DOE/CF-0165
Volume 4

# Department of Energy
## FY 2021 Congressional Budget Request

# Science

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**FY 2021 Congressional Budget Request**

**Science**

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**DEPARTMENT OF ENERGY**
**Appropriation Summary**
FY 2021
(Dollars in Thousands)

| | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs. FY 2020 Enacted $ | FY 2021 Request vs. FY 2020 Enacted % |
|---|---|---|---|---|---|
| **Department of Energy Budget by Appropriation** | | | | | |
| Energy Efficiency and Renewable Energy | 2,379,000 | 2,777,277 | 719,563 | -2,057,714 | -74.09% |
| Electricity | 156,000 | 190,000 | 195,045 | 5,045 | 2.66% |
| Cybersecurity, Energy Security and Emergency Response | 120,000 | 156,000 | 184,621 | 28,621 | 18.35% |
| Nuclear Energy* | 1,180,000 | 1,340,000 | 1,042,131 | -297,869 | -22.23% |
| Uranium Reserve | 0 | 0 | 150,000 | 150,000 | 0.00% |
| Interim Storage and Nuclear Waste Fund Oversight | 0 | 0 | 27,500 | 27,500 | 0.00% |
| Fossil Energy Research and Development | 740,000 | 750,000 | 730,601 | -19,399 | -2.59% |
| Strategic Petroleum Reserve | 235,000 | 195,000 | 187,081 | -7,919 | -4.06% |
| Naval Petroleum and Oil Shale Reserve | 10,000 | 14,000 | 13,006 | -994 | -7.10% |
| Strategic Petroleum Reserve Petroleum Account | 10,000 | 10,000 | 0 | -10,000 | -100.00% |
| Northeast Home Heating Oil Reserve | 10,000 | 10,000 | 0 | -10,000 | -100.00% |
| **Total, Fossil Energy Petroleum Reserve Accounts** | **265,000** | **229,000** | **200,087** | **-28,913** | **-12.63%** |
| **Total, Fossil Energy Programs** | **1,005,000** | **979,000** | **930,688** | **-48,312** | **-4.93%** |
| Uranium Enrichment Decontamination and Decommissioning (D&D) Fund | 841,129 | 881,000 | 806,244 | -74,756 | -8.49% |
| Energy Information Administration | 125,000 | 126,800 | 128,710 | 1,910 | 1.51% |
| Non-Defense Environmental Cleanup | 310,000 | 319,200 | 275,820 | -43,380 | -13.59% |
| Science | 6,585,000 | 7,000,000 | 5,837,806 | -1,162,194 | -16.60% |
| Artificial Intelligence Technology Office | 0 | 0 | 4,912 | 4,912 | 0.00% |
| Advanced Research Projects Agency - Energy | 366,000 | 425,000 | -310,744 | -735,744 | -173.12% |
| Departmental Administration | 165,858 | 161,000 | 136,094 | -24,906 | -15.47% |
| Indian Energy Policy and Programs | 18,000 | 22,000 | 8,005 | -13,995 | -63.61% |
| Inspector General | 51,330 | 54,215 | 57,739 | 3,524 | 6.50% |
| International Affairs | 0 | 0 | 32,959 | 32,959 | 0.00% |
| Title 17 Innovative Technology Loan Guarantee Program | 12,311 | 29,000 | -160,659 | -189,659 | -654.00% |
| Advanced Technology Vehicles Manufacturing Loan Program | 5,000 | 5,000 | 0 | -5,000 | -100.00% |
| Tribal Energy Loan Guarantee Program | 1,000 | 2,000 | -8,500 | -10,500 | -525.00% |
| **Total, Credit Programs** | **18,311** | **36,000** | **-169,159** | **-205,159** | **-569.89%** |
| **Total, Energy Programs** | **13,320,628** | **14,467,492** | **10,057,934** | **-4,409,558** | **-30.48%** |
| Federal Salaries and Expenses | 410,000 | 434,699 | 454,000 | 19,301 | 4.44% |
| Weapons Activities | 11,100,000 | 12,457,097 | 15,602,000 | 3,144,903 | 25.25% |
| Defense Nuclear Nonproliferation | 1,930,000 | 2,164,400 | 2,031,000 | -133,400 | -6.16% |
| Naval Reactors* | 1,788,618 | 1,648,396 | 1,684,000 | 35,604 | 2.16% |
| **Total, National Nuclear Security Administration** | **15,228,618** | **16,704,592** | **19,771,000** | **3,066,408** | **18.36%** |
| Defense Environmental Cleanup | 6,024,000 | 6,255,000 | 4,983,608 | -1,271,392 | -20.33% |
| Nuclear Energy | 146,090 | 153,408 | 137,800 | -15,608 | -10.17% |
| Other Defense Programs | 860,292 | 906,000 | 1,054,727 | 148,727 | 16.42% |
| **Total, Environmental and Other Defense Activities** | **7,030,382** | **7,314,408** | **6,176,135** | **-1,138,273** | **-15.56%** |
| **Total, Atomic Energy Defense Activities** | **22,259,000** | **24,019,000** | **25,947,135** | **1,928,135** | **8.03%** |
| Southwestern Power Administration | 10,400 | 10,400 | 10,400 | 0 | 0.00% |
| Western Area Power Administration | 89,372 | 89,196 | 89,372 | 176 | 0.20% |
| Falcon and Amistad Operating and Maintenance Fund | 228 | 228 | 228 | 0 | 0.00% |
| Colorado River Basins Power Marketing Fund | 0 | -42,800 | -21,400 | 21,400 | **-50.00%** |
| **Total, Power Marketing Administrations** | **100,000** | **57,024** | **78,600** | **21,576** | **37.84%** |
| | | | | | |
| **Total, Energy and Water Development and Related Agencies** | **35,656,628** | **38,527,516** | **36,083,669** | **-2,443,847** | **-6.34%** |
| Excess Fees and Recoveries, FERC | -16,000 | -16,000 | -9,000 | 7,000 | -43.78% |
| Title XVII Loan Guarantee Program Section 1703 Negative Credit Subsidy Receipt | -107,000 | -15,000 | -49,000 | -34,000 | 226.67% |
| Sale of Northeast Home Heating Oil Reserve | 0 | 0 | -75,000 | -75,000 | 0.00% |
| Sale of Oil from Strategic Petroleum Reserve** | 0 | 0 | -589,000 | -589,000 | 0.00% |
| **Total, Funding by Appropriation** | **35,533,628** | **38,512,516** | **35,361,669** | **-3,150,847** | **-8.18%** |
| | | | | | |
| **DOE Budget Function** | **35,533,628** | **38,512,516** | **35,361,669** | **-3,150,847** | **-8.18%** |
| NNSA Defense (050) Total | 15,228,618 | 16,704,592 | 19,771,000 | 3,066,408 | 18.36% |
| Non-NNSA Defense (050) Total | 7,030,382 | 7,314,408 | 6,176,135 | -1,138,273 | -15.56% |
| *Defense (050)* | *22,259,000* | *24,019,000* | *25,947,135* | *1,928,135* | *8.03%* |
| Science (250) | 6,585,000 | 7,000,000 | 5,837,806 | -1,162,194 | -16.60% |
| Energy (270) | 6,689,628 | 7,493,516 | 3,576,728 | -3,916,788 | -52.27% |
| *Non-Defense (Non-050)* | *13,274,628* | *14,493,516* | *9,414,534* | *-5,078,982* | *-35.04%* |

* Funding does not reflect statutory transfer of funds from Naval Reactors to Nuclear Energy for maintenance and operation of the Advanced Test Reactor ($85.5M in FY19; $88.5M in FY20).

**Includes a $50M sale from the Northeast Gasoline Supply Reserve.

# Science

# Science

**Science**
**Proposed Appropriation Language**

For Department of Energy expenses including the purchase, construction, and acquisition of plant and capital equipment, and other expenses necessary for science activities in carrying out the purposes of the Department of Energy Organization Act (42 U.S.C. 7101 et seq.), including the acquisition or condemnation of any real property or any facility or for plant or facility acquisition, construction, or expansion, and purchase of not more than [33] *35* passenger motor vehicles [including one bus] *for replacement only*, [$7,000,000,000] *$5,837,806,000*, to remain available until expended: Provided, That of such amount, [$186,300,000] *$190,306,000* shall be available until September 30, [2021] *2022*, for program direction.
*(Energy and Water Development and Related Agencies Appropriations Act, 2020.)*

**Explanation of Change**

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

**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 108-423, "Department of Energy High-End Computing Revitalization Act of 2004"
- Public Law 109-58, "Energy Policy Act of 2005"
- Public Law 110-69, "America COMPETES Act of 2007"
- Public Law 111-358, "America COMPETES Reauthorization Act of 2010"
- Public Law 115-246, "American Super Computing Leadership Act of 2017"
- Public Law 115-246, "Department of Energy Research and Innovation Act", 2018
- Public Law 115-368, "National Quantum Initiative Act", 2018

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**
**(dollars in thousands)**

| FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request |
|---|---|---|
| $6,585,000 | $7,000,000 | $5,837,806 |

**Overview**

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

SC accomplishes its mission and advances national goals by supporting:

- *The frontiers of science*—exploring nature's mysteries from the study of fundamental subatomic particles, atoms, and molecules that are the building blocks of the materials of our universe and everything in it to the DNA, proteins, and cells that are the building blocks of life. Each of the programs in SC supports research probing the most fundamental disciplinary questions.
- *The 21st Century tools of science*—providing the nation's researchers with 28 state-of-the-art national scientific user facilities - the most advanced tools of modern science - propelling the U.S. to the forefront of science, technology development, and deployment through innovation.
- *Science for energy and the environment*—paving the knowledge foundation to spur discoveries and innovations for advancing the Department's mission in energy and environment. SC supports a wide range of funding modalities from single principal investigators to large team-based activities to engage in fundamental research on energy production, conversion, storage, transmission, and use, and on our understanding of the earth systems.

SC is an established leader of the U.S. scientific discovery and innovation enterprise. Over the decades, SC investments and accomplishments in basic research and enabling research capabilities have provided the foundations for new technologies, businesses, and industries, making significant contributions to our nation's economy, national security, and quality of life. Select scientific accomplishments in FY 2018 enabled by the SC programs are described in the program budget narratives. Additional descriptions of recent science discoveries can be found at http://science.energy.gov/news/highlights.

**Highlights and Major Changes in the FY 2021 Request**

The FY 2021 Request for SC is $5,838 million, a decrease of 16.6 percent below the FY 2020 Enacted level to implement the Administration's objectives in order to advance bold, transformational leaps in U.S. science and technology (S&T), build a diverse workforce of the future, and ensure America remains the global S&T leader for generations to come[a]. The FY 2021 Request supports a balanced research portfolio of basic scientific research probing some of the most fundamental questions in areas such as: high energy, nuclear, and plasma physics; materials and chemistry; biological and environmental systems; applied mathematics; next generation high-performance computing and simulation capabilities; and basic research for advancement in new energy technologies. The Request includes ongoing investments to support the Administration's Industries of the Future (IOTF) initiative through research in quantum information sciences (QIS) and artificial intelligence (AI) and machine learning (ML). The Request also supports research efforts in next-generation microelectronics, genomic sciences to inform biosecurity research, and critical scientific infrastructure needs at DOE laboratories. The Request also initiates new multidisciplinary research initiatives to include data and computational collaboration with NIH, integrated computational and data infrastructure for scientific discovery, next generation biology, rare earth and separation science, revolutionizing polymer upcycling, and strategic accelerator technology. These new initiatives position SC to meet new research demands in a more collaborative effort. The Request supports SC's basic research portfolio, which includes extramural grants and contracts supporting over 23,000 researchers located at over 300

[a] M-19-25, OMB/OSTP Memo: *FY 2021 Administration R&D Budget Priorities* (American Leadership in Industries of the Future, American Security, American Energy and Environmental Leadership, American Health & Bioeconomic Innovation, Building and Leveraging a Diverse, Highly Skilled American Workforce, Creation and Support of Research Environments that Reflect American Values, Support Transformative Research of High Risk and Potentially High Reward, Leverage the Power of Data, and Build, Strengthen, and Expand Strategic Multisector Partnerships.)

institutions and the 17 DOE national laboratories, spanning all fifty states and the District of Columbia. In FY 2021, SC's suite of 28 scientific user facilities will continue to provide unmatched tools and capabilities for over 33,000 users per year from universities, national laboratories, industry, and international partners. The Request will also support the construction of new user facilities and the R&D necessary for future facilities and facility upgrades to continue to provide world class research capabilities to U.S. researchers. SC allocates Working Capital Fund charges for common administrative services to the research programs and the Program Direction account.

