPC except D&D			
Conceptual Planning	1,980	1,980	N/A
Conceptual Design	23,408	23,658	N/A
Research and Development	1,972	1,972	N/A
Start-Up	15,790	11,550	N/A
Contingency	8,750	9,440	N/A
Total, OPC[b]	51,900	48,600	N/A
Contingency, OPC	8,750	9,440	N/A
Total, TPC[b]	1,045,000	965,000	N/A
Total, Contingency	205,000	240,070	N/A

[a] Costs through FY 2015 reflect actual costs; costs for FY 2016 and the outyears are estimates.

[b] This project has not yet received CD-2 approval; funding and cost estimates are preliminary. Amounts shown include MIE funding of $67,000,000 in the TEC, $18,600,000 in the OPC, and $85,600,000 in the TPC.

7. Schedule of Appropriations Requests

(dollars in thousands)

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

8. Related Operations and Maintenance Funding Requirements

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

(Related Funding Requirements)

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

The numbers presented are the incremental lifecycle operations and maintenance costs above the existing LCLS. The estimate will be updated and additional details provided after CD-2.

[a] FY 2013 funding was requested as a line item, but due to a Continuing Resolution, FY 2013 funds were executed as an MIE.
[b] This project has not yet received CD-2 approval; funding and cost estimates are preliminary. 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.

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 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.

Biological and Environmental Research

Overview

The mission of the Biological and Environmental Research (BER) program is to support fundamental research and scientific user facilities to achieve a predictive understanding of complex biological, climatic, and environmental systems for a secure and sustainable energy future.

The program seeks to understand the biological, biogeochemical, and physical principles needed to predict a continuum of processes occurring at the molecular and genomics-controlled smallest scales to environmental and Earth system change at the largest scales. Starting with the genetic potential encoded by organisms' genomes, BER research seeks to define the principles that guide the translation of the genetic code into 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 can enable more confident redesign of microbes and plants for sustainable biofuels production, improved carbon storage, and controlled biological transformation of materials such as nutrients and contaminants in the environment. BER research also advances understanding of how the Earth's dynamic, physical, and biogeochemical systems (the atmosphere, land, oceans, sea ice, and subsurface) interact and cause future climate and environmental change to provide information that will inform plans for future energy and resource needs.

BER's scientific impact has been transformative. Mapping the human genome, including the U.S.-supported international Human Genome Project that DOE began in 1990, initiated the era of modern biotechnology and genomics-based systems biology. Today, with its Genomic Sciences activity and the DOE Joint Genome Institute (JGI), BER researchers are using the powerful tools of plant and microbial systems biology to pursue fundamental breakthroughs needed to develop sustainable, cost-effective cellulosic biofuels as outlined in the latest DOE Quadrennial Technology Review (DOE QTR 2015, Chapter 7.3)[a]. The three DOE Bioenergy Research Centers lead the world in fundamental biofuels-relevant research.

Since the 1950s, BER has been a critical contributor to climate science research, beginning with atmospheric circulation studies that were the forerunners of modern climate models. Today, BER research contributes to model development and analysis using community-based models, e.g., Community Earth System Model (CESM), the Accelerated Climate Model for Energy (ACME), and the Global Change Assessment Model (GCAM). These leading U.S. models are used to address two of the most critical areas of uncertainty in contemporary climate science—the impacts of clouds and aerosols—with data provided by the Atmospheric Radiation Measurement Climate Research Facility (ARM), a DOE user facility serving hundreds of scientists worldwide. Also, BER has been a pioneer of ecological and environmental studies in terrestrial ecosystems and seeks to describe the continuum of biological, biogeochemical, and physical processes across multiple scales that control the flux of climate and 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 instruments and a high performance computer to characterize biological organisms and molecules as well as atmospheric aerosol particulates.

Highlights of the FY 2017 Budget Request

Biological and Environmental Research will support core research and scientific user facilities in key areas of bioenergy, climate, and environmental sciences. In the FY 2017 Budget Request, most funding for the Working Capital Fund (WCF) is transferred to Program Direction to establish a consolidated source of funding for goods and services provided by the WCF. CyberOne is still funded through program dollars. In FY 2016 and prior years, WCF costs were shared by SC research programs and Program Direction.

<u>Biological Systems Science</u>
Investments in Biological Systems Science will provide the fundamental understanding to underpin advances in sustainable bioenergy production and to gain a predictive understanding of carbon, nutrient and contaminant transformation in support of DOE's environmental missions. These investments are strongly aligned with national priorities[b] in Clean Energy and Innovation in life sciences. Genomic Sciences research activities continue with core research to provide a scientific basis for

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[a] http://energy.gov/epsa/downloads/quadrennial-energy-review-full-report
[b] https://www.whitehouse.gov/sites/default/files/omb/memoranda/2015/m-15-16.pdf

sustainable and cost effective bioenergy production; this includes the DOE Bioenergy Research Centers (BRCs) and Mission Innovation funding to speed translation of basic research results to industry for contributions to clean energy. Biosystems design research increases to develop the knowledge necessary to engineer specific beneficial traits into plants and microbes for making clean energy biofuels or products from renewable biomass. A new investment in microbiome research is also proposed that builds on BER's considerable experience in fundamental genomic science of plants and microbes and extends that expertise to understand the fundamental principles governing microbiome establishment, function, and interactions in diverse environments[a]. 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 sustainable bioenergy production and environmental research. These fundamental genomic science activities are supported by ongoing efforts to combine molecular and genomic scale information and to develop integrated networks and computational models of system dynamics and behavior. 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, as well as provide broader user access to DNA synthesis capabilities in support of the BRAIN initiative.

Climate and Environmental Sciences

Climate and Environmental Research activities will focus on scientific analysis of the sensitivity and uncertainty of climate predictions to physical and biogeochemical processes, with emphasis on both Arctic and Tropical environments, as part of the Next Generation Ecosystem Experiments (NGEEs) in Alaska and at tropical sites. These investments reflect national priorities[1] in Global Climate Change, Information Technology and High Performance Computing, Ocean and Arctic Issues, and R&D for informed policy-making and management. Each major field study, including the two NGEEs, contains a modeling component; investments in Climate Model Development and Validation focus 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. Increased investment will produce an earth system model capability that includes a human component involving vulnerability analysis and integrated assessment, tailored to DOE requirements, e.g., new research to understand the interdependencies of water, energy and climate change, for a variety of scenarios applied to spatial scales as small as 10km. The model system will have improved resolution that will include new codes 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 continues long-term measurements at fixed sites in Alaska, Oklahoma, and the Azores, selected for scientific impact on improving climate models. The ARM mobile facilities will deploy to three climate-sensitive regions demanding focused and targeted measurements in the Arctic, Antarctic, and the Atlantic Ocean.

EMSL will focus on an aggressive research agenda aligned with BER program research areas and highlighting opportunities with the new High Resolution and Mass Accuracy Capability (HRMAC) instrument; with greatly improved dynamic range and sensitivity, HRMAC will enable a characterization and quantitation of the chemical constituents and dynamics of complex natural systems in the environment including microbial communities, atmospheric aerosols, and the soil and rhizosphere ecosystem. EMSL funding levels are enhanced to support characterization of novel biosensors and biomaterials relevant to the goals of the BRAIN initiative.

The Data Management effort will focus on advancing the Climate and Environmental Data Analysis and Visualization activity that will incorporate high resolution Earth system models with interdependent components involving energy and infrastructure sector models, field observations, raw data from environmental field experiments, and analytical tools for system diagnostics, validation, and uncertainty quantification.

Within the FY 2017 Budget Request, Climate and Environmental Sciences, specifically, Climate and Earth System Modeling Integrated Assessment activities, supports the DOE Energy-Water Nexus (EWN) crosscut. EWN is a set of cross-program collaborations designed to accelerate the Nation's transition to more resilient energy and coupled energy-water systems.

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[a] https://www.whitehouse.gov/sites/default/files/microsites/ostp/NSTC/ftac-mm_report_final_112015_0.pdf

There is increasing urgency to address EWN challenges in an integrated way due to changing precipitation and temperature patterns, changes in extreme weather, accelerated drawdown of critical water supplies, population growth and regional migration trends, and the introduction of new technologies that could shift water and energy demands. The BER contribution to the EWN crosscut is in its first key focus area: advanced, integrated data, modeling, and analysis platform to improve understanding and inform decision-making for a broad range of users and at multiple scales.

Increased BER funding for energy-water efforts in FY 2017 will support a set of regional-scale data, modeling and analysis (DMA) test beds focusing on the integration of diverse observational data and modeling outputs, data assimilation, and both analytic and visualization tools to exercise and extend capabilities, and test limits for predictive insights. The regional-scale DMA test beds will serve as the basis for a new high resolution modeling capability for impact, adaptation, and vulnerability (IAV) analysis of energy-water systems.

Exascale computing systems, capable of at least one billion billion (1×10^{18}) calculations per second are needed to support diverse areas of research that are critical to national security objectives and applied research advances in areas such as climate and energy modeling. Exascale systems' computational power is needed to develop the science base and allow for increasingly complex modeling and data-analytic and data-intense applications across the entire Federal complex. The Exascale Computing Initiative (ECI) is a product of long-term collaboration between the SC's Advanced Scientific Computing Research (ASCR) program and the National Nuclear Security Administration's (NNSA) Advanced Simulation and Computing Campaign (ASC) program.

As part of the ECI, BER will be responsible for determining the scope and management of the Climate Modeling programs that in turn demand access to extreme scale computational capabilities. Climate modeling science requires very high resolution representations of atmospheric, oceanic, and terrestrial processes across multiple scales, to project how systems such as aerosols, clouds, precipitation, surface hydrology, ecosystems, and Arctic tundra, sea ice, and ice sheets will shift in highly variable and complex ways in response to and as part of climate change. Energy and infrastructure planning will require precise projections of temperature exceedances, water availability, sea-level rise, storm likelihood, and crop potentials. The Extreme Challenges workshop series and the Advanced Scientific Computing Advisory Committee Subcommittee report on Exascale climate science described the need to understand the dynamic physical, hydrological, biogeochemical, and ecological evolution of the climate system, with quantification of the uncertainties in regional projections as well as the impacts on regional and sub-decadal to multi-decadal scales.

FY 2017 Crosscuts ($K)

	EWN	ECI	Total
Biological and Environmental Research	24,300	10,000	34,300

Biological and Environmental Research
Funding ($K)

	FY 2015 Enacted	FY 2015 Current[a]	FY 2016 Enacted	FY 2017 Request[b]	FY 2017 vs FY 2016
Biological Systems Science					
Genomic Science					
Foundational Genomics Research	73,228	73,228	76,125	104,171	+28,046
Genomics Analysis and Validation	10,000	10,000	9,248	9,248	0
Metabolic Synthesis and Conversion	16,262	16,262	16,262	16,262	0
Computational Biosciences	16,395	16,395	16,395	16,395	0
Bioenergy Research Centers	75,000	75,000	75,000	89,550	+14,550
Total, Genomic Science	**190,885**	**190,885**	**193,030**	**235,626**	**+42,596**
Mesoscale to Molecules	**9,680**	**9,680**	**9,623**	**10,623**	**+1,000**
Radiological Sciences					
Radiochemistry and Imaging Instrumentation	2,665	2,665	1,000	0	-1,000
Radiobiology	2,409	2,409	1,000	0	-1,000
Total, Radiological Sciences	**5,074**	**5,074**	**2,000**	**0**	**-2,000**
Biological Systems Facilities and Infrastructure					
Structural Biology Infrastructure	14,895	14,895	10,000	10,000	0
Joint Genome Institute	69,500	69,500	69,500	70,463	+963
Total, Biological Systems Facilities and Infrastructure	**84,395**	**84,395**	**79,500**	**80,463**	**+963**
SBIR/STTR	9,858	0	10,118	12,339	+2,221
Total, Biological Systems Science	**299,892**	**290,034**	**294,271**	**339,051**	**+44,780**
Climate and Environmental Sciences					
Atmospheric System Research	**25,892**	**25,966**	**26,392**	**26,392**	**0**
Environmental System Science					
Terrestrial Ecosystem Science	44,034	44,034	40,035	40,035	0
Subsurface Biogeochemical Research	23,533	23,533	23,207	23,207	+0
Total, Environmental System Science	**67,567**	**67,567**	**63,242**	**63,242**	**+0**
Climate and Earth System Modeling					
Climate Model Development and Validation	0	0	15,448	10,000	**-5,448**
Regional and Global Climate Modeling	26,159	26,029	30,088	30,088	**0**
Earth System Modeling	35,303	35,303	35,569	35,569	**0**
Integrated Assessment	9,733	9,789	17,567	27,874	**+10,307**
Total, Climate and Earth System Modeling	**71,195**	**71,121**	**98,672**	**103,531**	**+4,859**

[a] Reflects the transfer of Small Business Innovation/Technology Transfer Research (SBIR/STTR) funds within the Office of Science.
[b] A transfer of $1,269,000 to Science Program Direction is to consolidate all Working Capital Funds in one program.

	FY 2015 Enacted	FY 2015 Current[a]	FY 2016 Enacted	FY 2017 Request[b]	FY 2017 vs FY 2016
Climate and Environmental Facilities and Infrastructure					
Atmospheric Radiation Measurement Climate Research Facility	67,429	67,429	65,429	65,429	**+0**
Environmental Molecular Sciences Laboratory	45,501	45,501	43,191	45,552	**+2,361**
Data Management	5,000	5,000	7,066	7,066	**+0**
Total, Climate and Environmental Facilities and Infrastructure	**117,930**	**117,930**	**115,686**	**118,047**	**+2,361**
SBIR/STTR	9,524	0	10,737	11,657	**+920**
Total, Climate and Environmental Sciences	**292,108**	**282,584**	**314,729**	**322,869**	**+8,140**
Total, Biological and Environmental Research	**592,000**	**572,618**	**609,000**	**661,920**	**+52,920**

SBIR/STTR Funding:

- FY 2015 transferred: SBIR $17,033,000 and STTR $2,349,000.
- FY 2016 projected: SBIR $18,135,000; STTR $2,720,000.
- FY 2017 Request: SBIR $21,038,000; STTR $2,958,000.

[a] Reflects the transfer of Small Business Innovation/Technology Transfer Research (SBIR/STTR) funds within the Office of Science.
[b] A transfer of $1,269,000 to Science Program Direction is to consolidate all Working Capital Funds in one program.

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

	FY 2017 vs FY 2016
Biological Systems Science: Investments in Genomic Science increase integrative and knowledge transfer efforts at the DOE Bioenergy Research Centers with continued complementary research on potential bioenergy feedstock plants, sustainability research for bioenergy, biosystems design, microbial community impacts on carbon and nutrient cycling, and integrative computational approaches for systems biology research. Increased investment in Genomic Science will build on BER's fundamental genomic science research and extend these activities to understanding how microbes and plants interact in a range of microbiomes of relevance to DOE's bioenergy and environmental missions. Additionally, the development of new bioimaging technology through the Mesoscale to Molecules activity will expand efforts to create new integrative imaging platforms to understand the expression and function of genome information encoded within cells. JGI continues to provide DNA sequencing, analysis and synthesis support to researchers, as well as for targeted efforts relevant to the BRAIN initiative. Final funding for Radiological Sciences is provided in FY 2016.	**+44,780**
Climate and Environmental Sciences: Climate and Earth System modeling continues investments in new research to evaluate an additional set of geographic regions that complement existing efforts in the Arctic and the Tropics, which are poorly represented in climate models yet are cause for significant sources of prediction uncertainty. New data, modeling and analysis efforts in support of the energy-water nexus crosscut will be structured around regional-scale test beds. Climate Model Development and Validation is decreased in response to model architecture restructuring that initially uses only the ARM Oklahoma site as a research testbed plus limited data collection for the ARM Alaska sites, uses new software engineering and computational upgrades, and incorporates scale-aware physics in all model components. Environmental System Science continues and will seek greater efficiencies by aggregating a higher fraction of its research into decadal-scale climate-ecosystem science campaigns e.g., NGEE Arctic, NGEE Tropics, a northern peatland experiment, and AmeriFlux. The Environmental Molecular Sciences Laboratory (EMSL) increase will address a more focused set of scientific topics that exploit recently installed capabilities involving HRMAC, live cell imaging, and radiological science capabilities, as well as more extensive use of integrating data from other EMSL instrumentation into process and systems models and simulations to address challenging problems in the biological, environmental, and climate sciences, and to benefit the BRAIN initiative. The Climate and Environmental Data Analysis and Visualization activity continues to provide an integrated capability that allows compatibility and interoperability involving both observed and model generated climate information. Information as part of this activity involves multiple model products in the Earth System Grid Federation (ESGF), and data from environmental field experiments, ARM facility observations, and components of the EMSL data base. ARM continues its investments in planned field deployments of the ARM Mobile Facilities (AMFs) to under-observed regions and develops new Unmanned Aerial Vehicle (UAV) capabilities.	**+8,140**
Total, Biological and Environmental Research	**+52,920**

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 understanding that can be used to develop new bioenergy crops and improved biofuel production processes that enable a more sustainable bioeconomy, as outlined in the latest DOE Quadrennial Technology Report (QTR[a]) and highlighted in a recent 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, including DOE's Office of Energy Efficiency and Renewable Energy (EERE) and the Advanced Research Projects Agency-Energy (ARPA-E), and the U.S. Department of Agriculture. Coordination with other federal agencies on priority 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, and under the White House Office of Science and Technology Policy (OSTP). 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). Microbiome research is coordinated by OSTP through the Life Science Subcommittee of the National Science and Technology Council (NSTC) and priorities articulated in a recent NSTC report[c]. BER, along with other SC program offices, is in close coordination with the National Institutes of Health (NIH) and the Presidential BRAIN Initiative to develop next generation tools and technologies to optimally align exascale developments with research into the brain. The major goals for the DOE contribution to the BRAIN Initiative focus on the development of these enabling technologies, with respect to three major themes: developing the specialized, high-resolution tools for measuring key neurological processes, developing the capabilities for obtaining a dynamic, real-time read-out of these measurements, and developing the integrated computational framework for analyzing and interpreting this dynamic multi-modal data. Developing the tools to integrate and synthesize multimodal data on the brain and nervous system would be unprecedented and would inform other analyses of complex systems. A workshop will be held in FY 2016 to inform the priority requirements for developing novel biosensors and probes that can measure key molecular components or processes relevant to neuroscience.

BER research to understand and predict future changes in the earth's climate system provides important tools that link climate predictions to evaluations of new energy policies and help to guide the design criteria for next generation energy infrastructures. An example is water and the role that water plays in energy extraction, supply and transmission over a range of potential climate states including, for example, multi-year drought, and its role as a balancing factor for energy production when wind and solar energy renewables are included. Water and energy bring together SC, energy technology offices, and energy policy offices of the Department. Coordination among these offices is important for understanding not only water required for all facets of energy production, from biofuels to thermoelectric cooling, but also the energy required to provide water for various uses. 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 climate science needs occurs through the interagency U.S. Global Climate Change Research Program (USGCRP) under OSTP.

Program Accomplishments

Fundamental Bioenergy Research. Research results from the DOE Bioenergy Research Centers (BRCs) continue to demonstrate significant progress towards developing new dedicated bioenergy feedstocks and new products from renewable biomass. Switchgrass, specifically modified to be less recalcitrant to cellulosic sugar extraction, thrived in field trials demonstrating the environmental robustness of this potential bioenergy crop. Upon harvest, the modified switchgrass displayed superior bioenergy conversion characteristics relative to native switchgrass demonstrating the development of a new potential bioenergy feedstock. New insights into the composition and structure of lignin have identified ways to recover value-added products from this otherwise by-product of cellulose extraction. Research on the bond structure of lignin has led to new ways to recover aromatic chemicals from this polymer. Likewise, components of ionic liquids, used for the deconstruction of biomass to cellulosic sugars, can be synthesized from compounds derived from lignin. Combined, these results advance the ability to recover and/or make useful products from biomass-derived lignin, a notoriously recalcitrant

[a] http://energy.gov/epsa/downloads/quadrennial-energy-review-full-report
[b] http://www.nap.edu/catalog/19001/industrialization-of-biology-a-roadmap-to-accelerate-the-advanced-manufacturing
[c] https://www.whitehouse.gov/sites/default/files/microsites/ostp/NSTC/ftac-mm_report_final_112015_0.pdf

structural component of plant cell walls. Because lignin makes up a significant percentage of biomass by weight, these findings represent new potential methods to increase the overall efficiency and range of products that can be produced from renewable biomass.

Biosystems Design Research. Recent advances in the Genomic Science activity are making progress on developing the required techniques to underpin a burgeoning biotechnology industry focused on the production of biofuels and bioproducts from renewable biomass. Researchers within the Genomic Science activity recently developed a new genetic system for photosynthetic diatoms that will enable investigations of the biofuel and bioproduct production potential of these microbes. Lack of a robust genetic system often limits the use of most microorganisms as platforms for genetic engineering. This new technique, while applicable to diatoms, may also hold promise for a range of other currently genetically intractable microorganisms needed for biotechnological purposes. Similarly, new high throughput methods to track genetic manipulations within genetically tractable microorganisms are needed to accelerate biotechnological research. A new technique (TRACE) has recently been demonstrated that can more efficiently track genetic modifications in tens of thousands of individual test microbes at a time. The new method efficiently maps combinations of engineered genomic mutations to track and identify those microbes with an enhanced tolerance to biofuel compounds. The technique is broadly applicable to a range of microbial species and will enable rapid screening of modified microbes for bioenergy and bioproducts production. Rapid advances in genetic modification of microorganisms have raised concerns over the potential for proliferation of modified organisms in the environment. New insights into genomic recoding techniques show how microorganisms could be engineered for not only beneficial bioenergy or bioproduct production purposes but also to strictly limit their survival to laboratory settings. New results show how microbial genomes can be recoded to rely on nonstandard amino acids (not available in Nature) thereby restricting their survival to laboratory settings. This research is important to demonstrate new biocontainment strategies that could be employed as developments in biotechnology continue to advance at a very rapid pace in concert with concerns over its use.

Plant Genomes for Bioenergy Research. Researchers at the DOE Joint Genome Institute (JGI) recently completed the genome of the eucalyptus tree. JGI is a primary source of complex plant and microbial community genomes for bioenergy and environmental research and completion of the eucalyptus genome is a milestone for BER's bioenergy research efforts. Eucalyptus is one of the most widely planted hardwood trees in the world and represents a globally significant resource for pulp, paper, biomaterials and bioenergy. The complex genome extending across 11 chromosomes is significant because eucalyptus produces a rather diverse set of metabolites that can be readily developed into a range of biofuels or other bioproducts. With the completed genome researchers can also use the information for comparative genomic studies of hardwood trees to identify other beneficial bioenergy traits.

Improving Climate Models to Better Predict Precipitation. While climate models are adept at predicting future temperature changes on regional and global scales, the quality of precipitation predictions has not kept pace. To address this need, scientists used observations from the DOE Atmospheric Radiation Measurement Climate Research Facility (ARM) to discover that precipitation forecasts are limited largely by overly simplistic formulas for Secondary Organic Aerosols (SOAs) that influence droplet initiation and cloud formation. Using laboratory and field experimental data, the research has improved the understanding of SOA chemistry, including better understanding of how SOAs serve as cloud condensation nuclei. The improved formulas were incorporated into a climate model with significantly improved predictability of clouds and precipitation.

Simulating Agricultural Irrigation in Earth System Models. World agriculture consumes about 87 percent of global fresh water withdrawal, acting as a dominant component of the global water cycle with impacts on local and regional climates. Previous studies of irrigation impacts on climate have focused on a subset of local surface processes, but no study has applied uncertainty quantification methodologies to the combination of atmospheric, terrestrial, and water cycle interdependencies. Scientists upgraded the land component (CLM4) of the Community Earth System Model (CESM), to simulate irrigation water use and climatic feedbacks. Drawing upon two widely-used data sets from the agriculture census, they found that CLM4 could be improved by applying updated calibrations and incorporating information on the spatial distribution and intensity of irrigated areas. More importantly, the team identified a way to realistically assess the impacts of irrigation on climate and strategies to improve water management practices. Their results integrate a new set of CLM4 modules into CESM that describe groundwater pumping and irrigation efficiency, stream flow routing, and water management.

Biological and Environmental Research
Biological Systems Science

Description

Biological Systems Science integrates discovery- and hypothesis-driven science with technology development on plant and microbial systems relevant to national priorities in clean energy 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 approaches employed include 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 operation of a scientific user facility, the DOE Joint Genome Institute (JGI), and use of structural biology facilities through the development of instrumentation at DOE's national scientific user facilities. Support is also provided 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, climate, and the environment. 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 national challenges in sustainable bioenergy production, understanding how microbial activity impacts the fate and transport of materials such as nutrients and contaminants in the environment, and developing new approaches to examine the role of biological systems in carbon cycling, biosequestration, and global climate.

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; develop "-omics" experimental capabilities and enabling technologies needed to achieve a dynamic, system-level understanding of organism and community functions; and 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 biofuel 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; increased funding will speed translation of basic research results to industry for contributions to clean energy. Genomic Science 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. A new effort in microbiome research will build on and complement existing genomic-based research, through the study of natural microbiomes and model microbiomes in targeted field environments relevant to BER's bioenergy and climate science research efforts. With a long history in microbial genomics-based research coupled with substantial biotechnological and computational capabilities available within the DOE user facilities, BER is well positioned to make significant contributions to understanding microbiome function.

Finally, these systems biology efforts are supported by the ongoing development of bioinformatics and computational biology capabilities within the DOE Systems Biology Knowledgebase (KBase). The integrative KBase project seeks to develop the necessary hypothesis-generating analysis techniques and simulation capabilities on high performance computing platforms to accelerate collaborative and reproducible systems biology research within the Genomic Sciences.

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 continue to encourage the development of new measurement and imaging technologies to visualize the spatial and temporal relationships of key metabolic processes governing phenotypic expression in plants and microbes. This information is crucial towards developing an understanding of the impact of various environmental and/or biosystems designs on whole cell or community function. The activity also has relevance to visualizing cell-cell or cell-plant interactions within a microbiome association.

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 biofuels 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 new capabilities are part of the JGI's latest strategic plan to provide users with additional capabilities supporting biosystems design efforts for biofuels and environmental process research, and can also provide synergistic capabilities in partnership with other SC user facilities for the BRAIN initiative. 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 a new effort 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, in collaboration with the other SC program offices. 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 university, research institute, 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 Systems Biology KBase to help accelerate practical applications of this knowledge for energy and the environment.

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Change FY 2017 vs FY 2016 Enacted
Biological Systems Science $294,271,000	**$339,051,000**	**+$44,780,000**
Genomic Science $193,030,000	**$235,626,000**	**+$42,596,000**
Genomic Science continues to remain a top priority. Foundational Genomics increases 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 continues research on improving the functional characterization of microorganisms and microbial communities relevant to biofuel production. Metabolic Synthesis and Conversion continues 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 is provided for studies on the environmental, ethical, legal, and societal impacts. Computational Biosciences continues 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 continues to provide a fundamental scientific basis for cellulosic biofuels production.	Microbes rarely exist in isolation in nature and in fact interact in myriad dynamic ways with each other and with changing signals from the environment. These collective interactions constitute a microbiome and most of BER's basic bioenergy and environmental process research depends on gaining a more predictive understanding of microbiome function. Foundational Genomics will increase to support a new effort in microbiome research to evaluate interactions between microorganisms and plants in microbiomes of relevance to BER's bioenergy and environmental science missions. Biosystems design efforts will increase to pursue innovative techniques to manipulate microbe and plant genomes for beneficial purposes and sustainability research will provide new insights into bioenergy crop production for clean energy. Genome Analysis and Validation will continue research on improving the functional characterization of microorganisms and microbial communities relevant to biofuel production. Metabolic Synthesis and Conversion will continue research to expand the range of model plant and microbial systems for bioenergy research and, to understand the impact of microbial communities on the fate of carbon, nutrients and contaminants in the environment. Computational Biosciences will continue to develop the computational platforms, analysis techniques and bioinformatics tools needed within the DOE KBase to accelerate systems biology research. Bioenergy research at the DOE BRCs will begin its tenth year of operations providing DOE with a fundamental scientific basis for cellulosic biofuels production.	The increase will support a new effort in microbiome research, which will provide insight into multiple microbiomes of relevance to DOE's sustainable bioenergy and environmental missions. It will also provide funding to initiate new work in biosystems design research to allow the selective transfer of genomic traits among plants and microbes. This facilitates developing the metabolic potential of plants and microbes for clean energy and a bio-based economy. The BRCs will receive increased funding for the final year of their funding period, which will support efforts to speed translation of basic research results to industry for contributions to clean energy.

FY 2016 Enacted	FY 2017 Request	Explanation of Change FY 2017 vs FY 2016 Enacted
	Additional funding will accelerate knowledge transfer. A competitive FOA issued in FY 2016 will determine the selection of the next phase of the BRCs in FY 2017.	
Mesoscale to Molecules $9,623,000	**$10,623,000**	**+$1,000,000**
The program continues to develop new enabling technologies to visualize key metabolic processes in plants and microbes. These new techniques provide integrative information on the spatial and temporal relationships of metabolic processes occurring within and among cells. This information is crucial to 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.	The program will continue efforts to develop new integrative bioimaging technologies. These efforts dovetail with the ongoing research in the genomic science activity and seek to provide ways to visualize the dynamic processes of gene expression and function in vivo. Increased funding will broaden the activity to a more diverse set of potential bioimaging applications under development.	Increased funding will expand the current set of bioimaging projects under development within the portfolio.
Radiological Sciences $2,000,000	**$0**	**-$2,000,000**
Funding supports the orderly closeout of Radiological Science activities in FY 2016.	Activities are completed.	
Biological Systems Science Facilities and Infrastructure $79,500,000	**$80,463,000**	**+$963,000**
The JGI remains an essential component for genomic research within BER. The facility continues 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 continues to collaborate closely with the DOE Systems Biology KBase to provide not only community access to sequenced genomes but access to computational systems to experimentally interrogate those genomes.	The JGI will continue to provide essential genome sequencing and new genome analysis capabilities for BER programs. The facility will continue to evolve with the scientific user community as it revises and implements its strategic plan. The facility will continue to focus on complex plant and microbial communities' genome sequencing efforts that are the hallmark of the facility and of fundamental importance to BER's genomic science-based efforts in bioenergy and environment. The JGI will continue to collaborate closely with the DOE Systems Biology Knowledgebase to provide community access to sequenced genomes and access to high performance computational systems to experimentally interrogate those genomes. The JGI will partner with other SC user facilities to provide targeted user access to recently developed	This increase supports JGI partnerships with other SC user facilities to provide targeted user facility access for the BRAIN initiative.

FY 2016 Enacted	FY 2017 Request	Explanation of Change FY 2017 vs FY 2016 Enacted
	new capabilities for high throughput functional assays and DNA writing and manipulation techniques, aligned with priorities identified in a scientific workshop held in FY 2016. These new capabilities would be uniquely synergistic with the BRAIN initiative efforts to develop bioprobes and bio-compatible electronics for neurological networks.	
Access to the Structural Biology Infrastructure at the DOE synchrotron light and neutron sources continues 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 Systems Biology Knowledgebase (KBase).	Access to the Structural Biology Infrastructure at the DOE synchrotron light and neutron sources will continue. These capabilities will continue to provide access to instrumentation to evaluate structural features of biomolecules and make this information available to the larger research community through the Protein Data Base and the DOE Systems Biology Knowledgebase.	

Description

The Climate and Environmental Sciences subprogram supports fundamental science and research capabilities that enable major scientific developments in climate-relevant atmospheric and ecosystem process and modeling research, in support of DOE's mission goals for basic science, energy, and national security. This includes research on clouds, aerosols, and the terrestrial carbon cycle; large-scale climate change and Earth system modeling; the interdependence of climate change and ecosystems; and integrated analysis of climate change impacts on energy and related infrastructures, with a view toward increasing fractions of renewable energy of total U.S. energy production. It also supports subsurface biogeochemical research that advances fundamental understanding of coupled physical, chemical, and biological processes controlling both the terrestrial component of the carbon cycle and the environmental fate and transport of energy byproducts, including greenhouse gases. 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 climate change and other energy-related environmental challenges. The Department will continue to advance the science necessary to further develop predictive climate and Earth system models targeting resolution at the regional spatial scale and interannual to centennial time scales and to focus on areas of critical uncertainty including Arctic ecology and permafrost thaw, tropical ecological change, and carbon release, in close coordination with the U.S. Global Change Research Program (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 major data activity. The two national scientific user facilities are the Atmospheric Radiation Measurements Climate 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 are needed to develop and test understanding of the central role of clouds and aerosols on climate scales and on spatial scales extending from local to global. EMSL provides integrated experimental and computational resources needed 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 climate modeling platforms.

Atmospheric System Research

Atmospheric System Research (ASR) is the primary U.S. activity addressing two major areas of uncertainty in climate change model projections: 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 climate-sensitive 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 a diversity of locations and atmospheric conditions. ASR research results are incorporated into Earth system models developed by Climate and Earth System Modeling to both understand the processes that govern atmospheric components and to advance Earth system model capabilities with greater certainty of predictions. ASR seeks to develop integrated, scalable test-beds that incorporate process-level understanding of the life cycles of aerosols, clouds, and precipitation into dynamic models.

Environmental System Science

Environmental System Science supports research to provide a robust, predictive understanding of terrestrial surface and subsurface ecosystems, including the effects of climate change, from the subsurface to the top of the vegetated canopy and from molecular to global scales. This includes understanding the role of ecosystems in climate with an emphasis on carbon cycling and the role of subsurface biogeochemical processes in the fate and transport of carbon, nutrients, radionuclides, and heavy metals.

A significant fraction of the CO_2 released to the atmosphere during fossil fuel combustion is taken up by terrestrial ecosystems, but the impacts of climatic change, particularly warming, on the uptake of CO_2 by the terrestrial biosphere remain poorly understood. The significant sensitivity of climate models to terrestrial carbon cycle feedback and the uncertain signs of that feedback make resolving the role of the terrestrial biosphere on the carbon balance a high priority.

Using decadal-scale investments such as the Next Generation Ecosystem Experiments (NGEEs) to study the variety of time scales and processes associated with ecological change, the research focuses on understanding, observing, and modeling the processes controlling exchange rates of greenhouse gases, in particular CO_2 and methane (CH_4), between atmosphere and terrestrial biosphere, evaluating terrestrial source-sink mechanisms for CO_2 and CH_4, and improving and validating the representation of terrestrial ecosystems in coupled Earth system models. This research supports the USGCRP interagency priority to understand the impacts of global change on the Arctic Region and resulting effects on global climate. 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.

Climate and Earth System Modeling
Climate and Earth System Modeling develops physical, chemical, and biological model components, as well as fully coupled Earth system models that combine with sophisticated representations of human activities. This research includes the interactions of human and natural Earth systems needed to simulate climate variability and change from years to decades to centuries at regional and global scales. The research specifically focuses on quantifying and reducing the uncertainties in Earth system models based on more advanced model development, diagnostics, and climate 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. This research supports the USGCRP interagency priority in intraseasonal to centennial predictability, predictions and projections, including focus on extreme events.

Climate Model Development and Validation continues at reduced levels. The focus of the investment involves model architecture restructuring, exploiting new software engineering and computational upgrades, and incorporating scale-aware physics in all model components, as part of the DOE-wide Exascale Computing Initiative (ECI) crosscut. DOE 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 certainty of predictions in a flexible structure. Because model development requires systematic validation at each step, investment in model assessment and validation will continue. Examples include the use of ARM data combined with scale-aware Large Eddy Simulation products. High resolution ARM and model ensemble data bases will be integrated into the advanced data management infrastructure effort, the Climate and Environmental Data Analysis and Visualization activity, for use by the scientific research community. Other validation platforms include the sensitivity and uncertainty of climate predictions to explore climate sensitive geographies or processes as well as the representation of extreme events in these next generation models.

The Regional and Global Climate modeling activity will increase investments in scientific analyses using DOE's capabilities in climate and Earth system modeling. Models will be utilized in order to develop and analyze a new set of high resolution simulations of extreme events, that directly support the DOE-wide Energy-Water Nexus crosscut objectives, with particular focus on evaluating the influence of extremes on the interdependence of energy and water, in the context of Sankey diagrams. The Regional and Global Climate modeling activity will additionally conduct scientific analyses to study the predictability of statistical distributions of future weather extremes that exhibit short repeat times, i.e., that in turn have the potential to cause cascading impacts on energy-water infrastructures. The Regional and Global Climate Modeling activity will continue to analyze the causes and distributions of droughts; biogeochemical controls on abrupt climate change; the role of the highly resolved patterns of carbon budgets on regional and global climate change; and the roles of cryospheric phenomena (sea ice, glaciers, ice sheets, and permafrost thaw) on Arctic climate, sea level rise, and large scale modes of variability. Also, research will explore model–derived analogs that combine historical and projected climate changes, with an objective to validate and improve the uncertainty characterization of future climate projections based on the prediction successes using existing data testbeds. To rapidly and efficiently advance model capabilities, BER supports a unique and powerful intercomparison resource, the Program for Climate Model Diagnosis and Intercomparison (PCMDI), for global climate model development, validation, diagnostics, and outputs, using over 40 world-leading climate 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 climate research programs.

The Earth System Modeling activity in BER will continue to coordinate with the National Science Foundation (NSF) to provide support for greater sophistication of Earth system models, in particular the Community Earth System Model system (CESM) that is co-funded by DOE and NSF. CESM is designed by the research community with open access and broad use by climate researchers worldwide. In addition, DOE will continue to advance a new version of CESM, i.e., the Accelerated Climate

Model for Energy (ACME), as a computationally efficient model adaptable to emerging computer architectures and with greater sophistication and fidelity for high resolution simulation. This system of models provides a critical capacity for regional climate projections, including information on how the frequency of occurrence and intensity of storms, droughts, heat waves, and regional sea-level will change as climate evolves. The scientific priorities for improvement of the community models are based on efforts to quantify uncertainties relative to specific scientific questions; and the outputs of the intercomparison and validation resource allow one to determine best features of all global models that can be considered for incorporation into DOE's ACME modeling platform. DOE also has provided computational capability and expertise to the climate research community through a partnership between BER and the Office of Science's Advanced Scientific Computing Research (ASCR) program, which is investing in innovative code and algorithm designs for optimal model computation on its petascale computers. Climate 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.

The Integrated Assessment activities in BER develop integrated assessment (IA) models and impacts analyses, and will continue efforts to integrate adaptation and vulnerability (IAV) capabilities into the modeling and predictive capabilities. Expanded efforts will specifically support the Energy-Water Nexus objectives, with focus on development and demonstration of a novel high–resolution community IA-IAV hybrid model system, improving not only the resolution but also the detailed process representations for autonomous elements as well as for coupled energy-water-land system interdependencies. Also, efforts will be dedicated to establish a set of three to four regional-scale data, modeling and analysis test beds, outputs from which provide a foundation for future development of an Integrated Field Laboratory (IFL), an instrumented field research and observation site to conduct sophisticated research that utilizes the enhanced data, modeling, and analytical capabilities of the regional test beds to understand process and infrastructure interdependencies under water-stressed conditions. The Integrated Assessment activity will address uncertainty characterization of both the individual physical, biogeophysical, and sectoral (including energy infrastructure as well as emerging clean energy technology deployment) drivers, extending from macroscale (greater than 50 km resolution) to the much finer scales of Earth system prediction (order of 10 km).

<u>Climate and Environmental Facilities and Infrastructure</u>
Climate and Environmental Facilities and Infrastructure include two scientific user facilities, and climate data management for the climate science community. The scientific user facilities—the Atmospheric Radiation Measurement Climate Research Facility (ARM), and the Environmental Molecular Sciences Laboratory (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-platform, multi-site, national scientific user facility, providing the world's most comprehensive continuous field measurements of climate data to advance atmospheric process understanding and climate models through precise observations of atmospheric phenomena. ARM currently consists of three fixed, long-term measurement facility sites (in Oklahoma, Alaska, and the Azores), three mobile facilities, and an airborne research capability that operates at sites selected by the scientific community. The ARM fixed sites and mobile measurement campaigns are distributed around the world in locations where the scientific community most critically needs enhanced understanding and data to incorporate into climate models, thereby improving model performance and predictive 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 to study the impact of evolving clouds, aerosols, and precipitation on the Earth's radiative balance and rate of climate change address the two most significant scientific uncertainties in climate 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 climate projections 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 climate, energy, and environmental challenges facing DOE and the Nation. This includes science supporting alternative energy sources, improved catalysts and materials for industrial applications, insights into factors influencing climate change and carbon sequestration processes, and subsurface biogeochemical drivers. EMSL will address a more focused set of scientific topics that capitalize on recently installed capabilities involving HRMAC, live cell imaging, and radiological science capabilities, and more extensive utilization of other EMSL instrumentation into process and systems models and simulations to address challenging problems in the biological, environmental, and climate 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, and technological innovation. DOE’s data management activities will be coordinated with the Big Data Research and Development Initiative,[a] and internally collaborative with ASCR programs.

In FY 2017, the BER Data Management activity will continue efforts to harmonize and integrate metadata from the Earth System Grid Federation, ARM and NGEE field experiments, and relevant components of data. Analytical tools will be integrated into the program, including capabilities for diagnostics, validation, and uncertainty quantification.

[a] http://www.whitehouse.gov/sites/default/files/microsites/ostp/big_data_press_release_final_2.pdf

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs FY 2016 Enacted
Climate and Environmental Sciences $314,729,000	**$322,869,000**	**+$8,140,000**
Atmospheric System Research (ASR) $26,392,000	**$26,392,000**	**$0**
ASR continues to focus on atmospheric cloud and aerosol issues that limit climate modeling capabilities, with a particular emphasis on Arctic mixed phase clouds and tropical systems with large variations of aerosol characterization. ASR exploits Large Eddy Simulation (LES) as a tool to understand scale-aware physics governing aerosol transformations, cloud nuclei formation and growth, and cloud evolution. ASR utilizes 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 coordinate with Climate and Earth System Modeling to focus activities on atmospheric cloud and aerosol issues that limit climate modeling capabilities, with increasing emphasis on very high resolution process representations and new efforts on land-atmosphere interactions that impact aerosol and cloud processes. Research on Arctic mixed phase clouds and marine stratocumulus clouds will exploit new observational capabilities. Increased use of Large Eddy Simulation (LES) as a tool to understand scale-aware physics governing aerosol transformations, cloud nuclei formation and growth, and cloud evolution will benefit from enhanced ARM measurements at the Oklahoma site and case study data sets for northern Alaska.	Funding continues at the FY 2016 Enacted level. Research will exploit new data generated by Large Eddy Simulations available from ARM sites, newly developed airborne data sets collected with Unmanned Aerial Systems, and new marine, Arctic, and Antarctic observations. A new class of ASR research efforts will couple observations and the ARM Facility Large Eddy simulation database to extend process level understanding.
Environmental System Science (ESS) $63,242,000	**$63,242,000**	**+$0**
Research continues 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 supports efforts to improve terrestrial land modeling component, to test new concepts and build testbeds for high resolution land model validation.	Research will continue in Alaska, using a larger set of field stations expanded from Barrow. NGEE tropics will continue model analysis with field measurements collected in a variety of tropical regimes, e.g., in Puerto Rico and Brazil, where diverse ecological conditions are exposed to significant climate forcing.	Funding continues at the FY 2016 Enacted level. Research will begin to incorporate field experimental data into new climate model architectures.

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs FY 2016 Enacted
Climate and Earth System Modeling $98,672,000	**$103,531,000**	**+$4,859,000**
Research continues to extend capabilities for the Accelerated Climate Model for Energy (ACME) 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 initiates 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 climate change. Regional modeling analysis addresses interdependencies involving the water and energy sectors, using details on existing and projected infrastructures. In addition, funding for this program supports 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 climate system analysis, as well as developing vulnerability analysis techniques to treat the energy-water nexus with existing and projected infrastructure.	Research to extend ACME capabilities will continue to focus on enhancing the land component (including ecological processes) to address the more rapidly changing conditions expected for a variety of geographic domains. Statistical and dynamical uncertainty methods will be incorporated for all components of the ACME system, including land, ocean, atmosphere, cryosphere, and the human component. This will considerably enhance the human component, with the development of a hybrid model that combines Integrated Assessment and Impact, Adaptation, and Vulnerability; and this hybrid modeling approach will be exercised to describe the energy-water nexus of challenges facing U.S. energy and water infrastructures. The program will apply advanced software upgrades to all modeling components. A set of science topics involving future extremes in climate states, including drought, will be studied with both the ACME model and other models (such as the Community Earth System Model) that have a sufficient level of process level sophistication that is needed to address mission challenges of relevance to the Department.	Increases will be dedicated to new efforts in integrated assessment modeling to understand process interactions involving the energy-water nexus, and will fund a set of three to four regional-scale data, modeling, and analysis test beds to accelerate synthesis of integrated toolsets in diverse environments and explore predictive challenges associated with the energy-water nexus.
Climate Model Development and Validation focus 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 will continue to develop model architecture restructuring, exploiting new software engineering and computational upgrades, incorporating scale-aware physics in all model components and efforts to assess and validate model results.	
Core research in Regional and Global Climate Modeling, Earth System Modeling and Integrated Assessment continues to underpin high-resolution	Efforts will continue to focus on the dynamical and statistical analysis of climate extremes, with supporting efforts specifically focused on arctic-	

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs FY 2016 Enacted
predictability using adaptive grids and uncertainty characterization, and more sophisticated data management.	midlatitude interactions, drought evolution, atmospheric rivers, carbon-nutrient cycle feedbacks, and impacts of interannual variations of ocean circulations (such as El Nino and the Arctic Oscillation).	
Climate and Environmental Facilities and Infrastructure $115,686,000	**$118,047,000**	**+$2,361,000**
ARM continues to support its long-term measurements at fixed sites, and the mobile facilities are deployed to three climate-sensitive regions demanding targeted measurements. The first mobile facility remains in the Amazon Basin for the first quarter, thereafter undergo maintenance; the second is deployed to Antarctica; and the third continues 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. Incorporation of modeling and simulation as part of ARM data acquisition is initiated	ARM will continue to support and enhance its long-term measurements at fixed sites. To support the goal of better linking ARM observations to global climate models to reduce key climate uncertainties, ARM will increase the measurement density around its Oklahoma and Alaska sites, enhance observations for land-atmosphere coupling, develop higher order data products that are more suitable for model evaluation, and develop instrument simulators for direct evaluation of models with observational data. Dedicated high resolution Large Eddy Simulations will be integrated routinely into ARM data acquisition. New Unmanned Aerial Vehicle capabilities will provide unprecedented observations in extreme Arctic conditions. ARM mobile facilities will be deployed to under-observed climate-sensitive regions where targeted measurements will provide critical data to the science community.	The ARM mobile facility will provide the first scanning cloud radar data in Antarctica to the scientific community. Data generated by Large Eddy Simulations and newly deployed Unmanned Aerial Vehicles at the Oklahoma and Alaska sites trigger a new level of sophisticated science on aerosol and cloud processes.
EMSL continues 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. Emphasis is placed on utilization of new capabilities in the Radiological Annex and Quiet wing. In FY 2016 the integrated HRMAC system is available for new research. The installation and availability of the HRMAC, with its 21Tesla magnet, provides unique enhancements to EMSL's capabilities available to the research community.	EMSL facility operations support experimental and computational user research in biological systems science, hydrobiogeochemistry, ecosystems science, vegetative emissions and aerosol chemistry, and interfacial chemistry and surface science relevant to climate, energy, and environmental challenges facing DOE and the Nation. Support will emphasize the use of advanced imaging capabilities in the Quiet wing to investigate processes in living plant and microbial cells and their interactions with the surrounding environment. The HRMAC 21 Tesla mass spec system will be used to identify the molecular composition of	EMSL expands user research on the new and unique HRMAC system to address previously unattainable research challenges and provide new scientific understanding of the molecular composition of aerosol particles and emissions from plants, interactions within microbial biofilms, intra- and intercellular processes, and imaging of intact proteins. EMSL will partner with other SC user facilities to provide targeted user facility access for the BRAIN initiative.

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs FY 2016 Enacted
	aerosol samples, microbial communities and cellular products. Molecular-level reaction chemistry of radioactive elements and materials from waste tanks and the subsurface will be explored using unique instruments in RadEMSL. EMSL (in partnership with other SC user facilities) will provide targeted user facility access to the JGI and EMSL, to address BRAIN and systems biology science priorities in cellular biochemical and metabolic flux, membrane protein dynamics, and develop modeling approaches that can be used to integrate multimodal data. These priorities will be informed by a scientific workshop held in FY 2016.	
The Climate and Environmental Data Analysis and Visualization activity continues 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 Large Eddy Simulation ensembles to provide statistics of sub-grid parameterizations for a wider range of conditions involving extreme events. Model-data fusion is explored with new visualization technologies.	The data activity will continue to develop an integrative framework of metadata, data standards, and interoperability, such that data holdings of the Carbon Dioxide Information Analysis Center, Earth System Grid Federation, and the Atmospheric Radiation Measurement Climate Research Facility will be linked by a common framework. In addition, data from other agencies of interest to DOE funded scientists, such as the NASA DAACs, will be established within the common framework. In order to support the requirements of the next Coupled Model Intercomparison Project of the IPCC, the framework will also be improved with capabilities to conduct server side analyses that utilize all data archives accessible by the framework.	The Climate and Environmental Data Analysis and Visualization activity will provide an integrated capability that allows compatibility and interoperability involving both observed and model generated climate information. Information as part of this activity involves multiple model products in the Earth System Grid Federation (ESGF), and data from environmental field experiments, ARM facility observations, and components of the EMSL data base.
Participation in the Big Earth Data Initiative continues.		

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. The following table shows the targets for FY 2015 through 2017. Details on the Annual Performance Report can be found at http://energy.gov/cfo/reports/annual-performance-reports.

	FY 2015	FY 2016	FY 2017
Performance Goal (Measure)	**BER Climate Model—Develop a coupled climate model with fully interactive carbon and sulfur cycles, as well as dynamic vegetation to enable simulations of aerosol effects, carbon chemistry, and carbon sequestration by the land surface and oceans and the interactions between the carbon cycle and climate**		
Target	Develop capabilities to extend temporal resolution to sub-decadal for earth system models.	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 Accelerated Climate Model for Energy (ACME), to simulate and evaluate human-natural interdependencies for the carbon and water cycles.
Result	Met	TBD	TBD
Endpoint Target	BER supports the Community Earth System Model, a leading U.S. climate model, and addresses two of the most critical areas of uncertainty in contemporary climate science—the impacts of clouds and aerosols. Delivery of improved scientific data and models (with quantified uncertainties) about the potential response of the earth atmosphere system to more accurately predict the earth's future climate is essential to plan for future energy needs, water resources, and land use. DOE will continue to advance the science necessary to further develop predictive climate and earth system models at the regional spatial scale and decadal to centennial time scales, involving close coordination with the U.S. Global Change Research Program and through the international science community.		
Performance Goal (Measure)	**BER Predictive Understanding of Biological Systems—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 1 new computationally enabled approach to analyze complex genomic datasets.	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.
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 sustainable bioenergy systems 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 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
Capital Operating Expenses Summary							
Total Non-MIE Capital equipment (projects under $5 million TEC)	n/a	n/a	4,667	5,139	4,500	4,500	0

Funding Summary ($K)

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
Research	375,293	375,293	400,025	446,480	+46,455
Scientific user facilities operations and research	197,325	197,325	188,120	191,444	+3,324
Other[a]	19,382	0	20,855	23,996	+3,141
Total, Biological and Environmental Research	**592,000**	**572,618**	**609,000**	**661,920**	**+52,920**

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 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
TYPE B FACILITIES					
Atmospheric Radiation Measurement Climate Research Facility (ARM)	**$67,429**	**$67,429**	**$65,429**	**$65,429**	**+0**
Number of users	900	900	950	1,000	+50
Joint Genome Institute	**$69,500**	**$69,500**	**$69,500**	**$70,463**	**+963**
Number of users	1,000	1,000	1,300	1,300	0
Environmental Molecular Sciences Laboratory	**$45,501**	**$45,501**	**$43,191**	**$45,552**	**+2,361**
Number of users	715	715	715	750	+35
Structural Biology Infrastructure[b]	**$14,895**	**$14,895**	**$10,000**	**$10,000**	**0**
Total Facilities	**$197,325**	**$197,325**	**$188,120**	**$191,444**	**+3,324**
Number of users	2,615	2,615	2,965	3,050	+85

[a] Includes SBIR and STTR.

[b] Structural Biology Infrastructure activities are at Basic Energy Sciences user facilities and the user statistics are included in the BES user statistics.

Scientific Employment

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Estimate	FY 2017 vs FY 2016
Number of permanent Ph.D.'s	1,295	1,295	1,350	1,410	+60
Number of postdoctoral associates	320	320	330	342	+12
Number of graduate students	440	440	450	470	+20
Other[a]	320	320	330	342	+12

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

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 interdisciplinary nature of modern fusion research is emphasized in the 2015 Quadrennial Technology Review.

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.

The knowledge base being established through FES research supports U.S. goals for future scientific exploration on ITER, a major international fusion facility currently under construction in St. Paul-lez-Durance, France. ITER will be the world's first magnetic confinement long-pulse, high-power burning plasma experiment aimed at demonstrating the scientific and technical feasibility of fusion energy. Execution and oversight of the U.S. contribution to the ITER project are carried out within FES.

To support the program mission and its major focus, the U.S. fusion program has four elements:

- Burning Plasma Science: Foundations;
- Burning Plasma Science: Long Pulse;
- Burning Plasma Science: High Power; and
- Discovery Plasma Science.

Highlights of the FY 2017 Budget Request

Notable changes in the FY 2017 budget include:

- *No funding is provided for Alcator C-Mod operation and research*—after the final year of operation of Alcator C-Mod in FY 2016, the research staff at the MIT Plasma Science and Fusion Center will shift focus to begin full-time collaborative research activities in the DIII-D and NSTX-U national research programs; in addition, some will engage in collaborations with international laboratories.
- *Increased support for DIII-D and National Spherical Torus Experiment-Upgrade (NSTX-U) research*—Funding for the DIII-D and NSTX-U research programs 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 collaborations with MIT researchers.
- *Continued support to the U.S. Contributions to ITER Project*—Funding will support 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. Funding is also provided toward the FY 2017 monetary contribution to the ITER Organization, which supports ITER Project common expenses.
- In the FY 2017 Budget Request, most funding for the Working Capital Fund (WCF) is transferred to Program Direction to establish a consolidated source of funding for goods and services provided by the WCF. CyberOne is still funded through program dollars in the SC Safeguards and Security program. In FY 2016 and prior years, WCF costs were shared by SC research programs and Program Direction.

Fusion Energy Sciences
Funding ($K)

	FY 2015 Enacted	FY 2015 Current[a]	FY 2016 Enacted	FY 2017 Request[b]	FY 2017 vs. FY 2016
Fusion Energy Sciences					
Burning Plasma Science: Foundations					
Advanced Tokamak	105,348	107,675	101,255	84,238	-17,017
Spherical Tokamak	72,919	71,169	74,000	73,199	-801
Theory & Simulation	34,670	35,006	33,500	33,170	-330
GPE/GPP/Infrastructure	3,125	3,600	6,000	5,000	-1,000
Total, Burning Plasma Science: Foundations	**216,062**	**217,450**	**214,755**	**195,607**	**-19,148**
Burning Plasma Science: Long Pulse					
Long Pulse: Tokamak	7,695	7,895	8,500	6,045	-2,455
Long Pulse: Stellarators	6,419	8,010	7,269	5,084	-2,185
Materials & Fusion Nuclear Science	24,842	23,033	25,252	20,226	-5,026
Total, Burning Plasma Science: Long Pulse	**38,956**	**38,938**	**41,021**	**31,355**	**-9,666**
Discovery Plasma Science					
Plasma Science Frontiers	46,024	44,643	46,784	31,916	-14,868
Measurement Innovation	3,575	3,575	6,700	4,000	-2,700
SBIR/STTR & Other	12,883	2,760	13,740	10,300	-3,440
Total, Discovery Plasma Science	**62,482**	**50,978**	**67,224**	**46,216**	**-21,008**
Subtotal, Fusion Energy Sciences	**317,500**	**307,366**	**323,000**	**273,178**	**-49,822**
Construction					
14-SC-60 International Thermonuclear Experimental Reactor (ITER)	150,000	150,000	115,000	125,000	+10,000
Total, Fusion Energy Sciences	**467,500**	**457,366**	**438,000**	**398,178**	**-39,822**

SBIR/STTR:

- FY 2015 Transferred: SBIR $8,906,000 and STTR $1,228,000
- FY 2016 Projected: SBIR: $9,333,000; STTR: $1,400,000
- FY 2017 Request: SBIR $8,436,000 and STTR $1,186,000

[a] Reflects the transfer of Small Business Innovation/Technology Transfer Research (SBIR/STTR) funds within the Office of Science.
[b] A transfer of $861,000 to Science Program Direction to consolidate all Working Capital Funds in one program.

Fusion Energy Sciences
Explanation of Major Changes ($K)

	FY 2017 vs FY 2016
Burning Plasma Science: Foundations: Overall funding for advanced tokamak research is decreased, as operation of Alcator C-Mod ceases. Funding for DIII-D and NSTX-U research is increased to support the enhanced collaboration by MIT research staff in those programs. Funding for Theory & Simulation is increased to accelerate progress toward whole-device modeling. Decreased funding for DIII-D and NSTX-U operations results in deferment of some facility enhancements and a slight reduction to operating weeks.	**-19,148**
Burning Plasma Science: Long Pulse: Overall funding is decreased for U.S. research collaborative activities on overseas long-pulse tokamaks and stellarators and on research and experimental capabilities that address the plasma-materials interface scientific challenge.	**-9,666**
Discovery Plasma Science: Overall funding is decreased, as the High Energy Density Laboratory Plasma science activity contracts to focus on supporting research utilizing the Matter in Extreme Conditions instrument of the Linac Coherent Light Source at the SLAC National Accelerator Laboratory. Decreases in Measurement Innovation and General Plasma Science activities result from the completion of targeted research enhancements fully funded in FY 2016.	**-21,008**
Construction: Funding is provided toward the FY 2017 monetary contribution (total $44M) to the ITER Organization.	**+10,000**
Total Funding Change, Fusion Energy Sciences	**-39,822**

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 National Science Foundation (NSF), with research extending to a wide range of natural phenomena, including the origin of magnetic fields in the universe and the heating of the solar corona. 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 Fusion Energy Sciences Advisory Committee (FESAC) provides technical and programmatic advice to FES and NNSA for the joint HEDLP program.

Program Accomplishments
Completion of the NSTX Upgrade project—the research capabilities of the NSTX user facility have been enhanced by doubling its maximum toroidal field and plasma current, lengthening the pulse length, and adding a second set of neutral beam sources for off-axis heating and current drive. These improvements make the NSTX-U experiment the highest performing spherical tokamak in the world and will allow NSTX-U researchers to explore unique spherical tokamak parameter regimes to advance predictive understanding of magnetically confined plasmas.

ITER component production and major deliveries—The U.S. ITER Project began the challenging task of winding the first 100-ton module for the ITER central solenoid, which, when completed, will be the most powerful pulsed superconducting electromagnet ever produced. U.S. vendors also successfully delivered one 100-meter superconducting length and two 800-meter production lengths of active conductor to the European Union's Toroidal Field Coil fabricator in Italy, and four lots of high-voltage substation transformers, which are part of the steady state electric network, to the ITER site. The U.S. ITER Project also completed fabrication and delivery of all five nuclear-grade tokamak cooling water system drain tanks.