Highlights of the FY 2021 Request by Program Office include:

- *Advanced Scientific Computing Research (ASCR)* supports research to discover, develop, and deploy computational and networking capabilities to analyze, model, simulate, and predict complex phenomena important to the DOE and the United States. The ASCR Request of $988.051 million, is an increase of $8.051 million, or 0.8 percent, above the FY 2020 Enacted level. The Request continues support for the Department's Exascale Computing Initiative (ECI), including final application and software preparations through the Exascale Computing Project, and enable delivery exascale-capable systems in calendar year 2021—reasserting U.S. leadership in this critical area. To ensure continued progress during and after the ECI, this Request prioritizes basic research for AI/ML with a focus on foundational research and data intensive science and on future computing technologies, including improving data accessibility and security, leveraging AI and other emerging technologies. Leveraging ASCR's world-class expertise in advanced computing across multiple science programs, disciplines, laboratories, and facilities, the Request includes funding to initiate development of an integrated computational and data infrastructure across the laboratories that will serve all six SC research programs. The Request maintains support for ASCR's Computational Partnerships with a focus on continuing strategic partnerships in quantum computing including the partnerships with other Science programs to support the QIS centers selected in FY 2020, building new data and AI partnerships with NIH, and on supporting multi-disciplinary microelectronics research with BES, FES, and HEP. The Request also provides strong support for ASCR user facilities operations to ensure the availability of high performance computing and networking to the scientific community and upgrades to maintain U.S. leadership in these essential areas. Funding for the Leadership Computing Facilities (LCF's) is increased to finish site preparations prior to the deployment for the of exascale systems at the Argonne Leadership Computing Facility (ALCF) and at the Oak Ridge Leadership Computing Facility (OLCF). The Request also supports the operations of the 200 petaflop (pf) Summit system at OLCF, and the 8.5 pf Theta system at the ALCF for existing users. The National Energy Research Scientific Computing Center (NERSC) will operate the 30 pf Cori supercomputer, and funding will support the final site and early application preparations for NERSC-9. The Request also supports continued operations of the Energy Sciences Network (ESnet) and the ESnet-6 upgrade to address the rapidly growing volume of scientific data transmission. Funds are also requested in FY 2021 to support early stage research associated with the first steps to establish a dedicated Quantum Network.

- *Basic Energy Sciences (BES)* supports fundamental research to understand, predict, and ultimately control matter and energy at the electronic, atomic, and molecular levels to provide foundations for new energy technologies. The BES Request of $1,935.673 million is a decrease of $277.327 million, or 12.5 percent, below the FY 2020 Enacted level. The Request focuses resources toward early-stage fundamental research, the operation and maintenance of a complementary suite of scientific user facilities, and the highest priority facility upgrades. High priority areas in core research include QIS, next-generation microelectronics, AI/ML, exascale computing, critical materials, polymer upcycling, next-generation biology, and strategic accelerator technology. The Request continues BES funding for the multi-disciplinary QIS centers to promote basic research and early stage development to accelerate the advancement of QIS through vertical integration between systems and theory and hardware and software. The Request also continues funding for the Energy Frontier Research Centers. The Request continues support for computational materials and chemical sciences to deliver shared software infrastructure to the research communities as part of the ECI, and supports the Batteries and Energy Storage and Fuels from Sunlight Energy Innovation Hubs. The Fuels from Sunlight Energy Innovation Hub will complete its second five-year term with FY 2019 funding. Funding is requested for continued support of early-stage fundamental research on solar fuels generation that builds on the Hub's unique capabilities and accomplishments to date. The Request also provides funds for the DOE Established Program to Stimulate Competitive Research. BES maintains a balanced suite of complementary tools, including supporting Linac Coherent Light Source (LCLS) operations at 97 percent of optimal. The Request also supports approximately 91 percent of optimal operations at the four other x-ray facilities, both BES-supported neutron sources, and five nanoscale science research centers (NSRCs). Funding for the Advanced Photon Source Upgrade project continues per the project plan. The Request provides continued support for the Advanced Light Source Upgrade project, the Linac Coherent Light Source-II High Energy project, the Proton Power Upgrade project, and the Second Target Station project. The Request includes one new construction project, a Cryomodule Repair and Maintenance Facility (CRMF). The Request continues two Major Item of Equipment projects: the NSLS-II Experimental Tools-II project for the phased build-out of beamlines at NSLS-II and the NSRC Recapitalization project.

- *Biological and Environmental Research (BER)* supports transformative science and scientific user facilities to achieve a predictive understanding of complex biological, earth, and environmental systems for energy and infrastructure security, independence, and prosperity. The BER Request of $516.934 million is a decrease of $233.066 million, or 31.1 percent, below the FY 2020 Enacted level. The Request implements Administration priorities for early-stage fundamental research focused on biological and earth and environmental systems that will contribute to a future of stable, reliable, and secure sources of American energy and advance transformative science for economic prosperity. The Request for Biological Systems Science supports core research areas of Genomic Sciences and fully supports the fourth year of the recompeted four DOE Bioenergy Research Centers (BRCs). The BRCs continue to perform new fundamental research underpinning the production of fuels and products from sustainable biomass resources and the building blocks of new technological advances for translation of basic research results to industry. Extended secure biosystems design activities will test the fundamental engineering principles that control plant and microbial systems, with a specific goal of enhancing the stability, resilience, and controlled performance of engineered biological systems. New efforts begin in next-generation biology for new tools, capabilities, and computational approaches to probe and understand natural and novel engineered cellular and materials architectures as well as to enable upcycling polymers for new functionalities. Biomolecular Characterization and Imaging Science research will continue to support structural, spatial, and temporal understanding of functional biomolecules and processes occurring within living cells. Efforts in QIS imaging and sensing approaches will expand experimental observation capabilities to advance systems-level predictive understanding of biological processes. In the Earth and Environmental Systems Sciences subprogram, the Request continues to prioritize development of the DOE high-resolution earth system model. Environmental System Science will integrate terrestrial ecosystem and subsurface sciences to provide a robust and scale-aware predictive understanding of ecosystems. The Request supports operations of BER's three scientific user facilities: the DOE Joint Genome Institute (JGI), the Environmental Molecular Sciences Laboratory (EMSL), and the Atmospheric Radiation Measurement Research Facility (ARM). AI/ML tools help validate user facility observations and data from environmental field experiments. The JGI will prioritize improved integration with the Systems Biology Knowledgebase. The ARM user facility will continue testing and evaluation of the aerial capability Major Item of Equipment (MIE) acquired in FY 2019.

- *Fusion Energy Sciences (FES)* supports research to expand the fundamental understanding of matter at very high temperatures and densities and to build the scientific foundation needed to develop a fusion energy source. The FES Request of $425.151 million is a decrease of $245.849 million, or 36.6 percent, below the FY 2020 Enacted. The Request prioritizes keeping SC fusion user facilities world-leading, investing in FES-related high-performance computing and preparing for exascale, exploring the potential of QIS and AI/ML, supporting high-impact research in fusion materials, strengthening collaborations that enable access to international facilities with unique capabilities, learning how to predict and control transient events in fusion plasmas, continuing stewardship of discovery plasma science including microelectronics-relevant low-temperature plasma science, and increasing partnership opportunities with the private sector. FES investments in DIII-D facility research and operations focus on utilizing the facility enhancements implemented during the FY 2018 – FY 2019 Long Torus Opening; the Request supports 13 weeks of research operations, which is 65 percent of optimal operations, along with machine improvements needed for new research capabilities. In FY 2021, the NSTX-U facility is down for recovery and repair; the Request for NSTX-U Operations will support high-priority activities to implement repairs and corrective actions required to achieve research operations, as well as to increase machine reliability. In addition, the Request includes funding for enhanced collaborative research at other facilities to support NSTX-U research program priorities. In FY 2021, the FES SciDAC portfolio, in partnership with ASCR, will continue to address challenges in burning plasma science, with emphasis on integration and whole-device modeling capability, as well as strengthening readiness for the Exascale era. In addition, research efforts focusing on emerging technologies with transformational potential, such as AI/ML and computing aspects of QIS, will be enhanced. The FY 2021 Request will continue support for leveraged research opportunities by U.S. scientists on international superconducting tokamaks, stellarators, and other facilities with unique capabilities, and core discovery plasma science experiments on intermediate-scale collaborative facilities. The Request also supports research conducted on medium-scale laser facilities through the LaserNetUS network, and explores research opportunities of high energy density science for QIS. Funding is requested for the Materials-Plasma Exposure eXperiment MIE project, which is expected to be baselined in FY 2021, and will be a world-leading facility for steady-state, high-heat-flux testing of fusion materials. The Request supports the initiation of a line-item construction project for a significant upgrade to the Matter in Extreme Conditions instrument at the LCLS facility at SLAC National Accelerator Laboratory to support research in high energy density laboratory plasmas. The FY 2021 Request includes funding for continued design and fabrication of the highest priority "in-kind" hardware systems for ITER.

- *High Energy Physics (HEP)* supports research to understand how the universe works at its most fundamental level by discovering the most elementary constituents of matter and energy, probing the interactions among them, and exploring the basic nature of space and time itself. The HEP Request of $818.131 million is a decrease of $226.869 million, or 21.7 percent, below the FY 2020 Enacted level. The Request will focus support on the highest priority elements identified in the 2014 High Energy Physics Advisory Panel (HEPAP) Particle Physics Project Prioritization Panel (P5) Report while minimizing significant impact to national laboratories, mainly to Fermi National Accelerator Laboratory (FNAL), which is funded primarily by HEP. Support for Research will prioritize efforts that address the science drivers of particle physics, Higgs boson, neutrinos, dark matter, dark energy, and exploring the unknown, and enable early and visible science results from HEP project investments. R&D that requires long-term investments, including Advanced Technology R&D, Accelerator Stewardship, and cross-cutting efforts in QIS and AI/ML to accelerate discovery in particle physics, will also be given higher priority in order to sustain world-leading efforts and support SC priorities. HEP, in coordination with SC, will support multi-disciplinary QIS centers to promote basic research and early stage development and to accelerate the advancement of QIS through vertical integration between systems and theory, and hardware and software. HEP Research will support multi-disciplinary microelectronics research with ASCR, BES and FES. The Traineeship Program for Accelerator Science and Technology will expand to research areas in Advanced Technology R&D. The P5 report identified the High-Luminosity Large Hadron Collider (HL-LHC) accelerator and A Toroidal LHC Apparatus (ATLAS) and Compact Muon Solenoid (CMS) Detector Upgrade Projects as the highest priority in the near-term, and Long-Baseline Neutrino Facility and Deep Underground Neutrino Experiment (LBNF/DUNE) as the highest-priority large project in its timeframe. To continue SC's strong international partnership with CERN, the FY 2021 Request will support these high-priority projects, and the Proton Improvement Plan II (PIP-II) construction project. The Request will support a new MIE start for the next generation Cosmic Microwave Background (CMB-S4) experiment, and design studies for a new Fermilab Accelerator Control System. The Request will support the operation of the Fermi National Accelerator Laboratory Accelerator Complex at 80 percent of optimal, the Brookhaven National Laboratory Accelerator Test Facility at 86 percent of optimal, the SLAC Facility for Advanced Accelerator Experimental Tests II (FACET-II) operations at 83 percent of optimal, and investments to enhance the Sanford Underground Research Facility (SURF) to meet DOE expectations for reliable, efficient, and safe operations.

- *Nuclear Physics (NP)* supports experimental and theoretical research to discover, explore, and understand all forms of nuclear matter. The NP Request of $653.327 million is a decrease of $59.673 million, or 8.4 percent, below the FY 2020 Enacted level. The Request will support the highest priority research and scientific user facilities to maintain U.S. leadership in nuclear science. The Request supports operations of the Relativistic Heavy Ion Collider (RHIC) to confirm the origin of intriguing new phenomena observed in quark gluon plasma formation, and continues support for the Strongly Pioneering High Energy Nuclear Interaction eXperiment (sPHENIX) MIE, which will further explore the properties of the quark gluon plasma. Operations support for the recently updated 12 gigaelectonvolt Continuous Electron Beam Accelerator Facility (CEBAF) will enable the highly anticipated science program to make progress towards unraveling the mechanism of quark confinement. At Argonne National Labratory, the Request also supports the operations of the Argonne Tandem Linac Accelerator System (ATLAS) to provide opportunities for research in nuclear structure and nuclear astrophysics. The Request will support the final year of construction of the Facility for Rare Isotope Beams (FRIB) according to the performance baseline profile, and continues support for the Gamma-Ray Energy Tracking Array (GRETA) and High Rigidity Spectrometer detector for FRIB. The Request will continue support for the Measurement of a Lepton-Lepton Electroweak Reaction (MOLLER) MIE, which will search for physics beyond our present understanding by measuring parity-violation in electron-electron scattering with the 12 GeV CEBAF machine is continued, and the Ton-Scale Neutrino-less Double Beta Decay (NLDBD) Experiment MIE, which will determine whether the neutrino is its own antiparticle. The Request continues to support R&D, conceptual design, and project engineering for the Electron Ion Collider at Brookhaven National Laboratory. The Request also increases support for the DOE Isotope Program to produce, and develop cutting-edge approaches for producing, critical isotopes in short supply. The Request also continues an Accelerator Improvement Project for the harvesting of isotopes at FRIB. The Request continues a construction project for the U.S. Stable Isotope Production and Research Center to produce critical enriched stable isotopes in short supply and mitigate U.S. dependence on foreign supply. The Request will continue activities in support of the National Isotope Strategy to promote U.S. core competencies in isotope enrichment technology. The Request for NP Research supports university and laboratory researchers to nurture critical core competencies and enable the highest priority theoretical and experimental activities to target compelling scientific opportunities at the frontier of nuclear science, including investments in QIS efforts in collaboration with other SC programs, the development of quantum sensors based on atomic-nuclear interactions and quantum control techniques, and the production of stable isotopes for next generation quantum information systems. The Request for NP Research also commences two efforts which align with SC priorities: Artifical Intelligence and Machine Learning, which will seek breakthroughs in AI/ML of relevance to nuclear science research, accelerator facility operations, and automated machine operations, and Strategic Accelerator R&D, which will pursue transformative accelerator R&D initiatives including next generation electron ion source developments and advanced approaches in superconducting radio frequency (SRF) technologies.

**Reorganization and Restructure Initiative**

SC continues to review its functions and the organizational structure to maximize efficiencies across all programs in an attempt to reduce and streamline the Federal footprint. Through workforce analysis and restructuring, we will continue to review, analyze, and prioritize mission requirements and identify those organizations and functions most in line with the Administration and Department program objectives and SC strategic goals. SC completed the implementation of a restructuring of the Field and mission support components following approval by the Secretary of Energy in November 2018. This restructuring merges two geographically separate service centers (Chicago and Oak Ridge) into a functionally consolidated center and consolidates corporate functions to improve consistency in operations, and pilots the merging of two SC federal site offices at national laboratories in the same geographic area (Lawrence Berkeley National Laboratory Site Office and the SLAC Site Office, both located in the San Francisco Bay area). This reorganization maximizes efficiencies across all SC field components programs and will reduce and streamline the Federal footprint. With the field reorganization complete, SC is focused on a reorganization of SC Headquarters. The changes for this reorganization are intended to address the needed evolution and re-alignment necessitated by current mission imperatives as well as to position SC for continued success in its strategic priorities. The reorganization will establish a new Principal Deputy Director position with transferred staff and functions from the existing Deputy Director positions along with new organizational elements. The vacant Deputy Director for Resource Management position will be eliminated and the reporting offices and staff reassigned to other SC HQ elements. Through workforce analysis and restructuring, SC reviewed, analyzed and prioritized mission requirements and identified those organizations and functions most in line with the Administration and Department program objectives and SC strategic goals.

**Basic and Applied R&D Coordination**

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

**High-Risk, High-Reward Research[a]**

SC incorporates high-risk, high-reward, basic research elements in all of its research portfolios; each SC research program considers a significant proportion of its supported research as high-risk, high-reward. Because advancing the frontiers of

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

science also depends on the continued availability of state-of-the-art scientific facilities, SC constructs and operates national scientific facilities and instruments that comprise the world's most sophisticated suite of research capabilities. SC's basic research is integrated within program portfolios, projects, and individual awards; as such, it is not possible to quantitatively separate the funding contributions of particular experiments or theoretical studies that are high-risk, high-reward from other mission-driven research in a manner that is credible and auditable. SC incorporates high-risk, high-reward basic research elements in its research portfolios to drive innovation and challenge current thinking, using a variety of mechanisms to develop topics: Federal advisory committees, triennial Committees of Visitors, program and topical workshops, interagency working groups, National Academies' studies, and special SC program solicitations. Many of these topics are captured in formal reports, e.g., *Basic Energy Sciences Roundtable: Chemical Upcycling of Polymers,* Basic Energy Sciences report (2019)[a]; *Basic Research Needs for Microelectronics*, joint BES, ASCR, and HEP workshop (2018) [b]; *Basic Research Needs for Scientific Machine Learning; Core Technologies for Artificial Intelligence*, ASCR workshop (2018)[c]; *Building for Discovery: Strategic Plan for U.S. Particle Physics in the Global* Context, by the High Energy Physics Advisory Panel (2014)[d]; *Quantum Computing Testbed for Science,* ASCR workshop report (2017)[e]; *Basic Energy Sciences Roundtable: Opportunities for Basic Research for Quantum Computing in Chemical and Materials Sciences*, Basic Energy Sciences report (2017); *Basic Energy Science Roundtable: Opportunities for Basic Research for Next-Generation Quantum Systems*, Basic Energy Sciences report (2017) [f]; *Challenges at the Frontiers of Matter and Energy: Transformative Opportunities for Discovery Science*, BES Advisory Committee (2015)[g]; *Basic Research Needs Workshop on Quantum Materials for Energy Relevant Technology,* BES workshop report (2016)[h]; *Grand Challenges for Biological and Environmental Research: Progress and Future* Vision, by the BER Advisory Committee (2017)[i]; *Technologies for Characterizing Molecular and Cellular Systems*, BER workshop report (2016)[j]; *Plasma: at the Frontier of Scientific Discovery*, FES workshop report (2017)[k]; *Transformative Enabling Capabilities for Efficient Advance Toward Fusion Energy*, FES Advisory Committee (2018)[l]; *FES Roundtable on QIS* (2018)[m]; *Advancing Fusion with Machine Learning,* joint FES-ASCR workshop report (2019)[n]; *Isotope Research and Production Opportunities and Priorities*, by the Nuclear Science Advisory Committee (NSAC) (2015)[o]; and *Nuclear Physics Long Range Plan*, by the NSAC (2015)[p] and *Quantum Computing and Quantum Information Sciences (QIS),* by the Nuclear Science Advisory Committee (NSAC)[l] (2019).

[a] https://science.osti.gov/-/media/bes/pdf/BESat40/Polymer_Upcycling_Brochure.pdf
[b] https://science.osti.gov/-/media/bes/pdf/reports/2019/BRN_Microelectronics_rpt.pdf
[c] https://science.energy.gov/ascr/community-resources/program-documents/
[d] http://science.osti.gov/~/media/hep/hepap/pdf/May%202014/FINAL_P5_Report_Interactive_060214.pdf
[e] https://science.osti.gov/~/media/ascr/pdf/programdocuments/docs/2017/QTSWReport.pdf
[f] https://science.osti.gov/~/media/bes/pdf/reports/2018/Quantum_computing.pdf
[g] http://science.osti.gov/~/media/bes/besac/pdf/Reports/CFME_rpt_print.pdf
[h] https://science.osti.gov/~/media/bes/pdf/reports/2016/BRNQM_rpt_Final_12-09-2016.pdf
[i] https://science.osti.gov/~/media/ber/berac/pdf/Reports/BERAC-2017-Grand-Challenges-Report.pdf
[j] http://science.osti.gov/~/media/ber/pdf/workshop%20reports/VirtualEcosystems.pdf
[k] https://science.osti.gov/~/media/fes/pdf/program-news/Frontiers_of_Plasma_Science_Final_Report.pdf
[l] https://science.osti.gov/-/media/fes/fesac/pdf/2018/TEC_Report_1Feb20181.pdf
[m] https://science.osti.gov/-/media/fes/pdf/workshop-reports/FES-QIS_report_final-2018-Sept14.pdf
[n] https://science.osti.gov/-/media/fes/pdf/workshop-reports/FES_ASCR_Machine_Learning_Report.pdf
[o] https://science.osti.gov/~/media/ber/pdf/community-resources/Technologies_for_Characterizing_Molecular_and_Cellular_Systems.pdf
[p] https://science.osti.gov/np/nsac/reports/

**Scientific Workforce**

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

**Cybersecurity**

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

[a] https://science. osti.gov/early-career/

## Science
## Funding by Congressional Control

| | (dollars in thousands) | | | |
|---|---|---|---|---|
| | **FY 2019 Enacted** | **FY 2020 Enacted** | **FY 2021 Request** | **FY 2021 Request vs FY 2020 Enacted** |
| **Advanced Scientific Computing Research** | | | | |
| Research | 702,794 | 791,265 | 819,106 | +27,841 |
| 17-SC-20, Office of Science Exascale Computing Project (SC-ECP) | 232,706 | 188,735 | 168,945 | -19,790 |
| **Total, Advanced Scientific Computing Research** | **935,500** | **980,000** | **988,051** | **+8,051** |
| | | | | |
| **Basic Energy Sciences** | | | | |
| Research | 1,757,700 | 1,853,000 | 1,751,673 | -101,327 |
| **Construction** | | | | |
| 21-SC-10, Cryomodule Repair & Maintenance Facility, SLAC | — | — | 1,000 | +1,000 |
| 19-SC-14, Second Target Station (STS), ORNL | 1,000 | 20,000 | 1,000 | -19,000 |
| 18-SC-10, Advanced Photon Source Upgrade (APS-U), ANL | 130,000 | 170,000 | 150,000 | -20,000 |
| 18-SC-11, Spallation Neutron Source Proton Power Upgrade (PPU), ORNL | 60,000 | 60,000 | 5,000 | -55,000 |
| 18-SC-12, Advanced Light Source Upgrade (ALS-U), LBNL *(19-SC-10)* | 60,000 | 60,000 | 13,000 | -47,000 |
| 18-SC-13, Linac Coherent Light Source-II-High Energy (LCLS-II-HE), SLAC *(19-SC-11)* | 28,000 | 50,000 | 14,000 | -36,000 |
| 13-SC-10, Linac Coherent Light Source-II (LCLS-II), SLAC | 129,300 | — | — | — |
| **Total, Construction** | **408,300** | **360,000** | **184,000** | **-176,000** |
| **Total, Basic Energy Sciences** | **2,166,000** | **2,213,000** | **1,935,673** | **-277,327** |
| | | | | |
| **Biological and Environmental Research** | **705,000** | **750,000** | **516,934** | **-233,066** |
| | | | | |
| **Fusion Energy Sciences** | | | | |
| Research | 432,000 | 414,000 | 313,151 | -100,849 |
| **Construction** | | | | |
| 20-SC-61, Matter in Extreme Conditions (MEC) Petawatt Upgrade | — | 15,000 | 5,000 | -10,000 |
| 14-SC-60, U.S. Contributions to ITER | 132,000 | 242,000 | 107,000 | -135,000 |
| **Total, Construction** | **132,000** | **257,000** | **112,000** | **-145,000** |
| **Total, Fusion Energy Sciences** | **564,000** | **671,000** | **425,151** | **-245,849** |