First fully remote operation of an overseas tokamak—the first-ever fully remote operation of the Experimental Advanced Superconducting Tokamak (EAST) tokamak in China was carried out by U.S. scientists from a purpose-built remote collaboration room at General Atomics. The integrated China/U.S. experimental team studied axisymmetric controllability and vertical displacement disruption events over six-hour periods on two consecutive days. Operating EAST remotely during the nighttime in China but during the U.S. working daytime is a key milestone in the DOE Scenarios and Control International Collaboration that involves several U.S. institutions. This approach is expected to enable EAST to achieve 24-hour utilization and effectively offer use of a full campaign of experimental time to U.S. scientists during its operating periods. Further remote operation sessions are being planned for next year.

Shining a light on the composition of the Sun—A discrepancy exists between theoretical models (based on spectroscopic observations) that describe the relative abundances of elements in the Sun and measurements of the solar interior that are made with acoustic wave observations. Scientists with the Z facility at Sandia National Laboratories discovered that the wavelength-dependent radiation absorption (opacity) of iron, heated to 2.2 million degrees Kelvin, is 30–400 percent higher than theoretically predicted. These new measurements suggest that the true opacity of solar matter is higher than previously believed, altering theoretical models of the sun in a direction that brings them closer to the helio-seismological observations. These results have impacted our understanding of the life cycle of the Sun and stellar evolution.

Chirping radio signals from space recreated in the laboratory—Researchers at the University of California, Los Angeles, successfully excited elusive plasma waves, known as whistler-mode chorus waves, in the Basic Plasma Science Facility's Large Plasma Device. Previously these waves had only been studied in the Earth's near-space environment. They were accidentally discovered during World War I by radio operators, who dubbed them "dawn chorus" since the radio signal of the waves sounded like the chirping of birds. These waves, which occur naturally in the Earth's magnetosphere, accelerate electrons to extremely high energies and are responsible for the creation of the Van Allen radiation belt encircling the Earth, which pose a threat to satellites in orbit. These new experiments allowed researchers, for the first time, to test under controlled laboratory conditions the current understanding of nonlinear excitation of whistler waves.

Fine-tuning tokamak magnetic fields to mitigate damaging energy bursts—Plasma confined by magnetic fields in a tokamak device is subject to intense heat bursts, called Edge Localized Modes (ELMs), which can damage the walls of the confining vessel. It had been known that ELMs could be suppressed by the application of small three-dimensional (3-D) magnetic fields at the edge of the tokamak plasma; unfortunately, doing so often destabilized the central core of the plasma. Utilizing a newly enhanced magnetic diagnostic system on DIII-D, a multi-institutional team of scientists found that application of a 3-D perturbative magnetic field that encircles the tokamak twice will mitigate the ELMs without adversely affecting the core plasma. The new results suggest further possibilities for tuning the magnetic fields to make ELM control easier. These findings point the way to overcoming a persistent barrier to sustained fusion reactions.

Multi-scale simulations of tokamak plasma confinement—High temperature plasmas are a soup of positively charged ions and negatively charged electrons. While faithful computer simulations of ion transport and confinement in high-temperature tokamak plasmas are now fairly standard, accurate simultaneous simulation of the electrons has proven very difficult due to their factor-of-2000 mass difference with ions. Recently, gyrokinetic simulations of both ion and electron transport dynamics, involving widely disparate time and space scales, have been successfully performed for the first time with a realistic ion/electron mass ratio. The simulations used 100 million CPU hours, mostly on the Edison supercomputer at the National Energy Research Scientific Computing Center (NERSC) user facility. The results demonstrated that such multi-scale simulations are required to match with the experimentally measured ion and electron thermal fluxes and profiles and thus resolved a longstanding mystery of electron heat conduction in tokamaks.

Helium bubble formation in fusion materials—it has been known for some time that neutrons from fusion reactions can cause bubbles of helium to form within plasma-facing materials, such as tungsten, which will be used in the ITER tokamak. These bubbles grow and can burst violently when they migrate to the surface, resulting in releases of debris that are detrimental to the plasma. This process of bubble formation, which is important for predicting large-scale material response to the extreme fusion environment, has been studied with atom-based simulations using resources at NERSC and the Oak Ridge Leadership Computing Facility. The results show how the growth rate can affect the bubble size, shape, pressure, and surface damage. This information is critically important to accurately predict how a tokamak divertor component made of tungsten behaves under fusion conditions.

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, including developing the predictive understanding needed for ITER operations and providing solutions to high-priority ITER concerns.
- 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 2017 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 ITER and future fusion reactors. Near-term targeted efforts address scientific issues important to the ITER design. Longer-term research focuses on advanced scenarios to maximize ITER performance. 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 continued operation in FY 2016 to complete student research and experimental work. The facility will cease operations by the end of FY 2016.

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 Princeton Plasma Physics Laboratory (PPPL) is designed to explore the physics of plasmas confined in a spherical torus (ST) configuration. A major advantage of this configuration is the ability to confine plasma at a pressure that is high compared to the magnetic field energy density, which could lead to the development of more compact and economical future fusion research facilities based on the ST concept. The ST configuration, with its very strong magnetic curvature, has different confinement and stability properties from those of conventional tokamaks.

The NSTX-U Major Item of Equipment (MIE) project was completed in FY 2015. The upgrade of the center stack assembly enables a doubling of the magnetic field and plasma current and an increase in the plasma pulse length from 1 to 5 seconds, making NSTX-U the world's highest-performance ST. The addition of a second neutral beam system doubles the available heating power and makes it possible to achieve higher plasma pressure and improve its current drive efficiency and profile control to achieve fully non-inductive operation. Together, these upgrades support a strong research program to develop the improved understanding of the ST configuration required to establish the physics basis for next-step ST facilities and broaden scientific understanding of plasma confinement. The capability for controllable fully non-inductive current drive will also contribute to an assessment of the ST as a potentially cost-effective path to fusion energy.

During its first year of research operations in FY 2016, NSTX-U will achieve magnetic fields and plasma currents about one and a half times higher than those prior to the upgrade project. During FY 2017, NSTX-U will achieve the design values for the magnetic field and plasma current, which are twice those achieved in NSTX.

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 Scientific Discovery through Advanced Computing (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 hugely 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 needs and priorities of ITER and burning plasmas. Three of these centers are set up as partnerships between FES and Advanced Scientific Computing Research (ASCR).

GPE/GPP/Infrastructure

Funding in this category provides support for general infrastructure improvements at the PPPL site consistent with the PPPL Campus Modernization Plan. This funding is based upon an analysis of safety requirements, equipment reliability, facility improvements, and research-related infrastructure needs.

Fusion Energy Sciences
Burning Plasma Science: Foundations

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Change FY 2017 vs. FY 2016
Advanced Tokamak $101,255,000	**$84,238,000**	**-$17,017,000**
DIII-D Research ($35,000,000) *DIII-D Operations ($45,000,000)* Operations funding supports fifteen 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 FY 2015 community workshops. Areas of research include 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 involve 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 ($37,000,000)* *DIII-D Operations ($44,100,000)* Operations funding supports fourteen weeks of research operations at the DIII-D facility. Research will be conducted to prepare for burning plasmas in ITER, determine the optimal path to steady-state tokamak plasmas, and develop the plasma material interaction boundary solutions necessary for future devices. Specific research goals will involve testing the predictive models of fast ion transport by multiple Alfven eigenmodes, studying the physical processes that determine the edge pedestal density structure, and examining the impurity generation and transport from the high-Z coated tiles. Targeted enhancements to the facility will involve completion and commissioning of an additional high-power microwave heating system, as well as continued work on improving the neutral beam heating control system and designing the modifications necessary for a second off-axis and co-/counter-directed neutral beam.	*DIII-D Research (+$2,000,000)* *DIII-D Operations (-$900,000)* Increases in research funding will support the enhanced collaboration in the DIII-D national research program by the MIT scientific staff, while decreases in operations funding will delay some planned facility enhancements and require a reduction of operating weeks.

FY 2016 Enacted	FY 2017 Request	Explanation of Change FY 2017 vs. FY 2016
C-Mod Research ($6,145,000) *C-Mod Operations ($11,855,000)* Operations funding supports five weeks of research operations at the Alcator C-Mod facility in its final year of operation in FY 2016. Research is focused on research needs as identified by the FY 2015 community workshops. Experiments are 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 will be closed after final operations. The scientific staff will complete analysis of existing C-Mod data and begin making a transition to collaborative research activities on other research facilities.	*C-Mod Research ($0)* *C-Mod Operations ($0)* Operation of Alcator C-Mod ceases. No funding is requested for this element.	*C-Mod Research (-$6,145,000)* *C-Mod Operations (-$11,855,000)* Support for Alcator C-Mod operation and research ends in FY 2016, and the MIT research staff will begin collaborative research activities at other national and international facilities.
Enabling R&D ($2,165,000) Support continues 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 ($2,165,000)* Support will continue 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 ($0)* Research efforts are maintained at the FY 2016 Enacted level.
Small-scale Experimental Research ($1,090,000) Small-scale tokamak plasma research provides experimental data in regimes of relevance to the mainline advanced tokamak magnetic confinement efforts and helps 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 ($973,000)* Research will continue to provide experimental data in regimes relevant to mainline tokamak confinement and experimental validation of models and codes.	*Small-scale Experimental Research: (-$117,000)* Experimental research and modeling efforts are reduced.

FY 2016 Enacted	FY 2017 Request	Explanation of Change FY 2017 vs. FY 2016
Spherical Tokamak $74,000,000	**$73,199,000**	**-$801,000**
NSTX-U Research ($30,000,000) *NSTX-U Operations ($41,000,000)* NSTX-U begins operations after successful completion of the upgrade. Machine performance is 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 are studied. The NSTX-U team also conducts experiments on disruption physics and on high-priority research needs as identified by the FY 2015 community workshops. In mid-FY 2016, a machine vent is scheduled to install a row of molybdenum tiles in the lower divertor region. A total of 18 weeks of operation is planned in FY 2016.	*NSTX-U Research ($31,410,000)* *NSTX-U Operations ($39,090,000)* The NSTX-U team will extend performance to full field and current (1 Tesla, 2 mega Amps—which is double what had been achieved prior to the upgrade). Experiments will address divertor heat flux mitigation and plasma confinement at full parameters, assess the performance and impact of the molybdenum divertor tiles, and continue experiments on high-priority research needs as identified by the FY 2015 community workshops. Also, the team will begin experiments on fully non-inductive current drive and sustainment. Finally, the team will begin to develop scenarios for achieving and controlling high-performance discharges. A total of 16 weeks of operation is planned in FY 2017.	*NSTX-U Research (+$1,410,000)* *NSTX-U Operations (-$1,910,000)* Increases in research funding will support the enhanced collaboration in the NSTX-U national program by the MIT research staff, while decreases in operations funding will delay some planned facility enhancements and require a reduction of operating weeks.
Small-scale Experimental Research ($3,000,000) Small-scale spherical torus plasma research provides experimental data in regimes of relevance to the mainline spherical torus magnetic confinement efforts and helps 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 ($2,699,000)* Research will continue to provide experimental data in regimes relevant to mainline spherical torus confinement and experimental validation of models and codes.	*Small-scale Experimental Research (-$301,000)* Experimental research and modeling efforts are reduced.
Theory & Simulation $33,500,000	**$33,170,000**	**-$330,000**
Theory ($24,000,000) The Theory activity continues to advance the scientific understanding of the fundamental physical processes governing the behavior of magnetically confined plasmas. Emphasis on addressing ITER priorities continues to guide the selection of new and renewal awards via competitive merit reviews.	*Theory ($21,170,000)* Theoretical research at universities, private industry and national laboratories will continue to address fundamental questions of magnetic confinement science. The selection of new awards via competitive merit reviews will place emphasis on closing gaps in burning plasma science as identified by the community workshops held in FY 2015 and on addressing high priority needs of integrated simulation efforts.	*Theory (-$2,830,000)* The reduction will result in approximately six fewer awards being made to universities and private industry, relative to FY 2016, under the annual Theory Funding Opportunity Announcement. Efforts at the national laboratories will be held flat with the FY 2016 Enacted level.

FY 2016 Enacted	FY 2017 Request	Explanation of Change FY 2017 vs. FY 2016
SciDAC ($9,500,000) The five SciDAC centers, pending a positive outcome of the merit review held in FY 2015, enter the final year of their research activities, while the three FES–ASCR SciDAC-3 partnerships continue their efforts in the areas of boundary physics, materials science, and multiscale integrated modeling. FES and ASCR develop a plan emphasizing integration for the science areas represented by the entire FES SciDAC portfolio and initiate preparations for a competitive merit review.	*SciDAC ($12,000,000)* The new SciDAC centers, selected via a competitive merit review and set up as partnerships with ASCR, will start their research activities. The new portfolio will have a strong emphasis on integration and whole-device modeling, focusing on the highest-priority research directions as identified by the community workshops held in FY 2015. This area supports Clean Energy.	*SciDAC (+$2,500,000)* The increased funding will strengthen integration efforts and accelerate progress toward whole-device modeling.
GPE/GPP/Infrastructure $6,000,000	**$5,000,000**	**-$1,000,000**
Continued support of NSTX-U operations, as well as enhanced International Collaborations, is provided through improvements to the Princeton Plasma Physics Laboratory Computer Center (PPPLCC) and establishment of remote collaboration room configurations. Environmental monitoring needs at PPPL will continue to be supported.	Funding will provide support for general infrastructure improvements for the PPPL site consistent with the PPPL Campus Modernization Plan, based upon an analysis of safety requirements, equipment reliability, and research-related infrastructure needs.	Funding maintains infrastructure repairs and maintenance, as well as, modernization of laboratory infrastructure, consistent with the PPPL Campus Modernization Plan, although the reduction slows the pace of the campus modernization efforts.

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 required to withstand the extreme conditions in a burning plasma environment. 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.

<u>Long Pulse: Tokamak</u>
Multi-institutional U.S. research teams will be supported to continue their successful work on the long-pulse international tokamaks that came on-line in the last few years. These collaborative teams are building on the experience gained from U.S. fusion facilities to conduct high-impact long-pulse research on the international tokamaks either onsite or via remote operation. Long plasma pulse research will enable the exploration of new plasma physics regimes and allow the U.S. fusion program to gain the knowledge needed to operate long plasma discharges in ITER and other fusion energy devices.

<u>Long Pulse: Stellarator</u>
Stellarators offer steady-state confinement regimes eliminating transient events such as harmful disruptions. The 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 Wendelstein 7-X (W7-X) in Germany provides an opportunity to develop and assess 3D 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, with opportunities for full U.S. participation 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.

<u>Materials and Fusion Nuclear Science</u>
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 used in the fusion environment. Materials that can withstand this environment, under the long-pulse or steady-state conditions anticipated in future 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 2017 Request	Explanation of Change FY 2017 vs. FY 2016
Long Pulse: Tokamak $8,500,000	**$6,045,000**	**-$2,455,000**
U.S. scientists will develop, install, and commission improved plasma control feedback systems for China's Experimental Advanced Superconducting Tokamak (EAST) and Korea's Superconducting Tokamak Advanced Research (KSTAR). ITER operating scenarios will be explored and evaluated on EAST and KSTAR. Radio-frequency heating and current drive and neutral beam injection actuator models for EAST and KSTAR will be developed and validated.	Multi-institutional U.S. research teams will continue to conduct high-impact research on the international superconducting long-pulse tokamaks, taking advantage of their upgraded capabilities.	The program will reduce the overall level of effort and will defer some scheduled research tasks. There will be additional limitations to the on-site presence of U.S. researchers, which will shift emphasis to remote operations.
Long Pulse: Stellarators $7,269,000	**$5,084,000**	**-$2,185,000**
Superconducting Stellarator Research ($4,200,000) U.S. scientists are participating in the first plasma operating campaign of W7-X. The U.S. team will be involved with characterizing the 3-D magnetic configuration and performing the first tests of U.S.-supplied equipment during plasma operation. The team will also prepare the Test Divertor Unit (TDU) scraper element for the second operating campaign.	*Superconducting Stellarator Research ($2,515,000)* U.S. scientists will participate in W7-X research on topics important for understanding the physics of long-pulse plasma confinement in 3-D magnetic configurations. Topics include error fields, magnetic island physics, energetic-particle transport, impurity studies, plasma-material interactions, core plasma transport, and plasma control. The U.S. team will collaborate in the preparation of equipment and plasma scenarios for long-pulse operation.	*Superconducting Stellarator Research (-$1,685,000)* The program will reduce participation by U.S. researchers in the second plasma operating campaign of the W7-X experimental activities.

FY 2016 Enacted	FY 2017 Request	Explanation of Change FY 2017 vs. FY 2016
Compact Stellarator Research ($3,069,000) Compact stellarator research provides experimental data in regimes of relevance to the mainline stellarator magnetic confinement efforts and helps 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 ($2,569,000)* Research will continue on experiments that are providing data in regimes relevant to mainline stellarator confinement and experimental validation of models and codes	*Compact Stellarator Research (-$500,000)* Experimental research and modeling efforts will be reduced.
Materials & Fusion Nuclear Science $25,252,000	**$20,226,000**	**-$5,026,000**
Fusion Nuclear Science ($11,252,000) The focus remains 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 continues. Scoping studies continue on characterizing significant research gaps in the materials and fusion nuclear sciences program.	*Fusion Nuclear Science ($10,000,000)* Utilization of existing experimental capabilities and development of new ones to conduct research in the areas of plasma-facing materials and plasma-material interactions will be a key emphasis. In addition, research on understanding tritium retention, permeation and processing, neutronics, and material-corrosion issues for blankets and scoping studies on future fusion facilities will continue.	*Fusion Nuclear Science (-$1,252,000)* The program will reduce research efforts across this program element.
Materials Research ($14,000,000) The focus remains 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 ($10,226,000)* The program will emphasize the utilization of existing experimental capabilities and development of new ones to conduct research in the area of material response to simulated fusion neutron irradiation. There will be a continued focus on research toward structural materials that can withstand high levels of damage, increasing the ductility of tungsten, and modeling of helium damage in numerous materials.	*Materials Research (-$3,774,000)* The program will decrease research efforts across this program element.

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, ranging from energy efficient lighting to atmospheric pressure plasma for medical applications.

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.

Plasma Science Frontiers

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 ultracold (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 translate 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 neutral 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* – Structural and dynamical studies of ionized matter at extreme densities and temperatures.
- *Exploratory Magnetized Plasma* – Basic and applied research directed at developing the understanding of 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 maintains a leadership role in the national stewardship of plasma science by partnering with the National Science Foundation (NSF) and the National Nuclear Security Administration (NNSA) and by leveraging access to best-in-class experimental facilities as well as stewarding and operating world-class plasma science user facilities at small and intermediate scales. Along with facilitating discovery, intermediate-scale platforms are also providing critical data for the verification and validation of plasma science codes.

Measurement Innovation

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 the Fusion Energy Sciences Advisory Committee (FESAC).

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Change FY 2017 vs. FY 2016
Plasma Science Frontiers $46,784,000	**$31,916,000**	**-$14,868,000**
General Plasma Science ($16,125,000) Research continues 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 is enhanced.	*General Plasma Science ($15,500,000)* Core research elements of this activity will continue.	*General Plasma Science (-$625,000)* The program will reduce support for user research on major FES user facilities.
High Energy Density Laboratory Plasmas ($20,250,000) Research emphasizes utilizing the Matter in Extreme Conditions (MEC) instrument at the Linac Coherent Light Source 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 is 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 (NDCX-II).	*High Energy Density Laboratory Plasmas ($7,000,000)* Research will emphasize utilizing the MEC at LCLS, including continued support for the MEC beam-line science team, the HEDLP research group at SLAC, and enhanced support of external HED science users of the MEC instrument.	*High Energy Density Laboratory Plasmas (-$13,250,000)* Contraction of the HEDLP program will result in no new research activities at either universities or DOE national laboratories and the cessation of operations and research at the NDCX-II.
Exploratory Magnetized Plasma ($10,409,000) This portfolio will be evaluated through a competitive peer-review process.	*Exploratory Magnetized Plasma ($9,416,000)* Research direction and emphasis will be informed by the high-priority research as identified by the plasma science frontiers workshops held in FY 2015.	*Exploratory Magnetized Plasma (-$993,000)* The program will reduce research efforts and/or scope, taking into consideration the outcomes of the plasma science frontiers workshops held in FY 2015.

FY 2016 Enacted	FY 2017 Request	Explanation of Change FY 2017 vs. FY 2016
Measurement Innovation $6,700,000	**$4,000,000**	**-$2,700,000**
Core research elements of the Measurement Innovation activity continue 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.	The program will reduce funding to address scientific issues identified in the FY 2015 community workshops.
SBIR/STTR & Other $13,740,000	**$10,300,000**	**-$3,440,000**
Funding continues 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 2017.	The decrease is due to consolidation of funding for the Working Capital Fund under Program Direction and reduction in the required SBIR/STTR funding.

Description

The exploration of high-power burning (self-heated) plasmas is the next critical area of scientific research for fusion. Previously the U.S. and European fusion programs had investigated burning plasmas at low power (10 megawatt level). The ITER facility, currently under construction in St. Paul-lez-Durance, France, will provide access to burning plasmas with fusion power output approaching reactor levels of hundreds of megawatts, for hundreds of seconds. ITER will thus be the first-ever facility capable of assessing the scientific and technical feasibility of fusion energy. As a collaborator in the ITER project, which was established though an international agreement (the "ITER Joint Implementing Agreement"), the U.S. contributes in-kind-hardware components, personnel, and direct monetary funding to the ITER Organization (IO) for the ITER construction phase, as established by the terms of the ITER Joint Implementing Agreement. The key objective of these efforts is the completion of all activities associated with the U.S. Contributions to ITER (USITER) project.

U.S. Contributions to ITER Project

The ITER international fusion project is designed to be the first magnetic confinement fusion facility to achieve a self-sustained burning plasma. As ITER construction activities continue, careful and efficient management of the U.S. contributions to the international project by the U.S. ITER Project Office (USIPO) at Oak Ridge National Laboratory (ORNL) continue to be a high priority for FES.

ITER is designed to generate the world's first sustained (300-second discharge, self-heated) burning plasma. It aims to generate fusion power 30 times the levels produced to date and to exceed the external power applied to the plasma by at least a factor of ten. ITER will be a powerful tool for discovery, capable of addressing the new challenges of the burning plasma frontier and assessing the scientific and technical feasibility of fusion energy.

The ITER Project is being designed and built by an international consortium consisting of the U.S., China, India, Japan, South Korea, the Russian Federation, and the European Union (the host); the central project execution authority is the ITER Organization (IO). The U.S. is committed to the scientific mission of ITER and will work with ITER partners to accomplish this goal, while maintaining a balanced domestic research portfolio. Executing a program with well-aligned domestic and international components will sustain U.S. international leadership in fusion energy sciences. The U.S. magnetic fusion research program in experiment, theory, and computation is configured to make strong contributions to ITER's science and to bring a high level of scientific return from it. ITER joins the broader FES research portfolio in elevating plasma sciences for both practical benefit and increased understanding.

The USITER project consists primarily of in-kind hardware components, with additional contributions of personnel and cash to the IO for the ITER construction phase, which are established by the terms of the ITER Joint Implementing Agreement. In exchange for the U.S. share of the ITER project, the U.S. gains access to 100 percent of the ITER research output, and U.S. scientists may conduct their own research experiments. The U.S. contributions are managed by the USIPO at ORNL, in partnership with PPPL and Savannah River National Laboratory (SRNL). The U.S. ITER Project is unique among major DOE projects in that U.S. in-kind hardware contributions are delivered to the IO, which is outside direct DOE oversight and management control. The risks associated with performing the installation, assembly, and commissioning work depend on the execution of project responsibilities by the IO.

The 2013 Management Assessment of ITER found a significant number of challenges and deficiencies in the organization. The installation of a new Director-General in April 2015 and his efforts to improve the organization's culture and lead the development of a revised project resource-loaded long-term schedule demonstrate a positive shift in the IO. An independent review of the updated schedule is underway, with expected delivery of the report in mid-April 2016. This will present an opportunity to review and gauge the international commitment to the ITER project in light of significant delays and increased costs.

The 2016 Omnibus Appropriations directed, "*Not later than May 2, 2016, the Secretary of Energy shall submit to the Committees on Appropriations of both Houses of Congress a report recommending either that the United States remain a partner in the ITER project after October 2017 or terminate participation, which shall include, as applicable, an estimate of either the full cost, by fiscal year, of all future Federal funding requirements for construction, operation, and maintenance of*

ITER or the cost of termination." There are numerous activities (e.g., 2013 Management Assessment Corrective Action Plan performance; 2015 Management Assessment conclusions and recommendations; independent schedule review conclusions and recommendations; ITER Council-approved milestone performance) that will factor into the decision by the Secretary of Energy. The $125 million requested in FY 2017 will allow the most critical USITER activities to make progress, as well as provide cash funds for ITER Organization operations and the Director General's Reserve Fund.The requested level of funding for FY 2017 supports U.S. in-kind hardware contributions; funds the USIPO staff and support contractors at ORNL, PPPL, and SRNL; and provides funding toward the FY 2017 monetary contribution to the IO.

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Change FY 2017 vs. FY 2016
U.S. Contributions to ITER Project $115,000,000 Funding supports 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.	**$125,000,000** Funding will support continued progress on critical in-kind hardware contributions, including central solenoid superconducting magnet modules and structures, toroidal field magnet conductor, steady-state electrical network components, diagnostics development, tokamak cooling water system, and vacuum system. Funding is also provided toward the FY 2017 cash contribution for ITER Organization operations and Director General's Reserve Fund.	**+$10,000,000** The increase provides funding toward the cash contribution for ITER Organization operations and the Director General's Reserve Fund.

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. The following table shows the targets for FY 2015 through FY 2017. Details on the Annual Performance Report can be found at http://energy.gov/cfo/reports/annual-performance-reports.

	FY 2015	FY 2016	FY 2017
Performance Goal (Measure)	**FES Facility Based Experiments—Experiments conducted on major fusion facilities (DIII-D, Alcator C-Mod, NSTX-U) leading toward predictive capability for burning plasmas and configuration optimization**		
Target	Conduct experiments and analysis to quantify the impact of broadened current and pressure profiles on tokamak plasma confinement and stability. Broadened pressure profiles generally improve global stability but can also affect transport and confinement, while broadened current profiles can have both beneficial and adverse impacts on confinement and stability. This research will examine a variety of heating and current drive techniques in order to validate theoretical models of both the actuator performance and the transport and global stability response to varied heating and current drive deposition.	Conduct research to detect and minimize the consequences of disruptions in present and future tokamaks, including ITER. 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 pre-existing 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, including ITER. 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.
Result	Met	TBD	TBD

	FY 2015	FY 2016	FY 2017
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 diagnostics needed to measure critical physics parameters, scientists will be able to develop optimum scenarios for achieving high performance plasmas in ITER and, ultimately, in reactors.		
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	Not Met	TBD	TBD
Endpoint Target	Many of the research projects that are undertaken at the SC 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 set back. 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	Perform massively parallel plasma turbulence simulations to determine expected transport in ITER. Starting from best current estimates of ITER profiles, the turbulent transport of heat and particles driven by various micro-instabilities (including electromagnetic dynamics) will be computed. Stabilization of turbulence by nonlinear self-generated flows is expected to improve ITER performance, and will be assessed with comprehensive electromagnetic gyrokinetic simulations.	Predicting the magnitude and scaling of the divertor heat load width in magnetically confined burning plasmas is a high priority for the fusion program and ITER. 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 DIII-D, 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 including ITER, 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.

	FY 2015	FY 2016	FY 2017
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 SC high-performance computing resources and associated advances in computational science. These simulations are able to address the multi-physics and multi-scale 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 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
Capital Operating Expenses Summary							
Capital equipment	n/a	n/a	7,798	11,388	6,899	5,229	-1,670
General plant projects (GPP)	n/a	n/a	2,500	2,500	5,000	4,321	-679
Accelerator Improvement Projects (AIP) (<$5M)							
Total, Capital Operating Expenses	**n/a**	**n/a**	**10,298**	**13,888**	**11,899**	**9,550**	**-2,349**
Capital Equipment							
Major items of equipment[a]							
National Spherical Torus Experiment Upgrade (TPC $94,300)	83,665	80,195	3,470	3,470	0	0	0
U.S. Contributions to ITER (TPC TBD)	TBD	673,385	0	0		0	0
Total MIEs	**n/a**	**729,880**	**3,470**	**3,470**	**0**	**0**	**0**
Total Non-MIE Capital Equipment	n/a	n/a	4,328	7,918	6,899	5,229	-1,670
Total, Capital equipment	**n/a**	**n/a**	**7,798**	**11,388**	**6,899**	**5,229**	**-1,670**
General Plant Projects[b]							
General Plant Projects under $2 million TEC	n/a	n/a	2,500	2,500	5,000	4,321	-679

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

[b] Each Plant Project (GPP/GPE) Total Estimated Cost (TEC) > $5M

Fusion Energy Sciences
Construction Projects Summary ($K)

	Total	Prior Years	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
14-SC-60, U.S. Contributions to ITER Project							
Total Estimated Cost (TEC)	TBD	797,905	144,639	144,639	115,000	125,000	+10,000
Other Project Cost (OPC)	TBD	74,980	5,361	5,361	0	0	0
Total, Project Cost (TPC), 14-SC-60	**TBD**	**872,885**	**150,000**	**150,000**	**115,000**	**125,000**	**+10,000**

Fusion Energy Sciences
Funding Summary ($K)

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs. FY 2016
Research	216,258	205,610	219,145	184,988	-34,157
Scientific user facility operations	94,647	94,686	97,855	83,190	-14,665
Major items of equipment	3,470	3,470	0	0	0
Other (GPP, GPE, and infrastructure)	3,125	3,600	6,000	5,000	-1,000
Construction	150,000	150,000	115,000	125,000	+10,000
Total, Fusion Energy Sciences	**467,500**	**457,366**	**438,000**	**398,178**	**-39,822**

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 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request[a]	FY 2017 vs. FY 2016
TYPE A FACILITIES					
DIII-D National Fusion Facility	**\$79,950**	**\$83,108**	**\$80,000**	**\$81,100**	**+1,100**
Number of Users	579	579	579	570	-9
Achieved operating hours	600	550	N/A	N/A	N/A
Planned operating hours	600	600	600	560	-40
Optimal hours	1,000	1,000	1,000	560	-440
Percent optimal hours	60%	55%	60%	100%	+40%
Unscheduled downtime hours	50	50	N/A	N/A	N/A
Alcator C-Mod	**\$22,260**	**\$21,429**	**\$18,000**	**0**	**-18,000**
Number of Users	170	170	140	0	-140
Achieved operating hours	0	400	N/A	N/A	N/A
Planned operating hours	384	384	160	0	-160
Optimal hours	800	800	800	0	-800
Percent optimal hours	48%	50%	20%	0	-20%
Unscheduled downtime hours	0	0	N/A	N/A	N/A

[a] For FY 2017 the number of optimal hours for DIII-D and NSTX-U is less than the typical amount due to planned enhancement activities at the facility that will preclude operation during part of the fiscal year.

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request[a]	FY 2017 vs. FY 2016
National Spherical Torus Experiment-Upgrade	**$72,919**	**$68,470**	**$71,000**	**$70,500**	**-500**
Number of Users	250	250	329	322	-7
Achieved operating hours	N/A	N/A	N/A	N/A	N/A
Planned operating hours	480	480	720	640	0
Optimal hours	500	500	1,000	640	-280
Percent optimal hours	96%	96%	72%	100%	+28%
Unscheduled downtime hours	0	480	N/A	N/A	N/A
Total Facilities	**$168,960**	**$173,007**	**$169,000**	**151,600**	**-17,400**
Number of Users	999	999	1,048	892	-156
Achieved operating hours	N/A	N/A	N/A	N/A	N/A
Planned operating hours	1,464	1,464	1,480	1,200	-280
Optimal hours	2,300	2,300	2,800	1,200	-1,600
Percent of optimal hours[a]	73.1%	70.6%	60.8%	100%	+39.2%
Unscheduled downtime hours	N/A	530	N/A	N/A	N/A

Scientific Employment

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs. FY 2016
Number of permanent Ph.D.'s (FTEs)	724	724	767	625	-142
Number of postdoctoral associates (FTEs)	93	93	98	80	-18
Number of graduate students (FTEs)	268	268	293	200	-93
Other[b]	1,102	1,102	1,025	947	-78

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

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

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 2016 CPDS and does not include a new start for FY 2017.

Summary

The FY 2017 Request for ITER is $125,000,000, $10,000,000 more than the FY 2016 Enacted level of $115,000,000. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range, which was approved on January 25, 2008 with a preliminary cost range of $1.45–$2.2 billion. Since CD-1, it has not been possible to baseline the project because of continued delays in the international ITERproject construction schedule. Until CD-2 can be approved, U.S. funding will be managed to address annual project priorities and to allow flexibility to adapt to the changing state of the project. Since the project does not have CD-2 approval, the schedule and cost estimates contained in this CPDS are identified as “TBD”. A substantial increase in the overall Total Project Cost of the project is anticipated once it is ready to be baselined.

The approving official for all critical decisions is the Director of the Office of Science (SC-1).

A Federal Project Director with certification level 3 has been assigned to this project and has approved this CPDS.

ITER is a major fusion research facility being constructed in Cadarache, 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 (USITER) project is not classified as a capital asset project. The USITER is a U.S. Department of Energy project to provide the U.S. share of in-kind hardware (e.g., subsystems, equipment, and components), as well as cash contributions to support the ITER organization in France. Sections of this CPDS have been tailored accordingly to reflect the nature of this project.

The USITER 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 beginning in FY 2014. This did not change SC’s overall program and project management approach for the USITER Project. 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. An approved Annual Performance Plan (APP) authorizes the work activities to be performed, as well as establishes milestones for project performance against which progress will be measured. Progress and performance against the APP is reported regularly in monthly performance metrics and project status reports.

The USITER project is making significant progress in the areas of design completion and fabrication of hardware. As of the end of December 2015, the USITER project is 29% complete overall;design of all twelve technical systems the U.S. is responsible for delivering is 58% complete; and hardare fabrication is 9% complete. Two of the largest U.S. systems, the Tokamak Cooling Water System (TCWS) and the Central Solenoid (CS) Magnets, are in or beyond the final design stage. Active fabrication is underway in four of the U.S. twelve hardware systems (TCWS, Steady State Electric Network [SSEN] Components, Toroidal Field [TF] Conductor and CS Magnets). The U.S. has completed the fabrication and delivery of five nuclear-grade cooling water drain tanks to the ITER site. These components, which are time critical for ITER construction sequencing and which are fabricated in accordance with French Nuclear regulations, are some of the first major hardware components delivered to the site in France. The U.S. has also been procuring 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 are continuing. Fabrication of the TF conductor is also well underway. The purchase of superconducting strand material is complete, and cabling activities are well underway with four of the nine lengths completed through November 2015. Jacketing of three conductor lengths has been completed. The U.S. has shipped finished lengths of conductors to the European Union, one of the ITER Members responsible for TF Magnet fabrication, and fabrication of TF conductor and final delivery will be completed in early FY 2017. The U.S. has contracted with General Atomics (GA) for the fabrication of the world’s largest superconducting magnets for the ITER CS Magnet system. The GA fabrication facility is essentially complete and commissioning is complete for six of the eleven work stations needed for fabrication of each of the seven modules the U.S. is responsible for delivering. In FY 2015, the U.S. started fabrication of a mockup (non-superconducting) coil to provide assurance of manufacturing processes; and most notably, started the winding of the first production module with superconducting CS conductor provided by the Japanese Domestic Agency. Initiation of fabrication activities in the GA facility represents the culmination of several years of preparation and a major accomplishment for the USITER project. By the end of CY 2017, all modules will be in fabrication. DOE has begun to award contracts for the assembly tooling necessary for CS Magnet installation in the ITER facility with fabrication of all tooling planned for FY 2018 completion, and contracts for CS Structures has begun with deliveries beginning in FY 2017 and planned fabrication complete in FY 2019. To date the USITER project has awarded and obligated over $794 million to U.S. industry, universtities, and DOE laboratories.

FY 2016 funding supports continued in-kind contributions and related support activities. No funding is provided for cash contributions to support the ITER organization in FY 2016. FY 2017 funding will support ITER Project Office operations, the U.S. cash contribution to the ITER Organization, and continued progress on U.S. in-kind contributions, including: central solenoid magnet modules and structures, toroidal field magnet conductor, steady state electric network, diagnostics development, tokamak cooling water system, and vacuum system.

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

[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 Assembly Tooling, 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; VAS 02 Supply; VAS Main piping (L3-L4); Pellet Injection Flight Tubes.

[l] TCWS Captive Piping; ICH Gallery: Radio Frequency (RF) Building; Port Plug Test Facility Transmission Line (PPTF TL); ECH TL System Design; RGA; Upper VIR Cameras; LFS.

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

3. Project Cost History

At the time of CD-1 approval in January 2008, the preliminary cost range was $1.45–$2.2 billion. Since then, however, it has not been possible to confidently baseline the project due to continued 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. DOE anticipates a substantial increase in the overall Total Project Cost of the project once the project is ready to be baselined.

4. Project Scope and Justification

<u>Introduction</u>
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 USITER 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.

<u>Scope</u>
<u>ITER Construction Project Scope</u>
The USITER project includes three major elements:

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

The USITER project hardware scope is limited to design, fabrication, and delivery of mission-critical tokamak subsystems and is described below. As of December 2015, the USITER project is 28% complete.

- **Tokamak Cooling Water System (TCWS)**: manages the thermal energy generated during the operation of the tokamak. The TCWS is 24% complete.
- **15% of ITER Diagnostics**: provides the measurements necessary to control, evaluate, and optimize plasma performance and to further the understanding of plasma physics. Diagnostics are 21% complete.
- **Disruption Mitigation Systems ($20M cost cap)**: limit the impact of plasma disruptions to the tokamak vacuum vessel, blankets, and other components. The Disruption Mitigation Systems are 25% complete.
- **Electron Cyclotron Heating (ECH) Transmission Lines**: bring additional power to the plasma and deposits power in specific areas of the plasma to minimize instabilities and optimize performance. The ECH is 19% complete.
- **Tokamak Exhaust Processing (TEP) System**: separates hydrogen isotopes from tokamak exhaust. The TEP system is 11% complete.

- **Fueling System (Pellet Injection)**: injects fusion fuels in the form of deuterium-tritium ice pellets into the vacuum chamber. The Pellet Injection system is 18% complete.
- **Ion Cyclotron Heating (ICH) Transmission Lines**: bring additional power to the plasma. The ICH is 17% complete.
- **Central Solenoid** (CS) **Magnet System**: confines, shapes and controls the plasma inside the vacuum vessel. The CS Magnet modules are 56% complete; the CS structures are 26% complete; and the CS tooling is 47% complete.
- **8% of Toroidal Field (TF) Conductor**: component of the TF magnet that confines, shapes, and controls the plasma. The TF Conductor is 95% complete.
- **75% of the Steady State Electrical Network (SSEN)**: supplies the electricity needed to operate the entire plant, including offices and the operational facilities. The SSEN is 59% complete.
- **Vacuum Auxiliary System**: creates and maintains low gas densities in the vacuum vessel and connected vacuum components. The Vacuum Auxiliary System is 20% complete,
- **Roughing Pumps**: evacuate the tokamak, cryostat, and auxiliary vacuum chambers prior to and during operations. Roughing Pumps system is 15% complete.

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.

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

5. Financial Schedule

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
Total Estimated Cost (TEC)			
Hardware			
FY 2006	13,754	13,754	6,169
FY 2007	34,588	34,588	24,238
FY 2008	25,500	25,500	24,122
FY 2009	85,401	85,401	26,278
FY 2010	85,266	85,266	46,052
FY 2011	63,875	63,875	84,321
FY 2012[b]	91,441	91,407	99,215
FY 2013[a]	107,635	107,669	110,074
FY 2014[a c]	161,605	161,605	153,368
FY 2015	128,682	128,682	105,908
FY 2016[d]	115,000	115,000	139,984
FY 2017	85,000	85,000	143,828
Subtotal	997,747	997,747	963,557
Total, Hardware	TBD	TBD	TBD

[a] Costs through FY 2015 reflect actual costs; costs for FY 2016 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 2016 Hardware funding amount.

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
Cash Contributions[a]			
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[b]	0	0	0
FY 2017	40,000	40,000	40,000
Subtotal	184,497	184,497	184,497
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
FY 2011	13,000	13,000	10,032
FY 2012[c]	345	345	22,336
FY 2013[a]	2,560	2,560	5,984
FY 2014[a d]	5,000	5,000	2,717
FY 2015	5,361	5,361	5,500
FY 2016	0	0	5,016
FY 2017	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[a]	124,000	124,034	129,863
FY 2014[ab]	199,500	199,500	188,980

[a] Includes cash payments, secondees, taxes and tax support.
[b] No FY 2016 funding is provided to support the ITER organization.
[c] Prior actuals adjusted to incorporate project funds utilized at PPPL and DOE. Obligation adjusted to reflect year-end PPPL settlement funding.
[d] 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.

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
FY 2015	150,000	150,000	127,365
FY 2016	115,000	115,000	145,000
FY 2017	125,000	125,000	183,828
Subtotal	1,262,885	1,262,885	1,228,695
Total, TPC	TBD	TBD	TBD

6. Details of the 2017 Project Cost Estimate

Since CD-1, it has not been possible to baseline the project because of continued delays in the international ITER construction schedule; therefore a Total Project Cost estimate cannot be formulated at this point in time. Until such time as CD-2 can be approved, U.S. funding will be managed to address annual project priorities and to allow flexibility to adapt to the changing state of the project.

7. Schedule of Appropriation Requests

(dollars in thousands)

Request Year		Prior Years	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	Outyears	Total
FY 2006	TEC	889,000	120,000	29,000	0	0	0	0	0	1,038,000
	OPC	74,400	6,200	3,400	0	0	0	0	0	84,000
	TPC	963,400	126,200	32,400	0	0	0	0	0	1,122,000
FT 2007	TEC	800,151	130,000	116,900	30,000	0	0	0	0	1,077,051
	OPC	44,949	0	0	0	0	0	0	0	44,949
	TPC	845,100	130,000	116,900	30,000	0	0	0	0	1,122,000
FY 2008	TEC	801,330	130,000	116,900	30,000	0	0	0	0	1,078,230
	OPC	43,770	0	0	0	0	0	0	0	43,770
	TPC	845,100	130,000	116,900	30,000	0	0	0	0	1,122,000
FY 2009[a]	TEC	266,366	0	0	0	0	TBD	TBD	TBD	TBD
	OPC	38,075	0	0	0	0	TBD	TBD	TBD	TBD
	TPC	304,441	0	0	0	0	TBD	TBD	TBD	TBD
FY 2010	TEC	294,366	0	0	0	0	TBD	TBD	TBD	TBD
	OPC	70,019	0	0	0	0	TBD	TBD	TBD	TBD
	TPC	364,385	0	0	0	0	TBD	TBD	TBD	TBD
FY 2011	TEC	379,366	0	0	0	0	TBD	TBD	TBD	TBD
	OPC	65,019	0	0	0	0	TBD	TBD	TBD	TBD
	TPC	444,385	0	0	0	0	TBD	TBD	TBD	TBD
FY 2012[b]	TEC	304,566	90,000	0	0	0	TBD	TBD	TBD	TBD
	OPC	60,019	15,000	0	0	0	TBD	TBD	TBD	TBD
	TPC	364,385	105,000	0	0	0	TBD	TBD	TBD	TBD
FY 2013[c]	TEC	371,366	104,930	140,965	0	0	TBD	TBD	TBD	TBD
	OPC	73,019	70	9,035	0	0	TBD	TBD	TBD	TBD
	TPC	444,385	105,000	150,000	0	0	TBD	TBD	TBD	TBD

[a] The Prior Years column for FY 2009 through FY 2012 reflects the total of appropriations and funding requests only through the year of that row. Thus, for example, in the FY 2010 row, it reflects only funding from FY 2006 to FY 2010.
[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.

(dollars in thousands)

Request Year		Prior Years	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	Outyears	Total
FY 2014[a]	TEC	371,366	104,930	105,572	225,000	0	TBD	TBD	TBD	TBD
	OPC	73,019	70	70	0	0	TBD	TBD	TBD	TBD
	TPC	444,385	105,000	105,642	225,000	0	TBD	TBD	TBD	TBD
FY 2015	TEC	377,010	104,930	121,465	194,500	144,639	TBD	TBD	TBD	TBD
	OPC	67,375	70	2,535	5,000	5,361	TBD	TBD	TBD	TBD
	TPC	444,385	105,000	124,000	199,500	150,000	TBD	TBD	TBD	TBD
FY 2016	TEC	377,010	104,930	121,465	194,500	144,639	150,000	TBD	TBD	TBD
	OPC	67,375	70	2,535	5,000	5,361	0	TBD	TBD	TBD
	TPC	444,385	105,000	124,000	199,500	150,000	150,000	TBD	TBD	TBD
FY 2017[a]	TEC	377,010	104,930	121,499	194,500	144,639	115,000	125,000		
	OPC	67,375	70	2,535	5,000	5,361	0	0	TBD	TBD
	TPC	444,385	105,000	124,034	199,500	150,000	115,000	125,000	TBD	TBD

8. Related Operations and Maintenance Funding Requirements

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

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

9. D&D Funding Requirements

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

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

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

10. Acquisition Approach for US Hardware Contributions

The USITER Project Office (USIPO) at Oak Ridge National Laboratory, with its two partner laboratories (Princeton Plasma Physics Laboratory and Savannah River National Laboratory), will procure and deliver in-kind hardware in accordance with the Procurement Arrangements established with the International Organization (IO).

The USIPO will subcontract with a variety of research and industry sources for design and fabrication of its ITER components, ensuring that designs are developed that permit fabrication, to the maximum extent possible, under fixed-price subcontracts (or fixed-price arrangement documents with the IO) based on performance specifications, or more rarely, on build-to-print designs. USIPO will use cost-reimbursement type subcontracts only when the work scope precludes accurate and reasonable cost contingencies being gauged and established beforehand.

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

USIPO will utilize best value, competitive source selection procedures to the maximum extent possible, including foreign firms on the tender/bid list where appropriate. Such procedures shall allow for cost and technical trade-offs during source selection.

For the large-dollar-value subcontracts (and critical path subcontracts as appropriate), USIPO will utilize unique subcontract provisions to incentivize cost control and schedule performance.

In addition, where it is cost effective and it reduces risk, the USIPO will participate in common procurements led by the IO, or request the IO to perform activities that are the responsibility of the U.S.

High Energy Physics

Overview

The High Energy Physics (HEP) program 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.

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 and research tools originally developed for high energy physics have proved widely applicable to other scientific disciplines as well as industry, medicine, and national security.

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 a strategy organized along three frontiers of particle physics:

- 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), 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 seek to reveal the nature of dark matter and dark energy by using naturally occurring particles to explore new phenomena. The highest-energy particles ever observed have come from cosmic sources, and the ancient light from distant galaxies allows the distribution of dark matter to be mapped and perhaps the nature of dark energy to be unraveled. Ultra-sensitive detectors deep underground may glimpse the dark matter passing through Earth. Observations of the cosmic frontier reveal a universe far stranger than ever thought possible.

These three frontiers are supported by the Theoretical and Computational Physics and the Advanced Technology R&D subprograms. Theoretical and Computational Physics provides the framework to explain experimental observations and gain a deeper understanding of nature. A thriving theory program is essential to support current experiments and identify new directions for the field. 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. Advanced computing tools are necessary for designing, operating, and interpreting experiments while performing the computational science and simulations that enable discovery research in the three frontiers. Advanced Technology R&D fosters fundamental research into particle acceleration and detection techniques and instrumentation. These in turn provide the enabling technologies and new research

methods that can 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, defense, energy and environmental applications; and long-term R&D for science and technology needed to build future generations of accelerators, with a focus on transformational opportunities.

Highlights of the FY 2017 Budget Request

In September 2013, the DOE and the National Science Foundation (NSF) charged the High Energy Physics Advisory Panel (HEPAP) to convene a Particle Physics Project Prioritization Panel (P5) in order to develop a ten-year strategic plan for U.S. high energy physics in the context of a 20-year global vision. The panel was charged to respond to three realistic budget scenarios provided by the funding agencies. In May 2014, HEPAP unanimously approved the P5 report and its recommendations. The report provides a practical, long-term strategy that enables discovery and maintains the U.S. position as a global leader in particle physics. The DOE accepted the recommendations in the P5 report and is committed to implementing a successful program based on this new vision.

The FY 2017 Budget Request continues implementation of the recommendations contained in the P5 report. The Request supports full operation of existing major HEP facilities and experiments; the planned construction funding profile for the Muon to Electron Conversion Experiment (Mu2e), and fabrication for recent major items of equipment (MIEs) for the Large Underground Xenon (LUX)–ZonEd Proportional scintillation in LIquid Noble gases (ZEPLIN) experiment (LZ) and the Super Cryogenic Dark Matter Search at Sudbury Neutrino Observatory Laboratory (SuperCDMS-SNOLab) experiment. The Request includes capital equipment funding to continue support of the planned funding profiles for the camera for the Large Synoptic Survey Telescope (LSSTcam) project, the Dark Energy Spectroscopic Instrument (DESI) project, the Muon g-2 Experiment, and the U.S. contributions to the LHC ATLAS (A Toroidal LHC Apparatus) Detector Upgrade, and the LHC Compact Muon Solenoid (CMS) Detector Upgrade. The Muon g-2 Experiment and LHC detector upgrades complete their funding profiles in FY 2017.

HEP's implementation of the P5 recommendation to reformulate the long baseline neutrino program in an international context has resulted in the formation of two multi-national efforts: the Long Baseline Neutrino Facility (LBNF), which will be responsible for the beamline at the Fermi National Accelerator Laboratory (Fermilab) and other experimental and civil infrastructure at Fermilab and Sanford Underground Research Facility (SURF); and the Deep Underground Neutrino Experiment (DUNE), an international experimental collaboration responsible for defining the scientific goals and technical requirements for the detectors and beamline as well as design, construction, commissioning of the detectors and subsequent research program. HEP proposes to manage both activities as a single project to be known as LBNF/DUNE. There has been significant progress in the development of these international partnerships in the past year, and the new DUNE science collaboration is moving forward expeditiously to implement an optimized detector design. HEP continues to pursue the development of this world-leading long-baseline neutrino experiment by recruiting additional partners and coordinating plans for the international facility that enables it.

In the FY 2017 Budget Request, most funding for the Working Capital Fund (WCF) is transferred to Program Direction to establish a consolidated source of funding for goods and services provided by the WCF. CyberOne is still funded through program dollars in the SC Safeguards and Security Program. In FY 2016 and prior years, WCF costs were shared by SC research programs and Program Direction.

Energy Frontier Experimental Physics
The LHC resumed operations in 2015 at collision energies of 13 TeV, a substantial increase from 8 TeV in the previous run that enabled the discovery of the Higgs boson. Higher energies will increase the reach of the LHC into the search for new physics, particularly in high-impact topics such as supersymmetry, dark matter candidates, and evidence for extra space-time dimensions. Physics results from this higher-energy data became available in 2015 and will continue well into 2017, critically informing future HEP research directions and opportunities. Investments are made for U.S. contributions to planned LHC detector upgrades that will exploit the full physics potential of LHC with much higher luminosities.

Intensity Frontier Experimental Physics

FY 2017 will feature full operations for the Neutrinos at the Main Injector (NuMI) Off-axis Electron Neutrino Appearance Experiment (NOvA) detector in the world's most intense neutrino beam from Fermilab. The physics goals of this experiment include improved measurements of neutrino mixing, first results on the neutrino mass hierarchy, and the search for matter-antimatter asymmetry in the neutrino sector. The MicroBooNE neutrino experiment will be in full operation in the Fermilab Booster Neutrino Beam (BNB), with a goal of resolving certain anomalies seen in several previous accelerator-based neutrino experiments. MicroBooNE is the first experiment in the Fermilab Short Baseline Neutrino (SBN) program, a coordinated set of liquid argon neutrino detector experiments that will advance neutrino science and serve as an international R&D platform for LBNF/DUNE. The SBN program will also include the Short Baseline Neutrino Detector (SBND) and the Imaging Cosmic and Rare Underground Signals (ICARUS) detector, which is being moved from Italy to Fermilab. Both detectors are scheduled to begin data taking in FY 2018.

The Muon g-2 MIE will complete fabrication, installation and commissioning in FY 2017 and the first data-taking run of the Muon g-2 Experiment will begin. Both experiments will probe energy scales beyond the LHC through the study of rare processes and precision measurements. The SuperKEKB electron-positron collider, located at the Japanese High Energy Accelerator Research Organization (KEK) laboratory in Tsukuba, Japan, will begin sending beam to the Belle II detector in FY 2017. The Belle II experiment will have unprecedented sensitivity to search for new physics and study rare decays in heavy quarks and tau leptons.

The FY 2017 Request includes funding for Other Project Costs (OPC) for the Proton Improvement Plan II (PIP-II) project. The original Proton Improvement Plan (PIP) included a series of equipment replacements and refurbishments necessary to keep the nearly 50 year old accelerator complex running efficiently. Fermilab is currently completing this work. In order to meet the currently foreseen goals of the HEP program, however, it will be necessary to go beyond the modest PIP improvements and replace the entire front end of the accelerator complex. This upgrade to the linac to increase the beam power and the energy is referred to as PIP-II. Unlike its predecessor, PIP-II will be a line item construction project once construction funding is requested. In FY 2017, only OPC funding is requested to support conceptual design activities.

Cosmic Frontier Experimental Physics

The Cosmic Frontier Experimental Physics program will continue a coordinated program of studies of the nature of dark energy and searches for dark matter particles. The program also includes experiments studying high energy cosmic rays, gamma rays, and the study of the cosmic microwave background (CMB) in order to gain insight into the nature of inflation in the early universe. Projects that will carry out the next generation imaging and spectroscopic dark energy studies, LSSTcam and DESI, will be in their fabrication phases in FY 2017. There are three second generation direct detection dark matter projects that will use a variety of technologies to provide complementary searches for dark matter particles. The Axion Dark Matter Search Generation 2 (ADMX-G2) is a series of small experiments that will search for axions, a proposed dark matter candidate, over different mass ranges. The LZ and SuperCDMS-SNOLab experiments will search for a different type of proposed dark matter candidate, Weakly Interacting Massive Particles (WIMPs), using complementary technologies to search over a broad range of masses. The LZ project will use liquid xenon in the SURF and will enter its fabrication phase in FY 2017. The SuperCDMS-SNOLab project will use cryogenic semi-conductor detectors in SNOLab and will be baselined and enter its final design phase in FY 2017. Planning for a large-scale Cosmic Microwave Background (CMB) experiment, which will be used to study the nature of inflation in the early universe, will continue in FY 2017, along with a suite of operating experiments and R&D efforts addressing priority science areas identified in the P5 report.

Theoretical and Computational Physics

The current high priority thrusts of the Theoretical Physics subprogram are to understand the LHC data and develop new search strategies that can be used at the LHC in the future; to develop new models of dark matter; and to suggest new experimental probes that can reveal physics beyond the Standard Model. The Computational Physics effort supports research and operations on computation, simulation, data tools, and software that cut across all HEP programs, and provides partnership opportunities with SC's Advanced Scientific Computing Research (ASCR) program as well as other agencies to develop innovative data and computational tools to address HEP computational and data challenges for the future.

Advanced Technology R&D

The General Accelerator R&D (GARD) activity supports the vibrant advanced plasma accelerator research at BELLA (Berkeley Lab Laser Accelerator) at LBNL and FACET (Facility for Advanced Accelerator Experimental Tests) at SLAC. BELLA set a new world record for laser-driven plasma wakefield accelerator technology in FY 2015, producing an energy gradient of 4.25 GeV over 9 cm. FACET is the first to accelerate positrons by multi-gigaelectronvolts (GeV) in energy with a narrow energy spread in a long plasma channel. Also, in collaboration with and using techniques developed in university research supported by GARD, FACET became the first to image the beam driven wakefield.

FACET will shut down in FY 2016 to make way for the Linac Coherent Light Source (LCLS)-II. A new and more capable facility, the FACET-II MIE project, will be in its fabrication phase in FY 2017 using the kilometer linac section between LCLS and LCLS-II, to continue the very successful electron-beam-driven plasma wakefield accelerator program. Operations of the BELLA facility continue in FY 2017.

The LHC Accelerator Research Program (LARP) develops powerful focusing magnets made from niobium-tin superconductors that have higher magnetic fields than those currently used in the LHC. Successful development of these new magnets will allow the U.S. to make a unique and critical contribution to the upgrade of the LHC to produce more particle collisions per second, which in turn will provide more data for the researchers. Funding for this effort is increased in FY 2017 to meet the schedule for delivery of prototype magnets. Following external technical reviews and recommendations in the P5 report, the Muon Accelerator Program (MAP) is being ramped down, and FY 2017 is the final year of funding for MAP. Key elements of MAP with broad applications will be redirected into GARD.

Accelerator Stewardship

The Brookhaven National Laboratory's (BNL) Accelerator Test Facility (ATF) was formally designated an SC User Facility in FY 2015, and its charter broadened to support the Accelerator Stewardship mission. The ATF provides a unique combination of high quality electron and infrared laser beams in a well-controlled user-friendly environment. The ATF will continue to support user operations in FY 2017.

Construction

Two construction projects are underway to support Intensity Frontier Physics. Mu2e completes its design phase in FY 2016 and proceeds with construction. LBNF/DUNE will continue its design phase and site preparation in FY 2016 and will commence underground excavation in FY 2017.

High Energy Physics
Funding ($K)

	FY 2015 Enacted	FY 2015 Current[a]	FY 2016 Enacted	FY 2017 Request[b]	FY 2017 vs. FY 2016
Energy Frontier Experimental Physics					
Research	78,782	84,387	77,270	76,811	-459
Facility Operations and Experimental Support	53,802	53,670	54,453	55,220	+767
Projects	15,000	7,983	19,000	18,967	-33
Total, Energy Frontier Experimental Physics	**147,584**	**146,040**	**150,723**	**150,998**	**+275**
Intensity Frontier Experimental Physics					
Research	55,181	54,122	56,104	56,509	+405
Facility Operations and Experimental Support	165,073	158,658	151,317	153,066	+1,749
Projects	43,970	46,970	35,700	24,569	-11,131
Total, Intensity Frontier Experimental Physics	**264,224**	**259,750**	**243,121**	**234,144**	**-8,977**
Cosmic Frontier Experimental Physics					
Research	49,310	48,777	49,910	49,934	+24
Facility Operations and Experimental Support	11,832	11,327	13,837	9,935	-3,902
Projects	45,728	46,403	66,835	70,200	+3,365
Total, Cosmic Frontier Experimental Physics	**106,870**	**106,507**	**130,582**	**130,069**	**-513**
Theoretical and Computational Physics					
Research					
Theory	50,224	52,323	48,465	49,620	+1,155
Computational HEP	8,050	8,525	8,618	8,036	-582
Total, Research	58,274	60,848	57,083	57,656	+573
Projects	1,000	1,000	2,000	2,000	0
Total, Theoretical and Computational Physics	**59,274**	**61,848**	**59,083**	**59,656**	**+573**

[a] Reflects the transfer of Small Business Innovation/Technology Transfer Research (SBIR/STTR) funds within the Office of Science.
[b] A transfer of $1,704,000 to Science Program Direction is to consolidate all Working Capital Funds in one program.