| | (dollars in thousands) | | | |
|---|---|---|---|---|
| | **FY 2019 Enacted** | **FY 2020 Enacted** | **FY 2021 Request** | **FY 2021 Request vs FY 2020 Enacted** |
| **High Energy Physics** | | | | |
| Research | 800,000 | 814,000 | 697,631 | -116,369 |
| **Construction** | | | | |
| 18-SC-42, Proton Improvement Plan II (PIP-II), FNAL | 20,000 | 60,000 | 20,000 | -40,000 |
| 11-SC-40, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment (LBNF/DUNE), FNAL | 130,000 | 171,000 | 100,500 | -70,500 |
| 11-SC-41, Muon to Electron Conversion Experiment, FNAL | 30,000 | — | — | — |
| **Total, Construction** | **180,000** | **231,000** | **120,500** | **-110,500** |
| **Total, High Energy Physics** | **980,000** | **1,045,000** | **818,131** | **-226,869** |
| | | | | |
| **Nuclear Physics** | | | | |
| Operation and Maintenance | 615,000 | 660,000 | 635,027 | -24,973 |
| **Construction** | | | | |
| 20-SC-51, U.S. Stable Isotope Production and Research Center, ORNL | — | 12,000 | 12,000 | — |
| 20-SC-52, Electron Ion Collider, BNL | — | 1,000 | 1,000 | — |
| 14-SC-50, Facility for Rare Isotope Beams, MSU | 75,000 | 40,000 | 5,300 | -34,700 |
| **Total, Construction** | **75,000** | **53,000** | **18,300** | **-34,700** |
| **Total, Nuclear Physics** | **690,000** | **713,000** | **653,327** | **-59,673** |
| | | | | |
| **Workforce Development for Teachers and Scientists** | **22,500** | **28,000** | **20,500** | **-7,500** |
| | | | | |
| **Science Laboratories Infrastructure** | | | | |
| Infrastructure Support | | | | |
| Payment in Lieu of Taxes | 1,713 | 4,540 | 4,650 | +110 |
| Oak Ridge Landlord | 6,434 | 5,610 | 5,860 | +250 |
| Facilities and Infrastructure | 45,543 | 56,850 | 6,200 | -50,650 |
| Oak Ridge Nuclear Operations | 26,000 | 26,000 | 6,000 | -20,000 |
| **Total, Infrastructure Support** | **79,690** | **93,000** | **22,710** | **-70,290** |

| | (dollars in thousands) | | | |
|---|---|---|---|---|
| | **FY 2019 Enacted** | **FY 2020 Enacted** | **FY 2021 Request** | **FY 2021 Request vs FY 2020 Enacted** |
| **Construction** | | | | |
| 21-SC-71, Princeton Plasma Innovation Center, PPPL | — | — | 2,000 | +2,000 |
| 21-SC-72, Critical Infrastructure Recovery & Renewal, PPPL | — | — | 2,000 | +2,000 |
| 21-SC-73, Ames Infrastructure Modernization | — | — | 2,000 | +2,000 |
| 20-SC-71, Critical Utilities Rehabilitation Project, BNL | — | 20,000 | 15,000 | -5,000 |
| 20-SC-72, Seismic and Safety Modernization, LBNL | — | 10,000 | 10,000 | — |
| 20-SC-73, CEBAF Renovation and Expansion, TJNAF *(19-SC-75)* | — | 2,000 | 2,000 | — |
| 20-SC-74, Craft Resources Support Facility, ORNL *(19-SC-76)* | — | 15,000 | 25,000 | +10,000 |
| 20-SC-75, Large Scale Collaboration Center, SLAC *(19-SC-77)* | — | 11,000 | 8,000 | -3,000 |
| 20-SC-76, Tritium System Demolition and Disposal, PPPL | — | 13,000 | 19,400 | +6,400 |
| 20-SC-77, Argonne Utilities Upgrade, ANL | — | 500 | 2,000 | +1,500 |
| 20-SC-78, Linear Assets Modernization Project, LBNL | — | 500 | 2,000 | +1,500 |
| 20-SC-79, Critical Utilities Infrastructure Revitalization, SLAC | — | 500 | 2,000 | +1,500 |
| 20-SC-80, Utilities Infrastructure Project, FNAL | — | 500 | 2,000 | +1,500 |
| 19-SC-71, Science User Support Center, BNL | 7,000 | 20,000 | 7,000 | -13,000 |
| 19-SC-72, Electrical Capacity and Distribution Capability, ANL | 30,000 | 30,000 | — | -30,000 |
| 19-SC-73, Translational Research Capability, ORNL | 25,000 | 25,000 | 10,000 | -15,000 |
| 19-SC-74, BioEPIC, LBNL | 5,000 | 15,000 | 6,000 | -9,000 |
| 18-SC-71, Energy Sciences Capability, PNNL | 24,000 | 23,000 | 23,000 | — |
| 17-SC-71, Integrated Engineering Research Center, FNAL | 20,000 | 22,000 | 12,000 | -10,000 |
| 17-SC-73, Core Facility Revitalization, BNL | 42,200 | — | — | — |
| **Total, Construction** | **153,200** | **208,000** | **151,400** | **-56,600** |
| **Total, Science Laboratories Infrastructure** | **232,890** | **301,000** | **174,110** | **-126,890** |
| | | | | |
| **Safeguards and Security** | **106,110** | **112,700** | **115,623** | **+2,923** |
| | | | | |
| **Program Direction** | **183,000** | **186,300** | **190,306** | **+4,006** |
| | | | | |
| **Total, Science** | **6,585,000** | **7,000,000** | **5,837,806** | **-1,162,194** |
| **Federal FTEs** | **810** | **785** | **785** | **—** |

**SBIR/STTR funding:**

- FY 2019 Enacted: SBIR $148,264,000 and STTR $20,851,000 (SC only)
- FY 2020 Enacted: SBIR $159,140,000 and STTR $22,279,000 (SC only)
- FY 2021 Request: SBIR $139,901,000 and STTR $19,390,000 (SC only)

## Advanced Scientific Computing Research

### Overview

The Advanced Scientific Computing Research (ASCR) program's mission is to advance applied mathematics and computer science; deliver the most sophisticated computational scientific applications in partnership with disciplinary science; advance computing and networking capabilities; and develop future generations of computing hardware and software tools for science and engineering in partnership with the research community, including U.S. industry. ASCR supports state-of-the-art capabilities that enable scientific discovery through computation. The Computer Science and Applied Mathematics activities in ASCR provide the foundation for increasing the capability of the national high performance computing (HPC) ecosystem by focusing on long-term research to develop software, algorithms, methods, tools and workflows that anticipate future hardware challenges and opportunities as well as science application needs. ASCR's partnerships and coordination with the other Office of Science (SC) programs and with industry are essential to these efforts. At the same time, ASCR partners with disciplinary sciences to deliver some of the most advanced scientific computing applications in areas of strategic importance to SC and the Department of Energy (DOE). ASCR also supports world-class, open access high performance computing facilities and high performance networks for scientific research.

For over half a century, the U.S. has maintained world-leading computing capabilities through sustained investments in research, development, and regular deployment of new computing systems and advanced networks along with the applied mathematics and software technologies to effectively use leading edge systems. The benefits of U.S. computational leadership have been enormous – huge gains in increasing workforce productivity, accelerated progress in both science and engineering, advanced manufacturing techniques and rapid prototyping, stockpile stewardship without testing, and the ability to explore, understand, and harness natural and engineered systems, which are too large, too complex, too dangerous, too small, or too fleeting to explore experimentally. Leadership in HPC has also played a crucial role in sustaining America's competitiveness internationally. As the Council on Competitiveness noted and documented in a series of case studies, "A country that wishes to out-compete in any market must also be able to out-compute its rivals." While this continues to be true, there is also a growing recognition that the nation that leads in artificial intelligence (AI) and machine learning (ML) and in the integration of the computing and data ecosystem will lead the world in developing new technologies, medicines, industries, and military capabilities. Most of the modeling and prediction necessary to produce the next generation of breakthroughs in science, energy, medicine, and national security will come not from applying traditional theory, but from employing data-driven methods at extreme scale tightly coupled to experiments and scientific user facilities.

ASCR-supported activities are entering a new paradigm driven by sharp increases in the heterogeneity and complexity of computing systems and the need to seamlessly and intelligently integrate simulation, AI, data analysis, and other tasks into coherent and usable workflows for science. HPC has become an essential tool for understanding complex systems in unprecedented detail; exploring systems of systems through ensembles of simulations; learning from extreme scale, complex data; and carrying out data analyses, especially when time is of the essence. These changes are being driven by enormous increases in the volume and complexity of data generated by SC user facilities – from simulations, experiments, and observations – and these new opportunities are propelled by advances already achieved through the DOE Exascale Computing Initiative (ECI). The convergence of AI technologies with these existing investments creates a powerful accelerator for progress and gives the U.S. a distinct advantage over nations with less integrated investments. The FY 2021 Request strengthens partnerships with the other SC programs to build the computational and data infrastructure needed to support scientific computing from the edge to ASCR high performance computing facilities.

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

The emerging field within quantum information science (QIS) – the ability to exploit intricate quantum mechanical phenomena to create fundamentally new ways of obtaining and processing information – is opening new vistas of science discovery and technology innovation that build on decades of investment across SC. QIS is currently at the threshold of a potentially disruptive revolution, creating opportunities and challenges for the Nation, as growing international interest and investments are starting a global quantum race. DOE envisions a future in which the cross-cutting field of QIS increasingly drives scientific frontiers and innovations toward realizing the full potential of quantum-based applications, from computing to sensing, connected through a quantum internet. This will require a detailed understanding of how quantum systems behave, accurate knowledge of how to integrate the components into complex systems, and precise control of the structures and functionalities. The traditional model of discovery science leading to design, development, and commercial deployment will not meet these goals alone within an acceptable time due to the urgency and scale of this mission. Rather, there is a need for bold approaches that better couple all elements of the technology innovation chain and combine the talents of the program offices in SC, universities, national labs, and the private sector in concerted efforts to define and construct an internationally competitive U.S. economy. In support of the National Quantum Initiative, SC QIS Centers established in FY 2020 constitute an interdisciplinary partnership between ASCR and the other SC programs. This partnership complements a robust core research portfolio stewarded by the individual SC programs, including ASCR, to create the ecosystem across universities, national laboratories, and industry that is needed to advance developments in QIS and related technology.

Moore's Law – the historical pace of microchip innovation whereby feature sizes reduce by a factor of two approximately every two years – is nearing an end due to limits imposed by fundamental physics and economics. As a result, numerous emerging technologies are competing to help sustain productivity gains, each with its own risks and opportunities. The challenge for ASCR is in understanding their implications for scientific computing and being ready for the potential disruptions from rapidly evolving technologies without stifling innovation or hampering scientific progress. ASCR's strategy is to focus on technologies that build on expertise and core investments across SC, continuing engagements with industry and the scientific community from the exascale computing project, investing in small-scale testbeds and increasing core research investments in Applied Mathematics and Computer Science.

Today, significant investments in Asia and Europe are challenging U.S. dominance in computing, and nations around the globe are enthusiastically investing in AI and QIS. The U.S. must invest in the fields and infrastructure that are critical to American prosperity. Public-private partnerships remain vital as we push our state-of-the-art fabrication techniques to their limit to develop an exascale-capable (one billion billion operations per second) system while simultaneously preparing for the artificial intelligence-big data surge, with its integration and infrastructure challenges, and the "Cambrian explosion" of specialized hardware expected as we reach the end of the current technology roadmap. Maximizing the benefits of U.S. leadership in computing in the coming decades will require an effective national response to increasing demands for computing capabilities and performance, emerging technological challenges and opportunities, and competition with other nations. DOE has a long history of making fundamental contributions to applied mathematics and computer science associated with strategic computing, and foresees making a similar set of contributions for AI/ML in the science domain and related investments in advanced architectures, scientific data infrastructure, and emerging technologies. ASCR's proposed activities are in line with the Administration's FY 2021 Research and Development (R&D) priority for American Leadership in AI, Quantum Information Science (QIS), and Strategic Computing.

SC and the National Nuclear Security Administration (NNSA) continue to partner in the Department's ECI to overcome key exascale challenges in parallelism, energy efficiency, and reliability, with emphasis on the implications for both simulation and data science at this scale, leading to deployment of a diverse set of two exascale systems by SC in the calendar year 2021-2022 timeframe. The ECI's goal for an exascale-capable system is a five-fold increase in sustained performance over the Summit HPC system at Oak Ridge National Laboratory (ORNL), with applications that address next-generation science, engineering, and data problems. The ECI focuses on delivering advanced simulation through an exascale-capable computing program, emphasizing sustained performance in science and national security mission applications and increased convergence between exascale and large-data analytic computing.