	FY 2015 Enacted	FY 2015 Current[a]	FY 2016 Enacted	FY 2017 Request[b]	FY 2017 vs. FY 2016
Advanced Technology R&D					
Research					
HEP General Accelerator R&D	45,452	45,903	46,722	44,510	-2,212
HEP Directed Accelerator R&D	22,570	23,000	20,640	21,500	+860
Detector R&D	21,914	19,314	16,282	17,350	+1,068
Total, Research	89,936	88,217	83,644	83,360	-284
Facility Operations and Experimental Support	30,318	35,870	29,750	26,925	-2,825
Projects	0	0	2,100	8,000	+5,900
Total, Advanced Technology R&D	**120,254**	**124,087**	**115,494**	**118,285**	**+2,791**
Accelerator Stewardship					
Research	5,900	4,891	3,378	6,853	+3,475
Facility Operations and Experimental Support	4,100	5,109	5,622	6,891	+1,269
Total, Accelerator Stewardship	**10,000**	**10,000**	**9,000**	**13,744**	**+4,744**
SBIR/STTR	**20,794**	**0**	**20,897**	**22,580**	**+1,683**
Subtotal, High Energy Physics	**729,000**	**708,232**	**728,900**	**729,476**	**+576**
Construction					
11-SC-40, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment	12,000	12,000	26,000	45,021	+19,021
11-SC-41, Muon to Electron Conversion Experiment	25,000	25,000	40,100	43,500	+3,400
Total, Construction	**37,000**	**37,000**	**66,100**	**88,521**	**+22,421**
Total, High Energy Physics	**766,000**	**745,232**	**795,000**	**817,997**	**+22,997**

SBIR/STTR:

- FY 2015 Transferred: SBIR: $18,251,000; STTR: $2,517,000
- FY 2016 Projected: SBIR: $18,171,000; STTR: $2,726,000
- FY 2017 Request: SBIR: $19,796,000; STTR: $2,784,000

[a] Reflects the transfer of Small Business Innovation/Technology Transfer Research (SBIR/STTR) funds within the Office of Science.

[a] A transfer of $1,704,000 to Science Program Direction is to consolidate all Working Capital Funds in one program.

High Energy Physics
Explanation of Major Changes ($K)

	FY 2017 vs. FY 2016 Enacted
Energy Frontier Experimental Physics: Funding continues for the LHC detector upgrade fabrication activities that are scheduled to complete their planned funding in FY 2017. Initial investments are made to support subsequent LHC detector upgrade activities for longer-term operations at much higher luminosities, in accordance with the P5 report. Research efforts are slightly reduced in order to provide additional support for experimental support activities.	**+275**
Intensity Frontier Experimental Physics: Completion of the Muon Campus AIP and GPP items account for the bulk of the funding reduction in this area. Future project R&D for the development of a new superconducting proton linac to replace the more than 40-year-old existing linac is completed in FY 2016. In FY 2017 continuing efforts will be funded as PIP-II OPC. Optimal operations of the upgraded NuMI beamline for NOvA continue, as do refurbishment of the oldest portions of the Fermilab accelerator complex, including a modernization of the front-end linac. The Short Baseline Neutrino (SBN) program at Fermilab will perform R&D and fabrication of liquid argon TPC detectors to address the observed anomalies in previous neutrino experiments while advancing the R&D necessary for LBNF/DUNE, as recommended in the P5 report. Research efforts are increased in order to maintain support for data analysis of operating experiments and ramp up support for physics studies and R&D for next-generation experiments.	**-8,977**
Cosmic Frontier Experimental Physics: Funding increases caused by the ramp-up of the MIE projects, which increase according to their planned funding profiles, are offset by several first generation dark matter experiments that end operations funding in FY 2016. These MIE projects include the next generation dark energy projects using complementary techniques of imaging (LSSTcam) and spectroscopic (DESI) surveys and measurements and the second generation direct detection dark matter experiments (LZ and SuperCDMS-SNOLab) that use complementary technologies and search in different mass ranges. The funding for these projects is in accordance with the P5 report.	**-513**
Theoretical and Computational Physics: Overall research increases slightly, with an increase in support for theory offsetting a slight reduction in computational research.	**+573**
Advanced Technology R&D: LARP increases to complete large scale prototypes of niobium-tin superconducting quadrupole magnets needed for the upgrade of the LHC. FY 2017 is the last year of funding for the MAP as deliverables for the Muon Ionization Cooling Experiment in England are completed. FACET does not run in FY 2017 and its funding is redirected to the FACET-II MIE.	**+2,791**
Accelerator Stewardship: Funding for research is increased to support targeted R&D efforts to develop new uses of accelerator technology with broad applicability. Facilities funding is increased as the relocation of BNL ATF reaches the peak years of activity.	**+4,744**
SBIR/STTR: Funding is provided in accordance with the legislatively directed percentage of HEP operating budgets.	**+1,683**

	FY 2017 vs. FY 2016 Enacted
Construction: Funding is provided according to the planned profile for construction of Mu2e. Funding for engineering design, site preparation and underground excavation for LBNF/DUNE is requested.	**+22,421**
Total, High Energy Physics	**+22,997**

Basic and Applied R&D Coordination
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 could have significant 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 all federal stakeholders have input in crafting funding opportunity announcements, reviewing applications, and evaluating the efficacy and impact of funded activities.

More broadly, HEP coordinates its program with other offices and agencies with related programs and missions. The U.S. LHC program is supported by the HEP and the NSF Division of Physics (NSF-PHY), and overseen by a Joint Oversight Group (JOG). Dark matter research is also jointly sponsored by these agencies, which are coordinating their activities on the next generation projects. Both HEP and NSF-PHY use HEPAP as part of their advisory structure. HEP also coordinates with NSF Division of Astronomical Sciences on the Dark Energy Survey (DES) experiment and the LSST and the DESI projects, each of which is overseen by a JOG. Both agencies as well as NASA receive advice from the Astronomy and Astrophysics Advisory Committee on areas of overlap and joint interest. HEP also coordinates with other SC programs to identify common scientific interests and to prevent duplication.

Program Accomplishments
Significant discoveries, substantial sensitivity improvements, and world-record achievements moved the frontiers of particle physics forward in FY 2015.

DOE, NSF, and CERN signed a new international cooperation agreement on May 7, 2015. This agreement was a vital component of the HEP strategic plan that called for a global vision of particle physics. The U.S. will continue to participate in the LHC program with accelerator and detector contributions for the High Luminosity LHC, and CERN will support the participation of European particle physicists in Deep Underground Neutrino Experiment through contributions to the Long Baseline Neutrino Facility being built by Fermilab. How CERN and the U.S. will work together under the international agreement has been detailed in four protocols on U.S. contributions to experiments at the LHC, U.S. contributions to the accelerator to raise its luminosity, CERN contributions to LBNF, and joint U.S.-CERN studies on new higher energy colliders that were signed on December 18, 2015. The value of the contributions being made under these protocols will be documented in addenda that are still being negotiated.

The NuMI Off-Axis ν_e Appearance (NOvA) experiment, the highest-intensity and longest-baseline neutrino oscillation experiment in the world, took its first science data in FY 2015 and has measured both muon disappearance and electron appearance neutrino oscillations (Intensity Frontier). The global scientific community recognized the importance of neutrino oscillation science with the awarding of the 2015 Nobel Prize in Physics to Takaaki Kajita and Arthur B. McDonald for the discovery of neutrino oscillations and the 2016 Breakthrough Prize in Fundamental Physics to five experiments investigating neutrino oscillations. All of the experiments recognized through these prizes received HEP support. The P5 report recommendations outline a plan to continue the highly successful pursuit of neutrino science with NOvA and the future U.S.-hosted international Deep Underground Neutrino Experiment (DUNE). The NOvA detector was completed in November 2014 and currently receives the highest intensity neutrino beam in the world, generated 500 miles away at Fermilab. Initial physics results from early data were announced in the summer of 2015. NOvA will run for another six years, increasing its statistics to improve the precision of oscillation measurements, study the neutrino mass hierarchy, and search for the source of matter-antimatter asymmetry in the universe.

Dedicated astronomical surveys usher in an era of precision measurement in cosmology (Cosmic Frontier). The Baryon Oscillation Spectroscopic Survey (BOSS) measured the scale of the universe at a time 5 billion years ago to a precision of 1% and the rate of cosmic structure growth to 10%, using the full data set from its successful five year survey of 1.5 million galaxies and quasars. David J. Schlegel (Lawrence Berkeley National Laboratory), principal investigator for BOSS, was awarded the 2014 Ernest Orlando Lawrence Award exceptional leadership of major projects making the largest two-dimensional and three-dimensional maps of the universe. The Dark Energy Survey (DES) completed its second year of a five-year survey using precision imaging observations, providing complementary measurements to BOSS data. In FY 2015, DES released the largest map to date of the dark matter distribution in the universe, measured by gravitational lensing. DES also discovered 17 new dwarf galaxies, satellites of our Milky

[a] Partner agencies for the Accelerator Stewardship program's initial two years 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, and the NSF's Physics Division and Chemical, Bioengineering, Environmental, and Transport Systems Division.

Way galaxy, that provide excellent laboratories to explore the physics of dark matter. Jointly with the Fermi Gamma-ray Space Telescope (FGST), the DES dwarf galaxy measurements were used to place tight limits on dark matter properties.

An experiment at the Facility for Advanced Accelerator Experimental Tests (FACET) demonstrated the acceleration of positrons, the antiparticle of the electron, in a beam-driven plasma wakefield accelerator for the first time (Advanced Technology R&D). Plasma wakefield particle acceleration is an advanced technology that could boost the energy and shrink the size of future linear particle accelerators and have broad impact within the DOE Office of Science. Electron plasma wakefield acceleration has been previously demonstrated at FACET using two beam pulses, a drive pulse of electrons that generate a plasma wake and a trailing pulse that is accelerated by “surfing” on the plasma wake. FACET has the unique capability to use positrons in a plasma wakefield accelerator and has successfully demonstrated a new technique for accelerating them. Within a single pulse of positrons, the front of the positron bunch generated a plasma wake that accelerated the trailing positrons. The acceleration of positrons in addition to electrons is needed to implement this technology in a future Energy Frontier collider.

High Energy Physics
Energy Frontier Experimental Physics

Description

The Energy Frontier Experimental Physics subprogram supports research at the LHC with the goal of determining to what extent the Standard Model correctly describes the natural world. Exploring new physics at the highest energies and new dynamics of already discovered elementary particles are now the foundation for much of the LHC research program.

Research activities at the Energy Frontier in FY 2017 will be focused on the LHC, which resumed operations in FY 2015 after a planned shutdown that began in FY 2013 to bring the collider to its full design energy of at least 13 TeV. Data collected during this period will be used to address at least three of the five primary 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. In July 2012, CERN announced the discovery of a new particle consistent, within the limited statistical accuracy, with being the Standard Model Higgs boson. Since the discovery, experiments at the LHC have continued to actively measure the particle's properties and results thus far have strongly indicated consistency of the Higgs boson with the Standard Model picture. However, more data are required to precisely measure its properties. Through such studies, scientists will be able to establish the particle's 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 hope to find 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. As the second run continues in FY 2017, the LHC detectors will be increasingly more sensitive to potential deviations from the Standard Model that may be exposed by the increase in collision energy from 8 TeV to at least 13 TeV.
- *Identify the new physics of dark matter.*
  If dark matter particles are light enough, they can be produced in LHC collisions and their general properties 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 where one tries to observe the very faint signal of ambient cosmic dark matter particles colliding with nuclei. Limits on dark matter production set by the LHC experiments already significantly constrain many theoretical models.

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.

The Energy Frontier Experimental Physics subprogram also supports the LHC detector operations program, which covers the maintenance of U.S. supplied detector systems for the ATLAS and CMS detectors at the LHC and the U.S. based computer infrastructure for the analysis of LHC data by U.S. physicists.

<u>Research</u>
University-based Energy Frontier research is carried out by groups at over 65 institutions performing experiments at the LHC. Grant-supported scientists typically constitute about 50–75% of the personnel needed to create, run, and analyze an experiment, usually working in collaboration with other university and laboratory groups. Grant-based research efforts are selected based on external competitive peer review, and funding allocations take into account the quality and scientific priority of the research proposed. Energy Frontier research also supports physicists from five national laboratories. These are typically large groups that also have significant responsibilities for detector operations, maintenance, and upgrades, particularly at the laboratories that host large computing and analysis-support centers as well as maintain unique instrumentation facilities. 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 2018 and evaluate progress.

<u>Facility Operations and Experimental Support</u>
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 at BNL. There are 13 LHC Tier 1 computing centers around the world. The Tier 1 centers provide round-the-clock support for the LHC Computing Grid and are responsible for storing a proportional share of raw and reconstructed data, as well as performing large-scale data reprocessing and storing the corresponding output. This program also supports investments in R&D activities aimed at improvements to the LHC detectors so they can operate in the long-term at higher luminosities.

Projects

CERN is upgrading the LHC machine to produce two to three times the particle collision rate (instantaneous luminosity) currently delivered. This work motivates upgrades to the ATLAS and CMS detectors in order to enable each experiment to fully exploit the physics opportunities offered by the LHC for exploration of new physics and to make precision measurements of properties of known phenomena. Project activities will therefore continue to support the fabrication of major items of equipment (MIE) for these two detector upgrades within the Energy Frontier subprogram. Upgrade fabrication efforts are planned to start ramping down in 2017 in preparation for installation of U.S.-delivered detector systems in their respective experimental collision halls during a planned shutdown in 2019-2020.

The ATLAS Detector Upgrade Project was baselined (CD-2) and approved for a fabrication start (CD-3) in FY 2015. Upgrades are needed to the Muon Subsystem, the Liquid Argon Calorimeter Detector, and Trigger and Data Acquisition System to take advantage of the increased luminosity. The last production readiness reviews will be completed in early FY 2017 and full production will continue in FY 2018.

The CMS Detector Upgrade Project was baselined (CD-2) and approved for a fabrication start (CD-3) in FY 2015. Upgrades are needed to the Pixelated Inner Tracking Detector, the Hadron Calorimeter Detector, and Trigger System to take advantage of the increased luminosity. The U.S. contributions to forward pixel detector subsystem and the trigger subsystem are planned to be completed in FY 2017.

During the period that spans the next two decades, CERN plans a major upgrade to the LHC machine to further increase the instantaneous luminosity by a factor of ten times its design value to explore new physics beyond the reach of the current LHC program, which will provide physicists insights to elementary particles and their interactions at unprecedented levels. Activities for the High Luminosity (HL)-LHC ATLAS and CMS Detector Upgrade projects are planned to begin in 2016 and are due to be completed by 2024. Based on recommendations in the P5 report, Mission Need Statements for these upgrades are expected to be approved in early 2016.

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
Energy Frontier Experimental Physics $150,723,000	**$150,998,000**	**+$275,000**
Research $77,270,000	**$76,811,000**	**-$459,000**
U.S. university and laboratory scientists begin analyzing the newly acquired data from LHC's second run that began in early-2015. Research activities focus on addressing key areas within the five science drivers outlined in the P5 report, which include using the Higgs boson as a new tool for discovery and exploring new particles and their interactions.	U.S. university and laboratory scientists will focus on continuing research activities during LHC's second run at collision energies of at least 13 TeV, pursuing new physics such as supersymmetry, dark matter candidates and evidence of extra space-time dimensions, and conducting high-profile studies such as precision measurements of the Higgs boson. U.S scientists will work on the preliminary design for the HL-LHC detector upgrades.	SC will reduce funding for the Energy Frontier research due to overall programmatic reductions in research activities to support current and future experimental capabilities. Some research staff previously supported under Research will be redirected to complete the fabrication of U.S. supplied detector systems for the LHC Detector Upgrade projects and to begin leading the HL-LHC ATLAS and CMS Detector Upgrade projects.
Facility Operations and Experimental Support $54,453,000	**$55,220,000**	**+$767,000**
Funding supports the operation of the LHC ATLAS and CMS detectors during LHC's second run. Major activities include continuing the routine maintenance and calibration of the detectors as well as the processing of newly acquired data. Initial investments support critical R&D activities for longer-term operations of the LHC detectors at higher luminosities.	The Request will continue to support maintenance and operational activities of the LHC ATLAS and CMS detectors during LHC's second run. Critical R&D activities will be completed in order to begin prototyping LHC detector systems for planned upgrades of the detectors at higher luminosities.	Increased funding supports ATLAS and CMS detector maintenance and operations during the LHC's second run and the critical R&D activities that will support prototyping for the HL-LHC detector upgrades.
Projects $19,000,000	**$18,967,000**	**-$33,000**
The LHC ATLAS and CMS Detector Upgrade projects were baselined in FY 2015 and fabrication activities continue into FY 2016.	Fabrication activities for the LHC ATLAS Detector Upgrade and the LHC CMS Detector Upgrade projects will be completed in FY 2017. The Request provides OPC funding for the HL-LHC ATLAS and CMS Detector Upgrades in order to take advantage of the increased LHC luminosity during the next decade. Mission Need (CD-0) for these upgrades is planned for early 2016.	The reduction in funding aligns with the approved profiles for the LHC ATLAS Detector Upgrade and the LHC CMS Detector Upgrade projects. Initial OPC funding for the HL-LHC ATLAS and CMS Detector Upgrades is provided.

High Energy Physics
Intensity Frontier Experimental Physics

Description

The Intensity Frontier Experimental Physics subprogram investigates some of the rarest processes in nature including unusual interactions of fundamental particles or subtle effects requiring large data sets to observe and measure. This subprogram in particular shares some deep intellectual connections with NP. 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 a high-background environment such as the LHC.

Activities at the Intensity Frontier will be focused primarily on operating new and existing facilities while continuing investments that maintain a world-leading program into the future and establish the scientific foundation for the future U.S.-hosted international LBNF/DUNE. These facilities and investments are concentrated primarily in the areas of neutrino and muon physics and primarily based at Fermilab. The Fermilab SBN program, established in response to the P5 report, will continue to advance neutrino physics while serving as an international platform for many of the research and development activities necessary to establish LBNF/DUNE. The MicroBooNE experiment will continue taking data as research and development activities continue for its SBN partners, SBND and ICARUS, that are scheduled to begin data taking in FY 2018.

The NOvA neutrino detector was completed in FY 2014 and will be in its third year of operations. NOvA is currently the world's longest-baseline neutrino experiment and studies neutrinos from the world's most powerful neutrino beam, the upgraded NuMI beam at Fermilab. NOvA may switch to antineutrino mode in FY 2017 based on physics results from its first two years of operation.

Operation of the Daya Bay Reactor Neutrino Experiment (Daya Bay) in China will conclude in FY 2017. Physics analyses on the very large Daya Bay experimental dataset will continue through 2021 with a focus on extracting high-precision measurements on neutrino parameters and searching for new physics. Fabrication funding for the Fermilab Muon g-2 Experiment concludes in FY 2017. Physics commissioning of the Muon g-2 detector continues, and first data taking for the Muon g-2 Experiment will begin in FY 2017. Mu2e will continue its construction phase.

Data collected from the supported 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. The three known varieties of neutrinos were all discovered by HEP researchers working at U.S. facilities. 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.
- *Identify the new physics of dark matter.*
  The lack of experimental evidence from current generation dark matter detectors has led some to propose 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 could be connected to the cosmic dark matter. Using intense accelerator beams at U.S. national laboratories outfitted with highly capable high-rate detectors allows for probes of these models via subtle quantum mechanical mixing effects. These experiments complement the searches for dark matter performed in Cosmic Frontier and Energy Frontier experiments.
- *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 HEP experimental research activity at the Intensity Frontier consists of groups at over 50 academic institutions and physicists from eight national laboratories, performing experiments at a variety of locations. These groups, as part of scientific collaborations, typically have a broad portfolio of significant responsibilities and leadership roles including R&D, experimental design, fabrication, commissioning, operations, and maintenance, as well as scientific simulations, computing, and data analysis on the experiments in the subprogram. Research efforts are selected based on a competitive peer-review process in order to maintain activities with the highest scientific merit and potential impact. HEP conducted an external peer review of all laboratory research groups in this subprogram in 2013 and the next review will be in 2017. These findings will be used to inform the funding decisions in subsequent years.

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. The operation of the accelerator, detectors, and computing are included in this activity. Improvements to the facility are supported via General Plant Project (GPP) and Accelerator Improvement Project (AIP) funding. Refurbishment of the oldest parts of the complex including the Linac and the BNB continues in FY 2017 in order to maintain the reliability and efficiency of the complex. The major experimental efforts will be the NOvA and MicroBooNE experiments using the NuMI and BNB. In addition, the Muon g-2 experiment will begin physics data taking in 2017. Operations support for the LUX and Majorana demonstrator experiments at the Homestake Mine is also provided under this activity.

Projects

This activity supports the fabrication of major items of equipment for the Intensity Frontier subprogram. It also covers preconceptual R&D and design for proposed new Intensity Frontier efforts and the other project costs (OPC) of line item construction for the Intensity Frontier. This effort also includes subsystems integration and infrastructure needed for the SBN program, such as cryogenics, electronics and data acquisition.

The Muon g-2 project is an MIE to provide equipment needed to adapt an existing muon storage ring from BNL to utilize the higher intensity proton beam at Fermilab. In FY 2015, the project completed critical tests of the storage ring's superconducting, and in FY 2016 and FY 2017, it will fabricate new detectors, a muon production target, and a muon beam transport.
The FY 2017 Request funds the engineering design, site preparation, and long-lead construction activities for LBNF/DUNE. It also provides funding for Future Project R&D funding for the short baseline neutrino experiments. These experiments are much smaller than NOvA and LBNF/DUNE and address other issues in neutrino physics, such as the possibility of a new type of neutrino that does interact with charged particles. For more complete information on the LBNF/DUNE project, please see the Construction section.

Future Project R&D funding is ending and funding for Other Project Costs is provided for 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. The P5 report recommended an increase in power for the Fermilab accelerator complex so that it could provide a 1.2 megawatt beam to LBNF/DUNE, which is higher than the 0.7 megawatt beam planned for NOvA. Critical Decision 0 was approved on October 20, 2015, which identified and defined the mission need to increase the beam power needed for neutrino and muon experiments and maintain the efficiency of the Fermilab accelerator complex. Fermilab has supported R&D on this concept for several years with some of the R&D activities in partnership with institutions in India. An international agreement between DOE and the Department of Atomic Energy of India will provide contributions from India worth approximately $60,000,000 towards the development of this project. Additional funds will become available after successful completion of the design phase.

Intensity Frontier Experimental Physics

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
Intensity Frontier Experimental Physics $243,121,000	**$234,144,000**	**-$8,977,000**
Research $56,104,000	**$56,509,000**	**+$405,000**
Physics analyses leading to first published results from the NOvA and MicroBooNE experiments occur. The Main Injector Neutrino Oscillation Search (MINOS+) experiment at Fermilab concludes in FY 2016; physics analyses on the very large MINOS+ experimental dataset will continue through 2020 with a focus on extracting precision measurements on neutrino parameters and searching for sterile neutrinos. LBNF/DUNE physics studies and optimization continue under the umbrella of a new, fully internationalized program. New research and development activities for the Fermilab SBN program are underway, following the P5 report. Other proposed small-scale efforts may be supported depending on the outcomes of peer review. Physics studies to optimize the operation of the under construction Mu2e experiment continue. Muon g-2 physics commissioning efforts ramp up in preparation for first data in FY 2017. Commissioning of the Belle II detector at KEK begins.	The neutrino program will see new and more precise results from the NOvA experiment. These results will inform possible switch from a neutrino beam to an antineutrino beam in FY 2017. The Fermilab SBN program will continue to advance as MicroBooNE produces new physics results. ICARUS, a 600 ton liquid argon detector, will arrive from Italy, after refurbishment at CERN in FY 2017. It will enhance the SBN program by being larger and at a greater distance from the neutrino source than MicroBooNE. These two experiments will take data together to study anomalies in the neutrino sector. Operations support for Daya Bay will ramp down to its planned completion. The Fermilab Muon g-2 experiment will begin physics data taking. R&D, physics studies and optimization will continue for Mu2e and LBNF/DUNE. Other proposed small-scale efforts may be supported depending on the outcomes of peer review. Physics commissioning of the Belle II detector is completed and will be followed by initial data taking.	Funding for the Intensity Frontier research increases to support current and future experimental capabilities. Some research staff previously supported under Research will be redirected to lead the internationalization of LBNF/DUNE or towards development of the Fermilab SBN program.

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
Facility Operations and Experimental Support $151,317,000	**$153,066,000**	**+$1,749,000**
The Fermilab Accelerator complex ($129,282,000) continues to operate to support neutrino physics. FY 2016 is an important funding year for two AIPs that provide enhancements for the future operations program: the delivery ring AIP, which modifies the antiproton accumulator to store protons for the muon program, and the Recycler RF AIP, which upgrade 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 is completed. Operational Support at Homestake Mine ($15,300,000) continues as LUX completes its data-taking and the Majorana demonstrator continues.	The Fermilab Accelerator complex ($130,781,000) will continue to operate to support neutrino physics. FY 2017 is the last year for AIP funding for the Muon Campus (MC). The refurbishment of the Linac and BNB continues in FY 2017. Construction of an addition to the Industrial Center Building is planned as GPP in FY 2017. This addition will provide high bay space needed for the assembly of large equipment like superconducting magnets, SRF cryomodules, and detectors. Operational support at Homestake Mine ($15,000,000) is for the Majorana demonstrator activities and preparations begin supporting the LZ experiment and LBNF/DUNE construction.	Increased funding supports refurbishments to the Fermilab Accelerator Complex to support the Intensity Frontier program.
Projects $35,700,000	**$24,569,000**	**-$11,131,000**
Funding for the Muon g-2 MIE project ($10,200,000) will continue accelerator modifications and fabrication of the beamline and detectors. A combination of Other Project Cost funding ($18,015,000) and preconceptual R&D funding supports the development of PIP-II, a new superconducting proton linac to replace the more than 40-year-old existing front-end linac at Fermilab. The goal of this development is to significantly increase the beam power of the entire complex and improve its reliability. This improvement to make the Fermilab neutrino and muon programs sustainable through the next decade was recommended in the P5 report. Funding for the SBN program supports subsystems integration and infrastructure needed for the program.	Funding for the Muon g-2 MIE project ($6,349,000) will continue accelerator modifications and fabrication of the beamline and detectors. Funding ($15,220,000) supports the Other Project Costs for the PIP-II project including the conceptual design for a new superconducting proton linac to replace the more than 40 year-old existing linac. The goal of this development is to increase the beam power of the entire complex and improve its reliability. This improvement to make the Fermilab neutrino and muon programs sustainable through the next decade was recommended in the P5 report. Funding for SBN program supports subsystems integration and infrastructure needed for the program.	The reduction in funding is dominated by the ramp down of funding for Muon g-2 and the end of funding for preconceptual R&D for Fermilab linac upgrade.

Description

The Cosmic Frontier Experimental Physics subprogram 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. In FY 2017, a varied suite of complementary, staged experiments are planned that will lead to measurements with greater precision as the operations and analysis of current experiments continues, while the next generation of experiments are being planned and built. The program includes investments in projects for the future in accordance with the P5 report.

Experiments in this subprogram can be classified into four main categories: direct-detection searches for dark matter; studies of the nature of dark energy; measurements of the cosmic microwave background (CMB) to study the inflationary epoch in the early universe and provide constraints on neutrino masses; and measurements of high-energy cosmic and gamma rays. Data collected 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*
  Since the Nobel Prize in Physics in 2011 was awarded for the discovery of the acceleration of the expansion of the universe, steady progress has been made in studying the nature of dark energy. BOSS has measured galactic distances to a precision of 1% and growth rates through galaxy clustering. DES has produced the largest area maps of dark matter, whose evolution reveals the behavior of dark energy. DES operations are ongoing and the final release of DES maps will cover 30 times the current sky area. 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 spacetime.
- *Identify the new physics of dark matter*
  Measurements of motions within galaxies, the cosmic web of structure, 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 search for the products of dark matter annihilation in the core of galaxies. The first generation of direct detection experiments have significantly tightened the limits on dark matter properties, and the second generation will soon be operational, aiming to measure the signature of dark matter interaction. These experiments are complemented by the searches for dark matter performed in Intensity Frontier and Energy Frontier experiments.
- *Explore the unknown: new particles, interactions, and physical principles*
  High-energy cosmic and gamma rays can probe energy scales well beyond what can be produced with man-made particle accelerators, albeit not in a controlled experimental environment. These experiments allow searches for indirect signals of dark matter, and the presence of primordial antimatter. Searches for new phenomena in high-energy cosmic surveys may yield surprising discoveries about the fundamental nature of the universe.

<u>Research</u>

The Cosmic Frontier experimental research program consists of groups at over 45 academic and research institutions and 8 national laboratories performing experiments at a wide variety of locations. These groups, as part of scientific collaborations, typically have a broad portfolio of significant responsibilities and leadership roles including R&D, experimental design, fabrication, commissioning, operations, and maintenance, as well as scientific simulations, computing, and data analysis on the experiments in the subprogram. Research efforts are selected based on a competitive peer-review process in order to maintain activities with the highest scientific merit and potential impact. A competitive review is conducted annually for new or renewal grant proposals. HEP conducted an external peer review of all laboratory research groups in this subprogram in 2013 and the next review will be in 2016. The findings from these reviews are used to inform the funding decisions in subsequent years. Research efforts are supported for operating or recently completed experiments. Research activities are continuing on dark energy experiments using imaging and spectroscopic surveys, including the Dark Energy Survey (DES) and the extended Baryon Oscillation Spectroscopic Survey (eBOSS) experiments, and the space-based Alpha Magnetic Spectrometer II (AMS-II) and the Fermi Gamma-ray Space Telescope (FGST). It also includes operations of the South Pole Telescope Generation 3 (SPT-3G) CMB experiment, the High Altitude Water Cherenkov (HAWC) gamma ray experiment, and the ADMX-G2 dark matter search experiment. HEP-funded final data analyses will be completed on the suite of first generation dark matter direct detection (DM-G1) experiments, the Pierre Auger cosmic-ray observatory, and on the VERITAS gamma ray observatory.

Research activities continue to support design, fabrication, and science planning for next generation dark energy, direct-detection dark matter, and CMB experiments, including LSST, DESI, LZ, and SuperCDMS-SNOLab. Support for R&D and science planning of possible future experiments in the program, such as the large-scale CMB experiment, is also included.

Facility Operations and Experimental Support
This activity supports the DOE share of personnel, data processing, and other expenses necessary for the successful maintenance, operations, and data production of Cosmic Frontier experiments. These experiments are typically not sited at DOE facilities. They are located at telescopes, in space, or underground. Many experiments have large multi-national collaborations and DOE's fraction of the support cost is based on the magnitude of U.S. roles and responsibilities. In addition, there are DOE-only experiments and partnerships with NSF and NASA. Support is provided for the experiments currently operating as listed above as well as early operations planning for the next generation experiments currently in the design or fabrication phase. HEP conducted a scientific peer review of Cosmic Frontier operations in early FY 2015 and findings from this review are being used to monitor the experiments, and inform decisions concerning the level of operations support needed and whether to continue specific activities in subsequent years. DOE support for operations of Auger, VERITAS, and the first generation dark matter direct detection experiments is planned to be completed in FY 2016 and final data analyses will continue in FY 2017.

Projects
This activity supports design and fabrication of Cosmic Frontier projects, including major items of equipment (MIEs) as well as development of small experiments and R&D for future experiments. The FY 2017 Budget Request supports the continued MIE fabrication efforts on the three billion pixel precision camera for the Large Synoptic Survey Telescope (LSSTcam) project, which is the DOE contribution to the NSF-led LSST Project, and design and fabrication efforts on the Dark Energy Spectroscopic Instrument (DESI), which is being done in coordination with NSF. These dark energy projects will provide complementary techniques using imaging (LSST) and spectroscopic (DESI) measurements to study the nature of dark energy. The FY 2017 Budget Request also supports the DM-G2 MIE projects selected in FY 2014: LZ, which is in its fabrication phase, and SuperCDMS-SNOLab, which is in its final design phase in FY 2017. These will provide second generation searches for dark matter using complementary techniques to search for WIMPs in different mass ranges. Support for fabrication of the small-scale ADMX-G2 dark matter experiment and the SPT-3G CMB experiment ends in FY 2016 and will move to their operations phase in FY 2017.

Cosmic Frontier Experimental Physics

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
Cosmic Frontier Experimental Physics $130,582,000	**$130,069,000**	**-$513,000**
Research $49,910,000	**$49,934,000**	**+$24,000**
Research efforts support the currently operating or recently-completed suite of cosmic-ray and high-energy gamma-ray telescope experiments, the suite of DM-G1 experiments, and dark energy experiments including DES, and eBOSS. Research activities continue to support design, fabrication and science planning for the next generation of dark energy, dark matter and CMB experiments, as well as R&D and science planning of possible future experiments.	The FY 2017 Budget Request supports research efforts for data analyses on the currently operating or recently completed experiments, as described above. Research activities will continue to support design, fabrication and science planning for the next generation of dark energy, dark matter and CMB experiments, as well as R&D and science planning of possible future projects and experiments.	Research efforts continue at a slightly increased level to support the planning for calibration, simulation, science planning, and operation of new projects and data analyses for operating or recently completed experiments.
Facility Operations and Experimental Support $13,837,000	**$9,935,000**	**-$3,902,000**
Operations support continues for experiments that are in the data-taking phase, including the AMS-II cosmic-ray experiment, the FGST and HAWC gamma-ray experiments, and for imaging and spectroscopic dark energy experiments including DES and eBOSS. Final data processing efforts continue while analyses are completed on experiments that have finished their science mission, including DM-G1 experiments, the VERITAS gamma-ray experiment and the Pierre Auger cosmic ray experiment.	Operations support will continue for experiments that are in the data-taking phase, including AMS-II, HAWC, FGST, DES, and eBOSS. SPT-3G and ADMX-G2 start operations in FY 2017. Funding will support the experiments currently operating as listed above as well as early planning for the next generation experiments currently in the fabrication phase.	Support for the operation of several first generation dark matter experiments ends in FY 2016. Other Facilities activities decrease for Working Capital Fund to SC Program Direction, which are offset by increased funding to support transitions to early operations planning activities for future experiments, particularly LSST.

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
Projects $66,835,000	**$70,200,000**	**+$3,365,000**
Funding is provided for LSSTcam according to its approved baseline funding profile. The DESI and LZ MIEs to study dark energy and dark matter, respectively, are expected to be baselined in FY 2016. The SuperCDMS-SNOLab MIE, to complement LZ in the study of dark matter, will support design work towards project baseline. Small projects below MIE thresholds are also included.	Fabrication activities will continue on the dark energy MIE projects, including a ramp up on LSSTcam and the DESI funding profile as planned. These projects will provide complementary next-generation techniques for studying dark energy. SuperCDMS-SNOLab is expected to be baselined in FY 2017 and will enter its final design phase. LZ will continue fabrication. The program will also support a small effort on R&D and development efforts for future experiments.	The increase will support final design for the SuperCDMS-SNOLab MIE and fabrication for the MIE projects, LSSTcam, DESI, and LZ, according to their planned profiles. Fabrication activities on the small projects ADMX-G2 and SPT-3G were completed in FY 2016. The increase will also support a small effort on R&D and development efforts for future experiments.

High Energy Physics
Theoretical and Computational Physics

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 forces, 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 research thrusts focus on the central science drivers for HEP as identified by the P5 report, intertwining the physics of the Higgs boson, neutrino mass, and the dark universe along with exploring the unknown. Theory and computation cross-cut the science drivers and the energy, intensity, and cosmic experimental frontiers.

This subprogram supports theoretical research ranging from detailed calculations of the predictions of the Standard Model to the formulation and exploration of possible theories of new phenomena such as dark matter and dark energy and the identification of experimental signatures that would validate these new ideas. This subprogram also supports computational approaches to advance understanding of fundamental physical laws describing the elementary constituents of matter and energy, including computational science and simulations for scientific discovery and computing and software tools to enable and advance experimental and theoretical research at the three High Energy Physics frontiers.

Theory

The HEP theory research activity supports groups at over 70 academic and research institutions supported by research grants and seven national laboratory research groups. 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 model-building and university groups additionally focusing on formal or mathematical theory. Research efforts are selected based on competitive peer review to maintain the activities with the highest scientific impact and potential. Laboratory research groups are generally reviewed every three to four years. The most recent review in this subprogram was held in 2014, and findings from this review are being used to inform the funding decisions in subsequent years.

Computational HEP

Computation is necessary at all stages of HEP experiments—from planning and constructing accelerators and detectors, to theoretical modeling, to supporting computationally intensive experimental research and large-scale data analysis. In addition, scientific simulation and advanced computing help extend the boundaries of scientific discovery to regions not directly accessible by experiments, observations, or traditional theory. Computational HEP partners with the ASCR program on projects that focus on HEP topics that benefit most strongly from advanced computational techniques, such as Scientific Discovery through Advanced Computing (SciDAC) and the National Strategic Computing Initiative (NSCI). Computational HEP also supports directed efforts to develop and maintain operations and R&D for some HEP specific computational tools and supports forward-looking HEP computational research to address the challenges of evolving computer architectures and massive increases in scientific data.

Projects

The Projects activity currently funds acquisition and operation of dedicated hardware for the Lattice Quantum Chromodynamics (LQCD) computing effort. Since lattice techniques can address both nuclear and high energy physics topics, this program is managed in partnership with NP in order to avoid any duplication of effort. The LQCD Project provides dedicated computer hardware for the simulation of the strong interaction of gluons and quarks in bound states. Within the HEP program, its goals are most directly applicable to the Intensity and Energy Frontiers, and the results generated by its users are critical for the interpretation of data from the HEP experimental program in these Frontiers. Based on strong peer reviews and following recommendations in the P5 report, the LQCD project was extended in FY 2015 for a five-year period.

Theoretical and Computational Physics

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
Theoretical and Computational Physics $59,083,000	**$59,656,000**	**+$573,000**
Theory $48,465,000	**$49,620,000**	**+$1,155,000**
This activity funds research for university and laboratory groups as well as the Particle Data Group. Research proposals in the general topic areas described above are selected based on peer review by technical experts.	This activity will fund research for university and laboratory groups as well as the Particle Data Group. Research proposals in the general topic areas described above are selected based on peer review by technical experts.	Slight increase to maintain a thriving theory program as recommended in the P5 report.
Computational HEP $8,618,000	**$8,036,000**	**-$582,000**
This activity supports the research, development, and operation of computational tools that enable scientific advances in the HEP program. SciDAC projects selected in FY 2015 will continue in FY 2016. Other ongoing projects continue at approximately the same funding level.	This activity supports the research, development, and operation of computational tools that enable scientific advances in the HEP program. SciDAC will be re-competed in FY 2017 in partnership with ASCR.	HEP is expanding its cooperation with ASCR on multiple computational projects and will rely less on the SciDAC program. This results in a lower level of funding for SciDAC within a slightly reduced overall budget.
Projects $2,000,000	**$2,000,000**	**$0**
FY 2016 funding plan includes acquisition of new hardware as well as continued operations of the LQCD.	FY 2017 funding plan includes acquisition of new hardware as well as continued operations.	Funding is provided according to the planned profile.

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. New developments are stimulated and supported through peer reviewed research. This subprogram supports and advances research at all three experimental Frontiers.

Advanced Technology R&D includes particle accelerator, detector, and beam physics areas. 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.

Research activity is categorized into five thrust areas: accelerator and beam physics; advanced acceleration concepts; particle sources and targetry; radiofrequency acceleration technology; and superconducting magnet and materials. GARD supports research at seven DOE national laboratories and about 30 academic or other research institutions. Research topics are prioritized based on input from recent HEPAP subpanels and funding is awarded based on external competitive peer reviews. The program also trains new accelerator physicists with approximately 50 graduate students supported per year through research grants. Graduate level training for students and laboratory staff in areas of accelerator physics and technology is supported in this program.

In the past six years, two accelerator R&D test facilities (BELLA at LBNL and FACET at SLAC) have been built and operated under this subprogram to support research using plasmas to accelerate charged particles much more effectively than conventional electromagnetic cavities. These techniques hold the promise of reducing the size of particle accelerators by approximately 90%, making them considerably less expensive to build. The energy to drive the plasma can come either from lasers (as in BELLA) or electron beams (as in FACET). Both techniques have successfully accelerated beams while maintaining good beam quality.

FACET will complete operations in FY 2016 to make way for LCLS-II. A new and more capable facility, FACET-II, will be in its fabrication phase in FY 2017 using the kilometer linac section between LCLS and LCLS-II. FACET-II will continue the very successful electron beam driven plasma accelerator program. Operations of the BELLA facility will continue in FY 2017.

In FY 2017, GARD will launch a new activity to revitalize education and innovation in the physics of particle accelerators for the benefit of HEP and other SC programs that rely on these enabling technologies. A component of this program will allow graduate students to participate in mentored accelerator research and technology development and enable leveraging the capabilities and assets of DOE laboratories. HEP will hold a competition for a traineeship program to support the projected workforce shortage. This will be aimed at a university/national laboratory consortium in order to provide the academic training and research experience needed to meet DOE’s anticipated workforce needs.

HEP Directed Accelerator R&D
HEP Directed Accelerator R&D supports strategic investments in innovative technologies for possible future HEP accelerator projects, with proof-of-principle demonstrations, prototype component development, and advancing technical readiness. This includes R&D and prototyping to bring new concepts to a stage of engineering readiness where they can be incorporated into existing facilities or be applied to the design of new facilities. Research efforts within this activity are generally limited in time and have concrete milestones associated with specific future accelerator facilities or technologies. The current components of the HEP Directed Accelerator R&D activity are the LHC Accelerator Research Program (LARP) and the Muon Accelerator Program (MAP).

LARP is carrying out R&D needed to produce prototypes for U.S. deliverables to the High Luminosity LHC (HL-LHC) that CERN is planning to begin building late in this decade. The MAP program was created to carry out R&D on the feasibility of creating and accelerating muon beams for either the production of neutrinos or a very high energy lepton collider. Following the P5 report, these applications are now seen as less scientifically compelling at this time. The Muon Accelerator Program is being ramped down, with FY 2017 being the last year of funding for this activity; some key elements with broad applications will be redirected into General Accelerator R&D.

Detector R&D

Detector R&D addresses the need for continuing development of the next generation instrumentation and detectors at the Energy, Intensity, and Cosmic Frontiers in order to maintain scientific leadership in a worldwide experimental program that is broadening into new research areas. In order to meet this challenge, HEP maintains 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 program supports 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. This activity supports research programs at five DOE national laboratories and about 20 academic research institutions, as well as extensive test and fabrication facilities at three laboratories. Research efforts are selected based on competitive peer review to maintain the activities with the highest scientific impact and potential. All laboratory research groups are reviewed every three years. HEP conducted an external peer review of all laboratory research groups in this subprogram in 2012 and the next review is planned for 2016.

Facility Operations and Experimental Support

This activity generally provides operations funding for proposal-driven accelerator R&D facilities like FACET at SLAC, as well as other laboratory experimental and test facilities, including BELLA at LBNL and superconducting RF and magnet facilities at Fermilab. The SRF facilities are centralized at Fermilab due to the cost to build and operate them.

FACET, and its planned successor, FACET-II, provide very high energy beams of electrons and positrons for testing wakefield acceleration and radiation production. BELLA provides the world's highest repetition rate high-power laser for experiments in laser plasma acceleration and the interaction of ultra-intense light with matter. Experiments at both BELLA and FACET have shown increases in both acceleration gradients and precision of the beam control over the last several years.

The current priorities for the Fermilab accelerator test facilities are the programs to develop higher field magnets for the LHC (LARP), LCLS-II cryomodule production and testing, and R&D on a future upgrade of the Fermilab Accelerator Complex front end linac.

HEP also supports test beams at SLAC and Fermilab for the testing of new detector concepts as well as detector fabrication facilities like the Microsystem System Laboratory at LBNL and Silicon Detector (SiDET) Facility at Fermilab.

Projects

In FY 2017, initial equipment funding for the FACET-II MIE project is requested. A new shield wall in Sector 10 will be constructed to allow for FACET-II commissioning and operation during LCLS-II construction in Sectors 0-10.

Advanced Technology R&D

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
Advanced Technology R&D $115,494,000	**$118,285,000**	**+$2,791,000**
HEP General Accelerator R&D $46,722,000	**$44,510,000**	**-$2,212,000**
The general portfolio of topics described in the narrative above continues to be supported, but the program adjusts the emphasis on each topic based on the detailed recommendation from the HEPAP Accelerator R&D Subpanel (report issued in April 2015[a]) to optimize alignment with the P5 report.	The program will adjust research topics based on the recommendations from the HEPAP Accelerator R&D Subpanel (report issued in April 2015) to optimize alignment with the P5 report. A new traineeship activity will revitalize education and innovation in the physics of particle accelerators for the benefit of HEP and other SC programs that rely on these enabling technologies.	The program receives $1,000,000 to initiate a new traineeship activity in the physics of particle accelerators, but overall funding is down as priority goes to P5 recommended projects.
HEP Directed Accelerator R&D $20,640,000	**$21,500,000**	**+$860,000**
LARP increases effort to develop a prototype superconducting quadrupole magnets with the large apertures needed to increase luminosity at the LHC. MAP effort will be ramping down as recommended by P5 according to a detailed ramp-down plan which was developed in FY 2015.	LARP will increase efforts to develop a prototype superconducting quadrupole magnets with the large apertures needed to increase luminosity at the LHC. MAP effort will ramp down as recommended by P5 according to a detailed ramp-down plan which was developed in FY 2015.	Reductions due to the ramp down of MAP effort are offset by an increase in LARP superconducting magnet effort to meet schedule for delivery of magnet prototypes.
Detector R&D $16,282,000	**$17,350,000**	**+$1,068,000**
Research activities continue at U.S. universities and national laboratories, with resources continuing to shift 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 U.S. universities and national laboratories, with resources shifted towards near-term requirements of the high-priority efforts and towards strengthening the university efforts, as recommended in the P5 report.	Detector research activities will receive modest support while focus remains on the high priority activities recommended in the P5 report.
Facility Operations and Experimental Support $29,750,000	**$26,925,000**	**-$2,825,000**
Support for operation of BELLA and SRF Infrastructure continues. This program provides support for superconducting magnet fabrication and test facilities. FACET is supported at a reduced level due to a shorter run dictated by a shutdown for LCLS-II construction.	Support for operation of BELLA, SC magnet test facility and SRF test facilities continues. FACET ceased operation in FY 2016 due to LCLS-II construction removing part of the linac used by FACET.	The reduction is dominated by the end of funding for the operation of FACET.

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

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
Projects $2,100,000	**$8,000,000**	**+$5,900,000**
Mission Need (CD-0) for the FACET-II MIE project was approved in September 2015, and the project will begin receiving funding for Other Project Costs in FY 2016.	The FACET-II project will begin fabrication with $5,000,000 of equipment funding and $3,000,000 for other project costs. FACET-II will continue the very successful program started by FACET. The larger and higher priority LCLS-II project sponsored by BES is taking over the first third of the SLAC linac. FACET-II will be designed to use only the middle third of the SLAC linac.	Increase supports the FACET-II project.

Description

This subprogram stewards accelerator science & technology through 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, defense, energy and environmental 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 Department of Defense, and the National Institutes of Health.

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

HEP and other SC programs will continue to conduct programmatic near- and mid-term R&D on accelerator and beam physics issues related to the scientific facilities they operate. This subprogram will not replace or duplicate those R&D efforts, which are driven by specific science goals and program priorities.

Research

Research funding supports activities that have been identified for applications in areas broader than just HEP. 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 R&D Stewardship subprogram supports facility operations through two mechanisms: a dedicated Accelerator Stewardship facility (the BNL ATF) and the Accelerator Stewardship Test Facility Pilot Program, which provides seed funding to engage a broader user community, including industry users, at SC national laboratories.

The BNL ATF is a low-power electron and laser test facility dedicated to accelerator studies. Experiments at the BNL ATF study the interactions of high power electromagnetic radiation and high brightness electron beams, including free-electron lasers and laser acceleration of electrons and the development of electron beams with extremely high brightness, photo-injectors, electron beam and radiation diagnostics and computer controls. Beam time at the BNL ATF is awarded based on a merit-based peer review process. The BNL ATF was formally designated as an SC User Facility in FY 2015.

The Accelerator Stewardship Test Facility Pilot Program was launched in FY 2015 and provides operations support for non-traditional users to access accelerator test infrastructure at DOE's SC national laboratories. Unlike the SC user facilities, this class of SC assets is frequently unseen and underexploited by the broader community. A public portal[a] has been created, and public outreach events held at six national laboratories in the winter/spring of 2015 reached more than 450 participants. The broader community was made aware of these facilities, and laboratories subsequently submitted seed-funding proposals for limited-scale use of these facilities. Experience from the pilot program will inform the implementation of a long-term mechanism for making the SC's unique accelerator test facilities more available.

[a] www.acceleratoramerica.org

Accelerator Stewardship

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
Accelerator Stewardship $9,000,000	**$13,744,000**	**+$4,744,000**
Research $3,378,000	**$6,853,000**	**+$3,475,000**
Research activities continue at laboratories, universities, and in industry. As funds allow, the program initiates research support for selected technology areas such as energy & environmental applications of accelerators, as identified by SC workshops.	The Request will continue to support research activities at laboratories, universities, and in industry for technology R&D areas such as laser, ion-beam therapy, and accelerator technology for energy and environmental applications.	Research funding increases to support targeted R&D efforts to develop new uses of accelerator technology with broad applicability.
Facility Operations and Experimental Support $5,622,000	**$6,891,000**	**+$1,269,000**
Support continues for ATF operations, continuation of the Accelerator Test Facility Pilot Program, and the completion of the relocation of the ATF to a larger building.	The Request will support ATF user facility operations and the continuation of the Accelerator Stewardship Test Facility Pilot Program.	The facilities request in FY 2017 increases as the BNL-ATF relocation to a larger building reaches a peak year of activity. The Accelerator Stewardship Test Facility Pilot Program is expanded.

High Energy Physics
SBIR/STTR

Description
The SBIR/STTR amount is adjusted to mandated percentages for non-capital funding.

Activities and Explanation Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
SBIR/STTR $20,897,000	**$22,580,000**	**+$1,683,000**
In FY 2016, SBIR/STTR funding is set at 3.45% of non-capital funding.	In FY 2017, SBIR/STTR funding is set at 3.65% of non-capital funding.	The SBIR/STTR amount is adjusted to mandated percentages for non-capital funding.

Description

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

Mu2e, under construction at Fermilab, will be an important component of the Intensity Frontier subprogram. It 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 (Critical Decision CD-2) and for civil construction and long-lead procurement of the most challenging superconducting solenoid magnets (Critical Decision CD-3B) on March 4, 2015. Civil construction was initiated shortly thereafter. The Mu2e Project will complete its technical design phase in FY 2016 and move into full construction at that time. FY 2017 construction funds will be 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 Long Baseline Neutrino Facility and its associated Deep Underground Neutrino Experiment (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.

DOE implemented the recommendations from the P5 report during FY 2015 by assessing and evaluating opportunities to incorporate in-kind contributions from international collaborators. The non-DOE scope is expected to focus on modular components of the accelerator beam and neutrino detectors. DOE scope is expected to incorporate all civil construction activities including excavation for large modular neutrino detectors, as well as integration and operation of the accelerator beam and detectors. The reformulated, international program is now identified jointly as LBNF/DUNE.

HEP proposes to use the successful management model of the LHC in delivering the long baseline neutrino program. Fermilab would lead the construction of the LBNF project and will be 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.

The Deep Underground Neutrino Experiment (DUNE) is a new 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 SURF; and the scientific research program conducted with the DUNE detectors. The DUNE collaboration currently consists of about 750 physicists from nearly 150 institutes from 26 different countries. Each of the collaborating institutions will be 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.

All DOE contributions to LBNF/DUNE will be managed according to the SC's implementation of DOE O413.3B. Fermilab, in its role as the 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, maintain a schedule, and provide design, production readiness, and operational readiness reviews in cooperation with the collaboration. This process follows the practice, systems, and procedures at CERN for the LHC detectors.

The reformulated and integrated project plan for the LBNF/DUNE project was reviewed successfully in July 2015 by a DOE Independent Cost Review (ICR) and a DOE Independent Project Review (IPR). The DOE ESAAB refreshed the approval for CD-1 on November 5, 2015, with a revised TPC cost range of $1,255,000,000 to $1,727,000,000 and a TPC point estimate of

$1,500,000,000 based on the new conceptual design. The revised scope and outyear funding projections have pushed the CD-4 date to FY 2030.

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. Before excavation can begin, critical site preparations are needed such as safety and reliability refurbishments for the underground infrastructure as well as a waste-rock handling system. This work will start with funding received in FY 2016. The FY 2017 Request would support continuing these site preparation activities as well as initiating civil construction for excavation of the underground equipment caverns beginning in late FY 2017.

Approval of a new Critical Decision, CD-3A, is needed for the excavation work planned for a FY 2017 start. Approval is anticipated in FY 2016 based on strong positive recommendations from a DOE ICR and an IPR, both of which were convened simultaneously at SURF on December 2-4, 2015.

Construction

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
Construction $66,100,000	**$88,521,000**	**+$22,421,000**
11-SC-40, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment $26,000,000	**$45,021,000**	**+$19,021,000**
Total Estimated Cost (TEC) funding supports 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.	TEC funding is requested to continue technical design of the facility and the experiment. The design of cryogenic infrastructure is the next part of the facility design that needs to be completed. The Request includes funding to continue site preparation and initiation of underground excavation of the large caverns for the neutrino detectors.	The increased TEC funding will support continued site preparation and the start of the excavation of caverns for the neutrino detectors and cryogenic infrastructure.
11-SC-41, Muon to Electron Conversion Experiment $40,100,000	**$43,500,000**	**+$3,400,000**
Construction funding continues for the civil construction and initiate accelerator modifications and fabrication of technical components (solenoid magnets and particle detectors).	The Request includes funding to finish civil construction and continue accelerator modifications and fabrication of technical components (solenoid magnets and particle detectors).	Funding is increased according to the planned funding profile as construction continues.

High Energy Physics
Performance Measures

In accordance with the GPRA Modernization Act of 2010, the Department sets performance targets for, and tracks progress toward, achieving performance goals for each program. The following table shows the performance targets for FY 2015 through FY 2017. Details on the Annual Performance Report can be found at http://energy.gov/cfo/reports/annual-performance-reports.

	2015	2016	2017
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 SC's scientific user facilities take a great deal of time, money, and effort to prepare and regularly have a very short window of opportunity to run. If the facility is not operating as expected the experiment could be ruined or critically setback. In addition, taxpayers have invested millions or even hundreds of millions of dollars in these facilities. The greater the period of reliable operations, the greater the return on the taxpayers' investment.		
Performance Goal (Measure)	**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 Neutrino Model—Carry out series of experiments to test the standard 3-neutrino model of mixing**		
Target	Physics analyses results from the first year of data taking with the full detector were presented by the NOvA and MicroBooNE experimental collaborations at the FY 2015 summer conferences.	Physics analyses results of data taking with the full detector will be presented by the NOvA and MicroBooNE experimental collaborations at the FY 2016 summer conferences.	Determine based on the data taken with NOvA, whether it is appropriate to switch to taking antineutrino data. This should be based on a proposal from the NOvA Collaboration and evaluated by the Fermilab Program Advisory Committee.
Result	Not 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 matter-antimatter asymmetry in the neutrino sector.		

High Energy Physics
Capital Summary ($K)

	Total	Prior Years	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs. FY 2016
Capital Operating Expenses Summary							
Capital equipment	n/a	n/a	74,452	61,455	104,325	99,046	-5,279
General plant projects (GPP)	n/a	n/a	12,463	12,463	9,160	7,400	-1,760
Accelerator improvement projects (AIP) (<$5M)	n/a	n/a	12,750	12,400	9,700	4,400	-5,300
Total, Capital Operating Expenses	**n/a**	**n/a**	**99,665**	**86,318**	**123,185**	**110,846**	**-12,339**
Capital Equipment							
Major items of equipment[a]							
Energy Frontier Experimental Physics							
LHC ATLAS Detector Upgrades[b]	20,821	0	7,500	2,821	9,500	8,500	-1,000
LHC CMS Detector Upgrades[c]	22,629	0	7,500	5,162	9,500	7,967	-1,533
Intensity Frontier Experimental Physics							
Belle II[d]	8,870	7,900	970	970	0	0	0
Muon g-2 Experiment[e]	27,549	2,000	8,000	9,000	10,200	6,349	-3,851
Cosmic Frontier Experimental Physics							
Large Synoptic Survey Telescope Camera (LSSTcam)[f]	150,300	19,700	35,000	35,000	40,800	45,000	+4,200
Dark Energy Spectroscopic Instrument[g] (DESI)	46,137	0	250	500	9,800	9,000	-800
LUX-ZEPLIN[h] (LZ)	46,550	0	250	500	10,500	10,500	0
SuperCDMS-SNOlab[i]	14,725	0	250	0	2,375	4,000	+1,625
Advanced Technology R&D							
FACET II	41,500	0	0	0	0	5,000	+5,000
Total MIEs	n/a	n/a	59,720	53,953	92,675	96,316	+3,641

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

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

[c] 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.

[d] Critical Decision CD-2 and 3 for Belle II were approved on April 23, 2014. The TPC is $15,000,000.

[e] Critical Decision CD-2 and 3 for Muon g-2 Experiment were approved August 20, 2015. The TPC is $46,400,000.

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

[g] Critical Decision CD-2 for DESI project was approved on September 17, 2015. The TPC is $56,328,000. Approval of Critical Decision CD-3 is expected in FY 2016.

[h] The LZ project MIE was one of two MIEs selected to meet the Dark Matter Second Generation Mission Need. CD-1 and -3A were approved April 24, 2015. The project is expected to be baselined in FY 2016. The estimated cost range at CD-1 was $46,000,000-$59,000,000.

[i] The SuperCDMS-SNOlab MIE was one of two MIEs selected to meet the Dark Matter Second Generation Mission Need. CD-1 was approved on December 21, 2015. The estimated cost range at CD-1 was $16,000,000–$21,500,000. The project expects to be baselined in 2017.

	Total	Prior Years	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs. FY 2016
Total Non-MIE Capital Equipment	n/a	n/a	14,732	7,502	11,650	2,730	-8,920
Total, Capital equipment	**n/a**	**n/a**	**74,452**	**61,455**	**104,325**	**99,046**	**-5,279**
General Plant Projects (GPP)							
MC-1 Building	9,500	9,000	500	500	0	0	0
Muon Campus Beamline Enclosure	8,700	4,100	4,600	4,600	0	0	0
Short Baseline Neutrino Far Hall	9,800	1,000[a]	6,287	5,298	3,502	0	-3,502
Short Baseline Neutrino Near Hall	5,350	0	0	2,050	3,300	0	-3,300
Industrial Center Building addition	7,513	0	0	0	0	6,750	+6,750
Other projects under $5 million TEC	n/a	n/a	1,076	15	2,358	650	-1,708
Total, Plant Project (GPP)	**n/a**	**n/a**	**12,463**	**12,463**	**9,160**	**7,400**	**-1,760**
Accelerator Improvement Projects (AIP)							
Muon Campus Cryogenics	9,600	6,200	1,300	1,300	700	1,400	+700
Recycler RF Upgrades	9,200	1,400	3,800	3,800	4,000	0	-4,000
Beam Transport	6,500	2,700	3,700	3,700	100	0	-100
Delivery Ring	9,100	1,900	3,300	3,300	3,900	0	-3,900
ATF-II Upgrade	5,000	2,200	650	300	1,000	1,500	+500
ATF-II Experimental Area	8,500	0	0	0	0	1,500	+1,500
Other projects under $5 million TEC	n/a	n/a	0	0	0	0	0
Total, Accelerator Improvement Projects	**n/a**	**n/a**	**12,750**	**12,400**	**9,700**	**4,400**	**-5,300**

[a] Updated information is consistent with the project profile.