**Highlights of the FY 2021 Request**

The FY 2021 Request of $988,051,000 for ASCR will strengthen U.S. leadership in strategic computing, the foundations of AI and QIS, and the infrastructure that enables data-driven science. To ensure ASCR is meeting SC's HPC mission needs during and after the exascale project, the Request prioritizes basic research in Applied Mathematics and Computer Science with emphasis on the challenges of data intensive science, including AI/ML, and future computing technologies, and significantly increases support for ASCR's Computational Partnerships with a focus on developing strategic partnerships in quantum computing and data intensive applications and new partnerships that broaden the impact of both exascale and data infrastructure investments in areas of strategic importance to DOE and SC. The Request also provides strong support for ASCR user facilities operations to ensure the availability of high performance computing, data, and networking to the scientific community and upgrades to maintain U.S. leadership in these essential areas. Funding supports upgrades at the Oak Ridge Leadership Computing Facility (OLCF), the Argonne Leadership Computing Facility (ALCF), the National Energy Research Scientific Computing Center (NERSC), and the Energy Sciences Network (ESnet). The Request supports testbeds both at the facilities and through the Advanced Computing Research activity. The Request maintains support for the Computational Sciences Graduate Fellowship (CSGF) with increased emphasis on foundational research in AI and QIS. It provides robust support for ECI, which includes the SC-Exascale Computing Project (SC-ECP) and site preparations, testbeds, and non-recurring engineering (NRE) activities at the LCFs in support of the delivery of at least one exascale computing system in calendar year 2021.

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

Research

- Advances in exascale computing, AI/ML, and a robust data infrastructure when combined can significantly improve scientific productivity by managing complex simulations and augmenting first principle simulations with data driven predictive models. The Request supports foundational research to improve the robustness, reliability, and transparency of Big Data and AI technologies, uncertainty quantification, and development of software tools to tightly couple simulation, data analysis, and AI for DOE mission applications. Investments focus on areas unique to science such as the transparency and interpretability of AI/ML, uncertainty quantification, and the computer science and software infrastructure for AI/ML applications, including tools for data management. The Request also supports partnerships among computer scientists, applied mathematicians, and domain scientists to develop hybrid models where current DOE applications, which are characterized by complex, multi-scale physics as well as large-scale, multi-faceted data, are merged with AI/ML techniques—providing the combined benefits of both techniques. These efforts will be combined with new efforts to develop the computational and data infrastructure to more seamlessly integrate SC user facilities and data repositories with compute resources and other tools for extracting scientific insights.

- Recognizing the limits of Moore's Law, ASCR began activities in FY 2017 to explore future computing technologies, such as QIS and neuromorphic computing, that are not based on silicon microelectronics. QIS remains a principal emphasis due to the potential for disruption and the significant expertise and investments across SC. ASCR will continue to partner with the other SC programs to support multi-disciplinary QIS Centers. These centers promote basic research and early stage development to accelerate the advancement of QIS through vertical integration between systems and theory and hardware and software. ASCR's Quantum Testbeds activities, which provide researchers with access to novel, early-stage quantum computing resources and services, will continue. In addition, basic research in quantum information networks will focus on the opportunities and challenges of transporting and storing quantum information over interconnects and networks toward a vision to deliver a fundamentally new capability. In FY 2021, ASCR will support early stage research associated with the first steps to establishing a dedicated Quantum Network.

- The Computer Science and Applied Mathematics activities in ASCR provide the foundation for increasing the capability of the national HPC ecosystem by focusing on long-term research to develop smart software, algorithms, and methods that explore the wide array of emerging technologies and anticipate future hardware challenges and opportunities as well as science application needs. In FY 2021, these activities will be expanded to address the combined challenges of increasingly heterogeneous computer architectures, and the changing ways in which HPC systems are used –

incorporating and addressing critical data science research to support the incorporation of AI into simulation and experiments including greater connectivity with distributed systems and resources, such as other SC user facilities. Emerging AI and data infrastructure technologies are a significant focus of this portfolio.

- The Computational Partnerships activity is primarily focused on the Scientific Discovery through Advanced Computing (SciDAC) computational partnerships and Institutes to advance and apply the software, tools, and methods developed by ASCR core research efforts in Applied Mathematics and Computer Science. This allows the other scientific programs in SC to more effectively use the current and immediate next-generation HPC facilities. The SciDAC portfolio will continue to support recently recompeted SciDAC Institutes, and will recompete the SciDAC applications with emphasis on ECP and emerging AI and data infrastructure technologies. The research results emerging from the ECI inform SciDAC investments, which will, whenever possible, incorporate the software, methods, and tools developed by that initiative. Building on the success of the ECI funded partnership with the National Cancer Institute, funding is requested to partner with the NIH to expand the capabilities of DOE's tools and address NIH's rapidly growing data and computational challenges.

- ASCR will partner with SC's Offices of Basic Energy Sciences (BES), High Energy Physics (HEP), and Fusion Energy Sciences (FES) to support multi-disciplinary microelectronics research that will promote basic research to accelerate the advancement of microelectronic technologies in a co-design innovation ecosystem in which materials, chemistries, devices, systems, architectures, algorithms, and software are developed in a closely integrated fashion.

- The current and predicted computing and data-intensive needs of DOE research and applications aggregate to a need for a robust, integrated, computing and data infrastructure. All research activities will also support partnerships with other SC programs to ensure the seamless integration of Big Data and AI with computing resources to support the large-scale computing and data requirements from SC user facilities as well as to prepare for future technology through partnerships in emerging areas such as QIS.

- To address the need for strong connections between core research and prototype development, the Research and Evaluation Prototypes (REP) activity is transferred from the Facilities subprogram to the Research subprogram under the Advanced Computing Research activity beginning in FY 2021. This activity continues to support, in partnership with NNSA, the Computational Sciences Graduate Fellowship in FY 2021 at $10,000,000 with increased focus on AI and QIS. This activity also supports the Quantum computing testbeds and early stage research activities associated with a Quantum internet (Qnet) as well as small investments in cybersecurity and microelectronics research.

Facility Operations

- In FY 2021, ASCR's high performance computing and high performance networking user facilities will continue to advance scientific discovery through optimal operations. The Leadership Computing Facilities (LCFs) will continue to deliver HPC capabilities for large-scale applications to ensure that the U.S. research community and DOE's industry partners continue to have access to the most capable supercomputing resources in the world. NERSC will provide an innovative platform to advance SC mission research. ESnet will continue to expand capacity to meet the Department's exponential growth in scientific data traffic while executing a major upgrade to the core network.

- In 2021, the ALCF will install the first U.S. exascale computing system, named Aurora, and begin acceptance and early science testing. In addition, the ALCF will continue to operate the Theta system and provide additional testbeds for testing SC applications and software technologies, including AI, at scale.

- The OLCF Summit system became the world's fastest supercomputer in June 2018 and remains the fastest according to the November 2019 Top500 List[a]. Summit will remain in operation throughout FY 2021. In addition to scientific modeling and simulation, Summit offers unparalleled opportunities for the integration of AI and data intensive scientific discovery, enabling researchers to apply techniques like machine learning and deep learning to problems in high energy physics, materials discovery, and other areas. ORNL will make final site preparations and NRE investments

[a] https://www.top500.org/list/2019/11/

for an exascale upgrade (OLCF-5), named Frontier, in the calendar year 2021-2022 timeframe. Frontier will be architecturally diverse from the Aurora ALCF-3 system.

- NERSC will continue operations of the 30 petaflop (pf) NERSC-8 supercomputer, named Cori and begin operations of the 75 petaflop NERSC-9 system, named Perlmutter after LBNL Nobel Laureate Saul Perlmutter. To keep pace with the increasing demand from SC researchers for AI, simulation, and data-intensive applications on NERSC, the Request also supports planning for expanded capacity and investments to ensure that the diverse NERSC user community is prepared to utilize exascale and emerging computing systems.

- In FY 2021, ESnet will continue to provide networking connectivity for large-scale scientific data flows while modernizing the network to meet the future needs of the DOE community. The last significant upgrade of the ESnet was in calendar year 2010, and the current optical and routing equipment is at or near the end of its operational effectiveness. The forthcoming delivery of exascale machines and the dramatically accelerating data rates from many SC user facilities and research projects demand not only ever-greater network capacity and security but also new flexibility and data infrastructure integration to deliver on-demand data management. The ESnet-6 upgrade is designed to achieve these capabilities and provide DOE with a fully integrated network backbone completely under DOE control with enhanced cyber resiliency. Funding for the upgrade continues in FY 2021.

- The Department recognizes the significant and sustained competition among employers for trained computational data/network professionals, and the impact of workforce needs on achievement of the accelerated timeline for the delivery of an exascale system. Experienced computational scientists who assist a wide range of users in taking effective advantage of DOE's advanced computing resources are critical assets at both the LCFs and NERSC. To address this DOE mission need, the Request continues support for post-doctoral programs at the ASCR user facilities for high end computational science and engineering through facilities operations funding. In addition, the three ASCR HPC user facilities will continue to prepare their users for future architectures through the deployment of experimental testbeds.

Projects

- Exascale computing is a central component of a long-term collaboration between SC's ASCR program and NNSA's Advanced Simulation and Computing (ASC) program to maximize the benefits of DOE's investments, avoid duplication, and leverage the significant expertise across the DOE complex. The ASCR FY 2021 Request includes $438,945,000 for SC's contribution to DOE's ECI to support the development of an exascale computing software ecosystem, prepare mission critical applications to address the challenges of exascale, and deploy at least one exascale system in calendar year 2021 to meet national needs.

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

- The results of Exascale's previous investments with vendors in the Hardware and Integration focus area were evident in the vendor's responses to the CORAL (Collaboration of Oak Ridge, Argonne and Livermore) II request for proposals and selected architectures for the exascale systems.

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

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

▪ Funding for ECI ($438,945,000) continues with a focus on final preparation of applications and software in SC-ECP and the final preparations at the LCFs to support the installation of Aurora at ANL, followed by Frontier at ORNL. This approach will reduce the project risk:

- A total of $168,945,000 for the SC-ECP project for the final preparation of applications and the software stack for testing on both exascale platforms, and continued support for co-design centers preparation for exascale system installation in calendar year 2021.
- A total of $270,000,000 in LCFs activity to support operations of the ALCF's Theta system and testbeds, final site preparation investments needed just prior to the installation of Aurora, and to support final site preparations at the OLCF needed just prior to installation of Frontier. The deployment of exascale systems to these two LCFs will occur as part of their usual upgrade processes and, once accepted, the systems' the lease payments will be funded as part of operations.

**FY 2021 Research Initiatives**

Advanced Scientific Computing Research supports the following FY 2021 Research Initiatives.

| | (dollars in thousands) | | | |
|---|---|---|---|---|
| | **FY 2019 Enacted** | **FY 2020 Enacted** | **FY 2021 Request** | **FY 2021 Request vs FY 2020 Enacted** |
| **New Research Initiatives** | | | | |
| Data and Computational Collaboration with NIH | — | — | 1,000 | +1,000 |
| Integrated Computational and Data Infrastructure for Scientific Discovery | — | — | 11,845 | +11,845 |
| **Total, New Research Initiatives** | **—** | **—** | **12,845** | **+12,845** |
| | | | | |
| **Ongoing Research Initiatives** | | | | |
| Artificial Intelligence and Machine Learning | 15,000 | 36,000 | 56,000 | +20,000 |
| Exascale Computing Initiative | 472,706 | 463,735 | 438,945 | -24,790 |
| Quantum Information Science | 33,666 | 54,680 | 86,162 | +31,482 |
| Microelectronics Innovation | — | — | 5,000 | +5,000 |
| **Total, Ongoing Research Initiatives** | **521,372** | **554,415** | **586,107** | **+31,692** |

**Advanced Scientific Computing Research**
**Funding**

(dollars in thousands)

| | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|
| **Mathematical, Computational, and Computer Sciences Research** | | | | |
| Applied Mathematics | 28,206 | 41,500 | 53,728 | +12,228 |
| Computer Science | 22,000 | 38,700 | 49,605 | +10,905 |
| Computational Partnerships | 75,667 | 69,142 | 75,051 | +5,909 |
| Advanced Computing Research | — | — | 76,007 | +76,007 |
| SBIR/STTR | 4,768 | 5,658 | 9,637 | +3,979 |
| **Total, Mathematical, Computational, and Computer Sciences Research** | **130,641** | **155,000** | **264,028** | **+109,028** |
| | | | | |
| **High Performance Computing and Network Facilities** | | | | |
| High Performance Production Computing | 104,000 | 110,000 | 85,000 | -25,000 |
| Leadership Computing Facilities | 339,000 | 375,000 | 370,000 | -5,000 |
| Research and Evaluation Prototypes | 24,452 | 39,000 | — | -39,000 |
| High Performance Network Facilities and Testbeds | 84,000 | 90,000 | 80,000 | -10,000 |
| SBIR/STTR | 20,701 | 22,265 | 20,078 | -2,187 |
| **Total, High Performance Computing and Network Facilities** | **572,153** | **636,265** | **555,078** | **-81,187** |
| **Subtotal, Advanced Scientific Computing Research** | **702,794** | **791,265** | **819,106** | **+27,841** |
| | | | | |
| **Construction** | | | | |
| 17-SC-20 Office of Science Exascale Computing Project (SC-ECP) | 232,706 | 188,735 | 168,945 | -19,790 |
| **Total, Advanced Scientific Computing Research** | **935,500** | **980,000** | **988,051** | **+8,051** |

SBIR/STTR funding:

- FY 2019 Enacted: SBIR $22,329,000 and STTR $3,140,000
- FY 2020 Enacted: SBIR $25,160,000 and STTR $3,538,000
- FY 2021 Request: SBIR $26,051,000 and STTR $3,664,000

| | (dollars in thousands) FY 2021 Request vs FY 2020 Enacted |
|---|---|
| **Mathematical, Computational, and Computer Sciences Research**<br>The Computer Science and Applied Mathematics activities will continue to increase their efforts on the combined challenges of increasingly heterogeneous architectures, and the changing ways in which HPC systems are used, incorporating AI and ML into simulations and data intensive applications while increasing greater connectivity with distributed systems and resources including other SC user facilities. The Computational Partnerships activity will continue to infuse the latest developments in applied math and computer science, particularly in the areas of AI and data infrastructure tools, into strategic applications, including new areas such as revolutionizing microelectronics, to get the most out of the leadership computing systems and data infrastructure investments. In addition, the Computational Partnerships activity will increase investments in new algorithms, applications, and data infrastructure, focused on both artificial intelligence and on future computing technologies, such as QIS and bio-inspired/bio-accelerated computing in partnership with the other SC programs and other partners such as NIH. Increases in Computer Science for quantum information networks will focus on addressing new opportunities and challenges of transporting and storing quantum information. Within the Advanced Computing Research activity, Research and Evaluation Prototypes provides support for emerging technology testbeds with emphasis on Quantum, in close coordination with the other SC programs. This includes early stage research activities for a Quantum internet (Qnet). This activity also supports the Computational Sciences Graduate Fellowship (CSGF). | **+109,028** |
| **High Performance Computing and Network Facilities**<br>Facilities funding is reduced due to the shift of Research and Evaluation Prototypes activities to the Research subprogram, and to the completion of significant site preparation activities at the LCFs and NERSC. The Request supports final site preparations to deploy an Aurora exascale system at the ALCF in calendar year 2021 and the architecturally distinct Frontier exascale system at the OLCF, to be deployed in the calendar year 2021-2022 timeframe. Both facilities will continue to provide testbed resources to the SC-ECP and other SC researchers to test and scale application codes and continuously test and deploy software technologies. In addition, funding supports operation of the NERSC-9 and Cori systems and supports the ESnet-6 upgrade to significantly increase capacity and security at all DOE sites. Funding also supports operations, including increased power costs, equipment, staffing, planning, and lease payments at ASCR's facilities. | **-81,187** |
| **Exascale Computing**<br>The FY 2021 Request will support efforts in the SC-ECP for the finalization of co-design efforts in application and software development for both planned exascale architectures and partnerships with the ASCR facilities that are providing resources for continuous integration and testing of exascale-ready software. The decrease represents completion of ASCR supported vendor partnerships with the six computer vendors that developed critical technologies, such as interconnects, processors and memory, needed for the exascale system and accelerated the transition from research to testing of applications and software on the exascale testbeds. | **-19,790** |
| **Total, Advanced Scientific Computing Research** | **+8,051** |

**Basic and Applied R&D Coordination**

Coordination across disciplines and programs is a cornerstone of the ASCR program. Partnerships within SC are mature and continue to advance the use of HPC and scientific networks for science. New partnerships with other SC Programs have been established in QIS; and the DOE activities in AI and QIS are coordinated with other agencies through the National Science and Technology Council (NSTC). There are growing areas of collaboration in the area of data-intensive science, AI, and readying applications for exascale. ASCR continues to have a strong partnership with NNSA for achieving the Department's goals for exascale computing. In April 2011, ASCR and NNSA strengthened this partnership by signing a memorandum of understanding for collaboration and coordination of exascale research within the DOE. Through the National Information Technology R&D Subcommittee of the NSTC Committee on Technology, the interagency networking and information technology R&D coordination effort, ASCR also coordinates with programs across the Federal Government. In FY 2021, cross-agency interactions and collaborations will continue in coordination with the Office of Science and Technology Policy.

**Program Accomplishments**

*Getting Ready for Exascale.*

The efficiency of the Spectral Neighbor Analysis Potential (SNAP) machine-learning kernel on various architectures displayed a worrisome decrease in terms of performance relative to the theoretical peak of the hardware, particularly on GPU accelerated architectures. Addressing this concern has become a central effort of the Exascale Computing Project's (ECP) Exascale Atomistics for Accuracy, Length, and Time (EXAALT) project. A team comprised of NERSC staff, the ECP Co-design center for Particle Applications (CoPA), and the ECP software team has completely re-engineered the SNAP kernel from the ground up. Beginning with a stand-alone Compute Unified Device Architecture (CUDA) prototype, re-engineered SNAP kernel has been implemented in the widely used molecular dynamics software, Large-scale Atomic/Molecular Massively Parallel Simulator (LAMMPS) using an ECP library for performance portability. This implementation reversed the trend and led to a five times improvement in performance. Deploying the new SNAP kernel on Summit results in a simulation throughput of 175,100 atoms-steps/wall-clock second per node, exploiting all 6 General Processing Units (GPUs) and 42 Central Processing Unit (CPU) cores.

*HP-CONCORD Enables Machine Learning in HPC at Unprecedented S*cale.

Understanding the interactions between millions of variables such as how a disease may be caused by a subset of the human genes is among the most challenging problems in data-driven science. A powerful machine learning algorithm called CONCORD can identify these relationships however until recently it could only be applied to modest-sized data sets. Researchers from LBNL supported by SciDAC along with their collaborators from Google Brain, University of California Santa Barbara and Carnegie Mellon University developed a high-performance computing version of the algorithm called HP-CONCORD. Using NERSC, they then demonstrated this parallel algorithm on an enormous set of data from the Human Connectome Project, which computed estimates for about 4 billion parameters, and an even larger demonstration problem with over 800 billion parameters. The HP-CONCORD team used functional magnetic resonance imaging data to estimate the underlying conditional dependency structure of the brain and then used the resulting estimate to automatically identify functional regions of the brain. The researchers expect that many other science areas will benefit from HP-CONCORD in the future: In biology it can be used to reconstruct gene regulatory networks, or in environmental sciences it can help in estimating temperature-to-environmental-proxy relationships. HP-CONCORD may also be useful for hypothesis generation in exploratory data analysis to guide further experimental study.

*Autonomous AI-driven approach maximizes the value of high-throughput experiments.*

What can be done to help a scientist decide which sequence of experiments to run in order to get the most information as quickly as possible? Researchers in the Center for Advanced Mathematics for Energy Research Applications (CAMERA) have developed a way to optimize beamline experiments and automatically choose the best next experiment to perform. New computational methods were developed to quickly explore the parameter space of predicted physical effects in a way that reduces the overall beamline time used and increases the yield from the experiment. Actions are carried out in real-time in beamline experiments at NSLS-II (BNL) and the ALS (LBNL). At BNL, beamline utilization increased from 20 percent to 80 percent, with a six-fold decrease in the number of experiments required to achieve similar results.

*Quantum Noise Mitigation for the Masses.*
While quantum computers today are very noisy, much of the noise is systematic and can be characterized with good precision. A team at ORNL and Virginia Tech have adapted a standard technique in experimental physics — amplifying noise in order to treat it as a “signal” and then examine how that noise varies with respect to a degree of freedom, or “knob” that we have control over – to develop a post-processing technique to mitigate the effect of noise on the output of today’s quantum processors. A U.S. company took note of the result and made a pull request to the ASCR-funded team, who responded by making their technique available as a new module in the company’s widely used, open source software development kit for quantum computing.

*Dark optical fiber proves to be a promising earthquake sensor.*
In one of the first case studies to employ a large regional network as an earthquake sensor, researchers from Lawrence Berkeley National Laboratory used distributed acoustic sensing along a 20-mile segment of the 13,000-mile-long ESnet Dark Fiber Testbed to collect and analyze seven months of passive seismic data. Because the ESnet Testbed has regional coverage, they were able to monitor seismic activity and environmental noise with finer detail than previous studies. The research team used ambient noise interferometry techniques to process 300 terabytes of collected data and extract surface wave velocity information, which enabled them to map shallow structural profiles and groundwater depth and detect regional and teleseismic earthquakes. In traditional seismology, researchers studying how the earth moves in the moments before, during, and after an earthquake rely on sensors that cost tens of thousands of dollars to make and install underground. This new approach could augment the performance of earthquake early warning systems currently being developed in the Western U.S., with higher sensitivity and at lower cost.

*Hackathon Leads to Game-Changing Code Speedup for General Electric (GE).*
GE Power technologies generate approximately one-third of the world’s electricity. In 2018, Hyperion Research published a case study on how GE engineers were able to nearly double the efficiency of their gas turbines with the help of supercomputing simulation[a]. Recently, GE has become increasingly interested in improving GPU performance to harness the power of new HPC architectures to run its codes faster to create more design iterations and better end designs. A team from GE participated in two of the OLCF’s 2019 hackathons—the first at Brookhaven National Laboratory last September and the second at the Massachusetts Institute of Technology—and used the CUDA programming model on the Summit supercomputer to gain 50-fold to 300-fold speedups in portions of their computational fluid dynamics code GEneralized Nonlinear Extension of Surface Integral Schemes (GENESIS). GENESIS can help engineers predict turbulence in complex geometries, such as those in multiple rows of turbine blades. These predictions can lead to more efficient gas turbine engines, increasing their competitiveness. The GE team has taken a typical month-long simulation down to just over two hours and has gained the ability to simulate several rows of turbine blades rather than just a single blade, demonstrating a leap from component-level to system-level simulations. Additionally, the simulations have better predictive accuracy and higher resolution than any of the company’s previous simulations. The value gained from running on Summit’s GPUs has also enabled the team to plan for GE’s next high-performance computing investment.

*New biofuel process is identified through HPC screening.*
Separation of ethanol from water, essential for biofuel production, is usually effected via distillation. A new, patented process—by which ethanol would be preferentially adsorbed from a water mixture through a zeolite-containing adsorbent or membrane—would permit significant energy savings over traditional distillation-based separation. The material for the membrane was identified by a team of researchers from the University of Minnesota who used ALCF resources to conduct high throughput computational screening to identify promising microporous zeolites for various biofuel production processes. The team scaled their codes to more than 100,000 cores and simulate approximately 400 zeolites over a range of solution-phase compositions (ranging from 0.1 to 40 percent ethanol by weight). Each candidate zeolite required numerous simulations so that meaningful statistics could be collected and subsequently averaged to attain a higher degree of fidelity. Without access to supercomputer and a large allocation of computer time, it would have taken much longer to examine far fewer zeolites and the best performing ones may not have been found.