Major Items of Equipment Descriptions

Energy Frontier Experimental Physics MIEs:

The *ATLAS Detector Upgrade Project* started as a new MIE in FY 2015 and subsequent ramp-up of fabrication activities for U.S. built detectors systems is planned in FY 2016. 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 received CD-1, Approve Alternative Selection and Cost Range, on October 17, 2013, with an estimated cost range of $32,200,000 to $34,500,000. The 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 planned completion date (CD-4) in FY 2019. The FY 2017 Request of TEC funding for the ATLAS Detector Upgrade Project is $8,500,000, which is $1,000,000 lower than the FY 2016 Enacted level of $9,500,000 and consistent with the approved baseline funding profile.

The *CMS Detector Upgrade Project* started as a new MIE in FY 2015 and subsequent ramp up of fabrication activities for U.S. built detector systems is planned in FY 2016. 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 received CD-1, Approve Alternative Selections and Cost Range on October 17, 2013, with an estimated cost range of $29,200,000 to $35,900,000. The 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 planned completion date (CD-4) in FY 2020. The FY 2017 Request of TEC funding for the CMS Detector Upgrade Project is $7,967,000, which is $1,533,000 lower than the FY 2016 Enacted level of $9,500,000 and consistent with the approved baseline funding profile.

Intensity Frontier Experimental Physics MIEs:

The *Belle II* project is fabricating detector subsystems for the upgraded Belle detector located at the Japanese B-Factory, which is currently being upgraded to deliver much higher luminosity. U.S. groups are making key contributions to the particle identification systems. CD-2/3 was approved April 23, 2014 with a TPC of $15,000,000 and a project completion date of September 30, 2016. No fabrication funding is requested for Belle II in FY 2017.

The *Muon g-2* project will fabricate an experiment that seeks to improve the measurement of the muon anomalous magnet moment, which is sensitive to new physical interactions such as supersymmetry. The project will repurpose a storage ring from a previous experiment at BNL with upgraded detectors located at Fermilab in order to utilize the high intensity proton beam available there to produce the needed muons. CD-1 was approved on December 19, 2013, with a TPC range of $43,000,000 to $50,100,000. The Muon g-2 Project was baselined and CD-2 & 3 were approved August 20, 2015, with a TPC of $46,400,000 and planned completion date (CD-4) in FY 2019. Transfer of the BNL storage ring to Fermilab occurred in FY 2013. New instrumentation for the storage ring will be provided, in part, by in-kind contributions from non-DOE sources including NSF. The FY 2017 Request of TEC funding for Muon g-2 is $6,349,000, which is $3,851,000 lower than the FY 2016 Enacted level of $10,200,000 and consistent with the approved baseline funding profile.

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 January 7, 2015, with a DOE TPC of $168,000,000 and a completion date of FY 2022. CD-3 was approved on August 27, 2015. The FY 2017 Request of TEC funding for the LSSTcam is $45,000,000, which is $4,200,000 higher 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. CD-2 was approved on September 17, 2015 with a TPC of $56,328,000, and a completion date of FY 2021. A review in preparation for CD-3 is scheduled for May 2016. The FY 2017 Request of TEC funding for DESI is $9,000,000, which is $800,000 lower than the FY 2016 Enacted level of $9,800,000 and consistent with the approved baseline funding profile.

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-1 was approved in April 28, 2015, together with CD-3a for long-lead procurement of photomultiplier tubes. CD-2 and CD-3b are planned for Q3 of FY 2016 with project completion (CD-4) in FY 2021. The FY 2017 Request of TEC funding for LZ is $10,500,000, which is flat with the FY 2016 Enacted level and consistent with the preliminary baseline funding profile.

The *Super Cryogenic Dark Matter Search at Sudbury Neutrino Observatory Laboratory (SuperCDMS-SNOLab)* project is a new MIE fabrication start in FY 2016. This MIE is one of two 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. CD-0 was approved in August 2012. CD-1 was approved on December, 21, 2015, and CD-2 is planned for FY 2017. SuperCDMS will be optimized to detect low mass WIMPs and will cover a range of WIMP mass that LZ is not sensitive to. The FY 2017 Request of TEC funding for SuperCDMS-SNOLab is $4,000,000, which is $1,625,000 higher than the FY 2016 Enacted level of $2,375,000 and consistent with the preliminary baseline funding profile.

<u>Advanced Technology R&D MIE:</u>
The *Facility for ACcelerator and Experimental Tests II (FACET-II)* is a new MIE fabrication start in FY 2017. 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 is ending due to the construction of the Linac Coherent Light Source II in a portion of the SLAC tunnel used by FACET. FACET-II will be designed to deliver the needed beams using only one third of the linac. The Mission Need Statement was signed August 24, 2015, and CD-0 was approved September 18, 2015. CD-1 was approved December 21, 2015. The FY 2017 Request of TEC funding for FACET-II is $5,000,000, which is consistent with the proposed funding profile.

High Energy Physics Construction Project Summary ($K)

	Total	Prior Years	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs. FY 2016
11-SC-40, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment							
TEC	1,414,461	23,781	12,000	12,000	26,000	45,021	+19,021
OPC	85,539	75,539	10,000	10,000	0	0	0
TPC	1,500,000	99,320	22,000	22,000	26,000	45,021	+19,021
11-SC-41, Muon to Electron Conversion Experiment							
TEC	250,000	67,000	25,000	25,000	40,100	43,500	+3,400
OPC	23,677	23,677	0	0	0	0	0
TPC	273,677	90,677	25,000	25,000	40,100	43,500	+3,400
Total, Construction							
TEC	n/a	n/a	37,000	37,000	66,100	88,521	+22,421
OPC	n/a	n/a	10,000	10,000	0	0	0
TPC	n/a	n/a	47,000	47,000	66,100	88,521	+22,421

Funding Summary ($K)

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs. FY 2016
Research	358,177	334,225	348,286	353,703	+5,417
Facilities Operations					
Scientific User Facilities Operations	150,798	144,173	138,882	136,472	-2,410
Other Facilities	114,327	120,461	116,097	115,565	-532
Total, Facilities Operations	**265,125**	**264,634**	**254,979**	**252,037**	**-2,942**
Projects					
Major Items of Equipment[a]	72,373	73,148	95,900	102,816	+6,916
Other Projects	23,325	26,225	11,720	5,700	-6,020
Construction[a]	47,000	47,000	84,115	103,741	+19,626
Total, Projects	**142,698**	**146,373**	**191,735**	**212,257**	**+20,522**
Total, High Energy Physics	**766,000**	**745,232**	**795,000**	**817,997**	**+22,997**

[a] 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 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs. FY 2016
TYPE A FACILITIES					
Fermilab Accelerator Complex	**$141,738**	**$134,613**	**$129,282**	**$130,781**	**+$1,499**
Number of Users	2,200	1,925	2,310	2,310	0
Achieved operating hours	TBD	4,866	N/A	N/A	N/A
Planned operating hours	4,200	4,200	4,800	4,800	0
Optimal hours	4,200	4,200	4,800	4,800	0
Percent optimal hours	100.0%	115.9%	100.0%	100.0%	N/A
Unscheduled downtime hours	TBD	882	N/A	N/A	N/A

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs. FY 2016
FACET (SLAC)	**$9,060**	**$9,560**	**$5,100**	**$0**	**-$5,100**
Number of Users	155	155	52	0	-52
Achieved operating hours	TBD	3,439	N/A	N/A	N/A
Planned operating hours	5,176	5,176	1,482	0	-1,482
Optimal hours	5,176	5,176	4,448	0	-4,448
Percent optimal hours	100.0%	66.4%	33.3%	N/A	N/A
Unscheduled downtime hours	TBD	530	N/A	N/A	N/A
Accelerator Test Facility (BNL)	**$0**	**$0**	**$4,500**	**$5,691**	**+$1,191**
Number of Users	0	0	50	52	+2
Achieved operating hours	N/A	N/A	N/A	N/A	N/A
Planned operating hours	N/A	N/A	2,400	1,800	-600
Optimal hours	N/A	N/A	2,500	1,825	-675
Percent optimal hours	N/A	N/A	96.0%	98.6%	+2.6%
Unscheduled downtime hours	N/A	N/A	N/A	N/A	N/A
Total Facilities	**$150,798**	**$144,173**	**$138,882**	**$136,472**	**-$2,410**
Number of Users	2,355	2,080	2,412	2,362	-50
Achieved operating hours	TBD	8,305	N/A	N/A	N/A
Planned operating hours	9,376	9,376	8,682	6,600	-2,082
Optimal hours	9,376	9,376	11,748	6,625	-5,123
Percent of optimal hours[a]	100.0%	112.6%	97.4%	99.9%	+2.5%
Unscheduled downtime hours	TBD	1,412	N/A	N/A	N/A

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

Scientific Employment

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Estimate	FY 2017 vs. FY 2016
Number of permanent Ph.D.'s (FTEs)	905	915	900	900	0
Number of postdoctoral associates (FTEs)	370	375	365	375	+10
Number of graduate students (FTEs)	485	500	475	480	+5
Other[a]	1,880	1,805	1,915	1,895	-20

[a] 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 2016 CPDS and does not include a new start for FY 2017. The Project 11-SC-40, the Long Baseline Neutrino Facility (LBNF), is being renamed as the Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment (LBNF/DUNE). The FY 2017 Request for LBNF/DUNE is $45,021,000, $19,021,000 more than the FY 2016 Enacted level of $26,000,000 and consistent with the preliminary cost profile approved at the CD-1 refresh.

The Particle Physics Project Prioritization Panel (P5) of the High Energy Physics Advisory Panel (HEPAP), in its 2014 *Strategic Plan for U.S. Particle Physics in the Global Context* report, recommended:

> *"The [LBNF] should be reformulated under the auspices of a new international collaboration, with Fermilab as host. There should be international participation in defining the program's scope and capabilities. The experiment should be designed, constructed, and operated by the international collaboration. The goal should be to achieve, and even exceed if physics eventually demands, the target requirements through the broadest possible international participation."*

HEP's implementation of the P5 recommendation to reformulate the long baseline neutrino program in an international context has resulted in the formation of two multinational, collaborative efforts—LBNF, which will construct the beamline at Fermilab and other experimental and civil infrastructure at Fermilab and at the Sanford Underground Research Facility (SURF); and the Deep Underground Neutrino Experiment (DUNE), an international experimental collaboration that is defining and implementing the scientific goals and technical requirements for the beamline, detectors and research program to be conducted at the LBNF facility. HEP proposes to manage both activities as a single project—LBNF/DUNE – and will use the successful Large Hadron Collider (LHC) management model for the collaborations.

LBNF, the host facility that will produce the neutrinos and house the experimental apparatus (neutrino detectors), will be built by Fermilab and a small number of international partners. The experimental apparatus, DUNE, will be built jointly by a large international collaboration (currently from 144 institutions in 26 countries). The DOE contributions to LBNF and DUNE together comprise a single project in terms of DOE Order 413.3B. Consequently, the DOE project's name has been expanded to the "Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment" (LBNF/DUNE). As host of the LBNF facility, DOE will provide the *majority* contribution to the LBNF facility and will provide a *minority* contribution to the DUNE international detector apparatus.

This management arrangement where a host facility provides by a major laboratory and detectors are provided by large collaborations is a very close match to the highly successful LHC model and its massive particle detectors at CERN. As the lead laboratory in the U.S., Fermilab was a major partner to CERN, providing key components to the LHC facility and detectors. U.S. scientists and engineers held key management and technical positions at CERN over the many years leading up to the Higgs discovery. Analogously, the construction of LBNF will be led by Fermilab, while the construction of the detectors will led by an international collaboration, supported by CERN, with Fermilab providing oversight and coordination. There will be two distinct management organizations to ensure effective execution by the partners in each. All DOE contributions to the facility and the detectors will be managed according to DOE Order 413.3B, and Fermilab will provide unified project reporting on both facets of the project.

Fermilab will be responsible for the design, construction, and operation of the major aspects of the LBNF facility: the neutrino beam, conventional civil facilities (including buildings and underground caverns), and technical infrastructure (including conventional civil construction, cryostats and cryogenic systems) required for the detectors.

Fermilab will oversee the new international DUNE experimental collaboration that has been formed to build the necessary detectors. The DUNE collaboration will be responsible for: the definition of the scientific goals and corresponding scientific and technical requirements on the detector systems and neutrino beamline; the design, construction, commissioning, and operation of the near detector at Fermilab and the far detectors at SURF; and the scientific research program conducted with the DUNE detectors.

The DUNE collaboration is led by elected co-spokespersons, currently one from the United Kingdom and the other from Switzerland. The collaboration has organized the development of the detector conceptual designs and is assigning the work scope among the collaboration members based on each collaborating institution's ability to carry it out. Each of the collaborating institutions will be responsible for delivering in-kind detector components and installing them in the detector. Presently the DOE contribution to the detectors is assumed to be less than a third of the total cost of the detectors.

Fermilab, in its role as the host, will oversee all LBNF and 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, maintain a schedule, and provide design, production readiness, and operational readiness reviews in cooperation with the collaboration. This process follows the practice, systems, and procedures at CERN for the LHC detectors.

Unlike DUNE with its many international participants, only a few international partners are expected to provide in-kind contributions to LBNF. For example, CERN is proposing to provide cryogenic infrastructure needed to support the detectors. CERN currently runs the largest cryogenic system in the world. HEP and Fermilab continue to recruit other partners that can similarly contribute their expertise as well as their financial resources. The international contributions to LBNF will be developed by Fermilab and its partner institutions under the oversight of DOE and other funding agencies. DOE will be responsible for developing any needed international agreements for LBNF.

The reformulated and integrated project plan for the LBNF/DUNE project was reviewed successfully in July 2015 by a DOE Independent Cost Review (ICR) panel and by a DOE Independent Project Review (IPR) panel, convened simultaneously at Fermilab in July 2015. Based on the recommendations of these panel reviews, the DOE ESAAB approved the revised CD-1 on November 5, 2015 with a TPC cost range of $1,260,000,000 to $1,860,000,000 and a TPC point estimate of $1,500,000,000 based on the new conceptual design. The revised scope and outyear funding projections have pushed the CD-4 date to FY 2030.

The FY 2016 funding for LBNF supports: 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 for support of modifications to the technical design of the experimental facility, infrastructure and detectors. Site preparation begins with maintenance activities to mine shaft, hoists, ventilation systems, and general support infrastructure to allow for safe and reliable work once construction begins. Site preparation also includes development of a waste rock handling system needed to support excavation.

The FY 2017 Request will support the completion of site preparation activities as well as initiating the procurement of civil construction for excavation of the underground equipment caverns beginning in late FY 2017. Approval of a new Critical Decision, CD-3A, will be needed before excavation work can start. The approval is anticipated in FY 2016 based on strong positive recommendations from a DOE ICR and an IPR. The DOE ESAAB for CD-3A is planned for Spring 2016.

Summary

The LBNF facility collaboration and DUNE experimental collaboration will create the premier facility and experiment for long-baseline neutrino science world-wide. 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 perhaps explain the puzzling matter-antimatter asymmetry observed in the universe.

The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-1R, which was approved November 5, 2015 with a preliminary TPC cost range of $1,260,000,000 to $1,860,000,000, a TPC point estimate of $1,500,000,000, and a CD-4 date of FY 2030. This 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.

Contributions from the international partners are currently being negotiated. For the DUNE detector the process is being driven from the principal investigator level up to the funding agencies as was done for the LHC. Proposals are under review by the other funding agencies. CERN has put funding into its medium-term budget plan for one detector cryostat worth $90 million in U.S. accounting. An addendum to the U.S. CERN agreement will document this commitment and others currently being negotiated.

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

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-3C	Performance Baseline Validation
FY 2017	11/5/2015	2Q FY 2016	3Q FY 2018	1Q FY 2020	1Q FY 2020

CD-1R – Refresh of CD-1 approval for the new Conceptual Design.
CD-3A – Approval for initiating excavation of the equipment caverns at the Far Site.
CD-3B – Approval for procurement of cryogenic system technical infrastructure at the Far Site, as well as for initiation of civil construction of an embankment for the neutrino-production beam line at Fermilab.
CD-3C – Approval for all project fabrication and construction (same as CD-3).

[a] No CPDS was submitted for FY 2013, FY 2014 or FY 2015 because no TEC funds were requested; however, design funds were provided in each year's appropriation.
[b] Critical Decision CD-1 was approved for the new conceptual design by an ESAAB approval (CD-1R) on November 5, 2015.

3. Project Cost History

(dollars in thousands)

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

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. The neutrino beam will be produced by a primary beam of protons 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 in order to provide the distance needed for the study of neutrino oscillations.

For the LBNF/DUNE project, Fermilab will be responsible for design, construction and operation of the major components of the LBNF facility 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 Prize for Physics in 1988, 1995, 2002 and 2015, provides the basis for further discovery opportunities. Determining relative masses and mass ordering of the three known neutrinos will give guidance and constraints to theories beyond the Standard Model of particle physics. The study and observation of the different behavior of neutrinos and antineutrinos will offer insight into the dominance of matter over antimatter in our universe and therefore, the very structure of our universe. The only other source of the matter-antimatter asymmetry, in the quark sector, is too small to account for the observed matter dominance.

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

[a] No CPDS was submitted for FY 2013, FY 2014 or FY 2015 because no TEC funds were requested; however, design funds were provided in each year's appropriation.
[b] The project is Pre-CD-2 and has not been baselined. All estimates are preliminary. The TPC point estimate is $1,500,000,000. The preliminary TPC range at CD-1 is $1,260,000,000 to $1,860,000,000.
[c] No construction, other than site preparation, approved civil construction or long-lead procurement will be performed prior to validation of the Performance Baseline and approval of CD-3.

neutrino beam to the Homestake mine and the current NuMI beam were compared. The new 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[a]	In addition to Threshold KPPs, additional DOE contributions to cryogenic subsystems installed and pressure tested for additional 20 kiloton fiducial detector mass[a]; DOE contributions to cryostats

[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.

Scope	Threshold KPP	Objective KPP
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[a], with cosmic ray interactions detected in each detector module	In addition to Threshold KPPs, additional DOE contributions to support up to 40 kiloton fiducial detector mass[a]

5. Financial Schedule[b]

(dollars in thousands)

	Appropriations	Obligations	Recovery Act Costs	Costs[c]
Total Estimated Cost (TEC)				
Design Only				
FY 2012	4,000	4,000	0	0[d]
FY 2013	3,781	3,781	0	801
FY 2014	16,000	16,000	0	7,109
FY 2015	12,000	12,000	0	15,791
FY 2016	0	0	0	12,080
Subtotal, Design Only	35,781	35,781	0	35,781
Design (Design and Construction)				
FY 2016	N/A	N/A	0	26,000
FY 2017	N/A	N/A	0	18,000
Outyears	N/A	N/A	0	44,000
Subtotal, Design (Design and Construction)	N/A	N/A	0	88,000
Total, Design	N/A	N/A	0	123,781

[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 TPC point estimate is $1,500,000,000. The preliminary TPC range at CD-1 is $1,260,000,000 to $1,860,000,000. Design and international collaboration plans are currently being developed; outyears are preliminary.
[c] Costs through FY 2015 reflect actual costs; costs for FY 2016 and the outyears are estimates.
[d]$1,078,000 was erroneously costed to this project in FY 2012, the accounting records were adjusted in early FY 2013.

(dollars in thousands)	Appropriations	Obligations	Recovery Act Costs	Costs[a]
Construction[b]				
FY 2016	N/A	N/A	0	0
FY 2017	N/A	N/A	0	14,000[c]
Outyears	N/A	N/A	0	1,276,680
Total, Construction	N/A	N/A	0	1,290,680
TEC[b]				
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[d]	26,000[d]	0	38,080[d]
FY 2017	45,021[c]	45,021[c]	0	32,000[c]
Outyears	1,307,659	1,307,659		1,320,680
Total, TEC	1,414,461	1,414,461	0	1,414,461
Other Project Cost (OPC)				
OPC except D&D				
FY 2009 Recovery Act	12,486[e]	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[f]	557[g]	17,940
FY 2013	14,107	14,107	0	13,022
FY 2014	10,000	10,000	0	11,505
FY 2015	10,000	10,000	0	10,079
FY 2016	0	0	0	2,850
Total, OPC	85,539	85,539	12,486	73,053

[a] Costs through FY 2015 reflect actual costs; costs for FY 2016 and the outyears are estimates.

[b] The project is Pre-CD-2 and has not been baselined. All estimates are preliminary. The TPC point estimate is $1,500,000,000. The preliminary TPC range at CD-1 is $1,260,000,000 to $1,860,000,000. Design and international collaboration plans are currently being developed; outyears are preliminary.

[c] Estimated costs are for initiating excavation of the equipment caverns at the Far Site, to be approved by CD-3A.

[d] Estimated costs are for Far Site preparation including procurement of the waste-rock handling system and for safety and reliability refurbishment of the underground infrastructure, which are needed prior to initiating excavation of the equipment caverns.

[e] $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).

[f] $18,000 of FY 2011 funding was attributed towards the Other Project Costs activities in FY 2012.

[g] During FY 2012, $1,000 of Recovery Act funding was recategorized from pre-conceptual design and so became part of the OPC. $3,000 was deobligated and expired because Recovery Act funds are no longer available for obligation.

	(dollars in thousands)			
	Appropriations	Obligations	Recovery Act Costs	Costs[a]
Total Project Cost (TPC)[b]				
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	13,823
FY 2014	26,000	26,000	0	18,614
FY 2015	22,000	22,000	0	25,870
FY 2016	26,000	26,000	0	40,930
FY 2017	45,021	45,021	0	32,000
Outyears	1,307,659	1,307,659	0	1,320,680
Total, TPC	1,500,000	1,500,000	12,486	1,487,514

6. Details of Project Cost Estimate[c]

	(dollars in thousands)		
	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	100,000	100,000	N/A
Contingency	23,781	27,781	N/A
Total, Design	123,781	127,781	N/A
Construction			
Site Preparation[d]	20,000	20,000	N/A
Far Site Civil Construction[e]	300,000	400,000	N/A
Fermilab Site Civil Construction[f]	270,000	N/A	N/A
Far Site Technical Infrastructure[g]	110,000	75,000	N/A

[a] Costs through FY 2015 reflect actual costs; costs for FY 2016 and the outyears are estimates.

[b] The project is Pre-CD-2 and has not been baselined. All estimates are preliminary. The TPC point estimate is $1,500,000,000. The preliminary TPC range at CD-1 is $1,260,000,000 to $1,860,000,000. Design and international collaboration plans are currently being developed; outyears are preliminary.

[c] The project is Pre-CD-2 and has not been baselined. All estimates are preliminary. The TPC point estimate is $1,500,000,000. The preliminary TPC range at CD-1 was $1,260,000,000 to $1,860,000,000.

[d] Site Preparation involves procurement of the waste-rock handling system and refurbishment of the existing underground infrastructure for improved safety and reliability at the Far Site, as well as for preparation of the Fermilab Site for construction.

[e] Far Site civil construction involves excavation of caverns at SURF, 4850 ft below the surface, for technical equipment including particle detectors and cryogenic systems.

[f] Fermilab Site civil construction involves construction of the housing for the neutrino-production beam line and the near detector.

[g] Technical equipment in the DOE scope, estimated here, will be supplemented by in-kind contributions of additional technical equipment, for the accelerator beam and particle detectors, from non-DOE partners as described in Section 1.

	(dollars in thousands)		
	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Fermilab Site Beamline[a]	130,000	75,000	N/A
DUNE Detectors	120,000	N/A	N/A
Contingency	340,680	160,612	N/A
Total, Construction	1,290,680	655,612	N/A
Total, TEC	1,414,461	783,393	N/A
Contingency, TEC	364,461	188,393	N/A
Other Project Cost (OPC)			
OPC except D&D			
R&D	18,000	16,000	N/A
Conceptual Planning	30,000	30,000	N/A
Conceptual Design	36,689	34,000	N/A
Contingency	850	9,539	N/A
Total, OPC	85,539	89,539	N/A
Contingency, OPC	850	9,539	N/A
Total, TPC	1,500,000	872,932	N/A
Total, Contingency	365,311	197,932	N/A

7. Schedule of Appropriation Requests[b]

Request Year		Prior Years	FY 2015	FY 2016	FY 2017	Outyears	Total
		(dollars in thousands)					
FY 2011	TEC	102,000	0	0	0	0	102,000
	OPC	22,180	0	0	0	0	22,180
	TPC	124,180	0	0	0	0	124,180
FY 2012	TEC	91,000	42,000	0	0	0	133,000
	OPC	42,621	0	0	0	0	42,621
	TPC	133,621	42,000	0	0	0	175,621
FY 2016	TEC	23,781	12,000	16,000	TBD	TBD	783,393
	OPC	75,539	10,000	4,000	TBD	TBD	89,539
	TPC	99,320	22,000	20,000	TBD	TBD	872,932
FY 2017[c]	TEC	23,781	12,000	26,000	45,021	1,307,659	1,414,461
	OPC	75,539	10,000	0	0	0	85,539
	TPC	99,320	22,000	26,000	45,021	1,307,659	1,500,000

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

[a] 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.
[b] Design and international collaboration plans are currently being developed; outyears are preliminary.
[c] The project is Pre-CD-2 and has not been baselined. All estimates are preliminary. The TPC point estimate is $1,500,000,000. The preliminary TPC range at CD-1 was $1,260,000,000 to $1,860,000,000.

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

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 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 the LBNF facility 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 the Sanford Underground Research Facility (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 will work through SDSTA to award and manage contracts needed to complete the LBNF and DUNE work at the remote site.
- 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 through SDSTA/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 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 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 reduced 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 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.

Prior to the start of far-site conventional facilities construction, DOE plans to enter into a land lease with SDSTA 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. 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 2016 CPDS and does not include a new start for FY 2017.

Summary

The FY 2017 Request for the Muon to Electron Conversion Experiment (Mu2e) is $43,500,000, $3,400,000 more than the FY 2016 Enacted level of $40,100,000 and consistent with the approved baseline funding profile. The most recent DOE Order 413.3B approved Critical Decisions (CDs) are CD-2 (Approve Performance Baseline) and CD-3B (Approve Long-Lead Procurement), both approved on March 4, 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. A new milestone, CD-3C, was established concurrent with completion of final design, which is anticipated to be in 3Q FY 2016. 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 (FPD) 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 2016.

The Mu2e project provides the accelerator beam and experimental apparatus to identify unambiguously 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 has started and long-lead procurement for the Transport Solenoid system began in 4Q FY 2015. In FY 2016, the long-lead procurement activities and civil construction will continue, and final design and prototyping for accelerator, beamline and particle detector systems will be completed. Fabrication of the accelerator, beamline and detector technical systems will be initiated in 4Q FY 2016, following Critical Decision CD-3C, and will continue throughout FY 2017.

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

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-3C
FY 2014		3Q FY 2013		
FY 2013 Reprogram-ming		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

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-3C – 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]

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 will modify the existing Fermilab accelerator complex (Booster, Recycler and Debuncher Rings) to deliver the primary proton beam to a muon production target, and 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.

The project will design and construct the detector system (consisting of a tracker, calorimeter, cosmic ray veto and data acquisition subsystem), a new beam line from the Debuncher Ring to the detector system, and three superconducting

[a] No construction, other than approved long-lead procurement and detector hall civil construction, will be performed until CD-3 has been approved.

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 will design and construct 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 field of a nucleus provides a unique window for discovery of charged lepton flavor symmetry violation and allows access to new physics at very high mass scales. In 2008, the Particle Physics Project Prioritization Panel (P5), a subpanel of the High Energy Physics Advisory Panel (HEPAP), recommended this type of experiment for the Intensity Frontier of particle physics. The most recent P5 Subpanel reiterated this recommendation in its 2014 report. This project provides accelerator beam and experimental apparatus to identify unambiguously neutrinoless muon-to-electron conversion events.

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.

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

	(dollars in thousands)		
	Appropriations	Obligations	Costs[b]
FY 2015	N/A	N/A	16,892
FY 2016	N/A	N/A	10,051
Total, Design	N/A	N/A	57,000
Construction			
FY 2014	N/A	N/A	0
FY 2015	N/A	N/A	9,907
FY 2016	N/A	N/A	59,000
FY 2017	N/A	N/A	30,000
FY 2018	N/A	N/A	30,000
FY 2019	N/A	N/A	30,000
FY 2020	N/A	N/A	20,000
FY 2021	N/A	N/A	10,000
FY 2022	N/A	N/A	4,093
Total, Construction	N/A	N/A	193,000
TEC			
FY 2012	24,000	24,000	0
FY 2013	8,000[c]	8,000	14,653
FY 2014	35,000[d]	35,000	15,404
FY 2015	25,000[e]	25,000	26,799
FY 2016	40,100	40,100	69,051
FY 2017	43,500	43,500	30,000
FY 2018	44,400	44,400	30,000
FY 2019	30,000	30,000	30,000
FY 2020	0	0	20,000
FY 2021	0	0	10,000
FY 2022	0	0	4,093
Total, TEC	250,000	250,000	250,000
Other Project Costs (OPC)			
OPC except D&D			
FY 2010	4,777	4,777	3,769
FY 2011	8,400	8,400	8,940
FY 2012	8,000	8,000	6,740
FY 2013	2,500	2,500	1,020

[a] Costs through FY 2015 reflect actual costs; costs for FY 2016 and the outyears are estimates.
[b] Costs through FY 2015 reflect actual costs; costs for FY 2016 and the outyears are estimates.
[c] Congress approved a reprogramming that reduced the FY 2013 funding to $8,000,000 from the $22,685,000 that was originally appropriated.
[d] $5,162,907 was for long-lead procurements of superconducting wire for the magnet systems.
[e] $25,000,000 was for long-lead procurements for the superconducting solenoid magnet modules and for civil construction of the detector hall.

FY 2014	0	0	2,136
FY 2015	0	0	159
FY 2016	0	0	913
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

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
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	69,964
FY 2017	43,500	43,500	30,000
FY 2018	44,400	44,400	30,000
FY 2019	30,000	30,000	30,000
FY 2020	0	0	20,000
FY 2021	0	0	10,000
FY 2022	0	0	4,093
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	52,000	55,000	49,000
Contingency	5,000	2,000	8,000
Total, Design	57,000	57,000	57,000
Construction			
Site Work	2,000	2,000	2,000
Construction	13,000	19,000	13,000
Equipment	133,000	119,000	133,000
Contingency	45,000	53,000	45,000
Total, Construction	193,000	193,000	193,000
Total, TEC	250,000	250,000	250,000
Contingency, TEC	50,000	55,000	53,000
Other Project Cost (OPC)			
OPC except D&D			
R&D	8,200	6,600	8,200
Conceptual Planning	2,300	4,350	2,300
Conceptual Design	13,177	12,727	13,177
Total, OPC	23,677	23,677	23,677

[a] Costs through FY 2015 reflect actual costs; costs for FY 2016 and the outyears are estimates.

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total, TPC	273,677	273,677	273,677
Total, Contingency	50,000	55,000	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	TEC	0	24,000	8,000[b]	35,000	32,000	44,000	45,000	23,000	0	211,000
Repro-	OPC	13,177	8,000	2,500	0	0	0	0	0	0	23,677
gram-											
ming	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	TEC	0	24,000	8,000	35,000	25,000	40,100	43,500	44,400	30,000	250,000
PB	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
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

[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.

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 has 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. FRA 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 will be 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 may be subcontracted to third party vendors, if a planned study of industrial vendor capabilities confirms that the technical risks are acceptable. The third solenoid is relatively unique, and no good industrial analog exists. This solenoid will be designed and fabricated at Fermilab, though most of the parts will be procured from third party vendors.

There are two major subcontracts for the civil construction for Mu2e. An architecture and engineering (A&E) contract was placed on a firm-fixed-price basis for Preliminary (Title I) Design, and Final (Title II) Design with an option for construction (Title III) support. The general construction subcontract was placed on a firm-fixed-price basis.

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

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 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 what forms of bulk, strongly interacting matter can exist in nature, such as the quark-gluon plasma.
- **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 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 a description of the interactions of quarks and gluons described by the theory of QCD, which employs 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 both 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 a variety of international collaborations. It provides more than 90 percent of the nuclear science research funding in the U.S. with an average of 85 Ph.D. degrees granted annually to students for research supported by the program. NP research is guided by DOE's mission and priorities, and it helps develop the core expertise needed to achieve the goals of the NP program. 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 detectors and facilities used in experiments. The national laboratories also provide state-of-the-art resources for targeted detector and accelerator R&D for future upgrades and new facilities. This research develops knowledge, technologies, and scientists to design and build next-generation NP accelerator facilities. It is also of relevance to such machines being developed by other domestic and international programs.

The world-class user facilities and the associated instrumentation necessary to advance the U.S. nuclear science program supported by NP 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). These facilities provide particle beams for an international user community of 3,000 research scientists. Approximately 38 percent of these researchers are from institutions outside of the U.S. and 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 (High Energy Physics, Basic Energy Sciences), DOE Offices (National Nuclear Security Administration [NNSA] and Nuclear Energy), Federal agencies (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 their research programs. Following completion in FY 2014 of the accelerator upgrade portion of the 12 GeV CEBAF Upgrade project and the successful demonstration in December 2014 of the key performance parameters for the gluonic excitations (GlueX) detector in Hall D, fabrication of the remaining detectors in experimental Halls B and C continues and will be completed in FY 2017. 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).

Involving students in the development and construction of NP facilities and advanced instrumentation, along with 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 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, 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 2017 Budget Request

Support for university and laboratory research in NP increases, continuing the commitment made in FY 2016 to advance high priority research in such areas as nuclear structure, nuclear astrophysics, the study of matter at extreme conditions, hadronic physics, fundamental properties of the neutron, neutrinoless double beta decay, and isotope production and processing techniques. The Request also supports the initiation of the Gamma-Ray Energy Tracking Array (GRETA) Major Item of Equipment (MIE), a premiere gamma-ray tracking device that will exploit world-leading capabilities of FRIB. GRETA was identified by the nuclear science community in the 2007 Long Range Plan as an instrument that will "revolutionize gamma-ray spectroscopy and provide sensitivity improvements of several orders of magnitude." The high priority and urgency placed upon realizing the advanced capabilities GRETA will provide was reaffirmed by the nuclear science community in the 2015 Long Range Plan for Nuclear Science which was released in October 2015[a]. GRETA is being initiated to exploit the full scientific potential of FRIB, providing unique opportunities to advance the rare-isotope science and investigate reactions of critical importance for nuclear structure and nuclear astrophysics. Although existing detectors enable the start of an initial science program at FRIB, GRETA will enable vast new nuclear structure studies. Funding increases for operations at CEBAF to support initiation of the full scientific program with the recently upgraded 12 GeV machine and new scientific equipment in the experimental halls. Operations of the RHIC facility are increased by 550 hours above the FY 2016 Enacted level to enable studies of spin physics and explorations of new phenomena to illuminate the properties of the quark gluon plasma. Operations of the ATLAS facility continue to exploit the capabilities of the Californium Rare Ion Breeder Upgrade (CARIBU) as well as newly completed instrumentation. Support for the Isotope Development and Production for Research and Applications subprogram (DOE Isotope Program) maintains mission readiness for the production of stable and radioactive isotopes that are in short supply for research and a wide array of applications. Research investments in this subprogram are increased for a new graduate traineeship activity in the fields of radiochemistry and nuclear chemistry with an emphasis in isotope production; and to develop new cutting-edge approaches for important isotopes that are not currently available to the public in sufficient quantities, such as the establishment of a full-scale production capability of the promising alpha-emitter, actinium-225, to enable clinical trials for cancer therapy. An increase in research in isotope production techniques is in line with the recently completed assessment of the DOE Isotope Program by the Nuclear Science Advisory Committee (NSAC)[b]. After several years of research supported by the Isotope Program, funding is requested for an MIE project, the Stable Isotope Production Facility (SIPF), to enable the production of a broad range of enriched stable isotopes, a capability that has not been available in the U.S. for almost 20 years. Finally,

[a] http://science.energy.gov/np/

[b] http://science.energy.gov/np/nsac/reports/

construction continues according to the baselined profile for the FRIB project, which will provide intense beams of rare isotopes for a wide variety of studies in nuclear structure, nuclear astrophysics, and fundamental symmetries. In the FY 2017 Budget Request, funding for the Working Capital Fund (WCF) is transferred to Science Program Direction to establish a consolidated source of funding for goods and services provided by the WCF. An exception is CyberOne, which will continue to be funded through the Office of Science (SC) Safeguards and Security program. In FY 2016 and prior years, SC WCF costs were shared by SC research programs and Science Program Direction.

Nuclear Physics
Funding ($K)

	FY 2015 Enacted	FY 2015 Current[a]	FY 2016 Enacted	FY 2017 Request[b]	FY 2017 vs. FY 2016
Medium Energy Nuclear Physics					
Research	35,646	35,429	37,802	40,017	+2,215
Operations	97,050	97,050	98,670	104,139	+5,469
SBIR/STTR and Other	18,196	1,863	19,321	19,643	+322
Total, Medium Energy Nuclear Physics	**150,892**	**134,342**	**155,793**	**163,799**	**+8,006**
Heavy Ion Nuclear Physics					
Research	33,894	33,013	35,822	36,431	+609
Operations	166,072	166,072	172,088	179,700	+7,612
Total, Heavy Ion Nuclear Physics	**199,966**	**199,085**	**207,910**	**216,131**	**+8,221**
Low Energy Nuclear Physics					
Research	48,377	50,764	51,383	54,394	+3,011
Operations	26,819	27,029	27,402	25,499	-1,903
Total, Low Energy Nuclear Physics	**75,196**	**77,793**	**78,785**	**79,893**	**+1,108**
Nuclear Theory					
Theory Research	35,715	35,620	38,033	38,583	+550
Nuclear Data	7,381	7,554	7,742	7,882	+140
Total, Nuclear Theory	**43,096**	**43,174**	**45,775**	**46,465**	**+690**
Isotope Development and Production for Research and Applications					
Research	4,815	4,815	6,033	10,344	+4,311
Operations	15,035	15,035	15,304	19,026	+3,722
Total, Isotopes[c]	**19,850**	**19,850**	**21,337**	**29,370**	**+8,033**
Subtotal, Nuclear Physics	**489,000**	**474,244**	**509,600**	**535,658**	**+26,058**

[a] Reflects the transfer of Small Business Innovation/Technology Transfer Research (SBIR/STTR) funds within the Office of Science.
[b] A transfer of $1,315,000 to Science Program Direction is to consolidate all Working Capital Funds in one program.
[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 2015 Enacted	FY 2015 Current[a]	FY 2016 Enacted	FY 2017 Request[b]	FY 2017 vs. FY 2016
Construction					
06-SC-01, 12 GeV CEBAF Upgrade, TJNAF	16,500	16,500	7,500	0	-7,500
14-SC-50, Facility for Rare Isotope Beams	90,000	90,000	100,000	100,000	0
Total, Construction	**106,500**	**106,500**	**107,500**	**100,000**	**-7,500**
Total, Nuclear Physics	**595,500**	**580,744**	**617,100**	**635,658**	**+18,558**

SBIR/STTR:

- FY 2015 Transferred: SBIR: $12,967,000; STTR: $1,789,000
- FY 2016 Projected: SBIR: $14,134,000; STTR: $2,120,000
- FY 2017 Request: SBIR: $15,824,000; STTR: $2,225,000

Nuclear Physics
Explanation of Major Changes ($K)

	FY 2017 vs. FY 2016
Medium Energy Nuclear Physics: Increased funding is provided for the ramp up from commissioning to operations of the upgraded CEBAF to launch the 12 GeV 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. The increase will support 12 GeV researchers from national laboratories and universities to implement, commission, and operate the new experiments at CEBAF.	**+8,006**
Heavy Ion Nuclear Physics: Funding for operations of RHIC is increased to support 550 hours above the FY 2016 Enacted level to enable world-leading research in heavy ion nuclear physics and spin physics, and deferred maintenance. A 3,040 hour run in FY 2017 will enable incisive tests of our understanding of QCD as applied to the spin structure of the proton and to explore new phenomena in quark gluon plasma formation. Targeted increases in research funding support participation in RHIC runs, U.S. commitments in LHC heavy ion computing, and continued modest participation in the heavy ion program at the LHC, including implementation of new experimental capabilities for the heavy ion LHC ALICE detector.	**+8,221**
Low Energy Nuclear Physics: Operations funding for the ATLAS facility is increased to reinstate critical mechanical engineering expertise and support needed for accelerator target development. The ATLAS facility continues to provide critical capabilities for nuclear structure and astrophysics research, with beam time demands from the user community continuing to far exceed availability. Increased research funding is requested for targeted, high priority activities, including development and implementation of instrumentation in nuclear structure and astrophysics at ATLAS and FRIB, and operations support of the KATRIN experiment (an international tritium-beta-decay experiment to determine the mass of the neutrino). The Request includes $500,000 to initiate the Gamma-Ray Energy Tracking Array (GRETA) MIE in FY 2017, a high resolution gamma array tracking device for FRIB to provide a combination of high efficiency, peak-to-background ratio, and excellent energy and position resolution needed to fully exploit the opportunities at FRIB, for both fast fragmentation and reaccelerated beams. GRETA will revolutionize gamma-ray spectroscopy providing more than an order of magnitude increased sensitivity for gamma ray coincidence measurements. It will provide world-unique opportunities to advance the rare-isotope science and investigate reactions of critical importance for nuclear structure and nuclear astrophysics. Disposition activities of the Holifield Radioactive Ion Beam Facility (HRIBF) ramp down.	**+1,108**
Nuclear Theory: The requested increase enhances support for theory research efforts at laboratories and universities, and the U.S. Nuclear Data Program. Increased support is provided for a collaborative theory effort focused on the science at FRIB to promote interpretation of future FRIB experimental results.	**+690**

	FY 2017 vs. FY 2016
Isotope Development and Production for Research and Applications: The Request includes $2,500,000 to initiate the Stable Isotope Production Facility (SIPF), an MIE to cost-effectively provide a domestic capability for production of enriched stable isotopes, building upon the R&D prototype supported by the subprogram to develop new technology for general stable isotope enrichment. This facility will help mitigate dependence of the U.S. on foreign suppliers and is aligned with NSAC recommendations to provide this capability. Many stable isotope supplies are depleted from the national inventory and are needed for important research and security applications. The stable isotope enrichment prototype is operated to enable optimization of future production campaigns and design of the future facility. Isotope research efforts at national laboratories and universities are enhanced, in particular to support R&D efforts on developing full-scale production capabilities of alpha-emitters for medical applications, such as cancer therapy; and a new graduate traineeship activity in the fields of radiochemistry and nuclear chemistry with an emphasis in isotope production is initiated. Mission readiness of the isotope production and processing facilities at Brookhaven, Oak Ridge, and Los Alamos National Laboratories are maintained for isotope production, and production capabilities at university facilities are also supported for research isotopes.	**+8,033**
Construction: FY 2017 construction funding will continue at the same level as the FY 2016 Enacted level for the Facility for Rare Isotope Beams according to the approved baseline profile; these are the peak funding years for this project. The final year of construction funding for the 12 GeV CEBAF Upgrade project was provided in FY 2016.	**-7,500**
Total, Nuclear Physics	**+18,558**

Basic and Applied R&D Coordination

The NP mission supports the pursuit of unique opportunities for R&D integration and coordination with other DOE Program Offices, Federal Agencies, and non-Federal entities. For example, researchers from the High Energy Physics (HEP), NP, and Advanced Scientific Computing Research (ASCR) programs coordinate and leverage forefront computing resources and technical expertise through the Lattice Quantum Chromodynamics (LQCD) and SciDAC projects to determine the properties of as-yet unobserved exotic particles predicted by the theory of 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 provides evaluated cross-section and decay data relevant to reactor design (e.g., of interest to the Nuclear Energy [NE] and Fusion Energy Sciences [FES] programs), materials under extreme conditions (of interest to the Basic Energy Sciences [BES] and FES programs), and nuclear forensics (National Nuclear Security Administration [NNSA], Department of Homeland Security [DHS], and Federal Bureau of Investigations [FBI]). NP research develops technological advances relevant to the development of advanced fuel cycles for next generation nuclear reactors (NE); advanced cost-effective accelerator technology and particle detection techniques for medical diagnostics and treatment (National Institutes of Health [NIH], HEP); and research in developing neutron, gamma, and particle beam sources with applications in cargo screening and nuclear forensics (NNSA, DHS, and FBI).

R&D coordination and integration are hallmarks of the NP Isotope Development and Production for Research and Applications subprogram (DOE Isotope Program), which produces commercial and research isotopes in short supply and critical for basic research and applications. It also supports research for the development of new or improved production and separation techniques of 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

RHIC engineers the shape of small drops of quark gluon plasma. The quark gluon plasma (QGP), discovered at RHIC, is a state of matter that existed under the extreme conditions that occurred shortly after the Big Bang. In recent experiments, scientists identified flow patterns in the particles coming from very high energy collisions of protons and lead nuclei in LHC data. The results implied that small droplets of QGP were surprisingly being formed in the proton-lead collisions. Utilizing its unique flexibility to collide Helium-3 and deuterium nuclei with gold nuclei, new data from RHIC provides strong evidence that small droplets of QGP can, in fact, be created in lighter systems. The emergent RHIC results provide important information on the size of those droplets, and key information on understanding the conditions needed for forming this exotic form of matter.

New science leadership capabilities enabled by construction of world-class facilities. Following on-budget and ahead-of-schedule completion of the accelerator upgrade portion of the 12 GeV CEBAF Upgrade project at TJNAF in FY 2014, the project is progressing towards completion with the fabrication of new detectors in three separate halls. One of these detectors, the gluonic excitations (GlueX) detector in the newly constructed experimental Hall D, was completed in December 2014, and successfully demonstrated its design performance. The detector is now being calibrated and commissioned in preparation for the launch of the full 12 GeV physics program in FY 2017.

"Coldest cubic meter in the universe." The Cryogenic Underground Observatory for Rare Events (CUORE) is an experiment to search for neutrinoless double beta decay, a rare process that would indicate whether neutrinos are their own antiparticle, which could have a profound effect on the understanding of the dominance of matter over anti-matter in the cosmos. CUORE, located at the Gran Sasso Laboratory in Italy, is an international experiment with strong U.S. participation. A large volume of detectors must be cooled to temperatures just above absolute zero. The thermally insulating detector container, called the CUORE Cryostat and is one cubic meter in volume, recently achieved a temperature of 6 thousandths of a degree Kelvin above absolute zero. At this temperature, the CUORE Cryostat contains the coldest cubic meter volume in the known universe. The cryostat is currently undergoing additional commissioning test runs before initiating measurements to surpass the record setting sensitivity of its predecessor, CUORE-0.

Reactor Antineutrino Anomaly Calculations from the U.S. Nuclear Data Program (USNDP). All nuclear reactors emit antineutrinos resulting from the decay of isotopes produced in the nuclear reactions. Several recent studies of the antineutrinos emitted by nuclear power reactors have suggested that there may be an "anomaly" of roughly 6% in the total measured antineutrino flux, conjectured to possibly provide evidence for "Beyond the Standard Model" physics, such as the existence of a fourth neutrino in addition to the three types currently known. Performing a comprehensive "bottom-up" analysis of the current state of knowledge, USNDP physicists used their extensive databases that store all known properties of all nuclei to calculate the expected reactor antineutrino flux in detail, summing over 800 important unstable secondary nuclei. The initial results suggest that some of the unusual aspects of reactor antineutrino emission may have their origin in previously unknown details of conventional nuclear physics, solving the apparent origin of this intriguing anomaly.

Improved calculations for neutrino scattering off nuclei. Precise theoretical knowledge of the interactions of neutrinos with nuclei is essential to interpreting the results of a suite of next generation experiments. This theoretical work is inherently a nuclear physics endeavor as it relates to interactions which occur within the nuclear medium. A collaboration of ANL, LANL, and Old Dominion University scientists carried out calculations of electron and neutrino interactions with helium-4 and carbon-12 nuclei. The new theoretical calculations are similar for neutrinos and electrons allowing for direct comparisons to electron scattering data to verify the calculations. The calculated helium-4 electron scattering results agree well with experiment and illuminate the essential ingredients that need to be taken into account in reliable calculations of electron and neutrino interactions with nuclei. This leads the way to calculations on heavier nuclei as more computer power becomes available, and will be the key for the interpretation of neutrino-scattering experiments in the future.
Novel method for electron spectroscopy to be applied to neutrino mass determination. Researchers participating in the Project-8 collaboration have made the first observation of radiation from a single electron using a new technique, dubbed Cyclotron Radiation Emission Spectroscopy (CRES). The technique allows precise measurement of the energies of moderately relativistic electrons, such as those emitted in the beta decay of tritium. This success opens a completely different pathway toward a sensitive measurement of neutrino mass. Previous methods have set a laboratory upper limit of 2 eV on the masses of the three neutrino states. Neutrino oscillations set a lower limit of 0.02 eV on their average mass. With further development, the CRES method may be able to improve current limits by a factor of ten, exploring a large part, and perhaps all, of the remaining window for neutrino mass. This research was recently identified as a top ten 2015 physics breakthrough of the year.

Technical feasibility of new production route demonstrated for lithium-7 hydroxide for power reactors. Lithium-7 hydroxide is essential to the safe and reliable operation of pressurized water reactors to produce electricity. The salt is used as a neutralizer to maintain proper alkalinity/acidity of the cooling water in these reactors. Domestic power-plant users are completely reliant upon imports of lithium-7 hydroxide from foreign countries. Unpredictable foreign production capacity and growing demand are increasing the risks that domestic users will be unable to obtain adequate supply. In research funded by the Isotope Program, scientists at ORNL and the Y-12 National Security Complex have demonstrated technical feasibility of a new method of production of highly enriched lithium-7 using an environmentally friendly technology. The feasibility of applying these research results to full-scale production is now being considered.

Nuclear Physics
Medium Energy Nuclear Physics

Description

The Medium Energy Nuclear Physics subprogram focuses primarily on experimental tests of the theory of the strong interaction, known as Quantum Chromodynamics (QCD). According to QCD, all observed nuclear particles, collectively known as hadrons, arise from the strong interaction of quarks, antiquarks, and gluons. The protons and neutrons inside nuclei are the best known examples of hadrons. QCD, although difficult to solve computationally, predicts what hadrons exist in nature, and how they interact and decay. Specific questions addressed within this subprogram include:

- What is the internal landscape of the protons and neutrons (collectively known as nucleons)?
- What does QCD predict for the properties of strongly interacting matter?
- What is the role of gluons and gluon self-interactions in nucleons and nuclei?

Various experimental approaches are used to determine the distribution of up, down, and strange quarks, their antiquarks, and gluons within protons and neutrons, as well as clarifying the role of gluons in confining the quarks and antiquarks within hadrons. Scattering experiments are used to clarify the effects of the quark and gluon spins within nucleons, and the effect of the nuclear environment on the quarks and gluons. The subprogram also supports experimental searches for higher-mass "excited state" and exotic hadrons predicted by QCD, as well as studies of their various production mechanisms and decay properties.

Medium Energy Nuclear Physics supports research and operations of the subprogram's primary research facility, CEBAF at TJNAF, as well as the spin physics research that is carried out using RHIC at BNL. 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 opens up exciting new scientific opportunities, and will secure continued U.S. world leadership in this area of physics. The project will be completed in FY 2017, and the highly anticipated science program will be launched. 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 detailed microscopic understanding of the internal structure of the proton, including the origin of its spin, and how this structure is modified when the proton is inside a nucleus. Research at RHIC in FY 2017 using colliding beams of spin-polarized protons, a capability unique to RHIC, will provide information on the origin of the spin of the proton in a kinematic range complementary to that at CEBAF to extend present knowledge beyond the kinematic boundaries accessible at CEBAF alone. Research support for both facilities includes laboratory and university scientific and technical staff needed to implement and execute experiments and to conduct the data analysis necessary to extract scientific results. Complementary special focus experiments that require different capabilities are also supported at the High Intensity Gamma Source (HIGS) at Triangle Universities Nuclear Laboratory, Europe, and elsewhere. Efforts are supported at the Research and Engineering Center of the Massachusetts Institute of Technology (MIT), which has specialized infrastructure used to develop and fabricate advanced instrumentation and accelerator equipment.

The "SBIR/STTR and Other" category within this subprogram provides funding in accordance with the Small Business Innovation Development Act and subsequent related legislation. It 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.

Research

Research groups at TJNAF, BNL, ANL, LANL, and LBNL, and approximately 130 scientists and 105 graduate students at 29 universities will carry out research programs and conduct experiments at CEBAF, RHIC, and elsewhere, and will participate in the development and fabrication of advanced instrumentation, including state-of-the-art detectors that also have applications in areas such as medical imaging instrumentation and homeland security. TJNAF staff research efforts will focus on launching the full 12 GeV experimental program, including the implementation of experiments, acquiring data, and performing data analysis at the four CEBAF experimental 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. An active visiting scientist program at TJNAF and bridge positions with regional universities are also supported 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. They also lead an experiment at Fermilab to determine the antiquark contribution to the structure of the proton. 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; first measurements were obtained in FY 2015. Research groups at BNL and LBNL play leading roles in determining the spin structure of the proton through data taking and the development and fabrication of advanced instrumentation for RHIC, as well as contributing to data acquisition and analysis efforts. Researchers at MIT and at TJNAF are developing high current, polarized electron sources for next generation NP facilities.

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.

Operations
CEBAF's polarized electron beam capabilities are used to study the contributions of quarks and gluons to the properties of hadrons by a user community with a strong international component. Accelerator Operations support is provided for the accelerator physicists at TJNAF that operate CEBAF as well as for maintenance, power costs, capital infrastructure investments, and accelerator improvements, as the facility transitions to full operations following the completion of the 12 GeV CEBAF Upgrade project. Investments in accelerator improvements, including the modernization of the accelerator injector components, aim to provide more than an order of magnitude improvement in the beam quality for 12 GeV era parity violating physics experiments. This class of experiments is very sensitive to false asymmetries and imperfections in beam properties in the polarized source and the injector area. Support is provided for the most important efforts in developing advances in superconducting radiofrequency (SRF) technology relevant to improving operations of the existing machine. The core competency in SRF technology plays a crucial role in many DOE projects and facilities outside of nuclear physics (such as the Basic Energy Sciences project LCLS II) and has broad applications in medicine and homeland security. For example, SRF research and development 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. Accelerator capital equipment investments are targeted toward instrumentation needed to support the laboratory's core competencies in SRF and cryogenics. TJNAF accelerator physicists help train the next generation of accelerator physicists, enabled in part by a close partnership with other institutions with accelerator physics expertise. Experimental Support is provided for the scientific and technical staff as well as for materials and supplies for implementation, integration, assembly, and operation of the large and complex CEBAF experiments. Modest capital equipment investments for experimental support at TJNAF provide scientific instrumentation for the major experiments, including data acquisition computing and supporting infrastructure.

Medium Energy Nuclear Physics

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
Medium Energy Nuclear Physics $155,793,000	**$163,799,000**	**+$8,006,000**
Research $37,802,000	**$40,017,000**	**+$2,215,000**
Researchers focused on the 12 GeV experimental program at TJNAF continue to implement and develop experimental instrumentation and prepare for the new Hall D physics capabilities and the 12 GeV experimental program which starts in full 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 continues.	The highly anticipated 12 GeV experimental program will be launched at CEBAF, taking data with new instrumentation in all halls, including the newly constructed Hall D. 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 participate in the RHIC spin run in FY 2017 to study the spin structure of the proton.	Increased funding supports the 12 GeV researchers from national laboratories and universities to mount, implement, and operate the new experiments at CEBAF.
Operations $98,670,000	**$104,139,000**	**+$5,469,000**
Funding supports 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 is provided for Other Project Costs (within project TPC), as part of the 12 GeV CEBAF Upgrade project profile. The major milestone in FY 2016 is to establish first beams to Halls B and C for commissioning activities.	The newly upgraded CEBAF facility will begin full operations. Funding will support a total of 2,890 hours (about 87% utilization) of running for beam commissioning, tuning and research, including about 330 hours funded from the final year of Other Project Costs as part of the 12 GeV CEBAF Upgrade project profile (within project TPC). Experiments will be implemented and commissioned in all four halls and are operated for data taking.	The increase supports the ramp-up in operating time from commissioning activities in FY 2016 to support of the 12 GeV scientific program in FY 2017, which includes the required operations staff, power costs, materials and supplies, and maintenance activities needed to bring this complex scientific user facility back to full operation mode.
SBIR/STTR and Other $19,321,000	**$19,643,000**	**+$322,000**
Funding is provided in accordance with the Small Business Innovation Development Act and subsequent related legislation, as well as for other DOE and Office of Science obligations.	Funding will be provided in accordance with the Small Business Innovation Development Act and subsequent related legislation, as well as for other DOE and Office of Science obligations.	The increase in SBIR/STTR funding, which reflects the increase in the mandated percentage set-aside from 3.45% to 3.65% in FY 2017, is partially offset by the transfer of $1,315,000 to Science Program Direction to consolidate funding for the Working Capital Fund.

Nuclear Physics
Heavy Ion Nuclear Physics

Description

The Heavy Ion Nuclear Physics subprogram focuses on studies of nuclear matter at extremely high densities and temperatures, directed primarily at answering the overarching questions within the Quantum Chromodynamics (QCD) scientific thrust, 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. Complementary research capability is also provided at the Large Hadron Collider (LHC) at CERN. In the aftermath of collisions at RHIC and at the LHC, 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, and locating the critical point for the transition between the plasma and normal matter.

The RHIC facility places heavy ion research at the frontier of discovery in nuclear physics. RHIC serves two large-scale international experiments called PHENIX and STAR. 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 performance records, with Run-15 integrated luminosity exceeding the sum of all previous runs. The FY 2017 run will test the present understanding of QCD as applied to the spin structure of the proton, and will explore new phenomena that have emerged in quark gluon plasma formation. R&D and pre-conceptual design aimed at upgrades of existing detectors at RHIC continue, with efforts focused on proposed upgrades to PHENIX to probe the QGP with precision, high rate measurements. Short and mid-term accelerator R&D is conducted at RHIC in a number of areas including the cooling of high-energy hadron beams; high intensity polarized electron sources; and high-energy, high-current energy recovery linear (ERL) accelerators. The RHIC facility is used by about 1,200 DOE, NSF, and foreign agency-supported researchers annually.

Collaboration in the heavy ion program at the LHC at CERN provides U.S. researchers the opportunity to investigate states of matter under substantially different initial conditions than those provided by RHIC, providing complementary information regarding the matter that existed during the infant universe. Data collected by the ALICE, CMS, and ATLAS detectors confirm that the quark-gluon plasma discovered at RHIC is also seen at the higher energy and comparison with the results at RHIC has led to important new insights. U.S. researchers are making important scientific contributions to the emerging results from all three LHC experiments. In ALICE and CMS U.S. researchers are participating in developing and upgrading instrumentation for future heavy ion campaigns at the LHC.

<u>Research</u>

Heavy ion research groups at BNL, LBNL, LANL, ORNL, and approximately 110 scientists and 85 graduate students at 24 universities are supported to participate in experiments at RHIC and the LHC.

The university and national laboratory research groups provide the scientific personnel and graduate students needed for taking data with the RHIC and LHC heavy ion experiments; 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 and LHC data in alliance with the National Energy Research Scientific Computing Center (NERSC), which is supported by SC's Advanced Scientific Computing Research (ASCR) program. Additional computing resources at ORNL and Vanderbilt University are provided for LHC data analysis.

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.

Operations

Support is provided for the operations, power costs, capital infrastructure investments, and accelerator improvement projects of the RHIC accelerator complex at BNL. 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. 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. RHIC accelerator physicists are providing leadership to the effort to address technical feasibility issues of relevance to a possible next-generation collider for the NP program, including beam cooling techniques and energy recovery linacs. Accelerator Improvement Projects focus 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 completed and commissioned in FY 2018. 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 NP 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.

Heavy Ion Nuclear Physics

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
Heavy Ion Nuclear Physics $207,910,000	**$216,131,000**	**+$8,221,000**
Research $35,822,000	**$36,431,000**	**+$609,000**
Researchers continue to participate in the collection and analysis of new data from RHIC enabled by the recently 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 will generate 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 provides 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 is also supported.	Researchers will continue to participate in the analysis and collection of data from RHIC to explore new phenomena in quark gluon plasma formation. Efforts continue to develop instrumentation aimed at probing the QGP with precision measurements. NP will continue to provide scientific leadership to the heavy ion efforts at the international ALICE, CMS, and ATLAS LHC experiments, as well as providing the required funding to the LHC for U.S. commitments for management and operating costs, computing, and contributions towards upgrades of the ALICE detector. Mid- and short-term accelerator R&D relevant to NP programmatic needs will also be supported.	Increased funding maintains high priority efforts at universities and national laboratories associated with implementing the RHIC science program, and provides support for U.S. scientists to participate in small-scale ALICE instrumentation upgrades at the LHC.
Operations $172,088,000	**$179,700,000**	**+$7,612,000**
RHIC operations will provide for 2,490 beam hours, which is approximately 20 weeks and equal to 61 percent 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) is essential to understand results on heavy quark propagation in the quark-gluon plasma discovered at RHIC. The high statistics data planned for Run-16 addresses these phenomena and are required for researchers to interpret the data acquired from the last two years.	RHIC operations increase by 550 hours over FY 2016 to a total of 3,040 beam hours, which is approximately 24 weeks and equal to 74 percent utilization, in support of the planned RHIC research program. RHIC staff will continue to develop and implement instrumentation needed for the experimental campaigns. Continued implementation of electron beam cooling will lead to further increases in luminosity. Accelerator science staff will continue to reduce technical risks associated with a proposed electron ion collider.	Funding provides for increased operations, staffing levels, power costs, maintenance, and materials needed to reliably deliver 3,040 hours of beam.

Nuclear Physics
Low Energy Nuclear Physics

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 demonstrate 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 is the only DOE-supported facility in Nuclear Structure and Nuclear Astrophysics, serving a combined international community of more than 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 on-track and continue with decreasing funding in FY 2017.

Accelerator operations are supported at two university Centers of Excellence with specific goals and unique physics programs: the Cyclotron Institute at Texas A&M University (TAMU) and accelerator facilities at the Triangle Universities Nuclear Laboratory (TUNL) at Duke University. A third university center, the Center for Experimental Nuclear Physics and Astrophysics (CENPA) at the University of Washington, provides unique expertise and capabilities for instrumentation development. NP also supports a small in-house nuclear science program at the LBNL 88-Inch Cyclotron, which provides important capabilities in materials irradiation to external users.

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 Gamma-Ray Energy Tracking Array (GRETA) MIE is one of the primary tools that the community. and NSAC have identified to leverage the capabilities of FRIB, and SC proposes to begin fabrication in FY 2017. GRETA will have ten times the gamma-ray resolving power 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.

Research

Low Energy research groups at ANL, BNL, LBNL, LANL, LLNL, ORNL, and PNNL, and approximately 170 scientists and 110 graduate students at 41 universities are supported. About two-thirds of the scientists conduct nuclear structure and astrophysics research primarily using specialized instrumentation at the ATLAS scientific user facility, as well as the smaller accelerator facilities at university-based Centers of Excellence. Scientists are also involved in the development of instrumentation for the ATLAS facility. The GRETA MIE, discussed above, will be initiated in FY 2017 to provide unprecedented gamma-ray tracking capabilities for the future FRIB facility. GRETA will revolutionize gamma-ray spectroscopy providing more than an order of magnitude increased sensitivity for gamma ray coincidence measurements. The remaining groups primarily conduct research in fundamental symmetries, including experiments at the Fundamental Neutron Physics Beamline (FNPB) at the Spallation Neutron Source; double beta-decay experiments such as the Cryogenic Underground Observatory for Rare Events (CUORE) experiment at Gran Sasso Laboratory in Italy and the Majorana Demonstrator R&D effort at the Sanford Underground Research Facility in Lead, South Dakota; a measurement of the neutrino mass with the Karlsruhe Tritium Neutrino (KATRIN) experiment at the Karlsruhe Institute of Technology in Karlsruhe, Germany; and R&D to measure the neutron electric dipole moment. Support is also provided to the university Centers of Excellence to maintain and nurture their unique capabilities.

Operations

ATLAS provides highly reliable stable and selected radioactive beams and specialized instrumentation for scientists to conduct research on nuclear structure and nuclear astrophysics. Support is provided for the operations, power costs, capital infrastructure investments, experimental support, and accelerator improvement projects of ATLAS. The recently installed Electron Beam Ion Source (EBIS) enhances the performance of the CARIBU radioactive beam system by increasing fluxes of radioactive ion beams and enabling shorter-lived isotopes to be reaccelerated, thereby offering new research capabilities to scientists. Researchers remain engaged in the continuous development of small-scale, yet cutting-edge instrumentation for new experiments at ATLAS, providing the facility with unique world-wide capabilities. Instrumentation efforts in FY 2017 will focus on developing and implementing 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.

The ATLAS facility nurtures a core competency in accelerator science with superconducting radio frequency cavities for heavy ions that are relevant to the next generation of high-performance proton and heavy ion linacs. This competency is important to the Office of Science mission and international stable and radioactive ion beam facilities. Efforts continue in developing technology that could reduce the backlog of experiments and increase available beam time, such as the capability to operate stable and radioactive ion beams simultaneously.

Low Energy Nuclear Physics

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
Low Energy Nuclear Physics $78,785,000	**$79,893,000**	**+$1,108,000**
Research $51,383,000	**$54,394,000**	**+$3,011,000**
University and laboratory nuclear structure and nuclear astrophysics efforts continue 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. Data taking continues at the Majorana Demonstrator to demonstrate technical feasibility of a next generation detector in double beta decay. Support continues 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).	University and laboratory nuclear structure and nuclear astrophysics efforts will continue to focus on research at ATLAS, university-based Centers of Excellence, and high priority instrumentation development efforts to realize unique scientific opportunities at FRIB and ATLAS. Data taking will continue with the Majorana Demonstrator to demonstrate feasibility of this candidate technology for a next generation detector in double beta decay. U.S. participation in the operations of the international KATRIN and CUORE experiments will continue, as does ongoing R&D at the FNPB on the feasibility of setting a world leading limit on the electric dipole moment of the neutron (nEDM). A new MIE, GRETA, will be initiated to provide world-unique opportunities to advance the rare-isotope science and investigate nuclear reactions of critical importance for nuclear structure and nuclear astrophysics at FRIB.	Funding is increased to initiate GRETA, a new MIE that will provide an order of magnitude increased sensitivity for gamma ray coincidence measurements at FRIB. Instrumentation development efforts increase to realize the unique opportunities at FRIB. R&D for the nEDM research effort increases to determine feasibility of setting world leading limit on the electric dipole moment of the neutron. U.S. commitments and obligations increase for the operating CUORE and KATRIN experiments.

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
Operations $27,402,000	**$25,499,000**	**-$1,903,000**
Continued operation of ATLAS in a 7 day per week mode is a high priority as demand for ATLAS beam time continues to far exceed availability. FY 2016 funding supports 5,900 hours of beam time, and a program of modest upgrades continues for the only operating DOE-supported scientific user facility in nuclear structure and astrophysics. Support continues for equipment disposition activities at HRIBF.	Operation of ATLAS in a 7 day per week mode continues to be a high priority as demand for ATLAS beam time continues to far exceed availability. ATLAS continues to operate extremely reliably, and funding will support 5,900 hours of beam time. The Request will provide modest funding for an additional mechanical engineer to reduce risk and address experimental support needs. Modest upgrades and equipment development will continue in order to maintain unique instrumentation capabilities and a vigorous research program in nuclear structure and nuclear astrophysics. Activities will decrease in FY 2017 for equipment disposition activities at HRIBF, as planned.	Funding decreases due to the ramp down of disposition activities at HRIBF, partially offset by an increase needed to support ATLAS operations.

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 second year of new five-year topical collaborations within the university and national laboratory communities will be supported in FY 2017 to address high-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 is 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.

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, is also supported within this subprogram. 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 will continue through FY 2016. A new group of SciDAC-4 awards will be selected in FY 2017.

Theory Research
The Nuclear Theory subprogram supports the research programs of approximately 160 university scientists and 120 graduate students at 50 universities, as well as nuclear theory groups at seven national laboratories (ANL, BNL, LANL, LBNL, LLNL, ORNL, and TJNAF). This research has the goals of improving our fundamental understanding of nuclear physics, interpreting the results of experiments carried out under the auspices of the experimental nuclear physics program, and identifying and exploring important new areas of research. 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, a new round of 5-year topical collaborations is being initiated in FY 2016 to bring together theorists to address specific high-priority theoretical challenges. The three new collaborations are: the Beam Energy Scan Theory (BEST) Collaboration, the Coordinated Theoretical Approach to Transverse Momentum Dependent Hadron Structure in QCD (TMD) Collaboration, and the Nuclear Theory for Double-Beta Decay and Fundamental Symmetries (DBD) Collaboration. The BEST and TMD proposals are intimately related to lattice QCD, 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 electron ion collider (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. A new focused effort on FRIB theory has been initiated and will be expanded in FY 2017. This effort is critical to ramping up 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 2017, 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.

Nuclear Theory

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
Nuclear Theory $45,775,000	**$46,465,000**	**+$690,000**
Theory Research $38,003,000	**$38,583,000**	**+$550,000**
Funding continues to support the highest priority theoretical research at universities and national laboratories for the interpretation of experimental results obtained at NP facilities. Theorists concentrate 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 focus 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 continues to support ongoing SciDAC-3 grants and the LQCD ext-II computing project. Support is provided to initiate the second round of theory topical collaborations.	Funding will continue to support the highest priority theoretical research at universities and national laboratories for the interpretation of experimental results obtained at NP facilities, and the exploration of new ideas and hypotheses that identify potential areas for future experimental investigations. Theorists will focus on applying QCD to a wide range of problems from nucleon structure and hadron spectroscopy, through the force between nucleons, to the structure of light nuclei. Advanced dynamic calculations to describe relativistic nuclear collisions, 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 a new group of SciDAC-4 grants, the second year of the theory topical collaborations initiated in FY 2016, and the ongoing LQCD ext-II computing project with HEP.	Funding increases to support the highest priority theoretical research efforts across the Nuclear Physics program, and to expand support for a theoretical collaboration focused on the science at FRIB.

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
Nuclear Data $7,742,000	**$7,882,000**	**+$140,000**
Nuclear data evaluation is the prime nuclear data product, combining experiment with theory and linking basic science with applications. The emphasis in FY 2016 is 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.	The primary emphasis in the Nuclear Data Program in FY 2017 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. In addition, a modest experimental component to address gaps in the existing nuclear data will be considered.	Funding increases to support recently established university efforts at MSU (in association with FRIB) and the University of California, Berkeley (in association with LBNL and LLNL), in support of USNDP activities.

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 research and development 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, environmental, archeological, and other research. Some examples are:

- strontium-82 for cardiac imaging;
- californium-252 for well logging, homeland defense, 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, 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 defense applications;
- lithium-7 as a coolant reagent for pressurized water nuclear power plants;
- tungsten-188, strontium-90, and cobalt-60 for cancer therapy;
- arsenic-73 as a tracer for environmental research; and
- silicon-32 for oceanographic studies related to climate modeling.

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 Environmental Protection Agency, the Department of Agriculture, the Department of Homeland Security (DHS), NNSA, and DOE Office of Science 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 isotope production research and availability, and to communicate concerns about potential constrained supplies of important isotopes to the federal

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[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.

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 (GARS). 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 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.

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

Research is supported 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. 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. Research into the development of methods to consistently provide high production and recovery yields of astatine-211 for cancer therapy at the University of Washington have also proven successful, and the university site is preparing to start the production of this promising isotope for the Isotope Program. 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.

Starting in FY 2017, NP will provide support for a graduate traineeship activity in radiochemistry and nuclear chemistry with an emphasis in isotope production to assure the ongoing availability of the very specialized workforce necessary to produce radioactive and enriched stable isotopes, including target processing and radionuclide purification using remote handling facilities such as hot-cells, glove-boxes, robotics and other forms of automation. The DOE Isotope Program, as well as other fields in the physical sciences, depend heavily on highly trained people in the disciplines of radiochemistry and nuclear chemistry to support its mission. Several recent reports have pointed to a shortage of production expertise and trained personnel in these disciplines. This new initiative is planned for $1,000,000 per year for 5 years, and will support 10-20 students per year.

Operations

The Isotope Program is 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 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 DOE Isotope Program has invested R&D funds since 2009 to develop stable isotope separation technology at ORNL, a high priority identified by the NSAC Subcommittee on Isotopes in 2009. The R&D effort is on track for completion in FY 2016, which will result in a prototype capability to produce small research quantities of enriched stable isotopes starting in FY 2017. The prototype demonstration has been established in a location that is capable of expansion and the resulting capability developed is completely scalable to produce kg quantities of enriched stable isotopes in a cost-effective manner. The FY 2017 Request includes funding to initiate 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. Examples of discovery research efforts which could benefit from the requested facility are neutrinoless double beta decay experiments in nuclear physics and dark matter experiments in high-energy physics that are interested in kg 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, environmental, 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 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
Isotope Development and Production for Research and Applications $21,337,000	**$29,370,000**	**+$8,033,000**
Research $6,033,000	**$10,344,000**	**+$4,311,000**
Funding continues support for competitive R&D awards to universities and laboratories, as well as for support to laboratory research groups at LANL, BNL, and ORNL. Development of production techniques for alpha-emitting radionuclides for medical therapy continues to be a priority, and is being 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 is also leading to new isotope production technologies and effectively engaging and training students and post-docs in nuclear chemistry and radiochemistry.	Funding will continue support for competitive R&D activities at universities and laboratories. Priorities for the development of production routes for isotopes in short supply will continue to be guided by the NSAC reports and federal input regarding what isotopes are needed to accomplish federal missions in research and homeland security. Development of production techniques for alpha-emitting radionuclides for medical therapy will continue to be a priority. Research at universities and national laboratories will also continue, leading to new isotope production technologies and effectively engaging and training students and post-docs in nuclear chemistry and radiochemistry. A new graduate traineeship activity in radiochemistry and nuclear chemistry with an emphasis in isotope production will be initiated in FY 2017.	Consistent with recommendations of the July 2015 NSAC report, support is increased in FY 2017 to enable innovative approaches to produce and process critical isotopes for the Nation, including R&D into the production of the high priority alpha-emitters for clinical trials; such isotopes could revolutionize cancer therapy by effectively treating cancers that have already metastasized. Another focus is R&D on developing domestic production capabilities for important isotopes for which the U.S. is dependent on foreign sources. The request also supports a traineeship for between 10 and 20 graduate students per year in radiochemistry and nuclear chemistry, nurturing a critical expertise needed for isotope production, and with benefits to many fields in physics and chemistry in general.

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
Operations $15,304,000	**$19,026,000**	**+$3,722,000**
Support provides for infrastructure and maintenance of facilities, core competencies in isotope production and development, and for the NIDC. The maintenance of aging facilities continues to be a funding priority to maintain isotope production capabilities. Funding for program investments and production of particular isotopes is 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.	Support will provide for infrastructure and maintenance of facilities, core competencies in isotope production and development, and for the NIDC. The maintenance of aging facilities continues to be a funding priority to maintain isotope production capabilities. Funding for program investments and production of particular isotopes will be informed by the recently released Nuclear Science Advisory Committee's updated long-range plan for the Isotope Program and by information obtained from the Isotope Program's annual Federal workshops. Operations support for the prototype capability to produce small research quantities of enriched stable isotopes will be initiated, and funding is requested for an MIE for a stable isotope capability.	Funding is requested to initiate the Stable Isotope Production Facility (SIPF) MIE to provide a domestic capability for the production of stable enriched isotopes for research and applications. Building upon R&D supported by the Isotope Program which established technical feasibility of a cost-effective approach for re-establishing this capability in the U.S., this MIE will enable replenishment of the U.S. stable isotope inventory which has been depleted for several key isotopes, and help mitigate U.S. dependence on foreign supplies of stable isotopes. Stable isotopic nuclides of heavier elements are used for agricultural, nutritional, industrial, environmental, ecological and computing applications. Increased funding is also requested to initiate operations of the prototype stable isotope capability and to maintain mission readiness of all isotope program facilities.

Nuclear Physics
Construction

Description

Funding in this subprogram provides for design and construction of scientific research facilities needed to meet overall objectives of the Nuclear Physics program. Currently NP has two ongoing projects, for which only one will be receiving construction line item funding in FY 2017.

The 12 GeV CEBAF Upgrade at TJNAF, which was identified in the 2007 NSAC Long-Range Plan as the highest priority for the U.S. Nuclear Physics program, will enable scientists to address one of the mysteries of modern physics—the mechanism of quark confinement. FY 2016 was the last year of construction funding for the project and FY 2017 will support the final year of commissioning. Completion is planned by September 2017.

Construction of the Facility for Rare Isotope Beams (FRIB) at Michigan State University (MSU) continues according to baselined project plans. 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 1,300 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 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
Construction $107,500,000	**$100,000,000**	**-$7,500,000**
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 support procurements, fabrication, installation, and commissioning of the experimental equipment primarily in Halls B and C; and address continuing project risks in order to optimize the successful completion of this project within the current TEC baseline. FY 2016 is the final year of TEC funding for the project as it works towards completion (CD-4B) by the end of FY 2017.	FY 2016 was the final year of TEC funding. Project completion (CD-4B) is planned by the end of FY 2017.	The decrease reflects the last year of construction line item funding in FY 2016.
14-SC-50, Facility for Rare Isotope Beams (FRIB) $100,000,000	**$100,000,000**	**$0**
Work on conventional facilities continues as well as construction of items such as the linear accelerator (linac) tunnel and the target, linac support, and cryoplant areas. The technical systems are fully underway including efforts such as major procurements, fabrication, and assembly for technical components such as the linac, cryomodules, and experimental systems.	FY 2017 funding will support the completion of some key conventional construction such as the target high bay, linac support area, and the cryoplant area. It also will enable the start of work on the cryogenics plant and distribution system which are on the project's critical path. The major procurements, fabrication, and assembly efforts will continue on the technical systems such as the linac front end, cryomodules, and experimental systems.	FY 2017 funding is the same as FY 2016, consistent with the baselined project profile; these are the peak years of funding for FRIB.

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. The following table shows the targets for FY 2015 through 2017. Details on the Annual Performance Report can be found at http://energy.gov/cfo/reports/annual-performance-reports.

	FY 2015	FY 2016	FY 2017
Performance Goal (Measure)	**NP Facility Operations—Average achieved operation time of NP user facilities as a percentage of total scheduled annual operation time.**		
Target	≥ 80%	≥ 80%	≥ 80%
Result	Met	TBD	TBD
Endpoint Target	Many of the research projects that are undertaken at the Office of Science's scientific user facilities take a great deal of time, money, and effort to prepare, and regularly have a very short window of opportunity to run. If the facility is not operating as expected the experiment could be ruined or critically setback. In addition, taxpayers have invested millions or even hundreds of millions of dollars in these facilities. The greater the period of reliable operations, the greater the return on the taxpayers' investment.		
Performance Goal (Measure)	**NP 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)	**Conduct fundamental research to discover, explore, and understand all forms of nuclear matter.**		
Target	Measure bulk properties, particle spectra, correlations and fluctuations in gold + gold collisions at Relativistic Heavy Ion Collider (RHIC) to search for evidence of a critical point in the Quantum Chromodynamics (QCD) matter phase diagram.	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.
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. Measure fundamental properties of neutrinos to improve our current understanding of the interactions of elementary particles.		

Nuclear Physics
Capital Summary ($K)

	Total	Prior Years	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
Capital Operating Expenses Summary							
Capital equipment	n/a	n/a	14,750	5,993	15,452	18,264	+2,812
General plant projects (GPP)	n/a	n/a	2,000	2,000	2,000	2,000	0
Accelerator improvement projects (AIP)	n/a	n/a	4,249	3,649	4,377	4,472	+95
Total, Capital Operating Expenses	**n/a**	**n/a**	**20,999**	**11,642**	**21,829**	**24,736**	**+2,907**
Capital Equipment							
Gamma-Ray Energy Tracking Array (GRETA) MIE[a]	52,000-67,000	n/a	0	0	0	500	+500
Stable Isotope Production Facility (SIPF) MIE[b]	9,500 -10,500	n/a	0	0	0	2,500	+2,500
Total Non-MIE Capital Equipment	n/a	n/a	14,750	5,993	15,452	15,264	-188
Total, Capital Equipment	**n/a**	**n/a**	**14,750**	**5,993**	**15,452**	**18,264**	**+2,812**
General Plant Projects							
General plant projects under $5 million TEC	n/a	n/a	2,000	2,000	2,000	2,000	0
Accelerator Improvement Projects (AIP)							
RHIC Low Energy Electron Cooling	8,300	2,800	2,300	2,300	1,869	1,331	-538
Other projects under $5 million TEC	n/a	n/a	1,949	1,349	2,508	3,141	+633
Total, Accelerator Improvement Projects	**n/a**	**n/a**	**4,249**	**3,649**	**4,377**	**4,472**	**+95**
General Plant Projects							
General plant projects under $5 million TEC			2,000	2,000	2,000	2,000	0
Accelerator Improvement Projects (AIP)							
Other projects under $5 million TEC			4,522	4,573	4,625	4,678	0
Total, Accelerator Improvement Projects			**4,522**	**4,573**	**4,625**	**4,678**	**0**

[a] This project is not yet baselined. This project received CD-0 in September, 2015 with a cost range of $52,000,000 to $67,000,000.
[b] This project is not yet baselined. This project received CD-0 in September, 2015 with a cost range of $9,500,000 to $10,500,000.

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. Particularly, 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 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 2017 Request for GRETA of $500,000 is the first year of Total Estimated Cost (TEC) funding.

Isotope Development and Production for Research and Applications

The *Stable Isotope Production Facility (SIPF).* The DOE Isotope Program has invested R&D funds since 2009 to develop stable isotope separation technology at ORNL, a high priority identified by the NSAC Subcommittee on Isotopes in 2009. The R&D effort is on track for completion in FY 2016, which will result in a prototype capability to produce small research quantities of enriched stable isotopes starting in FY 2017. The capability has been established in a location which is capable of expansion; the capability is completely scalable to produce kg 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, environmental, ecological and computing applications could also be produced. Funding is requested in FY 2017 for 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. Funding would provide the needed infrastructure and services, optimize the design of small centrifuges to isotopes of interest, and purchase multiple units of the electromagnetic separators and small gas centrifuge cascades. CD-0 was approved September 2015 with an estimated Total Project Cost of $9,500,000–$10,500,000. CD-1 is planned for FY 2017. The FY 2017 Request for SIPF of $2,500,000 is the first year of TEC funding.

Nuclear Physics
Construction Projects Summary ($K)

	Total	Prior Years	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
06-SC-01, 12 GeV CEBAF Upgrade, TJNAF							
TEC	310,500	286,500	16,500	16,500	7,500	0	-7,500
OPC	27,500	17,500	4,500	4,500	4,500	1,000	-3,500
TPC	338,000	304,000	21,000	21,000	12,000	1,000	-11,000
14-SC-50, Facility for Rare Isotope Beams							
DOE TPC	635,500[a]	128,000[b]	90,000	90,000	100,000	100,000	0
Total, Construction (TPC) All Construction Projects	**n/a**	**n/a**	**111,000**	**111,000**	**112,000**	**101,000**	**-11,000**

Funding Summary ($K)

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
Research	165,828	167,195	176,815	187,151	+10,336
Scientific User Facilities Operations	280,663	280,873	288,957	303,038	+14,081
Other Facility Operations	24,313	24,313	24,507	22,826	-1,681
Projects					
Major Items of Equipment	0	0	0	3,000	+3,000
Facility for Rare Isotope Beams	90,000	90,000	100,000	100,000	0
12 GeV Upgrade TEC	16,500	16,500	7,500	0	-7,500
Total Projects	106,500	106,500	107,500	103,000	-4,500
Other[c]	18,196	1,863	19,321	19,643	+322
Total Nuclear Physics	**595,500**	**580,744**	**617,100**	**635,658**	**+18,558**

[a] This is the DOE TPC; MSU's cost share is $94,500,000 bringing the total project cost to $730,000,000. FRIB is funded with operating dollars through a Cooperative Agreement financial assistance award with a work breakdown structure (WBS) that is slightly different from typical federal capital assets. The WBS totals $730,000,000 including MSU's cost share. Because the WBS scope is not pre-assigned to DOE or MSU funds, DOE's baseline of $635,500,000 cannot be broken down between TEC and OPC.

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

[c] Includes SBIR/STTR funding in FY 2015 Enacted and FY 2016–FY 2017.

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 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
TYPE A FACILITIES					
CEBAF (TJNAF)[a]	**$108,694**	**$109,512**	**$110,090**	**$114,365**	**+$4,275**
Number of Users	1,235	1,380	1,380	1,380	0
Achieved operating hours	0	0	N/A	N/A	N/A
Planned operating hours	0	0	0	2,890	+2,890
Optimal hours	0	0	0	3,330	+3,330
Percent optimal hours	N/A	N/A	N/A	86.8%	+86.8%
Unscheduled downtime hours	N/A	N/A	N/A	N/A	N/A

[a] During FY 2015–2016, there are no research hours to which the CEBAF facility will be held accountable while the 12 GeV upgrade is commissioned and reliability is low. In FY 2015, approximately 18 weeks and in FY 2016, approximately 16 weeks of machine development are supported. The user community remained active during the shutdown with instrumentation and equipment implementation for the upgraded facility so they continue to be shown in these years. 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 preops, that are part of the project TPC.

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
TYPE A FACILITIES					
RHIC (BNL)	**$172,579**	**$172,522**	**$179,152**	**$186,764**	**+$7,612**
Number of Users	1,200	1,200	1,200	1,200	0
Achieved operating hours[a]	3,389	3,389	N/A	N/A	N/A
Planned operating hours	2,770	2,770	2,490	3,040	+550
Optimal hours	4,100	4,100	4,100	4,100	0
Percent optimal hours	82.7%	82.7%	60.7%	74.1%	+13.4%
Unscheduled downtime hours	0	0	N/A	NA	NA
ATLAS (ANL)[b]	**$21,892**	**$21,892**	**$22,390**	**$23,390**	**+$1,000**
Number of Users	400	420	420	420	0
Achieved operating hours[c]	6,686	6,686	N/A	NA	N/A
Planned operating hours	5,900	5,900	5,900	5,900	0
Optimal hours	6,200	6,200	6,200	6,600	+400
Percent optimal hours	107.8%	107.8%	95.2%	89.4%	-5.8%
Unscheduled downtime hours	0	0	N/A	NA	NA
Total Scientific User Facility Operations	**$302,926**	**$303,926**	**$311,632**	**$324,519**	**+$12,887**
Number of Users	3,000	3,000	3,000	3,000	0
Achieved operating hours	10,075	10,075	N/A	N/A	N/A
Planned operating hours	8,670	8,670	8,390	11,830	+3,440
Optimal hours	10,300	10,300	10,300	14,030	+3,730
Percent of optimal hours[d]	85.5%	85.5%	64.6%	79.7%	+15.1%
Unscheduled downtime hours	0	0	N/A	N/A	NA

[a] While the length of the RHIC run was just slightly longer than planned (22.4 weeks vs. 22 weeks planned), RHIC was able to achieve 122% of the planned operating hours in FY 2015 as a result of outstanding performance and record reliability of the machine (87.5% vs. 82.5% planned). The high machine reliability, excellent performance of machine upgrades and of both detectors, and a very effective ramp-up of the luminosity allowed RHIC to exceed the luminosity goals for the two scheduled modes in FY 2015, p+p and p+Au.

[b] The optimal hours at ATLAS in FY 2015–2017 vary due to planned downtime for installation of upgrades.

[c] ATLAS was able to achieve 113% of the planned operating hours in FY 2015 as a result of postponing planned maintenance and installation of equipment in order to maximize the time and benefits of the reaccelerated CARIBU beam campaign with GRETINA.

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

Scientific Employment

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Estimate	FY 2017 vs. FY 2016
Number of permanent Ph.D.'s (FTEs)	844	844	820	825	+5
Number of postdoctoral associates (FTEs)	344	344	330	330	0
Number of graduate students (FTEs)	522	522	510	530	+20
Other[a]	1,050	1,050	1,035	1,035	0

[a] 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 2016 PDS and does not include a new start for FY 2017. There are no significant changes.

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 scope, cost, and schedule since the establishment of the project's baseline.

FRIB is funded through a cooperative agreement financial assistance award with MSU per 10 CFR 600, and the project is required by this agreement to follow the principles of the DOE Order 413.3B. Funding tables contained in sections 3, 5, and 6 of this PDS differ slightly in how the baseline is presented from a traditional PDS for a federal capital asset construction project in that they include the MSU cost share. The table in section 7, Schedule of Appropriation Requests, displays only DOE funding.

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

2. Critical Milestone History

(fiscal quarter or date)

	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3A	CD-3B	D&D Complete	CD-4
FY 2011	2/9/2004		4Q FY 2010	TBD	TBD	TBD	TBD	N/A	FY 2017–2019
FY 2012	2/9/2004		9/1/2010	4Q FY 2012	TBD	TBD	TBD	N/A	FY 2018–2020
FY 2013	2/9/2004		9/1/2010	TBD	TBD	TBD	TBD	N/A	TBD
FY 2014	2/9/2004		9/1/2010	3Q FY 2013	TBD	3Q FY 2013	TBD	N/A	TBD
FY 2015	2/9/2004		9/1/2010	8/1/2013	4Q FY 2014	8/1/2013	4Q FY 2014	N/A	3Q FY 2022
FY 2016	2/9/2004	9/1/2010	9/1/2010	8/1/2013	8/26/2014[a]	8/1/2013	8/26/2014	N/A	3Q FY 2022
FY 2017	2/9/2004	9/1/2010	9/1/2010	8/1/2013	8/26/2014[a]	8/1/2013	8/26/2014	N/A	3Q FY 2022

[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.

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

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.

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	113,000
FY 2017	100,000	100,000	102,000
FY 2018	97,200	97,200	98,200
FY 2019	75,000	75,000	76,000

[a] The funding profile represents DOE's portion of the baselined TPC to be provided through federal appropriations.

[b] Costs through FY 2015 reflect actual costs; costs for FY 2016 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	40,000	40,000	41,000
FY 2021	5,300	5,300	6,300
FY 2022	0	0	2,769
Total, DOE TPC	635,500	635,500	635,500

6. Details of Project Cost Estimate[a]

	(dollars in thousands)		
	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Design & Construction			
Management and Support	40,817	41,340	35,400
Conventional Facilities	191,302	165,720	165,300
Accelerator Systems	258,465	244,837	241,400
Experimental Systems	58,259	54,916	55,000
Contingency (DOE Held)	106,907	148,937	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	34,995	34,995	35,500
Contingency (DOE Held)	14,615	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)	121,522	163,552	172,800

7. Schedule of Appropriation Requests[b]

(dollars in thousands)

		Prior Years	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	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	51,000	22,000	TBD	TBD	TBD	TBD	TBD	TBD	TBD
FY 2014	TPC	51,000	22,000	55,000	TBD	TBD	TBD	TBD	TBD	TBD
FY 2015 PB[c]	TPC	51,000	22,000	55,000	90,000	100,000	100,000	97,200	120,300	635,500
FY 2016	TPC	51,000	22,000	55,000	90,000	100,000	100,000	97,200	120,300	635,500
FY 2017	TPC	51,000	22,000	55,000	90,000	100,000	100,000	97,200	120,300	635,500

[a] This section shows a breakdown of the total project cost of $730,000,000, which includes MSU's cost share. The scope of work is not pre-assigned to DOE or MSU funds.

[b] The funding profile represents DOE's portion of the baselined TPC to be provided through federal appropriations.

[c] The Performance Baseline was approved August 1, 2013. The first project data sheet submitted for FRIB was in the FY 2015 Congressional Budget Request. It was established as a control point in the FY 2014 appropriation. Funding for the project prior to that time was provided within the Low Energy subprogram.

8. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	3Q FY 2022
Expected Useful Life (number of years)	20
Expected Future Start of D&D of this capital asset	NA[a]

(Related Funding requirements)

(dollars in thousands)

	Annual Costs		Life Cycle Costs	
	Current Total Estimate	Previous Total Estimate	Current Total Estimate	Previous Total Estimate
Operations[b]	90,000	90,000	1,800,000[c]	1,800,000

9. D&D Information

The FRIB project is being constructed at MSU under a cooperative agreement financial assistance award. The one-for-one requirement, which requires the demolition of a square foot of space for every square foot added, is not applicable, since this is not a federal capital acquisition.

10. Acquisition Approach

FRIB project activities will be accomplished following all procurement requirements, which include using fixed-priced competitive contracts with selection based on best value. MSU has contracted for the services of an architect-engineer firm for the design of the conventional facilities. The Driver Linac and Experimental System components will be self-performed by the MSU design staff with assistance from outside vendors and from DOE national laboratories that possess specific areas of unique expertise unavailable from commercial sources. Integration of the conventional facilities with the Driver Linac and Experimental Systems will be accomplished by the MSU FRIB Project Team.

[a] Per the financial assistance award agreement, MSU is responsible for D&D.
[b] Utilities, maintenance, and repair costs are included within the Operations amounts.
[c] The total operations and maintenance (O&M) is estimated at an average annual cost of approximately $90,000,000 (including escalation) over 20 years.

06-SC-01, 12 GeV CEBAF Upgrade
Thomas Jefferson National Accelerator Facility, Newport News, Virginia
Project is for Design and Construction

1. Significant Changes and Summary

Significant Changes

This Construction Project Data Sheet (CPDS) does not include a new start for the budget year; it is an update of the FY 2015 PDS.

Summary

The most recent DOE O 413.3B approved Critical Decision (CD) is CD-4A, Approve Accelerator Project Completion and Start of Operations, which was signed on July 30, 2014 following completion and confirmation of the project achieving the CD-4A Key Performance Parameters.

The FY 2016 TEC funding will allow the completion of the planned procurements, assemblies, and installations of the experimental equipment (i.e., detectors) primarily in Halls B and C, prior to their commissioning. In addition, a recent DOE/SC Office of Project Assessment review recognized that this final year of TEC funds will be required to address the continuing high project risks in order to successfully complete this project within the current TEC baseline.

In 2014, the Federal Project Director (FPD) certification level required for the 12 GeV was lowered to Level 2. Therefore, the FPD is certified at the appropriate level for this project.

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-4A	CD-4B
FY 2007	3/31/2004		1Q FY 2007	4Q FY 2007	4Q FY 2009	4Q FY 2008	N/A	N/A	1Q FY 2014
FY 2008	3/31/2004		2/14/2006[a]	4Q FY 2007	4Q FY 2009	4Q FY 2008	N/A	N/A	1Q FY 2015
FY 2009	3/31/2004		2/14/2006	11/9/2007	4Q FY 2009	4Q FY 2008	N/A	N/A	3Q FY 2015
FY 2010	3/31/2004		2/14/2006	11/9/2007	4Q FY 2009	9/15/2008	N/A	1Q FY 2015	3Q FY 2015
FY 2011	3/31/2004		2/14/2006	11/9/2007	1Q FY 2010	9/15/2008	N/A	1Q FY 2015	3Q FY 2015
FY 2012	3/31/2004		2/14/2006	11/9/2007	12/31/2009	9/15/2008	N/A	1Q FY 2015	3Q FY 2015
FY 2013	3/31/2004		2/14/2006	11/9/2007	12/31/2009	9/15/2008	N/A	1Q FY 2015	3Q FY 2015

[a] CD-1 was approved on 2/14/2006. Engineering and design activities started in 4Q FY 2006 after Congress approved the Department of Energy's request to reprogram $500,000 within the FY 2006 funding for Nuclear Physics, per direction contained in H.Rpt. 109–275.

(fiscal quarter or date)

	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4A	CD-4B
FY 2014	3/31/2004		2/14/2006	11/9/2007	12/31/2009	9/15/2008	N/A	1Q FY 2015	3Q FY 2015
FY 2015	3/31/2004		2/14/2006	11/9/2007	12/31/2009	9/15/2008	N/A	1Q FY 2015	4Q FY 2017
FY 2016	3/31/2004	2/14/2006	2/14/2006	11/9/2007	12/31/2009	9/15/2008	N/A	7/30/2014	4Q FY 2017

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-4A – Approve Accelerator Project Completion and Start of Operations
CD-4B – Approve Experimental Equipment Project Completion and Start of Operations
D&D– Demolition & Decontamination

3. Project Cost History

(dollars in thousands)

	TEC, Design	TEC, Construction	TEC, Total	OPC Except D&D	OPC, D&D	OPC, Total	TPC
FY 2007	21,000	TBD	TBD	11,000	TBD	TBD	TBD
FY 2008	21,000	TBD	TBD	10,500	TBD	TBD	TBD
FY 2009 PB	21,000	266,500	287,500	22,500	N/A	22,500	310,000
FY 2010	21,000	266,500	287,500	22,500	N/A	22,500	310,000
FY 2011	21,000	266,500	287,500	22,500	N/A	22,500	310,000
FY 2012	21,000	266,500	287,500	22,500	N/A	22,500	310,000
FY 2013	21,000	266,500	287,500	22,500	N/A	22,500	310,000
FY 2014	21,000	266,500	287,500	22,500	N/A	22,500	310,000
FY 2015[a]	21,000	289,500	310,500	27,500	N/A	27,500	338,000
FY 2016	21,000	289,500	310,500	27,500	N/A	27,500	338,000

4. Project Scope and Justification

Scope

The 12 GeV CEBAF Upgrade directly supports the Nuclear Physics mission and addresses the objective to measure properties of the proton, neutron, and simple nuclei for comparison with theoretical calculations to provide an improved quantitative understanding of their quark substructure.

[a] The amounts reflect the revised baseline approved in September 2013. A Work-for-Others agreement was approved by DOE that provides $9,000,000 appropriated by the Commonwealth of Virginia to leverage the federal investment for an upgrade of the Jefferson Lab's research facilities. This funding is outside the DOE baseline cost and schedule.

The scope of the project includes upgrading the electron energy capability of the main accelerator from 6 GeV to 12 GeV, building a new experimental hall (Hall D: 11,110 sf) and associated counting house (3,601 sf) and beam-line, and enhancing the capabilities of the existing experimental halls to support the most compelling nuclear physics research.

CD-4A Key Performance Parameters

Subsystem	Technical Definition of Completion
Accelerator	12 GeV capable 5.5 pass machine installed
	11 GeV capable beam line to existing Halls A, B, and C installed
	12 GeV capable beam line to new Hall D tagger area installed
	Accelerator commissioned by transporting a ≥ 2 nA electron beam at 2.2 GeV (1pass)
Conventional Facilities	New Experimental Hall D and the Counting House: ≥ 10,500 square feet.

CD-4B Key Performance Parameters

Subsystem	Technical Definition of Completion
Hall B	Detector operational: events recorded with a ≥ 2 nA electron beam at > 6 GeV beam energy (3 pass)
Hall C	Detector operational: events recorded with a ≥ 2 nA electron beam at > 6 GeV beam energy (3 pass)
Hall D	Detector operational: events recorded with a ≥ 2 nA electron beam at > 10 GeV beam energy (5.5 pass)

Key Performance Parameters to achieve CD-4 are phased between the accelerator and conventional facilities (CD-4A) and the experimental equipment in Halls B, C, and D (CD-4B). The deliverables defining completion are identified in the Project Execution Plan and have not changed since CD-2. Mitigation plans exist for identified risks to help ensure successful project completion after approval of a baseline change proposal due to the directed change and technical challenges.

The project is being conducted in accordance with the project management requirements in DOE O 413.3B, *Program and Project Management for the Acquisition of Capital Assets*, and all appropriate project management requirements have been met.

Justification

The Continuous Electron Beam Accelerator Facility (CEBAF) at the Thomas Jefferson National Accelerator Facility is the world-leading facility for the experimental study of the structure of matter governed by the “strong force.” The energy upgrade of CEBAF, first identified by the nuclear science community as a compelling scientific opportunity in the 2007 Long Range Plan for Nuclear Science, was reaffirmed as a high priority in the 2013 Report by the Nuclear Sciences Advisory Committee (NSAC) on Major Nuclear Physics Facilities for the next decade, which stated that the 12 GeV upgrade of CEBAF was “absolutely central” in terms of its ability to contribute to world-leading science in the next decade. In the 2007 Long Range Plan, NSAC concluded that completion of the 12 GeV CEBAF Upgrade project was the highest priority for the Nation’s nuclear science program.

5. Financial Schedule

(dollars in thousands)

	Appropriations	Obligations	Recovery Act Costs	Costs
Total Estimated Cost (TEC)				
Design				

(dollars in thousands)

	Appropriations	Obligations	Recovery Act Costs	Costs
FY 2006	500	500	0	88
FY 2007	7,000	7,000	0	6,162
FY 2008	13,377[a]	13,377	0	9,108
FY 2009	123[a]	123	0	5,370
FY 2010	0	0	0	265
FY 2011	0	0	0	7
Total, Design	21,000	21,000	0	21,000
Construction				
FY 2009	28,500	28,500	0	5,249
FY 2009 Recovery Act	65,000	65,000	2,738	0
FY 2010	20,000	20,000	29,621	18,642
FY 2011[b]	35,928	35,928	25,890	40,801
FY 2012	50,000	50,000	5,203	45,537
FY 2013	40,572	40,572	1,545	51,211
FY 2014	25,500	25,500	3	29,755
FY 2015	16,500	16,500	0	21,000
FY 2016	7,500	7,500	0	11,500
FY 2017	0	0	0	805
Total, Construction	289,500	289,500	65,000	224,500
TEC				
FY 2006	500	500	0	88
FY 2007	7,000	7,000	0	6,162
FY 2008	13,377	13,377	0	9,108
FY 2009	28,623	28,623	0	10,619
FY 2009 Recovery Act	65,000	65,000	2,738	0
FY 2010	20,000	20,000	29,621	18,907
FY 2011	35,928	35,928	25,890	40,808
FY 2012	50,000	50,000	5,203	45,537
FY 2013	40,572	40,572	1,545	51,211
FY 2014	25,500	25,500	3	29,755
FY 2015	16,500	16,500	0	21,000
FY 2016	7,500	7,500	0	11,500
FY 2017	0	0	0	805
Total, TEC	310,500	310,500	65,000	245,500

[a] The baseline FY 2008 PED funding was reduced by $123,000 as a result of a FY 2008 rescission. This reduction was restored in FY 2009 to maintain the TEC and project scope.
[b] The baseline FY 2011 funding was reduced by $72,000 as a result of a FY 2011 rescission.

(dollars in thousands)

	Appropriations	Obligations	Recovery Act Costs	Costs
Other Project Cost (OPC)				
OPC except D&D				
FY 2004	700	700	0	77
FY 2005	2,300	2,300	0	2,142
FY 2006	4,000	4,000	0	3,508
FY 2007	2,500	2,500	0	2,751
FY 2008	1,000	1,000	0	1,802
FY 2009	0	0	0	155
FY 2010	0	0	0	62
FY 2013	2,500	2,500	0	2,178
FY 2014	4,500	4,500	0	3,795
FY 2015	4,500	4,500	0	4,500
FY 2016	4,500	4,500	0	5,000
FY 2017	1,000	1,000	0	1,530
Total, OPC	27,500	27,500	0	27,500
Total Project Cost				
FY 2004	700	700	0	77
FY 2005	2,300	2,300	0	2,142
FY 2006	4,500	4,500	0	3,596
FY 2007	9,500	9,500	0	8,913
FY 2008	14,377	14,377	0	10,910
FY 2009	28,623	28,623	0	10,774
FY 2009 Recovery Act	65,000	65,000	2,738	0
FY 2010	20,000	20,000	29,621	18,969
FY 2011	35,928	35,928	25,890	40,808
FY 2012	50,000	50,000	5,203	45,537
FY 2013	43,072	43,072	1,545	53,389
FY 2014	30,000	30,000	3	33,550
FY 2015	21,000	21,000	0	25,500
FY 2016	12,000	12,000	0	16,500
FY 2017	1,000	1,000	0	2,335
Total, TPC[a]	338,000	338,000	65,000	273,000

[a] The TPC reflects the revised baseline approved in September 2013.

6. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Estimate
Total Estimated Cost (TEC)			
Design			
Design	21,000	21,000	19,200
Contingency	0	0	1,800
Total, Design	21,000	21,000	21,000
Construction Phase			
Construction	30,295	30,347	27,450
Accelerator/Experimental Equipment/ Management	250,793	243,937	174,150
Contingency	8,412	15,216	64,900
Total, Construction	289,500	289,500	266,500
Total, TEC	310,500	310,500	287,500
Contingency, TEC	8,412	15,216	66,700
Other Project Cost (OPC)			
OPC except D&D			
Conceptual Design	3,445	3,445	3,500
R&D	7,052	7,052	6,400
Start-up	11,966	12,618	7,450
Contingency	5,037	4,385	5,150
Total, OPC	27,500	27,500	22,500
Contingency, OPC	5,037	4,385	5,150
Total, TPC	338,000	338,000[a]	310,000
Total, Contingency	13,449	19,601	71,850

7. Schedule of Appropriation Requests

(dollars in thousands)

		Prior Years	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	Total
FY 2007 (Design only)	TEC	21,000	0	0	0	0	0	0	0	0	21,000
	OPC	11,000	0	0	0	0	0	0	0	0	11,000
	TPC	32,000	0	0	0	0	0	0	0	0	32,000
FY 2008 (Design only)	TEC	21,000	0	0	0	0	0	0	0	0	21,000
	OPC	10,500	0	0	0	0	0	0	0	0	10,500
	TPC	31,500	0	0	0	0	0	0	0	0	31,500

[a] The TPC reflects the revised baseline approved in September 2013.

(dollars in thousands)

		Prior Years	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	Total
FY 2009[a] PB	TEC	49,500	59,000	62,000	66,000	40,500	10,500	0	0	0	287,500
	OPC	10,500	0	0	0	2,500	7,500	2,000	0	0	22,500
	TPC	60,000	59,000	62,000	66,000	43,000	18,000	2,000	0	0	310,000
FY 2010[b]	TEC	114,500	22,000	34,000	66,000	40,500	10,500	0	0	0	287,500
	OPC	10,500	0	0	0	2,500	7,500	2,000	0	0	22,500
	TPC	125,000	22,000	34,000	66,000	43,000	18,000	2,000	0	0	310,000
FY 2011	TEC	114,500	20,000	36,000	66,000	40,500	10,500	0	0	0	287,500
	OPC	10,500	0	0	0	2,500	7,500	2,000	0	0	22,500
	TPC	125,000	20,000	36,000	66,000	43,000	18,000	2,000	0	0	310,000
FY 2012	TEC	114,500	20,000	36,000	66,000	40,500	10,500	0	0	0	287,500
	OPC	10,500	0	0	0	2,500	7,500	2,000	0	0	22,500
	TPC	125,000	20,000	36,000	66,000	43,000	18,000	2,000	0	0	310,000
FY 2013	TEC	114,500	20,000	35,928[c]	50,000	40,572	26,500	0	0	0	287,500
	OPC	10,500	0	0	0	2,500	7,500	2,000	0	0	22,500
	TPC	125,000	20,000	35,928	50,000	43,072	34,000	2,000	0	0	310,000
FY 2014	TEC	114,500	20,000	35,928	50,000	50,306	25,500	1,000	0	0	287,500
	OPC	10,500	0	0	0	0	4,500	5,000	0	0	22,500
	TPC[d]	125,000	20,000	35,928	50,000	50,306[e]	30,000	6,000	0	0	310,000
FY 2015	TEC	114,500	20,000	35,928	50,000	40,572	25,500	16,500	7,500	0	310,500
	OPC	10,500	0	0	0	2,500	4,500	4,500	4,500	1,000	27,500
	TPC[f]	125,000	20,000	35,928	50,000	43,072	30,000	21,000	12,000	1,000	338,000
FY 2016	TEC	114,500	20,000	35,928	50,000	40,572	25,500	16,500	7,500	0	310,500
	OPC	10,500	0	0	0	2,500	4,500	4,500	4,500	1,000	27,500
	TPC	125,000	20,000	35,928	50,000	43,072	30,000	21,000	12,000	1,000	338,000

[a] The FY 2009 Congressional Budget was the first project data sheet to reflect the CD-2 Performance Baseline which was approved in November 2007.

[b] The project received $65,000,000 from the American Recovery and Reinvestment Act of 2009 which advanced a portion of the baselined FY 2010 and FY 2011 planned funding. The FY 2010 and FY 2011 amounts reflect a total of $65,000,000 in reductions to the originally planned baselined funding profile to account for the advanced Recovery Act funding.

[c] The baseline FY 2011 funding was reduced by $72,000 as a result of the FY 2011 rescission.

[d] The TPC did not reflect the estimated impact resulting from the reduced FY 2012 funding, which has since been assessed and a rebaseline was approved in September 2013.

[e] The FY 2013 amount shown reflected the P.L. 112-175 continuing resolution level annualized to a full year. The TEC, TPC, and outyear appropriation assumptions had not been adjusted to reflect the final FY 2013 funding level; the FY 2013 Request level of $40,572,000 for TEC, $2,500,000 for OPC, and $43,072,000 for TPC was assumed.

[f] The TPC reflects the revised baseline approved in September 2013.

8. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy (fiscal quarter or date)	4Q FY 2017
Expected Useful Life (number of years)	15
Expected Future start of D&D for new construction (fiscal quarter)	N/A

(Related Funding Requirements)

(dollars in thousands)

	Annual Costs		Life cycle costs	
	Current Total Estimate	Previous Total Estimate	Current Total Estimate	Previous Total Estimate
Operations	150,000	150,000	2,250,000[a]	2,250,000
Maintenance	Included above	Included above	Included above	Included above
Total, Operations & Maintenance	150,000	150,000	2,250,000	2,250,000

9. D&D Information

The new area being constructed in this project is not replacing existing facilities. The "one-for-one" requirement is met by offsetting 31,500 square feet of the 80,000 square feet of banked space that was granted to Jefferson Laboratory in a Secretarial waiver.

	Square Feet
Area of new construction	31,500
Area of existing facility(ies) being replaced and D&D'd by this project..............	0
Area of other D&D outside the project	0
Area of additional D&D space to meet the "one-for-one" requirement taken from the banked area.	31,500

10. Acquisition Approach

The Acquisition Strategy was approved February 14, 2006, with CD-1 approval. All acquisitions are managed by Jefferson Science Associates with appropriate Department of Energy oversight. Cost, schedule, and technical performance are monitored using an earned-value process that is described in the Jefferson Lab Project Control System Manual and consistent with DOE O 413.3B, Program and Project Management for the Acquisition of Capital Assets. The procurement practice uses firm fixed-price purchase orders and subcontracts for supplies, equipment, and services and makes awards through competitive solicitations. Project and design management, inspection, coordination, tie-ins, testing and checkout witnessing, and acceptance are performed by Jefferson Laboratory and Architectural-Engineering subcontractors as appropriate.

[a] The total operations and maintenance (O&M) is estimated at an average annual cost of approximately $150,000,000 (including escalation) over 15 years. Almost 90% of the O&M cost would still have been required had the existing accelerator not been upgraded and instead continued operations at 6 GeV.

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, graduate thesis research, and visiting faculty programs at the DOE laboratories; the Albert Einstein Distinguished Educator Fellowship for K–12 STEM teachers, administered by WDTS for DOE and for a number of other federal agencies; and annual, nationwide, middle- and high-school science competitions culminating in the National Science Bowl® in Washington, D.C. These investments help develop 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, 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.

Highlights of the FY 2017 Budget Request

The FY 2017 Request maintains support levels of workforce programs conducted at DOE Laboratories. These experience-based STEM learning opportunity programs enable highly qualified applicants to conduct research at the DOE laboratories, in support of the workforce mission.

Description

Activities at the DOE Laboratories

WDTS supports activities such as the Science Undergraduate Laboratory Internships program, the Community College Internships program, the Office of Science (SC) Graduate Student Research Program, and the Visiting Faculty Program. A goal of these programs is to encourage students to enter STEM careers 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 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 term and, beginning in 2016, 16 weeks during a pilot spring term.

The **Office of Science Graduate Student Research (SCGSR)** program goal is to prepare graduate students for STEM careers critically important to the SC mission by providing graduate thesis research opportunities at DOE laboratories. The SCGSR program provides supplemental awards for graduate students to pursue part of their graduate thesis research at a DOE laboratory 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 in collaboration with a DOE laboratory scientist. Research award terms range from three months to one year.

[a] http://www.whitehouse.gov/sites/default/files/microsites/ostp/stem_stratplan_2013.pdf

The **Visiting Faculty Program (VFP)** goal is to increase the research competitiveness of faculty members and students at institutions of higher education historically underrepresented in the research community in order to expand the workforce that addresses DOE mission areas. Through direct collaboration with research staff at DOE host laboratories, VFP appointments provide an opportunity for faculty and their students to develop skills applicable to programs at their home institutions; this helps increase the STEM workforce in DOE science mission areas at institutions historically under-represented within the DOE enterprise. Appointments are in the summer term for 10 weeks.

Albert Einstein Distinguished Educator Fellowship

The Albert Einstein Distinguished Educator Fellowship Act of 1994 charges the Department of Energy (DOE) with administering a fellowship program for elementary and secondary school mathematics and science teachers that focuses on bringing teachers' real-world expertise to government to help inform federal STEM education programs. Selected teachers spend eleven months in a Federal agency or a Congressional office. WDTS manages the Albert Einstein Distinguished Educator Fellowship (AEF) Program for the Federal government. Fellows are supported by DOE and other Federal agencies. Typically, SC supports six Fellows each year; four are placed in Congressional offices and two are placed in SC. Participating agencies have included the National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA), and the National Oceanic and Atmospheric Administration (NOAA), as well as other DOE offices. The Fellows provide educational expertise, years of teaching experience, and personal insights to these offices to advance science, mathematics, and technology education programs.

National Science Bowl®

The DOE National Science Bowl® (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. More than 250,000 students have participated in the National Science Bowl® throughout its 25-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 2015, 5,300 middle school students from 697 schools and 9,000 high school students from 1,314 schools participated in the regional competitions, with 48 middle school and 68 high school teams (565 students) participating in the National Finals in Washington, D.C. All 50 U.S. States, District of Columbia, Puerto Rico, and the U.S. Virgin Islands were represented at regionals. More than 5,000 volunteers also participated in the local and national competitions. In FY 2015, the National Science Bowl® championship finals were 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 the systems. In FY 2014, systems for the Albert Einstein Distinguished Educator Fellowship, the Office of Science Graduate Student Research Program, and National Science Bowl® were developed and launched. In FY 2015, emphasis was placed on administrative tool development and system updates. On the client side, new online tools were launched to guide SULI and CCI applicants when selecting a host lab and to provide application system self-help. On the program side, a streamlined VFP-Faculty review and a selection system was launched in time for the 2016 summer term application cycle, which opened in October 2015. Planned activities for FY 2016 include development of a management portal for the NSB question processes, development of new program evaluation toolsets, and development of alumni portals for tracking of past participants. In FY 2017, these new business management systems will be implemented.

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. Enhanced data analysis efforts initiated in FY 2014 will be completed, enabling the launch of analysis, visualization, and reporting toolsets required to support the determination of impacts and outcomes.

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.

A second triennial external peer review of participating host laboratories in the undergraduate and faculty programs, *viz*., SULI, CCI, and VFP programs is nearly complete. An outcome of the prior program review resulted in the development and system-wide adoption of a set of common Core Requirements that serve as the minimum standard for managing WDTS laboratory programs across the complex. Additionally, a set of Model Practices was developed to help host labs achieve the Core Requirements. Lastly, each host lab was required to develop and adopt an Implementation Plan, thereby establishing a roadmap for achieving the programmatic baseline requirements. This review will assess progress made, determine if an operational baseline has been uniformly achieved, and identify areas requiring improvement or benefiting from the formulation of additional operational elements. Outcomes of this review are expected in early FY 2016.

Evaluation Studies is aligned with the GPRA Modernization Act of 2010, the President's management priorities,[a] and the 2008 Congressionally-mandated Academic Competitiveness Council initiative, which emphasized 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, and the Albert Einstein Distinguished Educator Program. The WDTS website[b] 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 webinar virtual meetings that highlight the programs, their opportunities, and the WDTS internship experience. A portfolio of recorded webinars is available on the WDTS website.

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.

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[a] http://www.whitehouse.gov/administration/eop/ostp/nstc/committees/costem

[b] http://science.energy.gov/wdts/

Workforce Development for Teachers and Scientists
Funding ($K)

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs. FY 2016
Activities at the DOE Laboratories					
Science Undergraduate Laboratory Internships	8,300	8,300	8,300	9,300	+1,000
Community College Internships	1,000	1,000	1,000	1,250	+250
Graduate Student Research Program	2,500	2,500	2,500	2,575	+75
Visiting Faculty Program	1,700	1,700	1,700	1,800	+100
Total, Activities at the DOE Laboratories	**13,500**	**13,500**	**13,500**	**14,925**	**+1,425**
Albert Einstein Distinguished Educator Fellowship	**1,200**	**1,200**	**1,200**	**1,200**	**0**
National Science Bowl®	**2,900**	**2,930**	**2,900**	**3,000**	**+100**
Technology Development and On-Line Application	**750**	**750**	**750**	**675**	**-75**
Evaluation Studies	**600**	**600**	**600**	**600**	**0**
Outreach	**500**	**470**	**500**	**525**	**+25**
Laboratory Equipment Donation Program	**50**	**50**	**50**	**0**	**-50**
Total, Workforce Development for Teachers and Scientists	**19,500**	**19,500**	**19,500**	**20,925**	**+1,425**

Program Accomplishments

Science Undergraduate Laboratory Internships (SULI) - In FY 2015, the total number of participating DOE host laboratories/facilities increased from 16 to 17. This increased participation, largely due to the quality and impact of the program, serves to broaden participant STEM sub-field experience-based training opportunities and enhance their overlap with DOE mission-critical research areas, where in this case, especially addressing fusion energy and plasma sciences.