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[a] https://insidehpc.com/white-paper/understanding-behaviors-extreme-environment-natural-gas-turbine-generators/

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

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

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

<u>Computer Science</u>
The Computer Science research activity supports basic research that enables computing and networking at extreme scales and the understanding of extreme scale, or complex data from both simulations and experiments. Through the development of adaptive software tools, it aims to make high performance scientific computers and networks highly productive and efficient to solve scientific challenges while attempting to reduce domain science application complexity as much as possible. ASCR-supported activities are entering a new paradigm driven by sharp increases in the heterogeneity and complexity of computing systems. In addition, and in partnership with the other SC programs and their scientific user facilities, the Computer Science activity supports basic research that addresses the need to seamlessly and intelligently integrate simulation, data analysis, and other tasks into coherent and usable workflows— from the edge of experiments, through simulation and AI, to data analytics and visualization.

The Computer Science activity supports long-term, basic research on the software infrastructure that is essential for the effective use of the most powerful high performance computing systems in the country, tools and data infrastructure to manage and analyze data at scale, and cybersecurity innovation that can enable the scientific integrity of extreme scale computation, networks, and scientific data. ASCR Computer Science plays a key role in developing and evolving the specialized software required for future Leadership Computers. Supercomputer vendors often take software developed with ASCR Computer Science investments and integrate it with their own software.

<u>Computational Partnerships</u>

The Computational Partnerships activity primarily supports the SciDAC program, a recognized leader for the employment of high-performance computing (HPC) for scientific discovery. Established in 2001, SciDAC involves ASCR collaboration with the other SC programs and other DOE program offices with a goal to dramatically accelerate progress in scientific computing through deep collaborations between discipline scientists, applied mathematicians, and computer scientists. SciDAC does this by providing the intellectual resources in applied mathematics and computer science, expertise in algorithms and methods, and scientific software tools to advance scientific discovery through modeling and simulation in areas of strategic importance to SC and DOE.

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

<u>Advanced Computing Research</u>

This activity supports Research and Evaluation Prototypes (REP) and the Computational Sciences Graduate Fellowship (CSGF).

REP has a long history of partnering with U.S. vendors to develop future computing technologies and testbeds that push the state-of-the-art and enabled DOE researchers to better understand the challenges and capabilities of emerging technologies. This activity supports testbeds for next-generation systems and for future computing technologies beyond Moore’s law, specifically in the area of quantum computing testbeds and emulators. As the challenges in this regime are increasingly linked with advances in the research program, this activity is realigned from the Facilities subprogram to the Research subprogram beginning in FY 2021.

In addition, this activity partners with the NNSA to support the CSGF.

## Activities and Explanation of Changes

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| **Mathematical, Computational, and Computer Sciences Research** | **$155,000** | **$264,028** | **+$109,028** |
| Applied Mathematics | $41,500 | $53,728 | +$12,228 |
| Funding supports Applied Mathematics core programs in new algorithmic techniques and strategies that extract scientific advances and engineering insights from massive data for DOE missions. Applied Mathematics will increase investments in research to develop foundational capabilities in scientific AI/ML. | | The Request will expand support of core research efforts in algorithms, libraries and methods that underpin high-end scientific simulations, scientific AI/ML techniques, and methods that help scientists extract insights from massive scientific datasets with an emphasis on foundational capabilities in AI/ML. | The increase will support new efforts that develop the advanced mathematics and methods to enable an integrated computational and data infrastructure for scientific discovery. It also will support expanded investments to develop foundational capabilities in scientific AI/ML, with a focus on the requirements of SC's critical applications and scientific datasets. |
| Computer Science | $38,700 | $49,605 | +$10,905 |
| Funding supports Computer Science to address the combined challenges of increasingly heterogeneous architecture, and the changing ways in which HPC systems are used—incorporating more data intensive applications and greater connectivity with distributed systems and resources including other SC user facilities. The activity also expands funding for efforts in quantum networking. | | The Request will continue support for core investments in software that improves the utility of HPC and advanced networks for science, including AI techniques, workflows, tools, data management, analytics and visualizations with strategic increases focused on critical tools, including AI, to enable an integrated computational and data infrastructure. Funding for this activity will also expand long-term efforts that explore and prepare for emerging technologies, such as quantum networking, specialized and heterogeneous hardware and accelerators, quantum and neuromorphic computing. | The increase will support new efforts that develop workflows, software, and edge technologies to enable an integrated computational and data infrastructure for scientific discovery. Also, it will support expanded investments to develop scientific AI/ML software and tools with a focus on the requirements of SC's critical applications and scientific datasets. The increase will include additional funding for basic research in Quantum networking. |

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes<br>FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| Computational Partnerships | $69,142 | $75,051 | +$5,909 |
| Funding supports the SciDAC institutes and partnerships awarded in FY 2017- FY 2018, this activity maintains efforts in QIS in partnership with the other SC programs, and efforts to bring the power of HPC to data intensive science. | | The Request will continue support for the SciDAC Institutes, and ASCR will recompete partnerships with SC and DOE applications. Partnerships on scientific data and AI will be continued with new partners added. Building on these efforts, the Request will support the foundations of a new integrated computational and data infrastructure for science that will more effectively and efficiently address SC's data needs. A new partnership with NIH will leverage DOE infrastructure to address the data analytics needs of the connectome project and ensure that data is widely available for SC's AI development efforts to incorporate the results. The Request also includes support for a partnership with BES, HEP, and FES on microelectronics research. | The increase will support expanded efforts in AI data partnerships, QIS partnerships and Centers, and the recompetition of the SciDAC applications in partnership with other SC Programs. It also supports new efforts in data infrastructure and analytics, in microelectronics, and in partnerships with SC and interagency efforts, to maximize the public benefit and accelerate development of AI techniques for science. |
| Advanced Computing Research | $— | $76,007 | +$76,007 |
| *Research and Evaluation Prototypes* | *$—* | *$66,007* | *+$66,007* |
| In FY 2020, REP is funded within the High Performance Computing and Network Facilities subprogram. | | The Request will continue to support quantum testbed efforts, with emphasis on partnerships with the new QIS centers, as well as small investments in cyber security and testbeds for microelectronics research. Building on basic research in quantum information networks, ASCR will support early stage research associated with the first steps to establishing a dedicated Quantum Network. | To address the need for strong connections between core research efforts and beyond Moore's Law prototypes, this activity is realigned from the Facilities subprogram to the Research subprogram in FY 2021.<br><br>The increase will support early stage research for a Quantum internet and new testbed activities in support of SC efforts to revolutionize microelectronics. |

(dollars in thousands)

| FY 2020 Enacted | FY 2021 Request | Explanation of Changes<br>FY 2021 Request vs FY 2020 Enacted |
|---|---|---|
| *Computational Sciences Workforce Programs* *$—* | *$10,000* | *+$10,000* |
| In FY 2020, Computational Science Graduate Fellowship (CSGF) is funded within the High Performance Computing and Network Facilities subprogram. | The Request will provide support for the CSGF fellowship at $10,000,000, in partnership with NNSA. The goal of CSGF to increase availability of a trained workforce for exascale, AI, and beyond Moore's Law capabilities such as QIS. | To address the need for strong connections between core research efforts and beyond Moore's Law prototypes, this activity is shifted from the Facilities subprogram to the Research subprogram in FY 2021.<br>The fellowship will emphasize high performance computational applications of AI and QIS. |
| SBIR/STTR $5,658 | $9,637 | +$3,979 |
| In FY 2020, SBIR/STTR funding is set at 3.65 percent of non-capital funding. | In FY 2021, SBIR/STTR funding is set at 3.65 percent of non-capital funding. | The SBIR/STTR funding will be consistent with the ASCR total budget. |

**Advanced Scientific Computing Research**
**High Performance Computing and Network Facilities**

**Description**
The High Performance Computing and Network Facilities subprogram supports the operations of forefront computational and networking user facilities to meet critical mission needs. ASCR operates three high performance computing (HPC) user facilities: the National Energy Research Scientific Computing Center (NERSC) at Lawrence Berkeley National Laboratory (LBNL), which provides high performance computing resources and large-scale storage to a broad range of SC researchers; and the two Leadership Computing Facilities (LCFs) at Oak Ridge National Laboratory (ORNL) and Argonne National Laboratory (ANL), which provide leading-edge high performance computing capability to the U.S. research and industrial communities. ASCR's high performance network user facility, ESnet, delivers highly reliable data transport capabilities optimized for the requirements of large-scale science. Finally, operations of these facilities also include investments in upgrades: for the HPC user facilities, this scope includes electrical and mechanical system enhancements to ensure each remains state-of-the-art and can install future systems; for ESnet, the upgrades include rolling capacity growth to ensure no bottlenecks occur in the network. As the challenges within the Research and Evaluation Prototypes (REP) activity are increasingly linked with advances in the research program, this activity is being realigned to the Mathematical, Computational, and Computer Sciences Research subprogram beginning in FY 2021.

ASCR regularly gathers requirements from the other SC research programs through formal processes, including workshops and technical reviews, to inform upgrade plans. These requirements activities are also vital to planning for SciDAC and other ASCR research efforts to prioritize research directions and inform the community of new computing and data trends, especially as the computing industry moves toward exascale computing and explores new architectures and technologies.

Allocation of computer time at ASCR HPC facilities follows the merit review public-access model used by other SC scientific user facilities. Two of ASCR's allocation programs include the Innovative and Novel Computational Impact on Theory and Experiment (INCITE) projects for access to the LCFs and the ASCR Leadership Computing Challenge (ALCC) projects to provide an allocation path for critical DOE mission applications and to broaden the community of users.

<u>High Performance Production Computing</u>
This activity supports NERSC at LBNL to deliver high-end production computing services for the SC research community. Approximately 7,500 computational scientists conducting about 700 projects use NERSC annually to perform scientific research across a wide range of disciplines including astrophysics, chemistry, earth systems modeling, materials, high energy and nuclear physics, fusion energy, and biology. NERSC users come from nearly every state in the U.S., with about 49 percent based in universities, 46 percent in DOE laboratories, and 5 percent in other government laboratories and industry. NERSC's large and diverse user population ranges from experienced to neophyte. NERSC aids users entering the HPC arena for the first time, as well as those preparing leading-edge codes that harness the full potential of the machine.

NERSC currently operates the 30 petaflops (pf) Intel/Cray system (Cori). NERSC is a vital resource for the SC research community and is consistently oversubscribed, with requests exceeding capacity by a factor of 3–10. This gap between demand and capacity exists despite upgrades to the primary computing systems approximately every three to five years. NERSC will transition NERSC-9 to operations in FY 2021 while initiating preparations for a NERSC-10 upgrade that is needed to meet SC's growing computational needs.

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

The Oak Ridge Leadership Computing Facility (OLCF) at ORNL currently operates testbeds in support of ECI and the 200 pf IBM/NVIDIA system (Summit), which achieved the global number one ranking as the world's fastest system in June 2018, November 2018, June 2019, and November 2019. INCITE applications at Summit include: simulating how neutron star collisions produce heavy elements like gold and platinum; understanding how drug receptors select which signaling proteins to activate so as to enable the development of finely tuned medicines that yield desired effects with fewer side effects; closing, evaluating, and validating multiphase flow models in porous medium systems; new insights into the mechanisms leading to the complex phases and physical behavior observed in unconventional superconductors and quantum spin liquids and Monte Carlo simulations that will provide high-accuracy data for the adsorption of water on graphene with potential applications in water purification, desalinization and drug delivery. OLCF staff shares its expertise with industry to broaden the benefits of petascale computing for the nation. For example, OLCF works with industry to reduce the need for costly physical prototypes and physical tests in the development of high-technology products. These efforts often result in upgrades to in-house computing resources at U.S. companies. Also, the OLCF will undertake final preparations for the deployment of a Cray/AMD exascale system to be named Frontier in the calendar year 2021-2022 timeframe.