Community College Internships (CCI) – In FY 2015, a pilot for a spring 2016 semester term increased the portfolio of experiential-based learning opportunity sub-fields to include combustion science and technologies.

Office of Science Graduate Research (SCGSR) – In FY 2015, the SCGSR Program supported 100 supplemental awards to graduate students to conduct their thesis research at 15 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 50 different universities who will conduct graduate research in areas that span the research missions of the six Office of Science program offices.

Visiting Faculty Program (VFP) – A VFP faculty participant from Howard University is now a collaborator on the PHENIX experiment (for Pioneering High Energy Nuclear Interaction experiment) at the Relativistic Heavy Ion Collider (RHIC) user facility (Brookhaven National Laboratory). Howard University is the only HBCU (Historically Black Colleges and Universities) member on the PHENIX collaboration.

The ***National Science Bowl®*** – In FY 2015, the NSB celebrated its 25th annual competition. On Science Day, students heard from a two-time Academy Award winner (Dr. Doug Roble, Digital Domain), as well as from five leading computational scientists at DOE laboratories (Dr. Jacqueline Chen, Distinguished Member of Technical Staff at the Combustion Research Facility, Sandia National Laboratories; Dr. Timothy Germann**,** Director of the DOE "Exascale Co-Design Center for Materials in Extreme Environments," Los Alamos National Laboratory; Dr. Katherine Riley**,** Team Leader, Argonne Leadership Computing Facility; Dr. Kathy Yelick, Associate Laboratory Director for Computing Sciences, Lawrence Berkeley National Laboratory and Professor of Electrical Engineering and Computer Sciences at the University of California, Berkeley; and Robert French, Adam Simpson, Oak Ridge National Laboratory, and Dr. Carolyn Lauzon, Office of Science, demonstrating Tiny Titan), to learn about high-performance computing. To enhance the student's learning opportunities, new virtual experience kiosks were developed and used at the 4H Center, allowing students to self-explore and learn about scientific applications of high-performance computing. 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 championship finals were held for the first time at the Lisner Auditorium at George Washington University, with capabilities used to live stream broadcast the entire event.

Technology Development and On-Line Application – In FY 2015, new application and program tools for the SULI, CCI, and VFP programs were developed and launched, addressing needs of clients as well as administrators.

Workforce Development for Teachers and Scientists

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs FY 2016
Activities at the DOE Laboratories $13,500,000	**$14,925,000**	**$+1,425,000**
Science Undergraduate Laboratory Internships ($8,300,000) SULI supports approximately 820 students, including support for an additional 45 fall and spring semester students.	*Science Undergraduate Laboratory Internships ($9,300,000)* SULI will support approximately 905 students.	*Science Undergraduate Laboratory Internships ($+1,000,000)* Increased funding supports an additional 50 summer and 35 semester term placements.
Community College Internships ($1,000,000) CCI supports approximately 100 students.	*Community College Internships ($1,250,000)* CCI will support approximately 125 students.	*Community College Internships ($+250,000)* Increased funding supports an additional 25 placements.
Graduate Student Research Program ($2,500,000) The SCGSR program supports approximately 100 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 recent workforce training needs study.	*Graduate Student Research Program ($2,575,000)* The SCGSR program will support approximately 102 graduate students for periods of 3 months to 1 year to conduct a part of their thesis research at DOE laboratories. Targeted priority research areas will be informed by SC's workforce training needs studies.	*Graduate Student Research Program ($+75,000)* Increased funding supports additional graduate students conducting their thesis research in priority research areas.
Visiting Faculty Program ($1,700,000) VFP supports approximately 70 faculty and 35 students.	*Visiting Faculty Program ($1,800,000)* VFP will support approximately 70 faculty and 45 students.	*Visiting Faculty Program ($+100,000)* Increased funding supports 10 additional student placements.
Albert Einstein Distinguished Educator Fellowship $1,200,000	**$1,200,000**	**$0**
The FY 2016 request supports 6 Fellows.	The FY 2017 request will support 6 Fellows.	No change.
National Science Bowl® $2,900,000	**$3,000,000**	**$+100,000**
WDTS supports the finals competition and provides central management of 116 regional events, involving 14,500 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.	Increased funding supports development of an inventory of NSB questions, including additional visual bonus questions emphasizing energy science topics relevant to the DOE mission.

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs FY 2016
Technology Development and On-line Application Systems $750,000	**$675,000**	**$-75,000**
Funding supports development and operation of the on-line systems.	Funding will continue development and operation of the on-line systems.	Funding decreases due to efficiencies gained through leveraging prior code development.
Evaluation Studies $600,000	**$600,000**	**$0**
FY 2016 funding continues support for evaluation activities, including data archiving, curation, and analyses.	FY 2017 funding will continue support for evaluation activities, including data archiving, curation, and analyses.	No change.
Outreach $500,000	**$525,000**	**$+25,000**
Funding supports a public web portal to track the inventory of STEM workforce internship and outreach activities and opportunities across the DOE laboratory complex. Funding supports 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 a public web portal to track the inventory of STEM workforce internship and outreach activities and opportunities across the DOE laboratory complex. 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. Funding will also support Laboratory Education Equipment Donation Program (LEDP) activities.	Increased funding supports LEDP activities, which are being consolidated under Outreach; there is a small decrease to other Outreach activities due to be completed in FY 2016.
Laboratory Equipment Donation Program $50,000	**$0**	**$-50,000**
Funding supports the ongoing program.	Funding for this activity is now under Outreach.	Funding for this program is consolidated under Outreach. This consolidation does not alter the scope of this activity.

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 mission-ready infrastructure and fostering safe and environmentally responsible operations. The program provides state-of-the-art facilities and infrastructure that are flexible, reliable, and sustainable in support of scientific discovery. The SLI program also funds Payments in Lieu of Taxes (PILT) to local communities around the Argonne, Brookhaven, and Oak Ridge National Laboratories.

In November 2013, the DOE Secretary chartered[a] the National Laboratory Operations Board (LOB) to assess facilities and general purpose infrastructure across the national laboratory complex, among other things, using common standards and an enterprise-wide approach. These enterprise-wide assessments resulted in a rigorous and consistent analysis of the condition, utilization, and functionality of the facilities and infrastructure that are the most critical to mission accomplishment. Building on these assessments, SC worked with each of its laboratories to develop comprehensive Campus Strategies, 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 used these Campus Strategies to establish the corporate facilities and infrastructure priorities going forward.

Overall, SC invests over $400 million dollars annually in needed maintenance, repair, and upgrades of general purpose infrastructure. These investments are 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. This budget request for SLI reflects the rigor of and output from the broader SC-wide planning activities described above.

Highlights of the FY 2017 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. This request does so by providing funding for three on-going and two new line-item construction projects.

Included in this request is continued funding for the Materials Design Laboratory project at Argonne National Laboratory (ANL), the Photon Science Laboratory Building project at SLAC National Accelerator Laboratory (SLAC), and the Integrative Genomics Building project at Lawrence Berkeley National Laboratory (LBNL). New funding is requested to start the Integrated Engineering Research Center at Fermi National Accelerator Laboratory (FNAL) and the Core Facility Revitalization project at Brookhaven National Laboratory (BNL).

In addition, this request continues to focus on the Secretarial priority of addressing basic needs in core general purpose infrastructure as identified through the enterprise-wise LOB assessments. Funding requested in FY 2017 will enhance and update HVAC systems and controls at LBNL, support electrical distribution upgrades at SLAC, upgrade cryogenics infrastructure at Thomas Jefferson National Accelerator Laboratory (TJNAF), and will replace and upgrade electrical distribution systems at Ames Laboratory (AMES).

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[a] http://fimsinfo.doe.gov/Downloads/Infrastructure_Assessment_Group.pdf

Science Laboratories Infrastructure
Funding ($K)

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
Infrastructure Support	**13,590**	**13,590**	**44,690**	**66,549**	**+21,859**
Construction					
Integrated Engineering Research Center at FNAL (17-SC-71)	0	0	0	2,500	+2,500
Core Facility Revitalization at BNL (17-SC-73)	0	0	0	1,800	+1,800
Infrastructure and Operational Improvements at PPPL (15-SC-75)	25,000	25,000	0	0	–
Materials Design Laboratory at ANL (15-SC-76)	7,000	7,000	23,910	19,590	-4,320
Photon Science Laboratory Building at SLAC (15-SC-77)	10,000	10,000	25,000	20,000	-5,000
Integrative Genomics Building at LBNL (15-SC-78)	12,090	12,090	20,000	19,561	-439
Science and User Support Building at SLAC (12-SC-70)	11,920	11,920	0	0	–
Total, Construction	**66,010**	**66,010**	**68,910**	**63,451**	**-5,459**
Total, Science Laboratories Infrastructure	**79,600**	**79,600**	**113,600**	**130,000**	**+16,400**

Science Laboratories Infrastructure
Explanation of Major Changes ($K)

	FY 2017 vs FY 2016 Enacted
Science Laboratories Infrastructure	
Infrastructure Support: Funding continues to support general facility and infrastructure support at NBL, OSTI and ORISE, as well as landlord responsibilities at the Oak Ridge Reservation. Funding increases to support nuclear facilities at Oak Ridge National Laboratory (ORNL) as well as the Secretarial priority to address basic needs in core general purpose infrastructure by supporting four new GPP projects.	**+21,859**
Construction: Funding supports continuation of three on-going projects and the start of two new projects in FY 2017.	**-5,459**
Total, Science Laboratories Infrastructure	**+16,400**

Program Accomplishments

The SLI program has invested over $700 million in infrastructure and has successfully completed nine line item projects since FY 2006, when SC initiated the effort to modernize infrastructure across the laboratory complex. With these investments, the SLI program has constructed 875,000 gross square feet (gsf) of new space and has modernized 397,000 gsf of existing space. As a result, an estimated 2,230 laboratory users and researchers now occupy newly constructed and/or modernized buildings that better support scientific and technological innovation in a collaborative environment.

The *Research Support Building and Infrastructure Modernization project at SLAC National Accelerator Laboratory (SLAC).* The project was designed to integrate the accelerator science, technology, and support communities across programmatic boundaries in alignment with the Laboratory's multi-program mission. The project provided 132,000 GSF of new and renovated space. The project achieved CD-4, Approve Project Completion, on April 24, 2015.

The *Science and User Support Building project at SLAC National Accelerator Laboratory (SLAC).* Preliminary construction work, including the demolition of an existing cafeteria, commenced in September 2013. Construction of foundations was completed in June 2014 and erection of the steel frame structure began in July 2014. Beneficial Occupancy occurred in September 2015. The project is progressing ahead of schedule and within budget.

The *Utilities Infrastructure Modernization project at Thomas Jefferson National Accelerator Laboratory (TJNAF).* The project will upgrade, expand or replace portions of the cryogenics test facility and the electrical distribution, process cooling, and communications systems. Construction of the first phase began after achieving CD-3A, Approve Start of Construction for Phase A, and concurrently with CD-2, Approve Performance Baseline, on May 21, 2014. Construction of the second phase began upon achieving CD-3B, Approve Start of Construction for Phase B, on June 30, 2014 and the third phase began upon achieving CD-3C, Approve Start of Construction of Phase C, on February 20, 2015. The project is progressing ahead of schedule and within budget. The overall project is over 60 percent complete with all electrical distribution and process cooling work nearly complete.

The *Utilities Upgrade project at Fermi National Accelerator Laboratory (FNAL).* The project will design and construct upgraded Industrial Cooling Water and High Voltage Electrical Systems. The scope includes replacing components at or near end of service life and upgrading the distribution networks with secondary distribution and additional controls. Procurement of long lead items began after achieving CD-3A, Approve Start of Construction for Phase A, and concurrently with CD-2, Approve Performance Baseline, on February 18, 2015. Construction for the remainder of the project began upon achieving CD-3B, Approve Start of Construction for Phase B, on September 3, 2015. The project is proceeding within budget and ahead of schedule.

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 General Plant Project upgrades at various laboratories, general infrastructure support, de-inventory of nuclear material in the New Brunswick Laboratory (NBL) at ANL, and support for the nuclear facilities at Oak Ridge National Laboratory.

This subprogram also funds Payments in Lieu of Taxes (PILT) to local communities around the Argonne, Brookhaven, and Oak Ridge National Laboratories as well as stewardship type needs (e.g., roads and grounds maintenance) across the Oak Ridge Reservation.

Funding ($K)

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
Infrastructure Support					
Facilities and Infrastructure	6,100	6,100	24,800	32,603	+7,803
Nuclear Operations	0	0	12,000	26,000	+14,000
Oak Ridge Landlord	5,777	5,777	6,177	6,182	+5
Payments in Lieu of Taxes	1,713	1,713	1,713	1,764	+51
Total, Infrastructure Support	**13,590**	**13,590**	**44,690**	**66,549**	**+21,859**

<u>Facilities and Infrastructure</u>

The Infrastructure Support subprogram funds infrastructure support investments that focus on laboratory core infrastructure and operations. In support of Secretarial priorities, SC laboratories conducted a rigorous condition assessment of their core infrastructure which validated 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. In support of this activity, plans for FY 2017 funding include projects such as enhancing the HVAC system by adding more cooling capacity for approximately 130,000 square feet of space and updating control systems. At SLAC, multiple Klystron Gallery electrical items will be replaced and other electrical distribution components throughout the site will be upgraded. At TJNAF, cryogenic infrastructure will be upgraded to ensure reliability and capacity for future mission needs. Lastly, the electrical distribution system in the Metals Development Building at AMES will be replaced and upgraded and the capacity of the electrical distribution system in Wilhelm Hall will be enhanced.

This subprogram also supports general facilities and infrastructure support at the Office of Scientific and Technical Information (OSTI) and the Oak Ridge Institute for Science and Education (ORISE), as well as de-inventory, removal, and transfer of nuclear material in the NBL on the site of ANL.

<u>Nuclear Operations</u>

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 Payments in Lieu of Taxes (PILT). The Department is authorized to provide discretionary payments to state and local government authorities for real property that is not subject to taxation because it is owned by the United States and operated by the Department. Under this authorization, PILT is provided to communities around the Argonne and Brookhaven National Laboratories 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.

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs FY 2016
Infrastructure Support $44,690,000	**$66,549,000**	**+$21,859,000**
Facilities and Infrastructure $24,800,000	**$32,603,000**	**+$7,803,000**
FY 2016 funding provides general facility and infrastructure support at NBL, OSTI and ORISE as well as infrastructure investments for electrical upgrades at SLAC and ANL and renovations at FNAL.	The FY 2017 request will address top core infrastructure priorities and provide funding to enhance HVAC systems and controls at LBNL, support electrical distribution upgrades at SLAC and AMES, and upgrade the cryogenics infrastructure at TJNAF. The request also continues to support general facility and infrastructure support at OSTI and ORISE, as well as de-inventory and removal of nuclear material at NBL.	Funding increases to address basic needs in core general purpose infrastructure by supporting four new GPP projects.
Nuclear Operations $12,000,000	**$26,000,000**	**+$14,000,000**
FY 2016 funding supports the management of ORNL's nuclear facilities to current expectations, in accordance with federal regulations and DOE Directives.	The FY 2017 request continues to support critical nuclear operations and provides funding to manage ORNL's nuclear facilities to current expectations, in accordance with federal regulations and DOE Directives.	Funding increases to support ORNL's nuclear facilities and provides funding for critical nuclear complex equipment and infrastructure needed to ensure the facilities meet mission needs and safety standards.
Oak Ridge Landlord $6,177,000	**$6,182,000**	**+$5,000**
FY 2016 funding supports stewardship type needs across the Oak Ridge Reservation as well as PILT to Oak Ridge communities.	The FY 2017 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 increases for maintenance and other infrastructure support needs.

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs FY 2016
Payments in Lieu of Taxes $1,713,000	**$1,764,000**	**+$51,000**
FY 2016 funding supports PILT payments to communities around the Argonne and Brookhaven National Laboratories.	The FY 2017 request provides funding for PILT payments to communities around the Argonne and Brookhaven National Laboratories.	Funding increases to accommodate increases in PILT requirements.

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 2017 budget request includes funding for three ongoing projects that were new starts in FY 2015 and two new projects.

On-Going Projects

Infrastructure and Operational Improvements at PPPL (15-SC-75)

The Infrastructure and Operational Improvements project will provide critical improvements to infrastructure and operations that support plasma and fusion-energy sciences research. Existing facilities and infrastructure at PPPL are marginally adequate to support cost-effective research operations. For example, many researchers and engineers are housed in buildings that were originally built in the 1960s and include obsolete and inadequate enclosure, mechanical, electrical, and plumbing systems. This project will rectify the most significant infrastructure deficiencies as part of a comprehensive campus strategic facilities investment plan being developed by PPPL. Completion of this project will result in improved operational efficiency and modernized infrastructure that is essential to support fusion energy sciences research.

The most recent DOE O 413.3B approved Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range, which was approved on May 11, 2015. The estimated preliminary Total Project Cost (TPC) range for this project is $21,700,000 to $26,000,000. This cost range and schedule will be further evaluated and may change prior to CD-2 and until the project baseline is established. No funding is requested for this project in FY 2017.

This project was a new start in FY 2015 with full funding requested and appropriated.

FY 2016 Milestones	FY 2017 Milestones	FY 2018–2021 Key Milestones
CD-2 – Approve Performance Baseline	CD-3 – Approve Start of Construction	CD-4 – Approve Project Closeout

Materials Design Laboratory at ANL (15-SC-76)

The Materials Design Laboratory project will support research in materials science in energy and a range of other fields. It will entail construction of a new laboratory office building at least 97,000 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-1, Approve Alternative Selection and Cost Range, which was approved on January 30, 2015 with a cost range of $77,500,000 to $96,000,000.

The FY 2017 Request for the Materials Design Laboratory Project is $19,590,000, which is $4,320,000 less than the FY 2016 Enacted level and consistent with the preliminary baseline funding profile. FY 2017 funds will be used for construction (e.g. site work and long lead procurements) and project management and support activities.

FY 2016 Milestones	FY 2017 Milestones	FY 2018–2021 Key Milestones
CD-2 – Approve Performance Baseline	CD-3 – Approve Start of Construction	CD-4 – Approve Project Completion

Photon Science Laboratory Building at SLAC (15-SC-77)

The Photon Science Laboratory Building project will provide centralized modern laboratory and office space to enable the development and expansion of SLAC's photon science programs. The Photon Science Laboratory Building will support the Linac Coherent Light Source; the Stanford Synchrotron Radiation Lightsource; the Photon Ultrafast Laser Science and Engineering Institute; and the Stanford Institute for Materials and Energy Sciences.

When this project was proposed for initial funding in the FY 2015 Budget Request, the scope was to construct a facility that would provide a portion of the space that would eventually be needed on-site to support the increase in photon science users on campus. Since that time, Stanford University has designed a larger facility shell that is being constructed with University funds. This presented the Department with an opportunity to build out space in that facility for SLAC use, rather than build new. In the FY 2016 Request, the project was rescoped to provide utilities and services (e.g., elevators, stairways, building-wide mechanical/electrical/plumbing equipment) for the entire building and framing and furnishing up to 100,000 gsf in the Stanford University building. Because of space efficiencies (shared elevators, hallways, mechanical closets, etc.) gained in constructing one building versus two, the Office of Science will acquire significantly more useable space for the same funding than could be acquired under the original project proposal. Therefore, this project has been re-scoped to fund the build-out of specialized photon science laboratories and related infrastructure in the Stanford University building. This strategic approach allows DOE/SLAC to maximize the science capability by leveraging the Stanford University investment.

The most recent DOE O 413.3B approved Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range, which was approved on September 23, 2015. The estimated preliminary TPC range for this project is $45,300,000 to $57,000,000. This cost range and the project schedule will be further evaluated prior to CD-2.

The FY 2017 Request for the Photon Science Laboratory Building is $20,000,000, which is $5,000,000 less than the FY 2016 Enacted level and consistent with the preliminary baseline funding profile. The Request will support of construction of this project. FY 2017 funds will be used for construction (e.g. elevators and restrooms or areas that are not dependent on specific laboratory design) and project management and support activities.

FY 2016 Milestones	FY 2017 Milestones	FY 2018–2021 Key Milestones
	CD-2– Approve Performance Baseline CD-3 – Approve Start of Construction Activities	CD-4 – Approve Start of Operations or Project Closeout

Integrative Genomics Building at LBNL (15-SC-78)

The Integrative Genomics Building project will 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-1, Approve Alternative Selection and Cost Range, which was approved on February 20, 2015 with a cost range of $81,100,000 to $91,500,000. This cost range and the project schedule will be further evaluated prior to CD-2.

FY 2017 Request for the Integrative Genomics Building is $19,561,000, which is $439,000 less than the FY 2016 Enacted level and consistent with the preliminary baseline funding profile. FY 2017 funds will be used for construction (e.g. site work and long lead procurements) and project management and support activities.

FY 2016 Milestones	FY 2017 Milestones	FY 2018–2021 Key Milestones
CD-2 – Approve Performance Baseline	CD-3 – Approve Start of Construction	CD-4 – Approve Project Completion

New Starts for FY 2017

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 Fermilab (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 [Fermi National Accelerator Laboratory, FNAL or Fermilab] as host." The Office of Science (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, for example. 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 would complement the ongoing and planned renovations of Wilson Hall by establishing the main campus as the anchor point of the site. It would improve operational efficiency and collaboration because groups working on key projects would be in close proximity to one another. Such a facility would 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-0, *Approve Mission Need*, which was approved on July 17, 2015. The estimated preliminary total project cost range for this project is $45,000,000 to $146,000,000. These pre-CD-1 ranges encompass all possible alternatives. A preliminary total project cost of $87,000,000 reflects the alternative most consistent with SLI program goals and objectives because it is expected to provide a research center with the most cost effective infrastructure investment. The cost, scope, and schedule for executing the project will be determined at Critical Decision (CD)-1.

FY 2017 funding will support the start of Project Engineering and Design activities.

Preliminary Schedule

CD-0	CD-1	CD-2	CD-3	CD-4
07/17/2015	1Q FY 2017	3Q FY 2018	3Q FY 2019	4Q FY 2023

Preliminary Cost Estimates

(Dollars in Thousands)

	FY 2017 Appropriations	Total Appropriations
Design	$2,500	$10,000
Construction	0	$75,000
Other Project Costs	0	$2,000
Preliminary Total Project Cost	$2,500	$87,000

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 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-0, *Approve Mission Need,* was approved on September 10, 2015. The Mission Need Statement indicates a total project cost range of $39,000,000 to $96,000,000. These cost ranges encompass the most feasible preliminary alternatives. The preliminary total project cost of $64,500,000 reflects the preliminary alternative most consistent with the SLI program goals and objectives and primary research stakeholder priorities. The cost, scope, and schedule for executing the project will be determined at CD-1.

FY 2017 funds will only support Project Engineering and Design activities.

Preliminary Schedule

CD-0	CD-1	CD-2	CD-3	CD-4
09/10/2015	3Q FY 2017	3Q FY 2019	3Q FY 2020	4Q FY 2024

Preliminary Cost Estimates

(Dollars in Thousands)

	FY 2017 Appropriations	Total Appropriations
Design	$1,800	$6,400
Construction	0	$57,000
Other Project Costs	0	$1,100
Preliminary Total Project Cost	$1,800	$64,500

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs FY 2016
Construction $68,910,000	**$63,451,000**	**-$5,459,000**
Integrated Engineering Research Center at FNAL (17-SC-71) $0	**$2,500,000**	**+$2,500,000**
	Funding is requested in FY 2017 to initiate Project Engineering and Design activities for the project.	Start of Project Engineering and Design activities.
Core Facility Revitalization at BNL (17-SC-73) $0	**$1,800,000**	**+$1,800,000**
	Funding is requested in FY 2017 to initiate Project Engineering and Design activities for the project.	Start of Project Engineering and Design activities.
Materials Design Laboratory at ANL (15-SC-76) $23,910,000	**$19,590,000**	**-$4,320,000**
FY 2016 funding initiates construction of the project.	Funding is requested in FY 2017 to support on-going construction of the project.	Continuation of construction of the project.
Photon Sciences Laboratory Building at SLAC (15-SC-77) $25,000,000	**$20,000,000**	**-$5,000,000**
FY 2016 funding supports ongoing construction of the project.	Funding is requested in FY 2017 to support completion of construction of the project.	Completion of construction of the project. FY 2017 will be the final year of funding for this project.
Integrative Genomics Building at LBNL (15-SC-78) $20,000,000	**$19,561,000**	**-$439,000**
FY 2016 funding supports construction of the project.	Funding is requested in FY 2017 to support on-going construction of the project.	Continuation of construction of the project.

Science Laboratories Infrastructure
Capital Summary ($K)

	Total	Prior Years	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 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	9,000	+9,000
Electrical Distribution Upgrades at SLAC (TEC $10.0M)	10,000	0	0	0	0	10,000	+10,000
Cryogenics Infrastructure Upgrades at TJNAF (TEC $8.0M)	8,000	0	0	0	0	8,000	+8,000
Linac K-sub Remediation at SLAC (TEC $9.8M)	9,800	0	0	0	9,800	0	-9,800
Wilson Hall Renovations at FNAL (TEC $9.0M)	9,000	0	0	0	9,000	0	-9,000
Other GPP (TEC <$5M)	n/a	n/a	800	1,000	4,500	2,900	-1,600
Total, Capital Operating Expenses	n/a	n/a	**800**	**1,000**	**23,300**	**29,900**	**+6,600**

Construction Projects Summary ($K)

	Total Project Cost(TPC)	Prior Years	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
Integrated Engineering Research Center at FNAL (17-SC-71)							
TEC	85,000[a]	0	0	0	0	2,500	+2,500
OPC[b]	2,000	0	500	500	500	0	-500
TPC	87,000[a]	0	500	500	500	2,500	+2,000
Core Facility Revitalization at BNL (17-SC-73)							
TEC	63,400[a]	0	0	0	0	1,800	+1,800
OPC[b]	1,100	0	0	0	1,100	0	-1,100
TPC	64,500[a]	0	0	0	1,100	1,800	+700

[a] This project has not received CD-2 approval; therefore, preliminary cost estimates are shown for TEC and TPC.
[b] Other Project Costs shown are funded through laboratory overhead.

	Total Project Cost(TPC)	Prior Years	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
Infrastructure and Operational Improvements at PPPL (15-SC-75)							
TEC	25,000[a]	0	25,000	25,000	0	0	0
OPC[b]	1,000	1,000	0	0	0	0	0
TPC	26,000[a]	1,000	25,000	25,000	0	0	0
Materials Design Laboratory at ANL (15-SC-76)							
TEC	95,000[a]	0	7,000	7,000	23,910	19,590	-4,320
OPC[b]	1,000	682	318	318	0	0	0
TPC	96,000[a]	682	7,318	7,318	23,910	19,590	-4,320
Photon Sciences Laboratory Building at SLAC (15-SC-77)							
TEC	55,000[a]	0	10,000	10,000	25,000	20,000	-5,000
OPC[b]	2,000	230	242	242	0	459	+459
TPC	57,000[a]	230	10,242	10,242	25,000	20,459	-4,541
Integrative Genomics Building at LBNL (15-SC-78)							
TEC	90,000[a]	0	12,090	12,090	20,000	19,561	-439
OPC[b]	1,500	1,145	355	355	0	0	0
TPC	91,500[a]	1,145	12,445	12,445	20,000	19,561	-439
Science and User Support Building at SLAC (12-SC-70)							
TEC	64,000	52,080	11,920	11,920	0	0	0
OPC[b]	1,000	800	200	200	0	0	0
TPC	65,000	52,880	12,120	12,120	0	0	0
Total, Construction							
TEC	n/a	n/a	66,010	66,010	68,910	63,451	-5,459
OPC[b]	n/a	n/a	1,615	1,615	1,600	459	-1,141
TPC	n/a	n/a	67,625	67,625	70,510	63,910	-6,600

[a] This project has not received CD-2 approval; therefore, preliminary cost estimates are shown for TEC and TPC.
[b] Other Project Costs shown are funded through laboratory overhead.

17-SC-71 Integrated Engineering Research Center
Fermi National Accelerator Laboratory (FNAL), Batavia, Illinois
Preliminary Information for Design

1. Summary

Summary
This document contains preliminary information for a design and construction project requested as a new start in FY 2017. The FY 2017 Request for this new start is $2,500,000.

The most recent DOE O 413.3B Critical Decision (CD) is CD-0, Approve Mission Need, which was approved on July 17, 2015.

The Mission Need Statement shows a Total Estimated Cost (TEC) range of $44,000,000 to $144,000,000 and a Total Project Cost (TPC) range of $45,000,000 to $146,000,000. These preliminary cost ranges encompass all 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 TPC of $87,000,000 reflects the preliminary alternative most consistent with the Science Laboratories Infrastructure program goals and objectives and the most cost effective infrastructure investment. The preliminary cost, scope, and schedule for executing the project will be determined at CD-1.

A Federal Project Director with the appropriate certification level will be assigned to this project prior to CD-1 approval.

FY 2017 funds will only 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	07/17/2015	1Q FY 2017[a]	3Q FY 2018[a]	3Q FY 2019[a]	4Q FY 2023[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	10,000	75,000	85,000[a]	2,000	87,000[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

One potential approach to improving the infrastructure capability for an international neutrino campus as identified by P5 closing this capability gap is to collocate engineering and associated research staff in a new or renovated facility near the central campus. This approach would complement the ongoing and planned renovations of Wilson Hall by establishing the main campus as the anchor point of the site. It would improve operational efficiency and collaboration because groups working on key projects would be in close proximity to one another. Such a facility would provide technical and engineering staff the necessary environment for interdisciplinary collaboration necessary to establish an international neutrino program and support other High Energy Physics scientific research opportunities described in the P5 report. This project will meet the most urgent facilities and infrastructure needs by constructing new building space of at least 67,000 gross square feet.

This project has not yet received CD-1 approval; therefore the Key Performance Parameters (KPPs) are to be determined. 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."

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. 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 would improve collaboration because it would 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 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. 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	4,141	8,000	13,553
Contingency	1,035	2,000	3,388
Total, Design	5,176	10,000	16,941
Construction			
Construction	31,059	60,000	101,647
Contingency	7,765	15,000	25,412
Total, Construction	38,824	75,000	127,059
Total, TEC[a]	44,000	85,000	144,000
Contingency, TEC	8,800	17,000	28,800
Other Project Cost (OPC)[a]			
OPC except D&D			
Conceptual Planning	250	500	500
Conceptual Design	450	900	900
Start-up	150	300	300
Contingency	150	300	300
Total, OPC	1,000	2,000	2,000
Contingency, OPC	150	300	300
Total, TPC[a]	45,000	87,000	146,000
Total, Contingency	8,950	17,300	29,100

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 will be considered prior to achieving CD-1. The M&O contractor will be responsible for all awarding and administering all subcontracts related to this project. Project performance metrics are included in the M&O contractor's annual performance evaluation and measurement plan.

[a] Other project costs (OPC) are funded through laboratory overhead.

17-SC-73 Core Facility Revitalization
Brookhaven National Laboratory (BNL), Upton, New York
Preliminary Information for Design

1. Summary

Summary
This document contains preliminary information for a design and construction project requested as a new start in FY 2017.

The FY 2017 Request for this new start is $1,800,000. The most recent DOE O 413.3B Critical Decision (CD) is CD-0, Approve Mission Need, which was approved on September 10, 2015.

The Mission Need Statement indicates a Total Estimated Cost (TEC) range of $38,000,000 to $94,000,000 and a Total Project Cost (TPC) range of $39,000,000 to $96,000,000. These preliminary 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 the shortest amount of time. A TPC of $64,500,000 reflects the preliminary alternative most consistent with the Science Laboratories Infrastructure program goals and objectives and primary research stakeholder priorities. The preliminary cost, scope, and schedule for executing the project will be determined at CD-1.

A Federal Project Director with the appropriate certification level will be assigned to this project prior to CD-1.

FY 2017 funds will only 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]

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]

4. Project Scope and Justification

Scope
The Core Facility Revitalization project will provide facilities and infrastructure to enable the computational requirements of the Office of Science's (SC) Nuclear Physics (NP) program, High Energy Physics (HEP) program, and other research programs physically conducted at Brookhaven National Laboratory (BNL) and other locations.

This project has not yet received CD-1 approval; therefore the Key Performance Parameters (KPPs) are to be determined. The table below outlines preliminary KPPs.

[a] This project is pre-CD-2; schedule and funding estimates are preliminary.
[b] Other project costs (OPC) are funded through laboratory overhead.

Key Performance Parameters (Preliminary)

Description	Threshold Value (Minimum)	Objective Value (Maximum)
Computational Space	39,000 gross square feet	155,000 gross square feet

Justification
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 NP and US-ATLAS research operations funded by HEP). The RACF also provides mid-scale computing support to other research programs funded by SC, research efforts funded by strategic partners, and computationally-intensive research that indirectly supports the broader SC mission.

The data volume generated by the RHIC experiments and ATLAS is expected to increase three to six times over the next ten years and will require proportional increases in computation and data storage capacities. Almost half of the current RACF computing and data storage facility is expected become functionally obsolete and unable to accommodate future generations of computation and data storage technologies over the next five to ten years. Therefore, the projected capability gaps in computing infrastructure are due to a combination of decreases due to degrading capacities and increases in future requirements of mid-scale computing performed by RACF. Increases in computation and data storage will drive increased requirements for space, power, and cooling of computing facilities. A mission need therefore exists to provide sufficient, mid-range computation and data storage capabilities to support to current and planned experiments using RHIC and the ATLAS detectors, and potentially other programs.

FY 2017 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 413.3B, Program and Project Management for the Acquisition of Capital Assets.

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	3,069	5,120	7,591
Contingency	767	1,280	1,898
Total, Design	3,836	6,400	9,489
Construction			
Construction	25,623	42,750	63,383
Contingency	8,541	14,250	21,128
Total, Construction	34,164	57,000	84,511
Total, TEC[a]	38,000	63,400	94,000
Contingency, TEC	9,308	15,530	23,026

[a] This project is pre-CD-2; schedule and funding estimates are preliminary.

	(dollars in thousands)		
	Total Preliminary Cost Range: Minimum Estimate	Total Preliminary Cost: Current Point Estimate	Total Preliminary Cost Range: Maximum Estimate
Other Project Cost (OPC)[a]			
OPC except D&D			
Conceptual Planning	273	300	545
Conceptual Design	636	700	1,273
Contingency	91	100	182
Total, OPC	1,000	1,100	2,000
Contingency, OPC	91	100	182
Total, TPC[a]	39,000	64,500	96,000
Total, Contingency	9,399	15,630	23,208

6. Preliminary Acquisition Approach

Acquisition for this project will be performed by the BNL Management and Operating (M&O) Contractor, Brookhaven Science Associates. The M&O Contractor will be responsible for awarding and managing all subcontracts related to the project. The Brookhaven Site Office will be responsible for overseeing the performance of the M&O Contractor. Various acquisition and project delivery methods will be evaluated prior to achieving CD-1. The M&O Contractor will evaluate potential benefits of using a single or multiple contracts to procure materials, equipment, construction, commissioning and other project scope elements. Project performance metrics will be included in the M&O Contractor's annual performance and evaluation measurement plan.

[a] Other project costs (OPC) are funded through laboratory overhead.

15-SC-76 Materials Design Laboratory
Argonne National Laboratory (ANL), Argonne, IL
Project is for Design and Construction

1. Significant Changes and Summary

Significant Changes
This Construction Project Data Sheet (CPDS) is an update of the FY 2016 CPDS and does not include a new start for FY 2017.

Summary
The FY 2017 Request for the Materials Design Laboratory is $19,590,000, which is $4,320,000 less than the FY 2016 Enacted level and consistent with the approved baseline funding profile. The most recent DOE O 413.3B approved Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range, and was approved on January 30, 2015. The approved Total Estimated Cost (TEC) range for this project is $76,500,000 to $95,000,000. The approved Total Project Cost (TPC) range for this project is $77,500,000 to $96,000,000.

A Federal Project Director with certification level 2 has been assigned to this project.

This project will provide new laboratory and office space to support energy-related materials science and engineering research. Conceptual Design was completed in November 2014 and Preliminary Design was completed in September 2015. FY 2017 funds will be used for construction.

2. Critical Milestone History

(fiscal quarter or date)

	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2015	08/27/2010	N/A	4Q FY 2014	4Q FY 2015[a]	4Q FY 2016	3Q FY 2016[a]	N/A	2Q FY 2020[a]
FY 2016	08/27/2010	1Q FY 2015	2Q FY 2015	2Q FY 2016[a]	3Q FY 2017	1Q FY 2017[a]	N/A	3Q FY 2020[a]
FY 2017	08/27/2010	11/12/2014	01/30/2015	3Q FY 2016[a]	2Q FY 2017	4Q FY 2017[a]	N/A	3Q FY 2021[a]

CD-0 – Approve Mission Need
Conceptual Design Complete – Actual date the conceptual design was completed
CD-1 – Approve Alternative Selection and Cost Range
CD-2 – Approve Performance Baseline
Final Design Complete – 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	1Q FY 2017[a]
FY 2017	3Q FY 2016[a]

[a] This project is pre-CD-2 and schedule estimates are preliminary.

3. Project Cost History

(dollars in thousands)

	TEC, Design	TEC, Construction	TEC, Total	OPC[a] Except D&D	OPC, D&D	OPC, Total	TPC
FY 2015	7,000	88,000[b]	95,000[b]	1,000	N/A	1,000	96,000[b]
FY 2016	7,000	88,000[b]	95,000[b]	1,000	N/A	1,000	96,000[b]
FY 2017	7,000	88,000[b]	95,000[b]	1,000	N/A	1,000	96,000[b]

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 approved 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.

FY 2017 funds will be used for construction, project management, and support activities.

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.

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[a] Other Project Costs (OPC) are funded through laboratory overhead.

[b] This project has not received CD-2 approval; funding estimates are consistent with the approved cost ranges. The approved TEC range for this project is $76,500,000 to $95,000,000. The approved TPC range for this project is $77,500,000 to $96,000,000.

5. Preliminary Financial Schedule

(dollars in thousands)

	Appropriations	Obligations	Costs[a]
Total Estimated Cost (TEC)			
Design			
FY 2015	7,000	7,000	2,773
FY 2016	0	0	3,727
FY 2017	0	0	500
Total, Design	7,000	7,000	7,000
Construction			
FY 2016	23,910	23,910	0
FY 2017	19,590	19,590	10,000
FY 2018	24,500	24,500	35,000
FY 2019	20,000	20,000	25,000
FY 2020	0	0	18,000
Total, Construction	88,000	88,000	88,000
TEC			
FY 2015	7,000	7,000	2,773
FY 2016	23,910	23,910	3,727
FY 2017	19,590	19,590	10,500
FY 2018	24,500	24,500	35,000
FY 2019	20,000	20,000	25,000
FY 2020	0	0	18,000
Total, TEC[b]	95,000	95,000	95,000
Other Project Cost (OPC)[c]			
OPC except D&D			
FY 2010	412	412	412
FY 2011	-30[d]	-30[d]	-30[d]
FY 2014	300	300	300
FY 2015	318	318	318
Total, OPC except D&D	1,000	1,000	1,000
Total Project Cost (TPC)			
FY 2010	412	412	412
FY 2011	-30[d]	-30[d]	-30[d]
FY 2014	300	300	300
FY 2015	7,318	7,318	3,091
FY 2016	23,910	23,910	3,727
FY 2017	19,590	19,590	10,500

[a] Costs through FY 2015 reflect actual costs; costs for FY 2016 and the outyears are estimates.

[b] This project has not received CD-2 approval; funding estimates are consistent with the approved cost ranges. The approved TEC range for this project is $76,500,000 to $95,000,000. The approved TPC range for this project is $77,500,000 to $96,000,000.

[c] Other Project Costs (OPC) are funded through laboratory overhead.

[d] OPC Funding was adjusted in FY 2011 to reflect FY 2010 actuals ($382,000 for OPC funding in FY 2010).

(dollars in thousands)	Appropriations	Obligations	Costs[a]
FY 2018	24,500	24,500	35,000
FY 2019	20,000	20,000	25,000
FY 2020	0	0	18,000
Total, TPC[b]	96,000	96,000	96,000

6. Details of Project Cost Estimate

(dollars in thousands)	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	6,000	6,000	6,708
Contingency	1,000	1,000	292
Total, Design	7,000	7,000	7,000
Construction			
Construction	73,000	73,000	76,260
Contingency	15,000	15,000	11,740
Total, Construction	88,000	88,000	88,000
Total, TEC[b]	95,000	95,000	95,000
Contingency, TEC	16,000	16,000	12,032
Other Project Cost (OPC)[c]			
OPC except D&D			
Conceptual Planning	382	382	382
Conceptual Design	500	500	618
Contingency	118	118	0
Total, OPC	1,000	1,000	1,000
Contingency, OPC	118	118	0
Total, TPC[b]	96,000	96,000	96,000
Total, Contingency	16,118	16,118	12,032

[a] Costs through FY 2015 reflect actual costs; costs for FY 2016 and the outyears are estimates.
[b] This project has not received CD-2 approval; funding estimates are consistent with the approved cost ranges. The approved TEC range for this project is $76,500,000 to $95,000,000. The approved TPC range for this project is $77,500,000 to $96,000,000.
[c] Other Project Costs (OPC) are funded through laboratory overhead.

7. Schedule of Appropriation Requests

Request Year		Prior Years	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	Total
		(dollars in thousands)							
FY 2015	TEC	0	0	7,000	24,003	36,466	27,531	0	95,000[a]
	OPC[b]	382	500	0	0	0	118	0	1,000
	TPC	382	500	7,000	24,003	36,466	27,649	0	96,000[a]
FY 2016	TEC	0	0	7,000	23,910	25,090	39,000	0	95,000[a]
	OPC[b]	382	300	0	0	0	318	0	1,000
	TPC	382	300	7,000	23,910	25,090	39,318	0	96,000[a]
FY 2017	TEC	0	0	7,000	23,910	19,590	24,500	20,000	95,000[a]
	OPC[b]	382	300	318	0	0	0	0	1,000
	TPC	382	300	7,318	23,910	19,590	24,500	20,000	96,000[a]

8. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	3Q FY 2020
Expected Useful Life	50 years
Expected Future Start of D&D of this capital asset	3Q FY 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	376	N/A	18,800	N/A
Utilities	429	N/A	21,450	N/A
Maintenance and Repair	958	N/A	47,900	N/A
Total, Operations & Maintenance	1,763	N/A	88,150	N/A

[a] This project has not received CD-2 approval; funding estimates are consistent with the approved cost ranges. The approved TEC range for this project is $76,500,000 to $95,000,000. The approved TPC range for this project is $77,500,000 to $96,000,000.

[b] Other Project Costs (OPC) are funded through laboratory overhead.

9. D&D Information

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

	Square Feet
New area being constructed by this project at *Argonne National Laboratory*	97,000
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"	97,000
Total area eliminated	None

ANL will comply via the FY 2012 waiver from EM ETTP to ANL. ANL's net banked square footage as reported in the FY 2013 Report on DOE's disposition of excess real property for future one-for-one offsets stands at 577,955 SF.

10. Acquisition Approach

Acquisition for this project will be performed by the Management and Operating (M&O) contractor, UChicago Argonne, LLC, and will be overseen by the Argonne Site Office. Various acquisition approaches and project delivery methods were evaluated prior to achieving CD-1. A tailored Design-Bid-Build approach was selected as the overall best project delivery method with the lowest risk to DOE. The M&O contractor is responsible for awarding and administering all subcontracts related to this project. Project performance metrics are included in the M&O Contractor's annual performance evaluation and measurement plan.

15-SC-77 Photon Science Laboratory Building
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 2016 CPDS and does not include a new start for FY 2017.

The upper end of the Key Performance Parameter (KPP) range for the project has been updated from 75,000 gross square feet (GSF) to 100,000 GSF in accordance with the analysis at Critical Decision (CD)-1, Approve Alternative Selection and Cost Range.

Summary
The FY 2017 Request for the Photon Science Laboratory Building is $20,000,000, which is $5,000,000 less than the FY 2016 Enacted level and consistent with the preliminary funding profile. The most recent DOE O 413.3B approved Critical Decision (CD) is CD-1, *Approve Alternative Selection and Cost Range*, which was approved September 23, 2015. The Total Estimated Cost (TEC) range for the DOE funded portion of this project is $43,300,000 to $55,000,000. The estimated Total Project Cost (TPC) range for the DOE funded portion of this project is $45,300,000 to $57,000,000.

Stanford University has begun construction of a cold, dark shell including the building enclosure, foundation, structure, and infrastructure pathways. This project funds the design and fit-out of a large portion of the shell's interior for SLAC use, providing significantly more useable space than two separate buildings. The fit-out will include utilities and services (e.g. building-wide mechanical/electrical/plumbing equipment) for the entire building and offices and infrastructure in support of the approved mission need.

A 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 2015	4/18/2011	N/A	1Q FY 2015	4Q FY 2015[a]	1Q FY 2017	3Q FY 2016[a]	N/A[b]	1Q FY 2019[a]
FY 2016	4/18/2011	3Q FY 2015	3Q FY 2015	1Q FY 2016[a]	3Q FY 2016	3Q FY 2016[a]	N/A[b]	2Q FY 2018[a]
FY 2017	4/18/2011	5/04/2015	9/23/2015	1Q FY 2017[a]	3Q FY 2017	4Q FY 2017[a]	N/A[b]	2Q FY 2020[a]

CD-0 – Approve Mission Need
Conceptual Design Complete – Actual Date the conceptual design was completed
CD-1– Approve Alternative Selection and Cost Range
CD-2 – Approve Performance Baseline
Final Design Complete – Estimated date the project design will be completed
CD-3 – Approve Start of Balance of Construction Activities
D&D Complete – Completion of D&D work (see Section 9)
CD-4 – Approve Start of Operations or Project Closeout

[a] This project is pre-CD-2 and schedule estimates are preliminary.
[b] The project is not building additional space; therefore, D&D is not applicable.

	Performance Baseline Validation
FY 2015	N/A
FY 2016	4Q FY 2016[a]
FY 2017	4Q FY 2016[a]

3. Project Cost History

(dollars in thousands)

	TEC, Design	TEC, Construction	TEC, Total	OPC[b] Except D&D	OPC, D&D	OPC, Total	TPC
FY 2015	4,000	51,000[c]	55,000	2,000	0	2,000	57,000[c]
FY 2016	6,000	49,000[c]	55,000	2,000	0	2,000	57,000[c]
FY 2017	6,000	49,000[c]	55,000	2,000	0	2,000	57,000[c]

4. Project Scope and Justification

Scope

Upon construction of the shell by the Stanford University, the PSLB project will prepare a large portion of the shell's interior for SLAC use. Utilities and services (e.g., elevators, stairways, building-wide mechanical/electrical/plumbing equipment) for the entire building and framing and furnishing up to 100,000 GSF will be provided. The fit-out will be designed and constructed in order to provide a complete and usable facility.

Key Performance Parameters (Preliminary):

Description	Threshold Value (Minimum)	Objective Value (Maximum)
Laboratory building interior fit-out	55,000 gross square feet	100,000 gross square feet

Justification

To accommodate the growth in research programs that has occurred since 2011, and continues to accelerate in recent years, modern laboratory/office space is needed above and beyond the existing campus space for a range of simulation, theory and modeling, synthesis and characterization capabilities. The lab/office space will also support research collaborations with outside scientists engaged with SLAC's Linac Coherent Light Source (LCLS) and Stanford Synchrotron Radiation Lightsource (SSRL) user facilities. Fit-out by the Office of Science (SC) of the Photon Science Laboratory Building is needed to provide centralized modern laboratory and office space with the necessary performance capabilities and accommodate growth in the existing photon science program. The Photon Science Laboratory Building would leverage the capabilities of two of the country's world-class light sources, LCLS and SSRL, as well as the Photon Ultrafast Laser Science and Engineering (PULSE) and Stanford Institute for Materials and Energy Sciences (SIMES) photon institutes. Without modern facilities suitable for collocated and coordinated functionality, the laboratory's ability to successfully address and deliver on the long term strategic mission of the laboratory will be limited.

SLAC is an SC laboratory that supports a large national and international community of scientific users performing cutting-edge research in support of the DOE mission. SLAC was built in 1962 to perform research in accelerator-based particle

[a] This project is pre-CD-2 and schedule estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.
[c] This project has not received CD-2 approval; funding estimates are consistent with the preliminary cost ranges. The preliminary TEC cost range for this project is $43,300,000 to $55,000,000. The preliminary TPC cost range for this project is $45,300,000 to $57,000,000.

physics. Expansion and upgrade of the SSRL and the LCLS located at SLAC are producing rapid increases to photon science facility use, thereby increasing the need for space to accommodate the new and expanded research program.

The FY 2015 funds were used for preliminary design and project management and support activities. The FY 2016 funds were used for construction, project management, and support activities. FY 2017 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 413.3B, Program and Project Management for the Acquisition of Capital Assets.

5. Preliminary Financial Schedule

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
Total Estimated Cost (TEC)			
Design			
FY 2015	6,000	6,000	0
FY 2016	0	0	5,500
FY 2017	0	0	500
Total, Design	6,000	6,000	6,000
Construction			
FY 2015	4,000	0	0
FY 2016[b]	25,000	29,000	0
FY 2017[b]	20,000	20,000	34,000
FY 2018	0	0	15,000
Total, Construction	49,000	49,000	49,000
TEC			
FY 2015	10,000	6,000	0
FY 2016	25,000	29,000	5,500
FY 2017	20,000	20,000	34,500
FY 2018	0	0	15,000
Total, TEC[c]	55,000	55,000	55,000
Other Project Cost (OPC)[d]			
OPC except D&D			
FY 2014	230	230	230
FY 2015	242	242	242
FY 2017	459	459	459
FY 2018	1,069	1,069	1,069
Total, OPC except D&D	2,000	2,000	2,000

[a] Costs through FY 2015 reflect actual costs; costs for FY 2016 and the outyears are estimates.

[b] No construction will be performed until the project performance baseline has been validated and CD-3 has been approved.

[c] This project has not received CD-2 approval; funding estimates are consistent with the preliminary cost ranges. The preliminary TEC cost range for this project is $43,300,000 to $55,000,000. The preliminary TPC cost range for this project is $45,300,000 to $57,000,000.

[d] Other Project Costs are funded through laboratory overhead.

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
Total Project Cost (TPC)			
FY 2014	230	230	230
FY 2015	10,242	6,242	242
FY 2016	25,000	29,000	5,500
FY 2017	20,459	20,459	34,959
FY 2018	1,069	1,069	16,069
Total, TPC[b]	57,000	57,000	57,000

6. Details of Project Cost Estimate

	(dollars in thousands)		
	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	4,600	5,000	N/A
Contingency	1,400	1,000	N/A
Total, Design	6,000	6,000	N/A
Construction			
Construction	41,400	40,500	N/A
Contingency	7,600	8,500	N/A
Total, Construction	49,000	49,000	N/A
Total, TEC[b]	55,000	55,000	N/A
Contingency, TEC	9,000	9,500	N/A
Other Project Cost (OPC)[c]			
OPC except D&D			
Conceptual Design	500	1,200	N/A
Start-Up	1,000	450	N/A
Contingency	500	350	N/A
Total, OPC	2,000	2,000	N/A
Contingency, OPC	500	350	N/A
Total, TPC[b]	57,000	57,000	N/A
Total, Contingency	9,500	9,850	N/A

[a] Costs through FY 2015 reflect actual costs; costs for FY 2016 and the outyears are estimates.

[b] This project has not received CD-2 approval; funding estimates are consistent with the preliminary cost ranges. The preliminary TEC cost range for this project is $43,300,000 to $55,000,000. The preliminary TPC cost range for this project is $45,300,000 to $57,000,000.

[c] Other Project Costs (OPC) are funded through laboratory overhead.

7. Schedule of Appropriation Requests

Request Year		FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	Total
		(dollars in thousands)					
FY 2015	TEC	0	12,890	25,770	16,340	0	55,000[a]
	OPC[b]	1,341	0	200	459	0	2,000
	TPC	1,341	12,890	25,970	16,799	0	57,000[a]
FY 2016	TEC	0	10,000	25,000	20,000	0	55,000[a]
	OPC[b]	671	100	492	737	0	2,000
	TPC	671	10,100	25,492	20,737	0	57,000[a]
FY 2017	TEC	0	10,000	25,000	20,000	0	55,000[a]
	OPC[b]	230	242	0	459	1,069	2,000
	TPC	230	10,242	25,000	20,459	1,069	57,000[a]

8. Related Operations and Maintenance Funding Requirements

Start of Construction or Beneficial Occupancy (fiscal quarter and year)	2Q FY 2020
Expected Useful Life (number of years)	50
Expected Future Start of D&D of this capital asset (fiscal quarter and year)	2Q FY 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	340	N/A	10,925	N/A
Utilities	278	N/A	8,917	N/A
Maintenance	1,929	N/A	61,912	N/A
Total, Operations & Maintenance	2,547	N/A	81,754	N/A

9. D&D Information

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

[a] This project has not received CD-2 approval; funding estimates are consistent with the preliminary cost ranges. The preliminary TEC cost range for this project is $43,300,000 to $55,000,000. The preliminary TPC cost range for this project is $45,300,000 to $57,000,000.

[b] Other Project Costs (OPC) are funded through laboratory overhead.

SLAC National Accelerator Laboratory net banked square footage for future one-for-one offset as reported in FIMS stands at 263,000 SF. Since there will not be construction of any additional space in this project, the one-for-one offset is not applicable.

10. Acquisition Approach

Acquisition for this project will be performed by the Management and Operating (M&O) contractor, Stanford University and overseen by the SLAC Site Office. DOE will utilize SLAC to acquire the project under the existing DOE Management & Operations Contract (DE-AC02-76-SF00515). As such, SLAC has the ultimate responsibility to successfully execute the project under the direction of the Federal Project Director (FPD). SLAC has determined that a CM/GC approach would be most efficient and appropriate for interior construction of PSLB. All PSLB procurements will be based on firm fixed-price sub-contracts. Project performance metrics are included in the M&O contractor's annual performance evaluation and measurement plan.

15-SC-78, Integrative Genomics Building
Lawrence Berkeley National Laboratory (LBNL), Berkeley, 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 2016 CPDS and does not include a new start for FY 2017.

The budgeted amount for PED funds in FY 2015 is reduced by $3,090,000 to $6,500,000 to reflect a slightly less conservative cost estimate for preliminary and final design. The budgeted amount of Construction funds was increased by the same amount to result in $83,500,000 for construction funding. The approved Total Estimated Cost (TEC) range for this project remains as $79,600,000 to $90,000,000.

Summary

The FY 2017 Request for the Integrative Genomics Building is $19,561,000, which is $439,000 less than the FY 2016 Enacted level and consistent with the approved baseline funding profile. The most recent DOE O 413.3B approved Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range*,* and was approved on February 20, 2015. The approved Total Estimated Cost (TEC) range for this project is $79,600,000 to $90,000,000. The approved Total Project Cost (TPC) range for this project is $81,100,000 to $91,500,000.

A Federal Project Director with certification level 2 has been assigned to this project.

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. Conceptual Design was completed in October 2014 and Preliminary Design was completed in December 2015. FY 2017 funds will be used for construction.

2. Critical Milestone History

(fiscal quarter to date)

	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2015	9/17/2013	N/A	1Q FY 2015	3Q FY 2016[a]	4Q FY 2016	3Q FY 2016[a]	N/A	1Q FY 2021[a]
FY 2016	9/17/2013	1Q FY 2015	2Q FY 2015	2Q FY 2016[a]	3Q FY 2016	4Q FY 2016[a]	N/A	1Q FY 2021[a]
FY 2017	9/17/2013	10/28/2014	02/20/2015	2Q FY 2016[a]	3Q FY 2016	1Q FY 2017[a]	N/A	1Q FY 2021[a]

CD-0 – Approve Mission Need
Conceptual Design Complete – Actual date the conceptual design was completed
CD-1 – Approve Alternative Selection and Cost Range
CD-2 – Approve Performance Baseline
Final Design Complete – 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

[a] This project is pre-CD-2and schedule estimates are preliminary.

	Performance Baseline Validation
FY 2015	N/A
FY 2016	N/A
FY 2017 PB	2Q FY 2016[a]

3. Project Cost History

(dollars in thousands)

	TEC, Design	TEC, Construction	TEC, Total	OPC[b] Except D&D	OPC, D&D	OPC, Total	TPC
FY 2015	12,090	77,910[c]	90,000[c]	1,500	0	1,500	91,500[c]
FY 2016	9,590	80,410[c]	90,000[c]	1,500	0	1,500	91,500[c]
FY 2017	6,500	83,500[c]	90,000[c]	1,500	0	1,500	91,500[c]

4. Project Scope and Justification

Scope

The scope of this project includes the design and construction of a new state-of-the-art facility for bioscience research approximately 79,000 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 recently demolished Bevatron particle accelerator.

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 2017 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 413.3B, Program and Project Management for the Acquisition of Capital Assets.

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[a] This project is pre-CD-2 and schedule estimates are preliminary.

[b] Other project costs (OPC) are funded through laboratory overhead.

[c] This project has not received CD-2 approval; funding estimates are consistent with the approved cost ranges. The approved TEC range for this project is $79,600,000 to $90,000,000. The approved TPC range for this project is $81,100,000 to $91,500,000.

5. Preliminary Financial Schedule

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
Total Estimated Cost (TEC)			
Design			
FY 2015	6,500	6,500	2,086
FY 2016	0	0	4,414
Total, Design	6,500	6,500	6,500
Construction			
FY 2015	5,590	5,590	0
FY 2016	20,000	20,000	0
FY 2017	19,561	19,561	23,500
FY 2018	38,349	38,349	24,000
FY 2019	0	0	24,000
FY 2020	0	0	12,000
Total, Construction	83,500	83,500	83,500
TEC			
FY 2015	12,090	12,090	2,086
FY 2016	20,000	20,000	4,414
FY 2017	19,561	19,561	23,500
FY 2018	38,349	38,349	24,000
FY 2019	0	0	24,000
FY 2020	0	0	12,000
Total, TEC[b]	90,000	90,000	90,000
Other Project Cost (OPC)[c]			
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	4,414
FY 2017	19,561	19,561	23,500
FY 2018	38,349	38,349	24,000
FY 2019	0	0	24,000
FY 2020	0	0	12,000
Total, TPC[b]	91,500	91,500	91,500

[a] Costs through FY 2015 reflect actual costs; costs for FY 2016 and the outyears are estimates.

[b] This project has not received CD-2 approval; funding estimates are consistent with the approved cost ranges. The approved TEC range for this project is $79,600,000 to $90,000,000. The approved TPC range for this project is $81,100,000 to $91,500,000.

[c] 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	5,964	8,590	5,964
Contingency	536	1,000	536
Total, Design	6,500	9,590	6,500
Construction			
Construction	71,265	68,210	71,265
Contingency	12,235	12,200	12,235
Total, Construction	83,500	80,410	83,500
Total, TEC[a]	90,000	90,000	90,000
Contingency, TEC	12,771	13,200	12,771
Other Project Cost (OPC)[b]			
OPC except D&D			
Conceptual Planning	355	400	355
Conceptual Design	1,145	1,000	1,145
Startup	0	0	0
Contingency	0	100	0
Total, OPC	1,500	1,500	1,500
Contingency, OPC	0	100	0
Total, TPC[a]	91,500	91,500	N/A
Total, Contingency	12,771	13,300	N/A

7. Schedule of Appropriation Requests

Request Year		FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	Total
FY 2015	TEC	0	12,090	17,299	30,148	30,463	0	90,000[a]
	OPC[b]	1,300	0	0	0	0	200	1,500
	TPC	1,300	12,090	17,299	30,148	30,463	200	91,500[a]
FY 2016	TEC	0	12,090	20,000	25,064	32,846	0	90,000[a]
	OPC[b]	1,500	0	0	0	0	0	1,500
	TPC	1,500	12,090	20,000	25,064	32,846	0	91,500[a]
FY 2017	TEC	0	12,090	20,000	19,561	38,349	0	90,000[a]
	OPC[b]	1,145	355	0	0	0	0	1,500
	TPC	1,145	12,445	20,000	19,561	38,349	0	91,500[a]

(dollars in thousands)

[a] This project has not received CD-2 approval; funding estimates are consistent with the approved cost ranges. The approved TEC range for this project is $79,600,000 to $90,000,000. The approved TPC range for this project is $81,100,000 to $91,500,000.

[b] Other Project Costs (OPC) are funded through laboratory overhead.

8. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	1Q FY 2020
Expected Useful Life	50 years
Expected Future Start of D&D of this capital asset	1Q FY 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	N/A	5,735	N/A
Utilities	324	N/A	11,919	N/A
Maintenance and Repair	644	N/A	20,662	N/A
Total, Operations & Maintenance	1,147	N/A	38,316	N/A

9. D&D Information

The new area that will be constructed in this project will not replace existing facilities.

	Square Feet
New area being constructed by this project at *Lawrence Berkeley National Laboratory*	79,000
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"	79,000
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

Lawrence Berkeley National Laboratory will comply via space previously "banked." Lawrence Berkeley National Laboratory net banked square footage for future one-for-one offset as reported in the last FIMS update of September 26, 2013 stands at 165,000 SF.

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.

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 electronic data while enabling the SC mission.

Highlights of the FY 2017 Budget Request

Ensuring adequate security for the special nuclear material housed in Building 3019 at the Oak Ridge National Laboratory (ORNL) is the highest priority for the SC S&S Program, and SC is proactive in evaluating and improving security at that facility. The FY 2017 Request includes funding to ensure adequate security at this important facility. The FY 2017 Request supports sustained levels of operations in all S&S functional areas and ensures the Cyber Security program is properly funded to detect, mitigate, and recover from cyber intrusions and attacks against protected information at the heart of the SC mission.

Within the FY 2017 Request, S&S supports the Cyber Security Departmental Crosscut. The Department of Energy (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 Credential and Access Management (ICAM).

FY 2017 Crosscuts ($K)

	Cyber Security
Safeguards and Security	33,236[a]

Finally, the FY 2017 Request continues to support the Department's strategy for managing enterprise-wide cybersecurity and identity authentication for DOE IT systems, referred to as "CyberOne." The CyberOne strategy provides improved Department-wide capabilities for incident management and logical access to federal IT systems.

Description

The S&S program is organized into seven functional areas: Protective Forces, Security Systems, Information Security, Cyber Security, Personnel Security, Material Control and Accountability, and Program Management.

Protective Forces

The Protective Forces 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 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 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,

[a] Cybersecurity amount includes $6,039,000 for CyberOne funded through the Working Capital Fund (WCF).

and power systems operated and used to support the protection of DOE property, classified information, and other interests of national security.

Information Security
The Information Security 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
The Cyber Security element provides appropriate staffing levels, risk management tools, training, and security controls to protect the sensitive and classified data electronically processed, transmitted, or stored on SC IT systems. This element provides site-specific security as well as enterprise-wide security through CyberOne. Risk management controls ensure that IT systems, including the data contained within these systems, maintain confidentiality, integrity, and availability in a manner consistent with the SC mission and federal requirements.

Personnel Security
The Personnel Security 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 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 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 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
Protective Forces	38,095	37,767	38,805	39,638	+833
Security Systems	12,601	11,314	12,019	10,357	-1,662
Information Security	4,252	4,268	4,416	4,467	+51
Cyber Security[a]	24,118	25,781	33,156	33,236	+80
Personnel Security	5,267	5,335	5,412	6,086	+674
Material Control and Accountability	2,223	2,256	2,454	2,458	+4
Program Management	6,444	6,279	6,738	6,758	+20
Total, Safeguards and Security	**93,000**	**93,000**	**103,000**	**103,000**	**0**

[a] Cybersecurity amount includes $7,351,000 in FY 2015, $6,086,000 in FY 2016, and $6,039,000 in FY 2017 for CyberOne through the Working Capital Fund (WCF).

Safeguards and Security

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs FY 2016
Protective Forces $38,805,000	**$39,638,000**	**+$833,000**
Provides funding to maintain protection levels, equipment, and training needed to ensure proper protection and effective performance at all SC laboratories.	The FY 2017 Request will provide funding to maintain proper protection levels, equipment, and technical training needed to ensure effective performance at all SC laboratories.	The increase for protective forces supports sustained levels of operations across all SC laboratories.
Security Systems $12,019,000	**$10,357,000**	**-$1,662,000**
Provides funding to maintain the security systems currently in place and to support investments in SC laboratory physical security systems.	The FY 2017 Request will provide funding to maintain security systems currently in place.	The decrease in security systems is the result of completed prior year investments in laboratory physical security systems.
Information Security $4,416,000	**$4,467,000**	**+$51,000**
Provides funding for personnel, equipment, and systems necessary to ensure sensitive and classified information is properly safeguarded at SC laboratories.	The FY 2017 Request will provide funding for personnel, equipment, and systems necessary to ensure sensitive and classified information is properly safeguarded at SC laboratories.	The increase for information security supports sustained levels of operations across all SC laboratories.
Cyber Security $33,156,000	**$33,236,000**	**+$80,000**
Provides funding to properly protect SC laboratories' computer resources and sensitive data. Funding is also provided to continue support of the Department's CyberOne strategy.	The FY 2017 Request provides funding to ensure the Cyber Security program is properly funded to detect, mitigate, and recover from cyber intrusions and attacks against protected information at the heart of the SC mission. The Request also continues support of the Department's CyberOne strategy.	The increase for cybersecurity supports sustained levels of operations across 12 sites and facilities and continued support for the Departments' CyberOne strategy.
Personnel Security $5,412,000	**$6,086,000**	**+$674,000**
Maintains Personnel Security efforts at SC laboratories.	The FY 2017 Request provides funding for Personnel Security efforts at SC laboratories.	The increase for personnel security supports increased levels of operations across 12 sites and facilities to include credit monitoring and background checks.

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs FY 2016
Material Control and Accountability $2,454,000	**$2,458,000**	**+$4,000**
Maintains proper protection of material at SC laboratories.	Funding in FY 2017 will provide funding to maintain proper protection of material at SC laboratories.	The increase for material control and accountability supports sustained levels of operations across all SC laboratories.
Program Management $6,738,000	**$6,758,000**	**+$20,000**
Provides funding for oversight, administration, and planning for security programs at SC laboratories and to ensure security procedures and policy support SC research missions.	The FY 2017 Request will provide funding for the oversight, administration, and planning for security programs at SC laboratories and will support security procedures and policy support SC Research missions.	The increase for program management supports sustained levels of operations across all SC laboratories.

Estimates of Cost Recovered for Safeguards and Security Activities ($K)

In addition to the direct funding received from the Safeguards and Security Program, sites recover Safeguards and Security costs related to Work for Others (WFO) activities from WFO customers, including the cost of any unique security needs directly attributable to the customer. Estimates of those costs are shown below.

	FY 2015 Planned Costs	FY 2016 Planned Costs	FY 2017 Planned Costs	FY 2017 vs FY 2016
Ames National Laboratory	80	80	40	-40
Argonne National Laboratory	1,100	1,100	1,100	0
Brookhaven National Laboratory	800	1,218	1,218	0
Lawrence Berkeley National Laboratory	733	733	733	0
Oak Ridge Institute for Science and Education	595	595	677	+82
Oak Ridge National Laboratory	4,500	4,500	4,732	+232
Pacific Northwest National Laboratory	4,633	5,000	5,000	0
Princeton Plasma Physics Laboratory	50	40	50	+10
SLAC National Accelerator Laboratory	76	120	133	+13
Total, Security Cost Recovered	12,567	13,386	13,683	+297

Program Direction

Overview

Program Direction (PD) in the Office of Science (SC) supports a skilled Federal workforce to develop and oversee SC investments in basic research and construction and operation of scientific user facilities, the tools of discovery science. SC investments transform our understanding of nature and advance the energy, economic, and national security of the United States. In addition, SC provides broad public access to DOE research and development findings to further leverage the Federal science investment and advance the scientific enterprise.

SC requires highly skilled scientific and technical program and project managers, as well as experts in acquisition; finance; legal; construction and infrastructure management; human resources; and environmental, safety, and health oversight. SC's basic research portfolio includes grants and contracts supporting over 24,000 researchers located at about 300 institutions and 17 national laboratories. SC's scientific user facility portfolio includes 28 in operations and several more under construction—the large machines of modern science—which support some 31,000 users annually. These facilities offer unique capabilities and place U.S. researchers and industries at the forefront of science, technology, and innovation.

In 2013, Secretary Moniz reorganized the Department's management structure, which expanded the role of the Under Secretary for Science to encompass both science and energy. The resulting Office of the Under Secretary for Science and Energy has oversight of SC, as well as the Offices of Fossil Energy (FE), Energy Efficiency and Renewable Energy (EERE), Nuclear Energy (NE), Electricity Delivery and Energy Reliability (OE), Indian Energy Policy and Programs (IE), and the Office of Technology Transitions (OTT). Funding for the permanent career staff reporting to the Office of the Under Secretary for Science and Energy (formally organized as the Office of Planning and Management Oversight) is requested within the SC budget. This office facilitates major initiatives to strategically align the Science and Energy programs and engage its National Laboratories, including the annual National Lab Big Ideas Summit, coordination of the Crosscut programs, and development of seminal documents such as the Quadrennial Technology Review and the Science and Energy Plan. In addition, the office coordinates ongoing operational, planning, budgetary, human resource, and physical and cyber security functions across the program reporting to the Under Secretary.

<u>Headquarters (HQ)</u>
SC HQ Federal staff:

- Conduct scientific program and research infrastructure planning, execution, and management across SC, in part by engaging the scientific community to identify research opportunities and develop priorities.
- Create and maintain a research portfolio that includes 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 more than 6,000 ongoing laboratory, university, non-profit, and private industry research awards and reviews between 5,000 and 6,000 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 information technology, grants and contracts, budget, and human capital.
- Respond to information requests from Congress, the Executive Office of the President, other executive branch offices, and the public.
- Provide subject matter expertise to the Office of the Under Secretary for Science and Energy and other Departmental elements as may be requested.

<u>Site Offices</u>
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 assure contractual mechanisms are managed effectively and consistently with guidelines and regulations, supporting over $3 billion per year of SC mission work.
- Evaluate laboratory activities including nuclear, radiological, and other complex hazards.
- Provide Federal Project Directors to oversee construction projects.

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:

- Manages 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 4,000 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.
- Manages the DOE Payments Processing Center, a DOE-wide enterprise which executes approximately $11.1 billion of accounts payable activities annually.

Office of Scientific and Technical Information (OSTI):
OSTI fulfills the Department's responsibilities for wide public access to the unclassified and classified results of its research investments. DOE researchers typically produce 30,000-40,000 research papers and reports annually, and OSTI's physical and electronic collections exceed one million research papers and reports. OSTI developed and is responsible for executing DOE's public access mandate consistent with the memorandum issued by the Office of Science and Technology Policy (OSTP) in February 2013. The DOE policy ensures that peer-reviewed publications (either accepted manuscripts or the version of record) resulting from DOE funding will be made available to the public within 12 months from the date of publication. In FY 2015, a subcommittee of the Advanced Scientific Computing Advisory Committee (ASCAC) conducted an initial review of the OSTI program and expressed strong support for DOE's and OSTI's implementation of the public access mandate.

Highlights of the FY 2017 Budget Request

- The FY 2017 Request of $204,481,000 is an increase of $19,481,000 (+10.5%) from the FY 2016 Enacted level and supports a total FTE level of 930.
- Working Capital Fund (WCF) estimates for FY 2017 have increased over the FY 2016 requirements to fund the third year of OMB-mandated OPM credit monitoring and projected inflation increases in existing WCF programs including corporate business systems, building occupancy, interagency transfers, and telecommunications. SC's share of this estimated increase is $2,872,000, and is included in the Program Direction Budget Request.
- In the FY 2017 Request, most SC research program funding for the Working Capital Fund (WCF) is transferred to PD to establish a consolidated source of funding for goods and services provided by the WCF. CyberOne is still funded through program dollars in the SC Safeguards and Security program. In FY 2016 and prior years, WCF costs were shared by SC research programs and Program Direction. This transfer accounts for an increase of $10,380,000 in the Program Direction FY 2017 Budget Request.
- The FY 2017 Request includes an increase in travel funding for senior scientific and technical staff. Several recent external Committee of Visitors program management reviews noted that inadequate travel resources for program managers have diminished their participation in major scientific meetings and hindered effective management and oversight of SC's science programs and user facilities. A recent internal review of travel funding for program managers corroborated those findings, revealing a systematic degradation of travel resources over the last decade.

- Consistent with Executive Order 13539, as amended December 19, 2011, the FY 2017 Request supports the President's Council of Advisors on Science and Technology (PCAST), providing $875,000 for salaries and benefits for three FTEs, committee member travel, meeting planning support, and other related expenses.
- The FY 2017 Request includes $2,500,000 to support salaries, benefits, travel, training, and other expenses for the ten permanent career FTEs in the Office of Planning and Management Oversight supporting the Office of the Under Secretary for Science and Energy. In FY 2016, funding for this office was requested in the Departmental Administration appropriation.

Science Program Direction
Funding ($K)

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request[1]	FY 2017 vs. FY 2016
Washington Headquarters					
Salaries and Benefits	51,962	51,776	54,394	56,475	+2,081
Travel	1,866	1,937	2,158	2,200	+42
Support Services	13,472	13,695	14,651	14,000	-651
Other Related Expenses	15,870	14,316	18,112	29,680	+11,568
Total, Washington Headquarters	**83,170**	**81,724**	**89,315**	**102,355**	**+13,040**
Office of Scientific and Technical Information					
Salaries and Benefits	6,181	5,882	6,063	6,384	+321
Travel	78	68	120	150	+30
Support Services	1,522	1,180	1,366	2,000	+634
Other Related Expenses	1,000	1,351	855	1,000	+145
Total, Office of Scientific and Technical Information	**8,781**	**8,481**	**8,404**	**9,534**	**+1,130**
Field Offices					
Chicago Office					
Salaries and Benefits	22,355	23,037	21,488	22,240	+752
Travel	305	368	248	270	+22
Support Services	800	668	914	661	-253
Other Related Expenses	1,958	2,847	2,275	1,957	-318
Total, Chicago Office	**25,418**	**26,920**	**24,925**	**25,128**	**+203**
Oak Ridge Office					
Salaries and Benefits	23,302	23,216	21,600	23,188	+1,588
Travel	300	471	345	386	+41
Support Services	1,469	2,530	1,660	1,354	-306
Other Related Expenses	3,434	3,831	4,025	4,197	+172
Total, Oak Ridge Office	**28,505**	**30,048**	**27,630**	**29,125**	**+1,495**

[1] $10,380,000 is transferred from Office of Science research programs to support the Working Capital Fund.

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request[1]	FY 2017 vs. FY 2016
Ames Site Office					
Salaries and Benefits	441	418	450	462	+12
Travel	24	42	22	25	+3
Support Services	2	0	2	2	0
Total, Ames Site Office	**467**	**460**	**474**	**489**	**+15**
Argonne Site Office					
Salaries and Benefits	3,531	3,605	3,496	3,720	+224
Travel	107	106	80	100	+20
Support Services	158	84	165	158	-7
Other Related Expenses	39	25	21	39	+18
Total, Argonne Site Office	**3,835**	**3,820**	**3,762**	**4,017**	**+255**
Berkeley Site Office					
Salaries and Benefits	3,465	2,930	2,780	3,360	+580
Travel	75	86	59	65	+6
Support Services	384	486	361	174	-187
Other Related Expenses	131	11	87	131	+44
Total, Berkeley Site Office	**4,055**	**3,513**	**3,287**	**3,730**	**+443**
Brookhaven Site Office					
Salaries and Benefits	4,329	4,042	4,140	4,576	+436
Travel	115	135	125	265	+140
Support Services	610	612	358	460	+102
Other Related Expenses	165	72	195	240	+45
Total, Brookhaven Site Office	**5,219**	**4,861**	**4,818**	**5,541**	**+723**
Fermi Site Office					
Salaries and Benefits	2,280	2,128	2,325	2,460	+135
Travel	75	52	75	80	+5
Support Services	73	77	55	60	+5
Other Related Expenses	44	20	41	40	-1
Total, Fermi Site Office	**2,472**	**2,277**	**2,496**	**2,640**	**+144**

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request[1]	FY 2017 vs. FY 2016
New Brunswick Laboratory					
Salaries and Benefits	3,575	2,889	2,363	2,793	+430
Travel	80	49	125	165	+40
Support Services	296	1,414	300	489	+189
Other Related Expenses	983	797	1,034	898	-136
Total, New Brunswick Laboratory	**4,934**	**5,149**	**3,822**	**4,345**	**+523**
Oak Ridge National Laboratory Site Office					
Salaries and Benefits	5,600	5,402	5,250	5,880	+630
Travel	110	78	100	130	+30
Support Services	281	320	461	430	-31
Other Related Expenses	30	37	30	30	0
Total, Oak Ridge National Laboratory Site Office	**6,021**	**5,837**	**5,841**	**6,470**	**+629**
Pacific Northwest Site Office					
Salaries and Benefits	4,641	4,689	4,386	4,726	+340
Travel	125	122	133	140	+7
Support Services	38	27	48	38	-10
Other Related Expenses	104	25	83	104	+21
Total, Pacific Northwest Site Office	**4,908**	**4,863**	**4,650**	**5,008**	**+358**
Princeton Site Office					
Salaries and Benefits	1,505	1,328	1,310	1,490	+180
Travel	30	19	38	45	+7
Support Services	10	48	16	14	-2
Other Related Expenses	88	24	44	74	+30
Total, Princeton Site Office	**1,633**	**1,419**	**1,408**	**1,623**	**+215**
SLAC Site Office					
Salaries and Benefits	2,052	2,259	2,124	2,160	+36
Travel	59	56	50	59	+9
Support Services	138	151	148	150	+2
Other Related Expenses	57	6	33	57	+24
Total, SLAC Site Office	**2,306**	**2,472**	**2,355**	**2,426**	**+71**

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request[1]	FY 2017 vs. FY 2016
Thomas Jefferson Site Office					
Salaries and Benefits	1,836	1,759	1,711	1,936	+225
Travel	50	48	60	70	+10
Support Services	49	46	10	10	0
Other Related Expenses	41	3	32	34	+2
Total, Thomas Jefferson Site Office	**1,976**	**1,856**	**1,813**	**2,050**	**+237**
Total Field Offices					
Salaries and Benefits	78,912	77,702	73,423	78,991	+5,568
Travel	1,455	1,632	1,460	1,800	+340
Support Services	4,308	6,463	4,498	4,000	-498
Other Related Expenses	7,074	7,698	7,900	7,801	-99
Total, Field Offices	**91,749**	**93,495**	**87,281**	**92,592**	**+5,311**
Total Program Direction					
Salaries and Benefits	137,055	135,360	133,880	141,850	+7,970
Travel	3,399	3,637	3,738	4,150	+412
Support Services	19,302	21,338	20,515	20,000	-515
Other Related Expenses	23,944	23,365	26,867	38,481	+11,614
Total, Program Direction	**183,700**	**183,700**	**185,000**	**204,481**	**+19,481**
Federal FTEs	940	902	**905**	**930**	**+25**
Technical Support					
Development of specifications	714	464	489	598	+109
System review and reliability analyses	700	701	732	1,192	+460
Surveys or reviews of technical operations	365	443	440	462	+22
Total, Technical Support	**1,779**	**1,608**	**1,661**	**2,252**	**+591**
Management Support					
Automated data processing	8,273	7,835	8,665	8,700	+35
Training and education	724	723	802	883	+81
Reports and analyses, management, and general administrative services	8,526	11,172	9,387	8,165	-1,222
Total, Management Support	**17,523**	**19,730**	**18,854**	**17,748**	**-1,106**
Total, Support Services	**19,302**	**21,338**	**20,515**	**20,000**	**-515**

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request[1]	FY 2017 vs. FY 2016
Other Related Expenses					
Rent to GSA	900	742	1,104	960	-144
Rent to others	1,556	2,516	1,893	1,273	-620
Communications, utilities, and miscellaneous	2,624	1,887	3,223	3,215	-8
Printing and reproduction	21	0	1	0	-1
Other services	1,834	534	2,211	1,148	-1,063
Operation and maintenance of equipment	103	530	143	142	-1
Operation and maintenance of facilities	1,044	2,339	1,333	1,413	+80
Supplies and materials	776	867	689	853	+164
Equipment	3,586	2,450	3,668	3,623	-45
Working Capital Fund	11,500	11,500	12,602	25,854	+13,252
Total, Other Related Expenses	**23,944**	**23,365**	**26,867**	**38,481**	**+11,614**

Program Direction

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
Program Direction $185,000,000	**$204,481,000**	**+$19,481,000**
Salaries and Benefits $133,880,000	**$141,850,000**	**+$7,970,000**
The FY 2016 Enacted level supports 905 FTEs to perform scientific oversight, project management, essential operations support associated with science program portfolio management, and administration of PCAST.	The FY 2017 Request will support 930 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.	The increase includes funding for salaries and benefits based on current projections for SC's grade distribution and annual pay/step increases. It also includes a $2,010,000 increase to support ten permanent career FTEs in the Office of Planning and Management Oversight supporting the Office of the Under Secretary for Science and Energy.
This funding also includes support for expenses such as increases in GS schedule pay rates, health insurance costs and retirement allocations in the Federal Employees Retirement System.	This funding also includes support for expenses such as increases in GS schedule pay rates, health insurance costs and retirement allocations in the Federal Employees Retirement System.	
Travel $3,738,000	**$4,150,000**	**+$412,000**
Ensuring scientific management, compliance, safety oversight, and external review of research funding across all SC programs requires staff to travel, since SC senior program managers are not co-located with grantees or at national laboratories. Travel is also required for facility visits where the use of electronic telecommunications is 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 increase in travel funding restores SC program manager participation in major scientific meetings and provide effective management and oversight of major programs and user facilities through on-site visits. Per Administration policy, travel costs were restricted from FY 2013 through 2016.
		The Committee of Visitors identified travel funding increases as the "highest and most urgent priority" in their 2015 review of the Office of Basic Energy Sciences. The requested increase is essential to fulfilling the SC mission and sustaining a vibrant technical staff.

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
	Travel is included to support travel requirements in the Office of the Under Secretary for Science and Energy.	An increase of $60,000 supports travel for ten permanent career FTEs in the Office of Planning and Management Oversight supporting the Office of the Under Secretary for Science and Energy.
Travel is 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. The Enacted level supports travel for the SC Federal Advisory Committee, 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.	Travel is 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. The Request supports travel 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.	
Support Services $20,515,000	**$20,000,000**	**-$515,000**
Technical expertise and business services sustain 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	Technical expertise and business services sustain 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	Funding for support services is requested based on current projections for SC requirements. This includes an increase of $55,000 which is requested to support training for ten permanent career FTEs in the Office of Planning and Management Oversight supporting the Office of the Under Secretary for Science and Energy.

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
monitor field work proposals; selected routine administrative services including travel processing and Federal staff training 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 funds essential information technology infrastructure, ongoing operations and maintenance of IT systems and safety management support, as well as training for the SC workforce. The FY 2016 Enacted continues to support the IT Modernization Plan.	monitor field work proposals; selected routine administrative services including travel processing and Federal staff training 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 2017 Request will fund essential information technology infrastructure, ongoing operations and maintenance of IT systems and safety management support, as well as training for the SC workforce. The FY 2017 Request will continue to support the IT Modernization Plan.	
Other Related Expenses $26,867,000	**$38,481,000**	**+$11,614,000**
The FY 2016 Enacted includes $14,265,000 for requirements not funded through the Department's Working Capital Fund (WCF). This includes 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 includes SC-wide assessments for payroll processing and the Corporate Human Resource Information System.	The FY 2017 Request includes $12,627,000 for requirements not funded through the Department's Working Capital Fund (WCF). This includes 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 includes SC-wide assessments for payroll processing and the Corporate Human Resource Information System.	The increase is for other related expenses (non-WCF) based on current projections for SC requirements. This includes an increase of $75,000 which is requested to support IT requirements for ten permanent career FTEs in the Office of Planning and Management Oversight supporting the Office of the Under Secretary for Science and Energy.

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs. FY 2016
The FY 2016 Enacted level includes $12,602,000 to support the SC contribution to the WCF. The WCF provides for common administrative services at HQ including: rent and building operations, telecommunications, network connectivity, supplies, printing/graphics, mail, purchase card surveillance, health centers, interagency transfers associated with E-gov initiatives and costs for staff administering the WCF.	The FY 2017 Request includes $25,854,000 to support the SC contribution to the WCF. The WCF provides for common administrative services at HQ including: rent and building operations, telecommunications, network connectivity, supplies, printing/graphics, mail, purchase card surveillance, health centers, interagency transfers associated with E-gov initiatives, procurement management, iManage, A-123 internal control, pension studies, financial statement audits, overseas presence, OPM credit monitoring, and costs for staff administering the WCF.	Increased funding of $13,252,000 supports WCF requirements. This includes $10,380,000 which is transferred to PD from the SC research programs in the FY 2017 Request for a consolidated source for most of the WCF. CyberOne is still funded in the Safeguards and Security program.
WCF costs represent 47% of the Other Related Expenses Request and is an estimate based on projected usage.	WCF costs represent 67% of the Other Related Expenses Request and are based on CFO estimates.	The increase also includes $300,000 which is requested for WCF requirements associated with ten permanent career FTEs in the Office of Planning and Management Oversight supporting the Office of the Under Secretary for Science and Energy.

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 2015 Planned Cost	FY 2015 Actual Cost	FY 2016 Planned Cost	FY 2017 Planned Cost
Brookhaven National Laboratory	6,254	5,271	5,228	5,432
Fermi National Accelerator Laboratory	147	1,042	0	0
Lawrence Berkeley National Laboratory	0	0	0	6,000
Notre Dame Radiation Laboratory	172	214	175	170
Oak Ridge National Laboratory	14,000	14,869	14,420	14,853
Oak Ridge Office	3,272	3,072	4,075	6,273
Office of Scientific and Technical Information	383	383	392	402
SLAC National Accelerator Laboratory	3,322	4,408	3,667	3,883
Thomas Jefferson National Accelerator Facility	69	114	71	73
Total, Direct-Funded Maintenance and Repair	**27,619**	**29,373**	**28,028**	**37,086**

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 2015 Planned Cost	FY 2015 Actual Cost	FY 2016 Planned Cost	FY 2017 Planned Cost
Ames Laboratory	1,900	1,850	2,300	2,300
Argonne National Laboratory	46,600	57,426	48,100	49,200
Brookhaven National Laboratory	37,808	43,578	39,388	40,634
Fermi National Accelerator Laboratory	17,738	15,959	18,383	19,251
Lawrence Berkeley National Laboratory	18,400	20,814	27,450	24,700
Lawrence Livermore National Laboratory	2,813	2,813	2,869	2,926
Los Alamos National Laboratory	599	599	611	623
Oak Ridge Institute for Science and Education	443	657	443	487
Oak Ridge National Laboratory	56,993	69,116	58,703	60,464
Oak Ridge National Laboratory facilities at Y-12	761	244	400	412
Pacific Northwest National Laboratory	4,442	5,468	7,608	5,061
Princeton Plasma Physics Laboratory	6,800	7,124	7,000	7,200
Sandia National Laboratories	2,883	2,883	2,940	2,998
SLAC National Accelerator Laboratory	10,014	10,208	9,240	10,670
Thomas Jefferson National Accelerator Facility	5,800	5,963	5,900	6,500
Total, Indirect-Funded Maintenance and Repair	**213,994**	**244,702**	**231,335**	**233,426**

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 2015 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 2015 to the amount planned for FY 2015, including Congressionally directed changes.

Science
Total Costs for Maintenance and Repair ($K)

	FY 2015 Planned Costs	FY 2015 Actual Costs
Ames Laboratory	1,900	1,850
Argonne National Laboratory	46,600	57,426
Brookhaven National Laboratory	44,062	48,849
Fermi National Accelerator Laboratory	17,885	17,001
Lawrence Berkeley National Laboratory	18,400	20,814
Lawrence Livermore National Laboratory	2,813	2,813
Los Alamos National Laboratory	599	599
Notre Dame Radiation Laboratory	172	214
Oak Ridge Institute for Science and Education	443	657
Oak Ridge National Laboratory	70,993	83,985
Oak Ridge National Laboratory facilities at Y-12	761	244
Oak Ridge Office	3,272	3,072
Office of Scientific and Technical Information	383	383
Pacific Northwest National Laboratory	4,442	5,468
Princeton Plasma Physics Laboratory	6,800	7,124
Sandia National Laboratories	2,883	2,883
SLAC National Accelerator Laboratory	13,336	14,616
Thomas Jefferson National Accelerator Facility	5,869	6,077
Total, Maintenance and Repair	**241,613**	**274,075**

Science
Research and Development ($K)

	FY 2015 Enacted	FY 2015 Current[a]	FY 2016 Enacted	FY 2017 Request	FY 2017 vs. FY 2016 Enacted
Basic	4,310,357	4,333,630	4,505,148	4,827,314	+322,166
Applied	0	65,075	0	0	0
Subtotal, R&D	4,310,357	4,398,705	4,505,148	4,827,314	+322,166
Equipment	182,472	161,849	178,476	161,839	-16,637
Construction	540,636	537,986	621,772	633,465	+11,693
Total, R&D	**5,033,465**	**5,098,540**	**5,305,396**	**5,622,618**	**+317,222**

[a] Reflects the transfer of Small Business Innovation/Technology Transfer Research (SBIR/STTR) funds within and to the Office of Science.

Science
Small Business Innovative Research/Small Business Technology Transfer (SBIR/STTR) ($K)

	FY 2015 Transferred	FY 2016 Projected	FY 2017 Request	FY 2017 vs. FY 2016
Office of Science				
Advanced Scientific Computing Research				
SBIR	15,457	18,450	21,062	+2,612
STTR	2,132	2,767	2,962	+195
Basic Energy Sciences				
SBIR	44,182	47,540	54,385	+6,845
STTR	6,094	7,132	7,649	+517
Biological and Environmental Research				
SBIR	17,033	18,135	21,038	+2,903
STTR	2,349	2,720	2,958	+238
Fusion Energy Sciences				
SBIR	8,906	9,333	8,436	-897
STTR	1,228	1,400	1,186	-214
High Energy Physics				
SBIR	18,251	18,171	19,796	+1,625
STTR	2,517	2,726	2,784	+58
Nuclear Physics				
SBIR	12,967	14,134	15,824	+1,690
STTR	1,789	2,120	2,225	+105
Total, Office of Science SBIR	**116,796**	**125,763**	**140,541**	**+14,778**
Total, Office of Science STTR	**16,109**	**18,865**	**19,764**	**+899**
Other DOE				
Nuclear Energy				
SBIR	11,992	TBD	TBD	TBD
STTR	1,654	TBD	TBD	TBD
Electricity Delivery & Energy Reliability				
SBIR	2,702	TBD	TBD	TBD
STTR	373	TBD	TBD	TBD
Energy Efficiency & Renewable Energy				
SBIR	25,765	TBD	TBD	TBD
STTR	3,333	TBD	TBD	TBD
Environmental Management				
SBIR	406	TBD	TBD	TBD
STTR	56	TBD	TBD	TBD

	FY 2015 Transferred	FY 2016 Projected	FY 2017 Request	FY 2017 vs. FY 2016
Defense Nuclear Nonproliferation				
SBIR	6,233	TBD	TBD	TBD
STTR	860	TBD	TBD	TBD
Fossil Energy				
SBIR	10,283	TBD	TBD	TBD
STTR	1,418	TBD	TBD	TBD
Total, Other DOE SBIR	**57,381**	**TBD**	**TBD**	**TBD**
Total, Other DOE STTR	**7,694**	**TBD**[a]	**TBD**[a]	**TBD**[a]
Total, DOE SBIR	**174,177**	**125,763**	**140,541**	**+14,778**
Total, DOE STTR	**23,803**	**18,865**	**19,764**	**+899**

[a] The DOE SBIR/STTR amounts are listed in the other DOE program budget volumes and will be reflected in the Science budget once transferred.

Science
Safeguards and Security Crosscut ($K)

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs. FY 2016 Enacted
Protective Forces	38,095	37,767	38,805	39,638	+833
Physical Security Systems	12,601	11,314	12,019	10,357	-1,662
Information Security	4,252	4,268	4,416	4,467	+51
Cyber Security	24,118	25,781	33,156	33,236	+80
Personnel Security	5,267	5,335	5,412	6,086	+674
Material Control and Accountability	2,223	2,256	2,454	2,458	+4
Program Management	6,444	6,279	6,738	6,758	+20
Total, Safeguards and Security Crosscut	**93,000**	**93,000**	**103,000**	**103,000**	**–**

Center/Appropriation/ Program	Date Established	Termination/ Review Date	Prior Year Funding	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	Total Funding
Energy Innovation Hubs: Batteries and Energy Storage							
Funded by SC, the Batteries and Energy Storage Hub focuses on discovery of new energy storage chemistries through the development of an atomic-level understanding of reaction pathways and development of universal design rules for electrolyte function. In response to a competitive Funding Opportunity Announcement in FY 2012, the Joint Center for Energy Storage Research (JCESR) received a five-year award starting 12/14/2012. The potential for a subsequent five-year renewal is contingent on progress in the first performance period, which is externally reviewed annually. The overarching goals of JCESR that drive the scientific and engineering research towards next-generation energy storage technologies are summarized as 5/5/5—five times the energy density of current systems at one-fifth the cost within five years.							
Science: Basic Energy Sciences							
Materials Sciences and Engineering	FY 2012	Reviewed Annually	$67,884	$24,175	$24,137	$24,088	$140,284

Center/Appropriation/ Program	Date Established	Termination/ Review Date	Prior Year Funding	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	Total Funding
Energy Innovation Hubs: Fuels from Sunlight							
Funded by SC, the Joint Center for Artificial Photosynthesis (JCAP) focuses on critical transformative advances in the development of artificial photosynthetic systems for converting sunlight, water, and carbon dioxide into a range of commercially useful fuels. In the initial award, JCAP primarily targeted the solar-driven production of hydrogen fuel and reached its five-year goal to design and develop a photocatalytic prototype capable of generating fuel, hydrogen, from sunlight. In December 2014, BES solicited a renewal proposal from JCAP for a final award term with a maximum duration of five years and directed JCAP to focus on the fundamental science of carbon dioxide reduction, a critical need for efficient solar-driven production of carbon-based liquid transportation fuels. Based on the outcome of external peer review, the Fuels from Sunlight Hub was renewed by BES for a second and final five-year award term starting on September 30, 2015, at an annual funding level of $15M. In this second phase, JCAP will discover and develop new materials and catalysts for the reduction of carbon dioxide using both direct and high throughput approaches. These discoveries would be key components in the development of an artificial photosynthetic system capable of efficient solar-driven production of carbon-based fuels.							
Science: Basic Energy Sciences							
Chemical Sciences, Geosciences, and Biosciences	FY 2010	Reviewed Annually	$94,737	$15,000	$15,000	$15,000	$139,737[a]

[a]Total funding does not included $22M appropriated to EERE for the first year of the Hub.

Center/Appropriation/ Program	Date Established	Termination/ Review Date	Prior Year Funding	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	Total Funding
Energy Frontier Research Centers							
The Energy Frontier Research Centers (EFRCs) support multi-disciplinary teams of leading scientists to conduct fundamental research aimed at accelerating innovation toward meeting critical energy challenges. These integrated, multi-investigator Centers involve partnerships among universities, national laboratories, nonprofit organizations, and for-profit firms that will conduct fundamental research focusing on one or more “grand challenges” and use-inspired “basic research needs” identified in major strategic planning efforts by the scientific community. The EFRC program was initiated by BES in 2009 with 46 five-year awards, 16 of which were fully funded through $277M in funds from the American Recovery and Reinvestment Act. The program was recompeted in FY 2014 with an open solicitation for both new and renewal proposals, resulting in 32 four-year awards (22 renewal and 10 new). During FY 2016 all 32 EFRCs will undergo a full mid-term progress review involving external peer reviewers. Funding for the final two years of these awards will be contingent upon a successful outcome of this review. The FY 2017 Request includes an additional $33.8M to fully fund up to five new EFRCs in topical areas in support of the Subsurface crosscut.							
Science: Basic Energy Sciences							
Materials Sciences and Engineering	FY 2009	Mid-term Reviews, FY 2016 Q2	$461,950	$50,800	$55,800	$55,800	$624,350
Chemical Sciences, Geosciences, and Biosciences	FY 2009	Mid-term Reviews, FY 2016 Q2	$415,070	$49,200	$54,200	$86,766	$605,236

Center/Appropriation/ Program	Date Established	Termination/ Review Date	Prior Year Funding	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	Total Funding
India Center							
The purpose of the Center is to facilitate joint research and development on clean energy by teams of scientists and engineers from India and the United States, and related joint activities, needed to deploy clean energy technologies rapidly with the greatest impact. For the Solar Energy Research Institute for India and the United States (SERIIUS) of high priority are new concepts and architectures in solar electricity production, including organic and hybrid organic/inorganic conversion systems, innovative nanoscale designs of interfaces and cells, and novel materials, as well as advanced theory, modeling and simulation of such systems. The overall goal of SERIIUS is to accelerate the development of solar-electric technologies by lowering the cost-per-watt of photovoltaics (PV) and concentrated solar power (CSP) through a binational consortium that is innovating, discovering, and readying emerging, disruptive, and revolutionary solar technologies that span the gap between fundamental science and applied research and development (R&D), leading to eventual deployment by sustainable industries. SERIIUS addresses critical issues in fundamental and applied research, analysis and assessment, outreach, and workforce development. Throughout this joint effort, a key element is the engagement of a significant base of Indian and U.S. industry that is dedicated and committed to developing solar energy for both India and the United States.							
Science: Basic Energy Sciences							
Materials Sciences and Engineering	FY 2013	Mid-term Reviews, FY 2016	$1,875	$625	$625	$625	$3,750
Chemical Sciences, Geosciences, and Biosciences	FY 2013	Mid-term Reviews, FY 2016	$1,875	$625	$625	$625	$3,750

Center/Appropriation/ Program	Date Established	Termination/ Review Date	Prior Year Funding	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	Total Funding
Bioenergy Research Center: Joint Bioenergy Institute							
Major multidisciplinary research center conducting research to achieve the breakthroughs in basic science needed to develop new methods of producing cellulosic biofuels sustainably and cost-effectively on a commercial scale.							
Science: Biological Environmental Research							
Biological Systems Science	9/27/2007	9/30/2017	$189,012	$25,000	$25,000	$29,850	$268,862

Center/Appropriation/ Program	Date Established	Termination/ Review Date	Prior Year Funding	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	Total Funding
Bioenergy Research Center: Bioenergy Science Institute							
Major multidisciplinary research center conducting research to achieve the breakthroughs in basic science needed to develop new methods of producing cellulosic biofuels sustainably and cost-effectively on a commercial scale.							
Science: Biological Environmental Research							
Biological Systems Science	9/27/2007	9/30/2017	$190,335	$25,000	$25,000	$29,850	$270,185

Center/Appropriation/ Program	Date Established	Termination/ Review Date	Prior Year Funding	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	Total Funding
Bioenergy Research Center: Great Lakes Bioenergy Research Centers							
Major multidisciplinary research center conducting research to achieve the breakthroughs in basic science needed to develop new methods of producing cellulosic biofuels sustainably and cost-effectively on a commercial scale.							
Science: Biological Environmental Research							
Biological Systems Science	9/27/2007	11/30/2017	$189,073	$25,000	$25,000	$29,850	$268,923

Center/Appropriation/ Program	Date Established	Termination/ Review Date	Prior Year Funding	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	Total Funding
U.S. - China Clean Energy Research Center (CERC)							
CERC focuses on research in areas where advances in technology can lead to major improvements in energy efficiency in buildings, development of vehicles with lower carbon emissions and deployment of clean coal technologies. The Center facilitates joint research and development on clean energy by teams of scientists and engineers from the U.S. and China, as well as serves as a clearinghouse to help researchers in each country with broad participation from universities, research institutions, and industry. U.S. funds will be used exclusively to support work conducted by U.S. institutions and individuals only, and Chinese funds will support work conducted by Chinese institutions and researchers.							
Science: Biological Environmental Research							
Climate and Environmental Sciences	2009	2019	$0	$299	$299	$299	$897

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 for 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] More than 17 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 2015, the Isotope Program organized its fourth 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

[a] http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/med-use-radioactive-materials.html
[b] http://www.snmmi.org/NewsPublications/NewsDetail.aspx?ItemNumber=9953

capabilities, including facilities at the University of Washington, Duke University, Washington University, Texas A&M University, the University of California at Davis, and the Missouri University Research Reactor. Most of these facilities reside in university medical departments.

In FY 2015, a total of $52.65 million was deposited in the revolving fund. This consisted of the FY 2015 appropriation of $19.85 million paid into the revolving fund from the Nuclear Physics program, plus collections of $32.80 million to recover costs related to isotope production and isotope services. Collections in FY 2015 included sales of californium-252, helium-3, selenium-75, 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; and strontium-82 has gained world-wide acceptance for use in heart imaging. In FY 2015, the Isotope Program served more than 140 customers including major pharmaceutical companies, industrial users, and researchers at hospitals, national laboratories, other Federal agencies, universities, and private companies, with the sale of more than 170 different radioactive and stable isotopes. Among the isotopes produced, seven 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

Production of high purity cobalt-60 to support cancer therapy. High purity cobalt-60 is necessary for surgical devices that can treat cancers—in some cases, inoperable tumors—in a less debilitating and more effective manner than alternative treatments. Such devices use high purity cobalt-60 sources to generate highly focused gamma-ray beams for the destruction of tumors with surgical precision without invasive open surgery. The precision of this technique facilitates the eradication of tumor cells while sparing surrounding healthy tissue. In response to the failure of a cobalt-60 production target at the Idaho National Laboratory (INL) that brought cobalt-60 production to a halt in 2012, a team of scientists and engineers from INL and the Oak Ridge National Laboratory designed a robust production target that can be used to resume production with the level of safety and reliability necessary for Department of Energy research reactors. In addition to increased safety and reliability, the new target design also increases production in each target, resulting in more cost-effective production of cobalt-60. Targets of the new design were placed in the Advanced Test Reactor at INL in FY 2015, alleviating a concern about the unavailability of high purity cobalt-60 that could impact the treatment of thousands of cancer patients.

Establishing a lithium-7 reserve and providing emergency supply for nuclear power plant operations. Many of the nation's nuclear power plants require high-enrichment lithium-7 hydroxide to maintain proper chemical conditions in reactor coolant systems. Domestic nuclear utilities are completely reliant upon foreign producers and imports to meet their needs. Owing to concerns about this supply chain, the DOE Isotope Program worked with NNSA to set aside a reserve of legacy Li-7 and is now processing that material at the Y-12 National Security Complex so DOE can mitigate potential domestic supply emergencies. Purification processing commenced in FY 2015.

Highlights of the FY 2017 Budget Request

For FY 2017, the Department foresees moderate growth in isotope demand. The portfolio of the isotope program continues to grow as isotope availability is increased by the program to meet rising demands. 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. Since FY 2009, investments have been made in R&D associated with the re-establishment of a Federal stable isotope enrichment capability, as recommended by the Nuclear Science Advisory Committee. The U.S. government has not had an isotope enrichment capability since 1998. Since that time, inventories of some enriched stable isotopes have been depleted, forcing researchers to rely upon uncertain international supplies. The R&D effort to develop stable isotope separation technology at ORNL is on track for completion in FY 2016 with a prototype capability to produce small research quantities of enriched stable isotopes starting in FY 2017. Building upon this R&D capability, funding to initiate the Stable Isotope Production Facility Major Item of Equipment is proposed in FY 2017 in the Nuclear Physics budget. The Facility will provide a cost-effective domestic capability for production of enriched stable isotopes.[a] This will help mitigate dependence of the U.S. on foreign suppliers.

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[a] See the Science/Nuclear Physics chapter for more information.

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Science	FY 2015 Current	FY 2016 Enacted	FY 2017 Request
Ames Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	95	98	0
Basic Energy Sciences			
Basic Energy Sciences	22,604	19,651	19,651
Biological and Environmental Research			
Biological and Environmental Research	200	200	200
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	480	0	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	0	0	2,000
Safeguards and Security			
Safeguards and Security	1,084	1,219	1,231
Total, Ames Laboratory	**24,463**	**21,168**	**23,082**
Ames Site Office			
Program Direction			
Program Direction	460	474	489
Total, Ames Site Office	**460**	**474**	**489**
Argonne National Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	107,220	91,999	84,152
Basic Energy Sciences			
Basic Energy Sciences	241,517	239,914	244,511
Biological and Environmental Research			
Biological and Environmental Research	30,723	28,716	26,706
High Energy Physics			
High Energy Physics	20,693	16,168	15,765
Nuclear Physics			
Nuclear Physics	28,288	28,846	29,543
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	1,246	0	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	7,000	27,510	19,590
Safeguards and Security			
Safeguards and Security	9,644	8,858	9,240
Total, Argonne National Laboratory	**446,331**	**442,011**	**429,507**
Argonne Site Office			
Program Direction			
Program Direction	3,820	3,762	4,017
Total, Argonne Site Office	**3,820**	**3,762**	**4,017**

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Science	FY 2015 Current	FY 2016 Enacted	FY 2017 Request
Berkeley Site Office			
Program Direction			
Program Direction	3,513	3,287	3,730
Total, Berkeley Site Office	**3,513**	**3,287**	**3,730**
Brookhaven National Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	710	200	200
Basic Energy Sciences			
Basic Energy Sciences	187,626	187,573	173,314
Biological and Environmental Research			
Biological and Environmental Research	14,809	10,558	9,690
High Energy Physics			
High Energy Physics	64,580	64,168	63,436
Nuclear Physics			
Nuclear Physics	183,472	190,229	197,547
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	2,008	0	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	0	0	1,800
Safeguards and Security			
Safeguards and Security	12,006	12,151	12,369
Total, Brookhaven National Laboratory	**465,211**	**464,879**	**458,356**
Brookhaven Site Office			
Program Direction			
Program Direction	4,861	4,818	5,541
Total, Brookhaven Site Office	**4,861**	**4,818**	**5,541**

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Science	FY 2015 Current	FY 2016 Enacted	FY 2017 Request
Chicago Operations Office			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	39,507	47,591	15,155
Basic Energy Sciences			
Basic Energy Sciences	302,083	294,051	342,612
Biological and Environmental Research			
Biological and Environmental Research	124,881	98,211	91,347
Fusion Energy Sciences			
Fusion Energy Sciences	162,565	95,694	86,503
High Energy Physics			
High Energy Physics	118,147	111,010	110,480
Nuclear Physics			
Nuclear Physics	169,947	174,515	173,433
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	1,401	1,713	1,764
Safeguards and Security			
Safeguards and Security	44	45	45
Program Direction			
Program Direction	26,920	24,925	25,128
Small Business Innovation/Technology Transfer Research			
Small Business Innovation/Technology Transfer Research	197,502	0	0
Total, Chicago Operations Office	**1,142,997**	**847,755**	**846,467**
Fermi National Accelerator Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	1,809	80	530
Basic Energy Sciences			
Basic Energy Sciences	675	0	0
High Energy Physics			
High Energy Physics	366,745	357,935	386,303
Nuclear Physics			
Nuclear Physics	755	25	25
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	210	0	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	0	9,000	2,500
Safeguards and Security			
Safeguards and Security	3,734	5,064	5,281
Total, Fermi National Accelerator Laboratory	**373,928**	**372,104**	**394,639**

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Science	FY 2015 Current	FY 2016 Enacted	FY 2017 Request
Fermi Site Office			
Program Direction			
Program Direction	2,277	2,496	2,640
Total, Fermi Site Office	**2,277**	**2,496**	**2,640**
Idaho National Laboratory			
Basic Energy Sciences			
Basic Energy Sciences	500	0	0
Fusion Energy Sciences			
Fusion Energy Sciences	3,101	2,700	2,500
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	436	0	0
Total, Idaho National Laboratory	**4,037**	**2,700**	**2,500**
Lawrence Berkeley National Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	149,089	145,158	148,793
Basic Energy Sciences			
Basic Energy Sciences	156,908	156,239	154,817
Biological and Environmental Research			
Biological and Environmental Research	147,974	144,490	128,614
Fusion Energy Sciences			
Fusion Energy Sciences	2,082	0	0
High Energy Physics			
High Energy Physics	67,235	84,273	76,979
Nuclear Physics			
Nuclear Physics	18,418	19,372	19,076
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	1,702	0	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	12,090	20,000	28,561
Safeguards and Security			
Safeguards and Security	6,033	7,085	7,169
Total, Lawrence Berkeley National Laboratory	**561,531**	**576,617**	**564,009**

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Science	FY 2015 Current	FY 2016 Enacted	FY 2017 Request
Lawrence Livermore National Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	64,469	6,026	3,418
Basic Energy Sciences			
Basic Energy Sciences	3,495	2,964	2,964
Biological and Environmental Research			
Biological and Environmental Research	21,200	19,789	20,160
Fusion Energy Sciences			
Fusion Energy Sciences	13,996	7,537	6,540
High Energy Physics			
High Energy Physics	15,670	1,245	1,150
Nuclear Physics			
Nuclear Physics	1,319	823	688
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	374	0	0
Total, Lawrence Livermore National Laboratory	**120,523**	**38,384**	**34,920**
Los Alamos National Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	9,063	6,503	2,045
Basic Energy Sciences			
Basic Energy Sciences	25,648	26,562	26,879
Biological and Environmental Research			
Biological and Environmental Research	25,791	23,640	20,033
Fusion Energy Sciences			
Fusion Energy Sciences	3,824	1,986	1,540
High Energy Physics			
High Energy Physics	3,382	2,070	2,100
Nuclear Physics			
Nuclear Physics	9,285	10,219	9,704
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	522	0	0
Total, Los Alamos National Laboratory	**77,515**	**70,980**	**62,301**
National Energy Technology Lab			
Basic Energy Sciences			
Basic Energy Sciences	150	150	150
Total, National Energy Technology Lab	**150**	**150**	**150**

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Science	FY 2015 Current	FY 2016 Enacted	FY 2017 Request
National Renewable Energy Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	266	173	0
Basic Energy Sciences			
Basic Energy Sciences	14,724	12,955	12,955
Biological and Environmental Research			
Biological and Environmental Research	880	886	500
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	968	0	0
Total, National Renewable Energy Laboratory	**16,838**	**14,014**	**13,455**
Nevada Field Office			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	0	0	0
Biological and Environmental Research			
Biological and Environmental Research	0	0	0
Total, Nevada Field Office	**0**	**0**	**0**
Nevada Operations Office			
Basic Energy Sciences			
Basic Energy Sciences	380	0	0
Total, Nevada Operations Office	**380**	**0**	**0**
New Brunswick Laboratory			
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	4,900	1,200	2,403
Program Direction			
Program Direction	5,149	3,822	4,345
Total, New Brunswick Laboratory	**10,049**	**5,022**	**6,748**

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Science	FY 2015 Current	FY 2016 Enacted	FY 2017 Request
Oak Ridge Institute for Science & Education			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	1,664	500	1,600
Basic Energy Sciences			
Basic Energy Sciences	1,606	250	250
Biological and Environmental Research			
Biological and Environmental Research	1,504	1,983	2,113
Fusion Energy Sciences			
Fusion Energy Sciences	1,529	444	546
High Energy Physics			
High Energy Physics	1,098	0	0
Nuclear Physics			
Nuclear Physics	542	353	467
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	9,616	2,500	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	1,000	1,000	1,000
Safeguards and Security			
Safeguards and Security	1,736	1,883	1,925
Total, Oak Ridge Institute for Science & Education	**20,295**	**8,913**	**7,901**
Oak Ridge National Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	123,927	115,256	111,077
Basic Energy Sciences			
Basic Energy Sciences	311,963	325,402	322,640
Biological and Environmental Research			
Biological and Environmental Research	77,354	75,029	61,539
Fusion Energy Sciences			
Fusion Energy Sciences	172,716	127,759	139,551
Nuclear Physics			
Nuclear Physics	19,698	19,265	18,643
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	0	12,000	26,000
Safeguards and Security			
Safeguards and Security	9,955	12,374	12,374
Total, Oak Ridge National Laboratory	**715,613**	**687,085**	**691,824**
Oak Ridge National Laboratory Site Office			
Program Direction			
Program Direction	5,837	5,841	6,470
Total, Oak Ridge National Laboratory Site Office	**5,837**	**5,841**	**6,470**

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Science	FY 2015 Current	FY 2016 Enacted	FY 2017 Request
Oak Ridge Office			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	0	0	0
Basic Energy Sciences			
Basic Energy Sciences	85	0	0
Biological and Environmental Research			
Biological and Environmental Research	0	0	0
Nuclear Physics			
Nuclear Physics	0	437	446
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	5,777	6,177	6,182
Safeguards and Security			
Safeguards and Security	19,982	21,017	21,740
Program Direction			
Program Direction	30,048	27,630	29,125
Small Business Innovation/Technology Transfer Research			
Small Business Innovation/Technology Transfer Research	433	0	0
Total, Oak Ridge Office	**56,325**	**55,261**	**57,493**
Office of Scientific & Technical Information			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	153	140	140
Basic Energy Sciences			
Basic Energy Sciences	195	138	138
Biological and Environmental Research			
Biological and Environmental Research	20	0	148
Fusion Energy Sciences			
Fusion Energy Sciences	150	0	0
High Energy Physics			
High Energy Physics	165	141	0
Nuclear Physics			
Nuclear Physics	157	143	146
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	70	0	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	200	200	200
Safeguards and Security			
Safeguards and Security	831	609	784
Program Direction			
Program Direction	8,481	8,404	9,534
Total, Office of Scientific & Technical Information	**10,422**	**9,775**	**11,090**

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Science	FY 2015 Current	FY 2016 Enacted	FY 2017 Request
Pacific Northwest National Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	7,816	7,464	2,893
Basic Energy Sciences			
Basic Energy Sciences	28,823	24,015	24,062
Biological and Environmental Research			
Biological and Environmental Research	109,432	107,250	103,436
Fusion Energy Sciences			
Fusion Energy Sciences	1,313	1,313	1,163
High Energy Physics			
High Energy Physics	3,526	2,725	3,375
Nuclear Physics			
Nuclear Physics	675	500	500
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	1,020	0	0
Safeguards and Security			
Safeguards and Security	11,701	13,126	12,839
Total, Pacific Northwest National Laboratory	**164,306**	**156,393**	**148,268**
Pacific Northwest Site Office			
Program Direction			
Program Direction	4,863	4,650	5,008
Total, Pacific Northwest Site Office	**4,863**	**4,650**	**5,008**
Princeton Plasma Physics Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	295	295	0
Basic Energy Sciences			
Basic Energy Sciences	435	435	435
Fusion Energy Sciences			
Fusion Energy Sciences	86,209	71,562	73,712
High Energy Physics			
High Energy Physics	200	200	200
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	148	0	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	3,100	0	0
Safeguards and Security			
Safeguards and Security	2,503	2,477	2,535
Total, Princeton Plasma Physics Laboratory	**92,890**	**74,969**	**76,882**

Department Of Energy
FY 2017 Congressional Budget
Funding By Appropriation By Site
($K)

Science	FY 2015 Current	FY 2016 Enacted	FY 2017 Request
Princeton Site Office			
Program Direction			
Program Direction	1,419	1,408	1,623
Total, Princeton Site Office	**1,419**	**1,408**	**1,623**
Sandia National Laboratories			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	14,969	8,883	2,240
Basic Energy Sciences			
Basic Energy Sciences	35,384	33,416	33,749
Biological and Environmental Research			
Biological and Environmental Research	10,351	9,851	9,572
Fusion Energy Sciences			
Fusion Energy Sciences	3,345	1,355	2,043
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	110	0	0
Total, Sandia National Laboratories	**64,159**	**53,505**	**47,604**
Savannah River National Laboratory			
Basic Energy Sciences			
Basic Energy Sciences	417	417	417
Biological and Environmental Research			
Biological and Environmental Research	50	0	0
Total, Savannah River National Laboratory	**467**	**417**	**417**

Department Of Energy
FY 2017 Congressional Budget
Funding By Appropriation By Site
($K)

Science	FY 2015 Current	FY 2016 Enacted	FY 2017 Request
SLAC National Accelerator Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	447	374	0
Basic Energy Sciences			
Basic Energy Sciences	342,792	400,159	396,583
Biological and Environmental Research			
Biological and Environmental Research	4,945	3,871	3,900
Fusion Energy Sciences			
Fusion Energy Sciences	5,490	4,750	5,250
High Energy Physics			
High Energy Physics	81,386	98,214	101,708
Nuclear Physics			
Nuclear Physics	134	0	0
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	280	0	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	17,920	34,800	30,000
Safeguards and Security			
Safeguards and Security	4,110	4,096	4,255
Total, SLAC National Accelerator Laboratory	**457,504**	**546,264**	**541,696**
Stanford Site Office			
Program Direction			
Program Direction	2,472	2,355	2,426
Total, Stanford Site Office	**2,472**	**2,355**	**2,426**

Department Of Energy
FY 2017 Congressional Budget
Funding By Appropriation By Site
($K)

Science	FY 2015 Current	FY 2016 Enacted	FY 2017 Request
Thomas Jefferson National Accelerator Facility			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	279	284	0
Basic Energy Sciences			
Basic Energy Sciences	500	500	500
Biological and Environmental Research			
Biological and Environmental Research	40	0	0
High Energy Physics			
High Energy Physics	325	0	0
Nuclear Physics			
Nuclear Physics	126,358	117,590	114,365
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	280	0	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	0	0	8,000
Safeguards and Security			
Safeguards and Security	1,853	2,563	2,709
Total, Thomas Jefferson National Accelerator Facility	**129,635**	**120,937**	**125,574**
Thomas Jefferson Site Office			
Program Direction			
Program Direction	1,856	1,813	2,050
Total, Thomas Jefferson Site Office	**1,856**	**1,813**	**2,050**

Department Of Energy
FY 2017 Congressional Budget
Funding By Appropriation By Site
($K)

Science	FY 2015 Current	FY 2016 Enacted	FY 2017 Request
Washington Headquarters			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	1,633	189,976	290,937
Basic Energy Sciences			
Basic Energy Sciences	4,414	124,209	180,103
Biological and Environmental Research			
Biological and Environmental Research	2,464	84,526	183,962
Fusion Energy Sciences			
Fusion Energy Sciences	1,046	122,900	78,830
High Energy Physics			
High Energy Physics	2,080	56,851	56,501
Nuclear Physics			
Nuclear Physics	21,696	54,783	71,075
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	30	17,000	20,925
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	26,212	0	0
Safeguards and Security			
Safeguards and Security	7,784	10,433	8,504
Program Direction			
Program Direction	81,724	89,315	102,355
Small Business Innovation/Technology Transfer Research			
Small Business Innovation/Technology Transfer Research	45	0	0
Total, Washington Headquarters	**149,128**	**749,993**	**993,192**
Total, Science	**5,136,075**	**5,350,200**	**5,572,069**

Advanced Research Projects Agency - Energy

Advanced Research Projects Agency - Energy

Advanced Research Projects Agency – Energy (ARPA-E)

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Advanced Research Projects Agency - Energy
Proposed Appropriation Language

For Department of Energy expenses necessary in carrying out the activities authorized by section 5012 of the America COMPETES Act (Public Law 110-69), as amended, [$291,000,000] *$350,000,000*, to remain available until expended: Provided, that of such amount [$29,250,000] *$32,000,000* shall be available until September 30, [2017] *2018* for program direction.

Explanation of Changes

The $350,000,000 request for FY 2017 is a $59,000,000 increase over the FY 2016 enacted level. The increase in funding will enable ARPA-E to fund additional early-stage, innovative energy technologies as well as exploit the technological opportunities developed in previous ARPA-E programs, leading to transformational energy technologies.

This discretionary funding request is coupled with a legislative proposal to create an ARPA-E Trust that would provide an additional $1,850,000,000 in mandatory funding over five years. $150,000,000 of this mandatory funding is requested for FY 2017. This legislative proposal will add specific targeted activities to create investable outcomes from ARPA-E's continued support of transformational energy technologies.

Public Law Authorizations
P.L. 95-91, "Department of Energy Organization Act" (1977)
P.L. 109-58, "Energy Policy Act of 2005"
P.L. 110-69, "America COMPETES Act of 2007"
P.L. 111-358, "America COMPETES Reauthorization Act of 2010"

Advanced Research Projects Agency - Energy
($K)

FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request
279,982	279,982	291,000	500,000

Overview
As defined by its authorization under the America COMPETES Act, the Advanced Research Projects Agency-Energy (ARPA-E) catalyzes transformational energy technologies to enhance the economic and energy security of the United States. ARPA-E funds high-potential, high-impact energy projects that are too early for private sector investment but could significantly advance the ways we generate, store, distribute and use energy. ARPA-E plays a unique role in DOE's research and development R&D organization, complementing and expanding the impact of DOE's basic science and applied energy programs.

ARPA-E focuses on energy technologies that can be meaningfully advanced with a targeted investment over a defined period of time. ARPA-E's rigorous program design, close coordination with other DOE offices and federal agencies, competitive project selection process, and hands-on engagement, ensure thoughtful expenditures while empowering America's energy researchers with funding, technical assistance, and market awareness.

ARPA-E was established by the America COMPETES Act of 2007 following a recommendation by the National Academies in the *Rising above the Gathering Storm* report. As of December 2015, ARPA-E has funded over 450 projects with approximately $1.3 billion through 29 focused programs and open funding solicitations.

Highlights and Major Changes in the FY 2017 Budget Request
Under the Budget Request for FY 2017, ARPA-E expects to release funding opportunity announcements (FOA) for seven to eight focused technology programs, slightly increase funding for Innovative Development in Energy-Related Applied Sciences (IDEAS) proposals, and potentially run a technology prize competition. In addition, funding will support opportunities for qualification and field testing, thereby further de-risking these technologies and increasing the likelihood that projects will receive private sector investment. In keeping with a multi-year cycle for OPEN solicitations (2009, 2012, and 2015), ARPA-E does not anticipate an open solicitation in FY 2017. In FY 2017, ARPA-E will continue its stand-alone Small Business Innovation Research / Small Business Technology Transfer (SBIR/STTR) program to provide additional support to small businesses beyond the significant number of awards that go to small businesses via ARPA-E's standard FOA process.

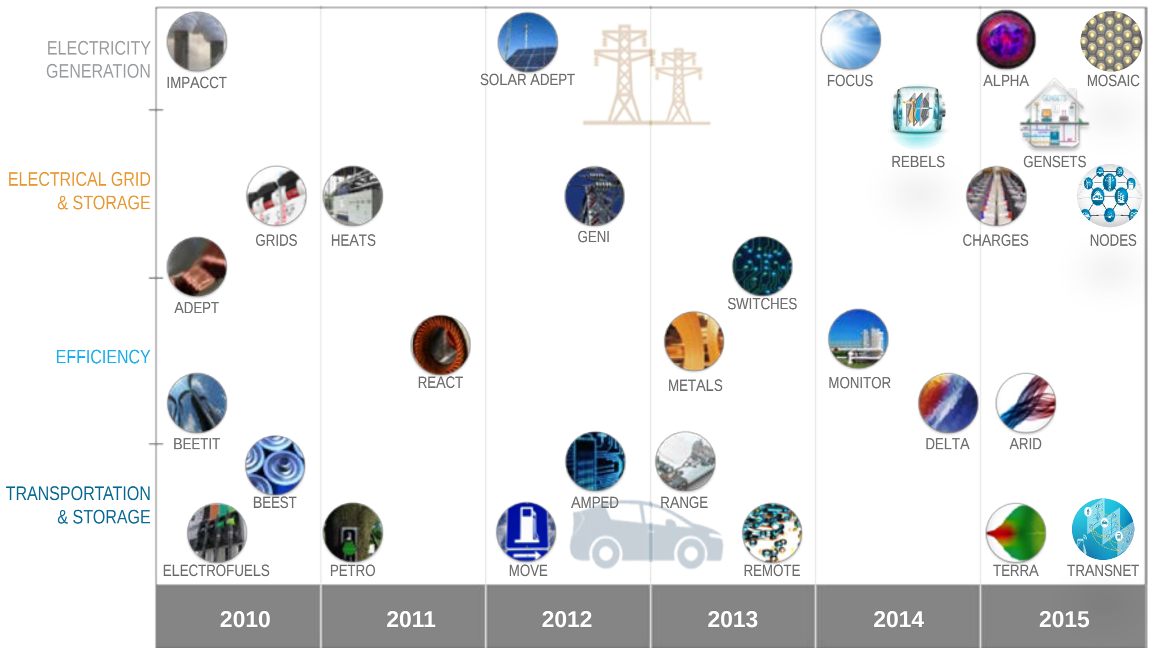
In addition to the FY 2017 Budget Request, an authorization proposal of $150 million in mandatory funding in 2017 as part of a larger, new legislative proposal, the "Advanced Research Projects Agency – Energy Trust" program, will be transmitted to Congress. This would provide a total FY 2017 Budget of $500 million. The full authorization proposal would seek $1.85 billion for ARPA-E over 5 years. In addition to the $150 million in FY 2017, this would include $250 million in FY 2018, $350 million in FY 2019, $450 million in FY 2020, and $650 million in FY 2021. These funds will provide a reliable stream of funding to create a complementary new effort that will expand ARPA-E's impact. A significant focus of this expanded effort will be on accelerating technologies that have demonstrated significant early-stage success toward readiness for private-sector investment. Combined with ARPA-E's annual appropriations, this will result in a total funding level of approximately $1 billion in 2021.

Background Narrative
In its first six years, ARPA-E has established a nimble, effective management structure and developed a portfolio of technical programs that is delivering innovative, investable opportunities to the commercial sector. ARPA-E will continue to deliver value to the US economy with continued emphasis on maintaining a healthy portfolio of projects. These projects cover a broad range of energy topics, with a growing focus on additional scale-up of the most promising projects that have demonstrated success in technical development, project management and definition of commercial pathways. Under the proposed mandatory funding, ARPA-E will add a new focus on innovative systems level development that will deliver larger, more rapid impacts from the transformational energy technologies developed under ARPA-E's existing core programs, while the dynamic core program activities will continue to be supported under discretionary funding.

Breadth and Increased Value Opportunity of the ARPA-E Portfolio

ARPA-E is tasked to identify and support revolutionary energy inventions and transformational energy technology advances, which requires constant evolution of its programmatic focus. This is accomplished by establishing dynamic technical programs (each lasting about 3 years) designed to accelerate innovation in high-potential areas. ARPA-E's FY 2016 funding level of $291 million can support development of about five to seven new $25-35 million programs per year and one $125 million to $175 million OPEN solicitation every three years. The breadth of the program portfolio that has developed over ARPA-E's lifetime is shown below, where new programs address different parts of the energy technology space from year to year. Each of the programs illustrated, as well as the OPEN programs, supports a range of individual projects that form a sustained investment in early-stage, innovative technologies that advance from early stage concepts to prototype levels of readiness under ARPA-E support.

Figure 1: ARPA-E Portfolio of Focused Programs: Each symbol indicates the start year for a new three-year program. The annual variability in program starts reflects the impact of tri-annual OPEN solicitations, funding variation, and appropriations dates.



ARPA-E addresses its establishment purpose, 'to overcome the long-term and high-risk technological barriers in the development of energy technologies,' by using a project portfolio funding approach to 'de-risk' areas of technological opportunity. To accomplish this, each program contains a portfolio of different, high-risk projects taking different approaches to the aggressive technical goals set by the program. Over the course of project execution, the most effective approaches emerge based on their technical performance. During the rigorous award selection process, significantly more projects that have the potential to add high value to the portfolio are identified than can be funded, which limits the number of technical options available to achieve the program goals. ARPA-E engages in an initial down-select process whereby only a subset of submitted concept papers is recommended for full applications. Within this more promising cadre of applications:

- Of 28 Focused FOAs: 34% of the submitted concept papers were selected for full applications and only 1/3 of the resulting full applications were selected for funding;
- Of 3 OPEN FOAs: 11% of the submitted concept papers were selected for full applications and only one eighth of the resulting full applications were selected for funding.

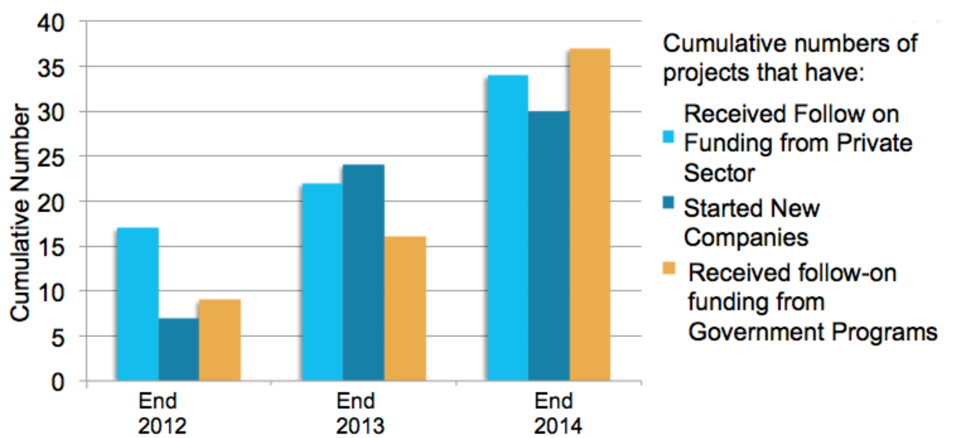
Sustaining project breadth is possible because of the opportunities presented by the U.S. energy entrepreneurs that ARPA-E (and the country as a whole) draws on for innovation. In parallel, the value proposition of sustaining breadth in ARPA-E's program and project portfolios includes strengthening opportunities for US innovation in energy technologies.

As ARPA-E identifies continuing areas of innovation, there are increasing opportunities to expand the breadth of topical areas to include technical opportunities that require more significant technical investments, such as innovations in manufacturing scale-up and new opportunities from unconventional integration of component-level advances. Maintaining a dynamic, broad portfolio of innovative programs that includes more complex projects, and further advancing successful mature projects toward investment-readiness, are essential to drawing full value from ARPA-E's investment in high-potential projects.

Depth and Increased Value Delivery of ARPA-E Investments

A significant component of ARPA-E's mission and goals involves accelerating the economic impact of US investments in energy R&D, and advancing the commercialization readiness of successful projects (depth of investment) is essential in doing so. Developing the pathway to commercial applications is an intrinsic component of all projects, and project teams are required to spend at least 5% of their budgets on activities such as techno-economic analysis, market research, intellectual property protection, and engagement with potential customers and investors. As project teams demonstrate success, ARPA-E's Technology-to-Market Advisors and Program Directors work closely with the teams to help identify pathways toward commercial deployment. Many of ARPA-E's alumni projects have been able to obtain follow-on funding from private investors, state agencies and/or federal programs, and ARPA-E's maturing portfolio is offering increasing opportunities for commercialization of ARPA-E funded technologies.

Figure 2: Early Success Metric: Between its inception in 2009 and February 2015, ARPA-E had invested approximately $1.1 billion across more than 400 projects through 23 focused programs and two open funding solicitations and 141 of those projects had completed their work under ARPA-E support. Some 34 ARPA-E projects had attracted more than $850 million in private-sector follow-on funding



However, as ARPA-investments have developed a healthy portfolio of mature, high-potential projects, the Agency is finding increasing needs for depth of investment – that is additional funding to continue to 'de-risk' projects to the point where they are ready for private-sector investment. Some highly innovative projects began at such an early stage that the project duration is not sufficient to reach a viable prototype. Other projects require significant qualification studies, field-testing, or scale-up assessment before private investors will consider investment. Furthermore, limited program size limits the important development of larger-scale systems solutions, which would, for instance, integrate opportunities from multiple programs for increased impact. Without additional support, promising technologies developed by ARPA-E risk being 'orphaned' before they have a chance to demonstrate their full potential. Expanding the depth to which ARPA-E can support more of its projects and thus deliver more economic impact, more rapidly is a key value opportunity for increased funding.

To sustain the potential economic value of the most promising technical projects, ARPA-E has begun creating opportunities for project teams to demonstrate the investment readiness of their prototypes through qualification and field testing. As an example of such a depth investment, in 2015 ARPA-E created a small program, CHARGES, to provide project teams with opportunities for the test and evaluation needed to advance their technologies for grid storage at scale and qualify them under utility regulations.

Funding Path to $1 Billion Annual Budget in Five Years

A funding path to an annual budget of $1 billion was proposed in the original Gathering Storm report that recommended the formation of ARPA-E. ARPA-E's discretionary funding along with ARPA-Energy Trust would provide approximately $1 billion in funding in 2021 and position ARPA-E to deliver expanded impact based on its nimble operational structure and growing opportunities created from its maturing portfolio of technical programs. Under the expanded budget, ARPA-E would add both breadth and depth, add some focused programs involving larger and more complex technical outcomes, and add more funds for developing commercial impact.

To manage the proposed expansion, ARPA-E will add a new focus on innovative systems level development that will deliver larger, more rapid impacts under the Trust Fund (see pages 21-28) that complements and builds on its on-going activities under the America Competes Act (discretionary funds, see pages 7-20). The new activities under the ARPA-E Trust will be implemented in stages that draw from the outcomes of the core program and, in the years after 2017, the outcomes of the previous years' Trust investments. In this way, the planned growth in funding requirement over the five year period will enable ARPA-E to scale up this new effort to deliver the maximum impact, while maintaining the agency's central focus on accelerating transformational energy technologies from concept to market. Expanding ARPA-E's budget will deliver high-yield, high value gains by accessing a greater breadth of the demonstrated U.S. entrepreneurial opportunities in energy technologies, and investing sufficiently to de-risk the most promising projects to the point that they are ready to move forward with private-sector investment.

Advanced Research Projects Agency - Energy
Funding by Congressional Control ($K)

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
ARPA-E Projects	252,000	252,000	261,750	318,000	+56,250
Program Direction	28,000	28,000	29,250	32,000	+2,750
Subtotal, Advanced Research Projects Agency - Energy	**280,000**	**280,000**	**291,000**	**350,000**	**+59,000**
Rescission of Prior Year Balance	-18	-18	0	0	+0
Total, Advanced Research Projects Agency - Energy	**279,982**	**279,982**	**291,000**	**350,000**	**+59,000**
Federal FTEs	**49**	**49**	**56**	**56**	**+0**
Advanced Research Projects Agency – Energy Trust[1]	**0**	**0**	**0**	**150,000**	**+150,000**

SBIR/STTR[2]:
- FY 2015 Current: $12,270 total (SBIR $11,380 / STTR $890)
- FY 2016 Projected: $9,030 total (SBIR $7,853 / STTR $1,177)
- FY 2017 Request: $11,607 total (SBIR $10,176 / STTR $1,431)

[1] Mandatory funding under legislative proposal, not subject to discretionary appropriations.
[2] In FY 2017, ARPA-E will continue its stand-alone Small Business Innovation Research/Small Business Technology Transfer (SBIR/STTR) program to provide additional support to small businesses beyond the significant number of awards to small businesses via ARPA-E's standard non-SBIR/STTR solicitations.

ARPA-E Projects – Discretionary Budget Request

Overview

The Advanced Research Projects Agency-Energy (ARPA-E) catalyzes transformational energy technologies to enhance the economic, environmental, and energy security of the United States by advancing high-potential, high-impact energy projects that are too early for private sector investment.

ARPA-E draws upon the Defense Advanced Research Projects Agency's successful model of program management, with targeted modification to meet ARPA-E's unique requirements for US economic impact through a strong focus on the commercialization potential of new energy technologies. The major adaptation in ARPA-E's model is the implementation of a strong Technology-to-Market (T2M) focus. ARPA-E offers funding opportunities to the nation's research and development community with a requirement of a clear techno-economic focus. This approach complements and seeks to extract maximum value from the nation's existing investments in fundamental energy research, including those of the DOE Office of Science.

In its first five years of program funding, ARPA-E has demonstrated the efficacy of its model for accelerating high-potential, novel technical approaches to existing and emerging US energy challenges. Program Directors, recruited for their technical expertise and experience in energy issues, are given significant autonomy in identifying potential high-impact areas for R&D investment. ARPA-E's Program Directors work to develop their proposals in the context of both private sector and federally funded work in the technical space, and ultimately propose a program designed to accelerate research and commercial development in the topic area. The T2M Advisors ensure the T2M focus is included throughout the development process and the execution of projects. As a complement to its focused technology programs, ARPA-E also supports OPEN and IDEAS solicitations. OPEN solicitations seek the most innovative new ideas in energy technology across the full spectrum of energy applications, allowing the Agency to support the development of important technologies that otherwise would fall outside the scope of its focused programs. OPEN solicitations were run in 2009, 2012, and 2015. The IDEAS solicitation was launched in 2013 and is continuing to provide small, short-term grants to develop proof-of-concept for innovative but unproven technical concepts.

Selection of project awards within each program occurs by a rigorous process of proposal and reviews. Selection criteria include the transformative character of the technology, the potential impact of the technology on ARPA-E's energy missions as defined in its authorizing statute, and the potential for the project to yield commercial applications that benefit US economic and energy security. Within these criteria the most highly rated proposals are selected for award negotiations. The majority of the funded projects involve more than one institution, and the lead institutions are distributed among universities, businesses, federally funded research and development centers (FFRDCs), and non-profit organizations.

The resulting portfolio of alumni and active R&D projects broadly covers the US energy technology landscape, from transportation fuels and energy storage, through residential, commercial and manufacturing efficiency to the storage, distribution and generation of electrical power. The programs are designed to deliver value given a targeted investment over a defined period of time. The projects are structured in a portfolio funding approach to 'de-risk' areas of technological opportunity by supporting multiple high-potential approaches to the program goals to the point where their relative value for further applications can be determined. This allows the most effective approaches to emerge based on their technical performance and potential. Under ARPA-E's rigorous project management process, project teams work to quarterly milestones for both technical and commercialization goals. Projects that prove unable to meet the goals are terminated.

Highlights of the FY 2017 Appropriations Budget Request

The selection of areas for new programs follows a rigorous evaluation and development process to assure that all new programs meet the following criteria:

1) A new program must be based on significant potential for transformational technological innovation. The technical opportunity must be too early stage or too high-risk for commercial investment.
2) The technical area must have the potential to have substantial impact on ARPA-E's legislated mission areas, which are Improving Energy Efficiency, Reducing Dependence on Energy Imports, and Reducing Harmful Energy Emissions, specifically and critically including reduction of greenhouse gas emissions.

3) Investment in the technical opportunity addresses DOE's energy mission and goals, but does not duplicate investment being carried out in other parts of DOE or other federal agencies.
4) There must be a pathway for advancing the technology toward hand-off to the private sector for commercial development and corresponding benefits to the economic and energy security of the U.S.

Program development includes input from the outcomes of previous programs and program assessments. The majority of the presently active programs were initiated in FY 2014 and 2015, when ARPA-E developed a strong cluster of programs in the power space, including carbon-free power generation, distributed generation, and grid integration, along with programs addressing natural gas emissions and the impacts of water scarcity on power-generation efficiency. New programs are being added in 2016, as older projects and programs end. As described in more detail in the 'Activities and Explanations of Changes' table, the following areas are in the final stages of assessment as new programs in FY 2016: building efficiency, biological carbon sequestration, zero-carbon fuels, improved transportation energy efficiency, reducing transportation demand, strategic materials for energy storage, and energy efficient data centers.

In FY 2017 ARPA-E expects to release funding opportunity announcements (FOAs) for seven to eight focused programs each funded in the range of $10 - $40 million. Those programs will be defined to address new areas not represented in the present portfolio, and to develop new opportunities opened by the outcomes of previous programs. The assessment process for the new programs is now underway as described below, and is structured to deliver strategic balance and strong opportunities for growth through emphasis on:

- exploiting advances in power electronics, systems and controls to accelerate the integration of storage, distributed generation and intermittent renewable sources into the grid
- integrating innovations across sectors to enable new routes to energy products or improve industrial energy efficiency while also improving economic competitiveness
- exploiting new approaches to materials discovery and development to target key technical barriers in areas including building and industrial efficiency, efficient power distribution, zero-carbon power, and zero-carbon fuels
- leveraging new data management and communications trends to discover new methods for energy savings

These opportunity areas are outlined in more detail in the 'Activities and Explanations of Changes' table. This careful assessment process is necessary to insure that ARPA-E meets its statutory requirement to identify and promote revolutionary advances in fundamental and applied energy research and development. In order to fund a broader range of possible technical solutions and thereby enhance the probability of program success, some of these programs may need to be initiated at up to $40 million.

Throughout FY 2016, workshops will be held to assess new program topics for FY 2017, building on the strategic innovation areas. Three workshops already planned are:

1. Innovative Approaches to Ocean Cultivation and Processing of Macro Algae for the Production of Low-carbon Fuels
   ARPA-E is interested in identifying critical R&D topics and targets, which need to be addressed to enable a successful transition from today's macro algae industry focused primarily on food and specialty chemicals to large-scale fuel opportunities. Technical areas for assessment are: advancing breeding of more productive macro algae (genomics, species selection, adaptation of terrestrial breeding techniques); new cultivation methods (site selection, cultivation system design, nutrient supply, robotics/automation); transport, storage and processing (dewatering and storage; processing/fractionation without freshwater); and ecosystem services and effects (excess nutrient removal; CO_2 sequestration).

2. Advanced Materials, Sensors, and Controls Enabling Inherently Safe and Secure Designs for MW Scale Nuclear Energy
   ARPA-E is interested in identifying how recently developed materials technologies can be combined with advanced sensors and controls to enable innovative, new designs for nuclear reactors at the 1-10 MW scale. Emphasis will be placed on how advances in materials, sensing, imaging, and controls can be incorporated into potentially transformative reactor designs with particularly careful attention to safety, security, and non-proliferation issues. Design concepts such as a solid/monolithic core with embedded heat transfer channels will be explored in a workshop bringing together experts in materials science, reactor design, non-proliferation/safeguards, and

monitoring/controls. The greenhouse gas reduction impacts for various use cases of nuclear power at this scale will also be examined. This area of assessment is being closely coordinated with the DOE Office of Nuclear Energy and non-proliferation experts in DOE NNSA, with additional input from the Nuclear Regulatory Commission.

3. High-Impact Building Efficiency through Data Analytics

   Energy technology has the potential to become much smarter – to make judicious use of the ubiquitous, nearly free data that we can now collect. In particular, building HVAC systems – one of the biggest energy consuming applications in the United States – are constantly running in modes that are not optimized for the true occupancy state of the building. ARPA-E is investigating the development of novel sensor technologies to capture data relating to occupancy (whether by direct measures, such as image capturing and processing, or by indirect measures, such as personal device connectivity via Wi-Fi) and use it to enable HVAC systems and controls to run at more appropriate states for the actual occupancy conditions. In addition, with advanced interface and algorithm development, this will enable completely "invisible" programmable thermostats – and expand to any alternative technologies that run more efficiently via occupancy detection.

Work to develop the additional workshops for defining FY 2017 programs is in progress. Broad areas under assessment (each may yield more than one potential workshop concept) are:

Applications in Efficient Power Conversion: Materials and component level advances in power electronics have potential applications across the energy sector, which can be advanced by technical innovation in integrating the new components into modules with specific applications. Opportunities span the range from grid-level power flow control at transmission voltages (69 kV and higher), to efficient connections for photovoltaics to power systems, and improved electric motor drives to lower power applications, such as the technologies that deliver power to computer microprocessors.

Hybrid Solar Systems: Innovative combination of advances in concentrated solar photo-voltaics and solar thermal storage, with advances in power electronics can be used to create integrated products that capture more of the available solar energy, provide intrinsic storage, and optimize coupling from both distributed and centralized generation to the electric power grid.

Expanded investments in Information and Computing Technologies (ICT): Advances in materials, photonics, and heat management provide efficiency-enhancing opportunities for communications and computing systems of all kinds. Reducing energy needs in personal devices and wireless access networks are examples of potential focus areas.

Light Metals in Transportation and Advanced Manufacturing: Light metals provide a key pathway to more efficient transportation, but cost – both financial and in terms of energy use – remains a barrier. Advances in processing and recycling techniques now offer opportunities to reduce those barriers. Combining these new approaches with designed materials properties to couple into advanced manufacturing, such as creating powdered materials for use in additive manufacturing, represent high-potential opportunities to transform vehicle light-weighting.

Innovations in production of fuels and chemicals: New technical approaches can address the scaling issues that today mandate large, capital and energy intensive processing facilities for producing fuels and chemicals. Areas of innovation range from efficient recovery of fuels and value-added products from renewable biological sources, lower-temperature and -pressure synthesis of commodity chemicals, and flexible, low-cost chemical infrastructure that can accommodate changes in feedstock supply volume and location. The new approaches would better exploit domestic bio-feedstocks and renewable resources to produce net-zero carbon fuels, and reduce the energy intensity and greenhouse gas emissions for the production of liquid fuels and chemicals.

In addition to the primary activity in new Programs, a portion of FY 2017 funding is likely to be used to supplement ongoing ARPA-E projects where a small amount of additional funding from ARPA-E could significantly advance commercial readiness, leading to future support from outside ARPA-E that will help advance the technology towards the market. In 2017, ARPA-E is evaluating a 'prize' competition in developing new optimization algorithms for power-flow control in transmission and distribution systems. ARPA-E will also continue its stand-alone SBIR/STTR program to provide additional support to small businesses beyond the significant number of awards to small businesses via ARPA-E's standard non-SBIR/STTR solicitations. ARPA-E will continue the use of IDEAS, a small rolling open solicitation to rapidly support innovative applied energy research that has the potential to lead to new focused programs or that may complement portfolios in ongoing focused programs.

ARPA-E Projects
Funding ($K)

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
ARPA-E Projects					
Transportation Systems	126,000	126,000	104,700	127,200	+22,500
Stationary Power Systems	126,000	126,000	157,050	190,800	+33,750
Total, ARPA-E Projects	**252,000**	**252,000**	**261,750**	**318,000**	**+56,250**

SBIR/STTR[1]:
- FY 2015 Current: $12,270 total (SBIR $11,380 / STTR $890)
- FY 2016 Projected: $9,030 total (SBIR $7,853 / STTR $1,177)
- FY 2017 Request: $11,607 total (SBIR $10,176 / STTR $1,431)

[1] In FY 2017, ARPA-E will continue its stand-alone Small Business Innovation Research/Small Business Technology Transfer (SBIR/STTR) program to provide additional support to small businesses beyond the significant number of awards to small businesses via ARPA-E's standard non-SBIR/STTR solicitations.

ARPA-E Projects
Explanation of Major Changes ($K)

	FY 2017 vs FY 2016
Transportation Systems: Based upon six years of experience in the development of focused technology programs and noting the distribution of applications to and awards made in the competitive OPEN solicitations in 2009, 2012 and 2015, ARPA-E anticipates a shift from an equal funding distribution between Stationary Power Systems and Transportation Systems to approximately a 60:40 split in FY 2016 and FY 2017.	**+22,500**
Stationary Power Systems: Based upon six years of experience in the development of focused technology programs and noting the distribution of applications and awards made in the first two competitive OPEN solicitations in 2009, 2012 and 2015, ARPA-E anticipates a shift from an equal funding distribution between Stationary Power Systems and Transportation Systems to approximately a 60:40 split in FY 2016 and FY 2017. A component of the shift is due to increasing effort in residential, commercial and industrial efficiency, which is included in the Stationary category.	**+33,750**
Total, ARPA-E Projects	**+56,250**

ARPA-E Projects

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs FY 2016
$261,750,000	**$318,000,000**	**+ $56,250,000**
In FY 2016 ARPA-E plans to release funding opportunity announcements for five to six focused programs. The funding opportunities to be supported in 2016 are in different stages of assessment, as noted below for each. It is likely, but not guaranteed, that FOAs will be released in each of these areas in FY 2016: Building efficiency: Re-inventing the single-pane window using advanced materials for either retrofit window coatings or new windows that provide thermal insulation and excellent optical quality while preventing condensation. Existing single-pane window stock constitutes a significant loss of heating energy in the U.S. and this program takes on the significant technical challenges in developing cost-effective retrofits or replacements. A FOA has been released in this area. Biofuel plant root phenotyping for improved growth properties and thereby provide a scalable approach to atmospheric carbon sequestration through plant roots to the soil. New technologies that measure structural and functional properties of plant roots and soils that lead to the development of improved root traits, which improve the sustainability of biofuel crop production by increasing soil carbon storage and improving fertilizer efficiency. These traits will reduce greenhouse gas emissions and are expected to create grower value by improving soil quality, nutrient use efficiency and water use	In FY 2017 ARPA-E plans to release funding opportunity announcements for seven to eight focused programs. ARPA-E anticipates new focused programs in both Transportation Systems and Stationary Power Systems (including energy efficiency). The assessment process to define the new program is underway, and will proceed through FY 2016, as described in the previous text section, 'Highlights of the FY 2017 Budget Request.' The assessment of new programs is taking place in the context of ARPA-E's identified technological innovation opportunities: Innovation opportunity: integration of storage, distributed generation and intermittent renewable sources for improved, more economical grid operations. New potential in this area arises from advances in power electronics, systems and controls, as well as the development of new capabilities in storage. Innovation opportunity: integrating cross-sector innovations to enable new routes to energy products or improve industrial energy efficiency. An example of such integration is combining innovative power electronics components to address specific power conversion needs such as low cost, high-speed, energy efficient battery chargers for electric vehicles. Similar new	The increase in funding will enable ARPA-E to fund approximately two more focused programs, and support proportional increases in SBIR, and IDEAS. The increase will also enable individual programs to be funded at a higher level, enabling the selection of additional projects and/or provision of additional funding for qualification and field testing of the most promising projects. The changes in Program focus between FY 2016 and 2017 are both essential to update ARPA-E's portfolio to address new developments in technical innovation. The exploitation of new developments in technical innovation will include greater (but not exclusive) focus on integrating the use of large-scale data, optimization, and distributed sensors and actuators to draw the greatest value from implementation of new technologies. A prize competition is under assessment for 2017 to incentivize development of optimized power control algorithms for energy transmission and distribution.

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs FY 2016
productivity. To select and breed for these traits, innovative technology platforms for the characterization of below ground plant growth and development will be required with demonstrated utility for field deployment. Final stages of assessment and development are underway prior to final decision on releasing a FOA. Renewable electricity to zero-carbon liquid fuels for transportation and stationary energy storage: Development of novel technologies to transform the way renewable electricity is stored and transported from remote generation sites to the end point customer to increase utilization of intermittent renewable energy and reduce carbon emissions. These include cost- effective and energy-efficient technologies that use renewable electricity to create energy dense liquid fuels from water, and CO_2 and/or N_2 from air. These fuels will be used for storage and subsequent conversion to electricity or as a clean fuel for zero-emission vehicles. Final stages of assessment and development are underway prior to final decision on releasing a FOA. New approaches to transportation energy efficiency: New vehicle and powertrain control technologies that can reduce the energy use associated with automotive transportation. These may include advanced vehicle and powertrain control concepts, optimization of individual vehicle operation facilitated by connectivity, and the reduction of the fuel and/or energy consumed by future vehicles undergoing either human operation or automated operation. An RFI has been released as part of	potential in this area arises from advances in biotechnology, distributed sensing, automation/robotics and new materials, as well as advanced manufacturing capabilities such as additive manufacturing. Innovation opportunity: exploiting new approaches to materials discovery and production to target technical barriers across all energy sectors. New potential in this area arises from the growing power of computational design of materials, new approaches to materials fabrication, and advances in high-throughput characterization. Innovation opportunity: leveraging new data management and communications trends to discover new methods for energy savings. New potential in this area arises from rapid developments in Information Technology and Telecommunications. Potential applications in this area can be used to support the improved development of energy systems from the components developed in previous programs. On-going assessments of the potential new programs in which combinations of these innovation opportunities would be applied are presented in the earlier text (Highlights of the FY 2017 Discretionary Budget Request).	

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs FY 2016
completing the assessment for this area prior to the final decision on releasing a FOA. Strategic development of solid-ion conductors for electrochemical technologies: Transform the properties of solid ion conductors for devices using alkaline exchange membranes (e.g., fuel cells and electrolyzers), lithium metal batteries, flow batteries, and other electrochemical technologies. Alleviate key deficiencies in solid ion conductors through co-optimization of ionic conductivity, selectivity, chemical stability, electronic conductivity, thermal stability, mechanical properties, processing, device integration, and cost. Final stages of assessment and development are underway prior to final decision on releasing a FOA. New technologies for energy efficient data centers: Integrated photonic interconnects and novel new switching networks to provide fundamentally more energy efficient manipulation and movement of data. Final stages of assessment and development are underway prior to final decision on releasing a FOA. Virtual transportation: Significant increases in the use of telecommunications could reduce the demand for human transportation, with benefits for energy imports, emissions and effective transportation efficiency. Significant reduction in the bandwidth of high-quality video transmission is needed to make this possible. A workshop is planned to assess the technical opportunities, and the magnitude of energy impact possible in this area.		

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs FY 2016
The technologies being developed under MONITOR (natural gas leak detection) will require qualification and field testing before they are accepted by regulatory agencies and commercial users. An RFI has been released to assess testing needs, and final stages of assessment are underway prior to final decision on creating a funding opportunity for a test facility.		

ARPA-E Projects
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 2015	FY 2016	FY 2017
Performance Goal (Measure)	**Award Funding** - Cumulative percentage of award funding committed 45 days after award selections are announced		
Target	70%	70%	70%
Result	100%	TBD	Not applicable
Endpoint Target	No endpoint - continuous measure of efficiency in awarding funds		
Performance Goal (Measure)	**New Company Formation** – Number of new companies formed as a direct result of ARPA-E funding. As of February 2015, ARPA-E funded research has led to the formation of at least 30 new companies.		
Target	≥+3	≥+3	≥+3
Result	Met[1]	TBD	Not applicable
Endpoint Target	No endpoint – continuous measure of impact of ARPA-E awards on creating new jobs and industries		

[1] Final quantitative metrics for FY 2015 will not be available until February 2016

Program Direction – Discretionary Budget Request

Overview
Program direction provides ARPA-E with the resources required to execute ARPA-E's mission. Program direction funds are utilized for salaries and benefits of federal staff; travel; support services contracts to provide technical advice and project management assistance; and other related expenses, including the DOE Working Capital Fund.

The key components of the ARPA-E model are the team, particularly the Agency's Program Directors and Technology-to-Market (T2M) advisors, and their hands-on engagement with awardees. ARPA-E Program Directors provide awardees with technical guidance that combines scientific expertise and real-world experience, while ARPA-E T2M advisors supply critical business insight and direction to enable awardees to develop strategies to move technologies towards the market. Each ARPA-E project includes clearly defined technical and commercial milestones that awardees are required to meet throughout the life of a project. Program Directors and T2M advisors work closely with each awardee, through regular meetings and on-site visits, to ensure that milestones are being achieved in a timely fashion. When a project is not achieving the goals of the program, ARPA-E works with the awardee to rectify the issue or, in cases where the issue cannot be corrected, ARPA-E discontinues funding for the project. To ensure the efficiency of ARPA-E's hands-on engagement with awardees, ARPA-E has in-house legal, procurement, and contracting staff, co-located with the Program Directors and T2M advisors, to provide direct access and timely communication. Finally, to help enable ARPA-E to rapidly move into new technology areas in response to scientific discoveries and breakthroughs, ARPA-E utilizes support contractors for technical advice and program management assistance.

Highlights of the FY 2017 Budget Request
The FY 2017 Request for program direction is $32 million, a $2.75 million increase over the FY 2016 Enacted level. The increase is needed to cover additional oversight and management of projects in ARPA-E's portfolio due to the requested increase in projects funding, as well as inflationary increases for salaries, overhead, and other expenses.

Program Direction – Appropriations Request
Funding ($K)

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
Program Direction Summary					
Washington Headquarters					
Salaries and Benefits	9,315	9,315	10,103	10,497	+394
Travel	1,003	1,003	1,316	1,500	+184
Support Services	12,895	12,895	12,858	14,730	+1,872
Other Related Expenses	4,787	4,787	4,973	5,273	+300
Total, Program Direction	**28,000**	**28,000**	**29,250**	**32,000**	**+2,750**
Federal FTEs	**49**	**49**	**56**	**56**	**+0**
Support Services and Other Related Expenses					
Support Services					
Technical Support	4,513	4,513	4,500	5,155	+655
Management Support	8,382	8,382	8,358	9,575	+1,217
Total, Support Services	**12,895**	**12,895**	**12,858**	**14,730**	**+1,872**
Other Related Expenses					
Rental payments to GSA	2,202	2,202	2,283	2,324	+41
Communications, utilities, and misc. charges	500	500	550	560	+10
Printing and reproduction	10	10	10	10	+0
Other services from non-Federal sources	465	465	475	484	+9
Other goods and services from Federal sources	1,510	1,510	1,550	1,788	+238
Supplies and materials	100	100	105	107	+2
Total, Other Related Expenses	**4,787**	**4,787**	**4,973**	**5,273**	**+300**

Program Direction – Appropriations Request

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs FY 2016
Program Direction $29,250,000	**$32,000,000**	**+$2,750,000**
Salaries and Benefits		
At the FY 2016 Enacted level, ARPA-E anticipates needing up to 56 Federal FTEs.	At the FY 2017 Request level, ARPA-E anticipates needing up to 56 Federal FTEs.	+$394,000: At a constant level of FTEs, salaries and benefits are projected to escalate 3.9% between FY 2016 and FY 2017.
Travel		
At the FY 2016 Enacted level ARPA-E Program Directors and Technology-to-Market advisers will continue to visit performers regularly as part of ARPA-E's hands-on engagement, which is the primary component of ARPA-E travel. The number of site visits will continue to be commensurate with the number of ongoing projects.	At the FY 2017 Request level ARPA-E Program Directors and Technology-to-Market advisers will continue to visit performers regularly as part of ARPA-E's hands-on engagement, which is the primary component of ARPA-E travel.	+$184,000: The increase in travel is commensurate with the increased number of projects expected in ARPA-E's portfolio.
Support Services		
At the FY 2016 Enacted level ARPA-E anticipates maintaining the use of support service contractors to support ARPA-E federal staff in the management and oversight of projects and other required functions. The level of support is commensurate to the number of ongoing and anticipated projects. ARPA-E will continue to optimize federal staff and contractor support based on funding levels and the number of projects under management.	At the FY 2017 Request level ARPA-E anticipates increasing support service contractors to support ARPA-E federal staff in the management and oversight of projects and other required functions. ARPA-E will continue to optimize federal staff and contractor support based on funding levels and the number of projects under management.	+$1,872,000: Additional supports services are needed to support federal staff in the oversight of projects in ARPA-E's growing portfolio.
Other Related Expenses		
The FY 2016 Enacted level for other related expenses primarily consists of Working Capital Fund and Information Technology support costs, which are commensurate with the level of FTEs and support services requested.	The FY 2017 Request level for other related expenses primarily consists of Working Capital Fund and Information Technology support costs, which are commensurate with the level of FTEs and support services requested.	+$300,000: Assumed constant level of other related expenses between FY 2016 and FY 2017. Most FY 2017 Budget Request miscellaneous expenses were escalated at 1.8%.

Advanced Research Projects Agency - Energy Trust

Overview

The Advanced Research Projects Agency-Energy Trust will provide a total of $1.85 billion in mandatory funds over five years to ARPA-E. These funds will provide a reliable stream of funding to expand the work of ARPA-E. This mandatory funding includes $150 million in FY 2017, $250 million in FY 2018, $350 million in FY 2019, $450 million in FY 2020, and $650 million in FY 2021.

Highlights of the FY 2017 Budget Request

Under the legislative proposal to create a mandatory funding stream, ARPA-E will add a new focus on innovative systems level efforts to maximize the impact of the transformational energy technologies developed under ARPA-E's existing core programs. The dynamic core program activities will continue to be supported under discretionary funding. ARPA-E will concurrently expand its present efforts to identify the highest impact technical innovations for the US energy sectors, engaging early and often with venture capital, strategic, and social investors as well as regional development agencies, the DOE technology offices, and other Federal agencies. ARPA-E will continue its requirement that project recipients expend at least 5% of their funding on T2M activities.

ARPA-E Trust programs will support projects with techno-economic goals designed to generate large impacts on the energy system and investable large-scale outcomes. The new activities under the ARPA-E Trust will be implemented in stages that draw from the outcomes of the core program and, in the years after 2017, the outcomes of the previous years' Trust investments. The new Trust Fund activities will continue to emphasize ARPA-E's central focus as a technology agency: accelerating transformative energy technologies from concept to market. But they will emphasize larger scale, more complex energy challenges than can be supported under the core, discretionary funding. Potential Trust Fund programs will be rigorously assessed against the same criteria as the core discretionary programs: transformative potential, impact on ARPA-E's mission areas, complementarity to other DOE programs, and a clear path toward hand-off to the private sector. Examples of topics that will be assessed in developing funding opportunities under the Trust Fund in FY 2017 and subsequent years include:

Technical challenges in scale-up

> EXAMPLE: The core GENI program supported the early stage development of transformational power flow control devices, which were demonstrated at distribution system voltages (~13kV), but significant technical challenges remain in scaling these devices to the higher voltages used in transmission systems (69 kV and higher). This scaling involves significant technical risk and may require integration of new power semiconductor technology developed under the core ADEPT, Solar ADEPT, OPEN, and SWITCHES programs.
>
> EXAMPLE: Revolutionary approaches to wind power: ARPA-E has shown great promise for novel approaches to wind power across several projects in sub-scale proof of concept and component-level demonstrations. These approaches all entail radically different design, engineering, and deployment challenges from traditional wind turbines, and in order to gain industry acceptance will require systems integration and testing at a multi-MW scale.

Integration of multiple technical advances to create new functionality

> EXAMPLE: Expanded integration of Grid-Scale Energy Storage: The ability to store energy generated when demand is low and deliver it at times when demand is high is essential to draw the maximum benefits from our generation and distribution of electrical power. ARPA-E programs have demonstrated multiple approaches to grid storage, with multiple ways in which they can improve economic returns. Opportunities to accelerate this process stem from the potential to integrate different storage types such as batteries and flow-cells, new options such as storage in liquid fuels, and operational approaches to create virtual storage. Larger scale programs would be developed to address the significant technical challenges of designing, scaling-up and optimizing such integrated solutions.
>
> EXAMPLE: While individual ARPA-E core programs have demonstrated the ability to remove a key technical roadblock, there will remain significant additional technical challenges in advancing new large-scale energy projects toward readiness for commercialization. There is additional opportunity to build specific functionality, longer-scale programs

or coordinated parallel programs that combine aspects of several ongoing or previous ARPA-E programs. An example is the coupling of improved thermal energy management and heat-to-electricity conversion from the core HEATS and ARID programs with hybrid solar PV-CSP technologies developed under the core FOCUS program.

Systems scale challenges

EXAMPLE: Soil Carbon Capture, Utilization and Storage scaled to provide significant reduction in atmospheric CO_2 concentrations: Increasing the storage of nitrogen and carbon in soils to levels present before extensive agriculture has the potential to sequester atmospheric carbon at scale while also reducing fertilizer use with its related issues of greenhouse gas emissions and water pollution. Opportunities to do so derive from advances in plant breeding, automated sensing and high-throughput screening, genomics, and data management. Large-scale systems investment is needed to optimize the development of appropriate crops and create the commercial drivers for their wide-spread deployment. This work would be designed to complement, but not duplicate US Department of Agriculture efforts to advance commercial agriculture for food and feed usage and related issues of sustainability.

Technological innovation to drive the creation of new business models

EXAMPLE: Energy-efficient transportation systems based on automated vehicles, advanced manufacturing, ubiquitous sensing and data sharing: Managing transportation as a system of vehicles offers new opportunities to supplement the benefits of vehicle light-weighting, engine efficiency, electrification and alternative low-carbon fuels. Opportunities arising as a result of vehicle-to-vehicle communication, vehicle-to-infrastructure communication, and control and optimization for local conditions can be exploited and integrated to minimize transportation energy expenditure. This work would be designed to complement, but not duplicate the work of Department of Transportation in developing automation approaches to deliver benefits in safety and commerce.

Advanced Research Projects Agency - Energy Trust
Funding ($K)

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
Advanced Research Projects Agency – Energy Trust					
Projects	0	0	0	135,000	+135,000
Program Direction	0	0	0	15,000	+15,000
Total, Advanced Research Projects Agency – Energy Trust	**0**	**0**	**0**	**150,000**	**+150,000**

Advanced Research Projects Agency - Energy Trust
Explanation of Major Changes ($K)

	FY 2017 vs FY 2016
Projects: The new $150 million in mandatory funding will create the Advanced Research Projects Agency – Energy Trust. Of the $150 million, $135 million with be allocated towards complex, larger-scale research efforts in areas such as: technical challenges in scale-up, integration of multiple technical advances to create new functionality, systems scale challenges and technical innovation to drive new business models.	**+135,000**
Program Direction: The new $150 million in mandatory funding will create the Advanced Research Projects Agency – Energy Trust. Of the $150 million, $15 million will be allocated to program direction.	**+15,000**
Total, ARPA-E - Energy Trust	**+150,000**

Advanced Research Projects Agency - Energy Trust

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs FY 2016
$0	**$135,000,000**	**+ $135,000,000**
No funding in FY 2016	New funding for FY 2017	The Trust provides a total of $1.85 billion in mandatory funding over 5 years including $150 million in FY 2017. The $150 million in FY 2017 would be used to support complex, larger-scale research efforts in areas such as: technical challenges in scale-up, integration of multiple technical advances to create new functionality, systems scale challenges, coordination across multiple ongoing programs, and technical innovation to drive new business models.

Program Direction – Advanced Research Projects Agency - Energy Trust

Overview

Program Direction provides the staffing resources and associated costs required to provide overall direction and execution of the ARPA-E Trust. This budget provides for salaries and benefits of new federal staff, travel expenses for federal staff and contractors, and the support services required for technical advisory and project management services. This budget further provides funding for other related expenses, including additional leased office space and increased contributions to the DOE Working Capital Fund that is related to the additional personnel needed for the ARPA-E Trust.

Highlights of the FY 2017 Budget Request

ARPA-E will allocate $15 million of the ARPA-E Trust funds to Program Direction in FY 2017 to supplement the $32 million in appropriated Program Direction requested. With expansion of the number and size of programs supported under the Trust, the number of technical personnel will need to increase roughly proportionally. To manage the accelerated growth path associated with Trust funding in subsequent years, ARPA-E would build on its agile project management structure and adapt accordingly, while roughly maintaining the present ratio of operational costs to programmatic expansion. To manage the greater size and scope, it is likely that the agency will need to adjust its structure, possibly building multiple technical offices reporting to the agency Director. The increasing breadth of activities supported by the Trust will require a greater spread of technical expertise in the Program Directors as well as an expanded experience-base in the T2M team to include venture and strategic investment, regional (state and local) development, start-up business development and engagement with other Federal agencies.

Program Direction – Energy Trust
Funding ($K)

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
Program Direction Summary					
Washington Headquarters					
Salaries and Benefits	0	0	0	1,874	+1,874
Travel	0	0	0	703	+703
Support Services	0	0	0	9,951	+9,951
Other Related Expenses	0	0	0	2,472	+2,472
Total, Program Direction	**0**	**0**	**0**	**15,000**	**+15,000**
Federal FTEs	**0**	**0**	**0**	**10**	**+10**
Support Services and Other Related Expenses					
Support Services					
Technical Support	0	0	0	3,483	+3,483
Management Support	0	0	0	6,468	+6,468
Total, Support Services	**0**	**0**	**0**	**9,951**	**+9,951**
Other Related Expenses					
Rental payments to GSA	0	0	0	1,089	+1,089
Communications, utilities, and misc. charges	0	0	0	263	+263
Printing and reproduction	0	0	0	5	+5
Other services from non-Federal sources	0	0	0	227	+227
Other goods and services from Federal sources	0	0	0	838	+838
Supplies and materials	0	0	0	50	+50
Total, Other Related Expenses	**0**	**0**	**0**	**2,472**	**+2,472**

Program Direction – Energy Trust

Activities and Explanation of Changes

FY 2016 Enacted	FY 2017 Request	Explanation of Changes FY 2017 vs FY 2016
Program Direction $0	**$15,000,000**	**+$15,000,000**
Salaries and Benefits		
N/A	New FY 2017 Request	+$1,874: Ten additional FTEs are needed in FY17 to support programs and projects funded by the ARPA-E Trust.
Travel		
N/A	New FY 2017 Request	+$703: ARPA-E personnel will visit performers regularly as part of ARPA-E's hands on engagement.
Support Services		
N/A	New FY 2017 Request	+$9,951: Support services are needed to support federal staff in the oversight of programs and projects in the ARPA-E Trust portfolio.
Other Related Expenses		
N/A	New FY 2017 Request	+$2,472: Incremental overhead and other related costs associated with the additional FTEs and support service personnel for the ARPA-E Trust.

Advanced Research Projects Agency - Energy
Research and Development ($K)[1]

	FY 2015 Enacted	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	FY 2017 vs FY 2016
Basic	0	0	0	0	0
Applied	140,000	140,000	145,500	250,000	+104,500
Development	140,000	140,000	145,500	250,000	+104,500
Subtotal, R&D	280,000	280,000	291,000	500,000	+209,000
Equipment	0	0	0	0	0
Construction	0	0	0	0	0
Total, R&D	**280,000**	**280,000**	**291,000**	**500,000**	**+209,000**

Advanced Research Projects Agency - Energy
Small Business Innovation Research/Small Business Technology Transfer (SBIR/STTR) ($K)

	FY 2015 Current	FY 2016 Projected	FY 2017 Request[2]	FY 2017 vs FY 2016
ARPA-E Projects				
SBIR	11,380	7,853	10,176	+2,323
STTR	890	1,177	1,431	+254
Total, SBIR/STTR	**12,270**	**9,030**	**11,607**	**+2,577**

[1] FY 2017 Congressional Budget Research and Development (R&D) table includes both discretionary and mandatory funding as well as allocated Program Direction for each funding. The FY 2016 Congressional Budget R&D table excluded Program Direction appropriations. This change is being made to better align with international standards on reporting funding for R&D. Since program direction is necessary in order for R&D to be performed, it is included in the conduct of R&D.
[2] In FY 2017, ARPA-E will continue its stand-alone Small Business Innovation Research/Small Business Technology Transfer (SBIR/STTR) program to provide additional support to small businesses beyond the significant number of awards to small businesses via ARPA-E's standard non-SBIR/STTR solicitations.

Department Of Energy
FY 2017 Congressional Budget
Funding By Appropriation By Site
($K)

Advanced Research Projects Agency - Energy	FY 2015 Current	FY 2016 Enacted	FY 2017 Request
Washington Headquarters			
Advanced Research Projects Agency - Energy			
Projects	252,000	261,750	318,000
Program Direction	28,000	29,250	32,000
Total, Advanced Research Projects Agency - Energy	**280,000**	**291,000**	**350,000**
Total, Washington Headquarters	**280,000**	**291,000**	**350,000**
Total, Advanced Research Projects Agency - Energy	**280,000**	**291,000**	**350,000**

GENERAL PROVISIONS—DEPARTMENT OF ENERGY
(INCLUDING TRANSFER [AND RESCISSIONS] 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 **[**described in section 4 (in the matter preceding division A of this consolidated**]** *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 **[**2016**]** *2017* until the enactment of the Intelligence Authorization Act for fiscal year **[**2016**]** *2017*.

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 **[**Independent**]** 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) None of the funds made available in this or any prior Act under the heading "Defense Nuclear Nonproliferation" may be made available to enter into new contracts with, or new agreements for Federal assistance to, the Russian Federation.

(b) The Secretary of Energy may waive the prohibition in subsection (a) if the Secretary determines that such activity is in the national security interests of the United States. This waiver authority may not be delegated.

(c) A waiver under subsection (b) shall not be effective until 15 days after the date on which the Secretary submits to the Committees on Appropriations of both Houses of Congress, in classified form if necessary, a report on the justification for the waiver.**]**

SEC. **[**308**]** *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. 309. Of the amounts made available by this Act for "National Nuclear Security Administration—Weapons Activities", up to $50,000,000 may be reprogrammed within such account for Domestic Uranium Enrichment, subject to the notice requirement in section 301(e).**]**

[SEC. 310. (a) Unobligated balances available from appropriations are hereby rescinded from the following accounts of the Department of Energy in the specified amounts:

(1) "Energy Programs—Energy Efficiency and Renewable Energy", $1,355,149.00 from Public Law 110–161; $627,299.24 from Public Law 111–8; and $1,824,051.94 from Public Law 111–85.

(2) "Energy Programs—Science", $3,200,000.00.

(b) No amounts may be rescinded by this section from amounts that were designated by the Congress as an emergency requirement pursuant to a concurrent resolution on the budget or the Balanced Budget and Emergency Deficit Control Act of 1985.**]**

[SEC. 311. Notwithstanding any other provision of law, the provisions of 40 U.S.C. 11319 shall not apply to funds appropriated in this title to Federally Funded Research and Development Centers sponsored by the Department of Energy.**]**

[SEC. 312. None of the funds made available in this Act may be used—

(1) to implement or enforce section 430.32(x) of title 10, Code of Federal Regulations; or

(2) to implement or enforce the standards established by the tables contained in section 325(i)(1)(B) of the Energy Policy and Conservation Act (42 U.S.C. 6295(i)(1)(B)) with respect to BPAR incandescent reflector lamps, BR incandescent reflector lamps, and ER incandescent reflector lamps.**]**

[SEC. 313. (a) Of the funds appropriated in prior Acts under the headings "Fossil Energy Research and Development" and "Clean Coal Technology" for prior solicitations under the Clean Coal Power Initiative and FutureGen, not less than $160,000,000 from projects selected under such solicitations that have not reached financial close and have not secured funding sufficient to construct the project prior to 30 days after the date of enactment of this Act shall be deobligated, if necessary, shall be utilized for previously selected demonstration projects under such solicitations that have reached financial close or have otherwise secured funding sufficient to construct the project prior to 30 days after the date of enactment of this Act, and shall be allocated among such projects in proportion to the total financial contribution by the recipients to those projects stipulated in their respective cooperative agreements.

(b) Funds utilized pursuant to subsection (a) shall be administered in accordance with the provisions in the Act in which the funds for those demonstration projects were originally appropriated, except that financial assistance for costs in excess of those estimated as of the date of award of the original financial assistance may be provided in excess of the proportion of costs borne by the Government in the original agreement and shall not be limited to 25 percent of the original financial assistance.

(c) No amounts may be repurposed pursuant to this section from amounts that were designated by the Congress as an emergency requirement pursuant to a concurrent resolution on the budget or the Balanced Budget and Emergency Deficit Control Act of 1985.

(d) This section shall be fully implemented not later than 60 days after the date of enactment of this Act.**]**

SEC. 308. Amounts made available by this title may be transferred to the Technology Commercialization Fund in amounts not to exceed 0.9% of the amounts appropriated for applied energy research and development. Amounts so transferred shall be available for a broad spectrum of energy technology or combination of technologies, consistent with section 1001 of the Energy Policy Act of 2005 (42 U.S. Code paragraph 16391(e)), and shall remain available until expended.

SEC. 309. Not to exceed 5 percent of any appropriation made available for Department of Energy activities funded in this Act or subsequent Energy and Water Development and Related Agencies Appropriations Acts may be transferred between such appropriations, but no such appropriation, except as otherwise provided, shall be increased or decreased by more than 5 percent by any such transfers, and notification of any such transfers shall be submitted promptly to the Committees on Appropriations of the House of Representatives and the Senate.

SEC. 310. Consolidated Emergency Operations Center. Amounts available for the Department of Energy under this title in this and prior appropriations Acts shall be available for the design of a consolidated Emergency Operations Center: Provided, That no amounts may be repurposed from amounts that were designated by the Congress as an emergency requirement pursuant to the Concurrent Resolution on the Budget or the Balanced Budget and Emergency Deficit Control Act of 1985, as amended.

SEC. 311. 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.

(Energy and Water Development and Related Agencies Appropriations Act, 2016.)

Title V – General Provisions

SEC. 501. None of the funds appropriated by this Act may be used in any way, directly or indirectly, to influence congressional action on any legislation or appropriation matters pending before Congress, other than to communicate to Members of Congress as described in 18 U.S.C. 1913.

[SEC. 502. (a) None of the funds made available in title III of this Act may be transferred to any department, agency, or instrumentality of the United States Government, except pursuant to a transfer made by or transfer authority provided in this Act or any other appropriations Act for any fiscal year, transfer authority referenced in the explanatory statement described in section 4 (in the matter preceding division A of this consolidated Act), or any authority whereby a department, agency, or instrumentality of the United States Government may provide goods or services to another department, agency, or instrumentality.

(b) None of the funds made available for any department, agency, or instrumentality of the United States Government may be transferred to accounts funded in title III of this Act, except pursuant to a transfer made by or transfer authority provided in this Act or any other appropriations Act for any fiscal year, transfer authority referenced in the explanatory statement described in section 4 (in the matter preceding division A of this consolidated Act), or any authority whereby a department, agency, or instrumentality of the United States Government may provide goods or services to another department, agency, or instrumentality.

(c) The head of any relevant department or agency funded in this Act utilizing any transfer authority shall submit to the Committees on Appropriations of both Houses of Congress a semiannual report detailing the transfer authorities, except for any authority whereby a department, agency, or instrumentality of the United States Government may provide goods or services to another department, agency, or instrumentality, used in the previous 6 months and in the year-to-date. This report shall include the amounts transferred and the purposes for which they were transferred, and shall not replace or modify existing notification requirements for each authority.**]**

SEC. **[**503**]** *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 Action to Address Environmental Justice in Minority Populations and Low-Income Populations). *(Energy and Water Development and Related Agencies Appropriations Act, 2016.)*