The Argonne Leadership Computing Facility (ALCF) at ANL operates an 8.5 pf Intel/Cray system (Theta) and testbeds to prepare their users and SC-ECP applications and software technology for the ALCF-3 upgrade, to be known as Aurora. Aurora, will be the Nation's first exascale system when deployed in calendar year 2021 and is being designed by Intel/Cray to support the largest-scale computational simulations possible as well as large-scale data analytics and machine learning. INCITE applications at the ALCF include developing an understanding of the structure and reactions of nuclei to guide new experiments at the Facility for Rare Isotope Beams and at Thomas Jefferson National Accelerator Facility; identifying novel therapies to rationally design new treatments for a broad range of human cancers; discovering how water cycles affects river flow and freshwater supplies; and increasing the fidelity of earthquake models to improve the accuracy of seismic hazard assessment. Through INCITE, ALCF also transfers its expertise to industry, for example, helping scientists and engineers to understand the fundamental physics of turbulent mixing to transform product design and to achieve improved performance, lifespan, and efficiency of aircraft engines. The ALCF and OLCF systems are architecturally distinct, consistent with DOE's strategy to foster diverse capabilities that provide the Nation's HPC user community with the most effective resources. The demand for 2018 INCITE allocations at the LCFs outpaced the available resources by more than a factor of two.

Research and Evaluation Prototypes

To address the need for strong connections between core research efforts and beyond Moore's Law prototypes, this activity is shifted to the Mathematical, Computational, and Computer Sciences Research subprogram under the Advanced Computing Research activity in FY 2021.

High Performance Network Facilities and Testbeds

The Energy Sciences Network (ESnet) is SC's high performance network user facility, delivering highly reliable data transport capabilities optimized for the requirements of large-scale science. ESnet is the circulatory system that enables the DOE science mission. ESnet currently maintains one of the fastest and most reliable science networks in the world that spans the continental United States and the Atlantic Ocean. ESnet interconnects all 17 DOE national laboratories, dozens of other DOE sites, and approximately 200 research and commercial networks around the world, enabling many tens of thousands of scientists at DOE laboratories and academic institutions across the country to transfer vast data streams and access remote research resources in real-time. ESnet also supports the data transport requirements of all SC user facilities. ESnet's traffic continues to grow exponentially—roughly 66 percent each year since 1990—a rate more than double the commercial internet. Costs for ESnet are dominated by operations and maintenance, including continual efforts to maintain dozens of external connections, benchmark future needs, expand capacity, and respond to new requests for site access and specialized services. As a user facility, ESnet engages directly in efforts to improve end-to-end network performance between DOE facilities and U.S. universities. ESnet is recognized as a global leader in innovative network design and operations. ESnet is currently designing and executing a complete upgrade of its backbone network (the ESnet-6 upgrade).

## Activities and Explanation of Changes

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| **High Performance Computing and Network Facilities** | **$636,265** | **$555,078** | **-$81,187** |
| High Performance Production Computing | $110,000 | $85,000 | -$25,000 |
| Funding continues operations and user support at the NERSC facility–including power, space, leases and staff. Funding also supports site preparation activities for the NERSC-9 upgrade, such as increased power and cooling capacity. | | The Request will support operations at the NERSC facility, including user support, power, space, system leases, and staff. The Request will also support completion and transition to operations for the NERSC-9 upgrade, including site preparation activities, system acquisition, and application readiness. | Funding will support the operations of the Cori and NERSC-9 systems as well as early stage designs for the NERSC-10 upgrade. |
| Leadership Computing Facilities | $375,000 | $370,000 | -$5,000 |
| Funding supports operations and user support at the LCF facilities–including power, space, leases, and staff. Long-lead site preparations for planned upgrades, such as increased power and cooling capacity and significant NRE efforts and testbeds, are also supported. | | The Request will support operations at the LCF facilities at ANL and ORNL, including user support, power, space, system leases, and staff. The Request also will support final site preparation for the ALCF-3 upgrade and OLCF-5 upgrade, and early access system testbeds. | Funding will support the 2021-2022 deployment schedule for both LCF upgrades. The decrease at the OLCF will result in the shifting of some milestone payments for Frontier to the lease agreement. |
| *Argonne Leadership Computing Facility (ALCF)* | *$150,000* | *$150,000* | *$—* |
| Funding supports continual operation of Theta and testbeds that were deployed in FY 2019 to support SC-ECP. The ALCF continues site preparations and significant NRE efforts to deploy a novel architecture capable of delivering more than an exaflop of computing capability in the calendar year 2021 timeframe as part of ECI, while decommissioning MIRA. | | The Request will continue support for the operation and competitive allocation of the Theta system. In support of ECP, the ALCF will provide access to Theta and other testbeds for ECP application and software projects. The ALCF will continue activities to enable deployment of the ALCF-3 exascale system, Aurora in the calendar year 2021 timeframe under CORAL I. | Funding will continue operations at the ALCF. |

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| *Oak Ridge Leadership Computing Facility (OLCF)* | *$225,000* | *$220,000* | *-$5,000* |
| Funding supports continual operation and allocation of Summit. In support of ECP, the OLCF provides access to Summit and other testbeds for the application and software projects to scale and test their codes. The OLCF also continues activities to enable deployment of an exascale system in the calendar year 2021-2022 timeframe under the CORAL II. | | The Request will continue support for the operation and competitive allocation of the Summit system. In support of ECP, the OLCF will provide access to Summit and other testbeds for ECP application and software projects. The OLCF will continue activities to enable deployment of the OLCF-5 exascale system, Frontier in the calendar year 2021-2022 timeframe under CORAL II. | The reduction at the OLCF will result in the shifting of milestone payments for Frontier to the lease agreement. |
| Research and Evaluation Prototypes | $39,000 | $— | -$39,000 |
| Funding supports the CSGF fellowship at $10,000,000 in partnership with the NNSA to increase availability of a trained workforce for exascale and beyond Moore's Law capabilities. In addition, funding provides continued support for quantum testbed efforts to provide resources for the researchers supported through the quantum information science partnerships with the other SC programs. | | To address the need for strong connections between core research efforts and beyond Moore's Law prototypes, this activity is realigned to the Advanced Computing Research activity within the research subprogram in FY 2021. | This reduction reflects the realignment of this program to the Research subprogram. |
| High Performance Network Facilities and Testbeds (ESnet) | $90,000 | $80,000 | -$10,000 |
| Funding supports operations of the ESnet at 99.9 percent reliability. In addition, funding supports the ESnet-6 upgrade to increase network capacity and modernize the network architecture. | | The Request will support operations of ESnet at 99.9 percent reliability, including user support, operations and maintenance of equipment, fiber leases, R&D testbed, and staff. The Request will continue support for the ESnet-6 upgrade to build the next generation network with new equipment, increased capacity, and an advanced network architecture. | Funding will support the upgrade in accordance with the project baseline as well as continued operation of ESnet-5. |
| SBIR/STTR | $22,265 | $20,078 | -$2,187 |
| In FY 2020, SBIR/STTR funding is set at 3.65 percent of non-capital funding. | | In FY 2021, SBIR/STTR funding is set at 3.65 percent of non-capital funding. | The SBIR/STTR funding will be consistent with the ASCR total budget. |

## Description

SC and NNSA will continue to execute the Exascale Computing Initiative (ECI), which is an effort to develop and deploy an exascale-capable computing system with an emphasis on sustained performance for relevant applications and analytic computing to support DOE missions. The deployment of these systems includes necessary site preparations and non-recurring engineering (NRE) at the Leadership Computing Facilities (LCF) that will ultimately house and operate the exascale systems.

The Office of Science Exascale Computing Project (SC-ECP) captures the research aspects of ASCR's participation in the ECI, to ensure the hardware and software R&D, including applications software, for an exascale system is completed in time to meet the scientific and national security mission needs of DOE. The SC-ECP is managed following the principles of DOE Order 413.3B, tailored for this fast-paced research effort and similar to that which has been used by SC for the planning, design, and construction of all of its major computing projects, including the LCFs at ANL and ORNL, and NERSC at LBNL.

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

The FY 2021 Request includes $168,945,000 for the SC-ECP. These funds will support the final preparation of mission critical applications and development of a software stack for exascale platforms, and the initiation of testing on exascale early access platforms. Deployment of exascale systems in calendar years 2021-2022 will be through the LCFs as part of their usual upgrade processes.

## Activities and Explanation of Changes

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| **Construction** | **$188,735**[a] | **$168,945** | **-$19,790** |
| 17-SC-20 Office of Science Exascale Computing Project (SC-ECP) | $188,735 | $168,945 | -$19,790 |
| Funding supports the acceleration of application and software stack development in preparation for delivery of the first exascale system in calendar year 2021. | | The Request will support project management; co-design activities between application and the software stack; and integration between SC-ECP and the LCF to provide continuous integration and testing of the ECP funded applications and software on exascale testbed. | Funding will decrease with the completion of vendor partnerships as well as the project's focus moving more to the final preparations for testing and final execution on the exascale platforms following acceptance rather than on exploratory research. |

[a] In addition, $275,000,000 of ECI funding is provided within the Leadership Computing Facilities activity in FY 2020 and $270,000,000 is requested in FY 2021 in the Leadership Computing Facilities activity to begin planning, non-recurring engineering, and site preparations for at least one exascale system to be delivered in calendar year 2021.

## Advanced Scientific Computing Research
## Capital Summary

(dollars in thousands)

| | Total | Prior Years | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|---|---|
| **Capital Operating Expenses** | | | | | | |
| Capital Equipment | N/A | N/A | 5,000 | 5,000 | 5,000 | — |
| **Total, Capital Operating Expenses** | **N/A** | **N/A** | **5,000** | **5,000** | **5,000** | **—** |

## Capital Equipment

(dollars in thousands)

| | Total | Prior Years | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|---|---|
| **Capital Equipment** | | | | | | |
| Total, Non-MIE Capital Equipment | N/A | N/A | 5,000 | 5,000 | 5,000 | — |
| **Total, Capital Equipment** | **N/A** | **N/A** | **5,000** | **5,000** | **5,000** | **—** |

## Funding Summary

(dollars in thousands)

| | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|
| Research | 408,500 | 405,000 | 453,051 | +48,051 |
| Facility Operations | 527,000 | 575,000 | 535,000 | -40,000 |
| **Total, Advanced Scientific Computing Research** | **935,500** | **980,000** | **988,051** | **+8,051** |

## Advanced Scientific Computing Research
## Scientific User Facility Operations

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

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

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

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

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

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

(dollars in thousands)

| | FY 2019 Enacted | FY 2019 Current | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|---|
| **TYPE A FACILITIES** | | | | | |
| **NERSC** | **$104,000** | **$104,000** | **$110,000** | **$85,000** | **-$25,000** |
| Number of users | 7,500 | 7,500 | 7,500 | 7,500 | — |
| Achieved operating hours | 8,482 | 8,482 | N/A | N/A | N/A |
| Planned operating hours | 8,585 | 8,585 | 8,585 | 8,585 | — |
| Optimal hours | 8,585 | 8,585 | 8,585 | 8,585 | — |
| Percent optimal hours | 99% | 99% | N/A | N/A | N/A |
| Unscheduled downtime hours | 1% | 1% | N/A | N/A | N/A |

(dollars in thousands)

| | FY 2019 Enacted | FY 2019 Current | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|---|
| **OLCF** | **$199,000** | **$199,000** | **$225,000** | **$220,000** | **-$5,000** |
| Number of users | 1,450 | 1,450 | 1,450 | 1,450 | — |
| Achieved operating hours | 7,000 | 7,000 | N/A | N/A | N/A |
| Planned operating hours | 7,008 | 7,008 | 7,008 | 7,008 | — |
| Optimal hours | 7,008 | 7,008 | 7,008 | 7,008 | — |
| Percent optimal hours | 99% | 99% | N/A | N/A | N/A |
| Unscheduled downtime hours | 1% | 1% | N/A | N/A | N/A |
| **ALCF** | **$140,000** | **$140,000** | **$150,000** | **$150,000** | **$—** |
| Number of users | 950 | 950 | 950 | 950 | — |
| Achieved operating hours | 6,945 | 6,945 | N/A | N/A | N/A |
| Planned operating hours | 7,008 | 7,008 | 7,008 | 7,008 | — |
| Optimal hours | 7,008 | 7,008 | 7,008 | 7,008 | — |
| Percent optimal hours | 99% | 99% | N/A | N/A | N/A |
| Unscheduled downtime hours | 1% | 1% | N/A | N/A | N/A |
| **ESnet** | **$84,000** | **$84,000** | **$90,000** | **$80,000** | **-$10,000** |
| Number of users | N/A | N/A | N/A | N/A | — |
| Achieved operating hours | 8,760 | 8,760 | N/A | N/A | N/A |
| Planned operating hours | 8,760 | 8,760 | 8,760 | 8,760 | — |
| Optimal hours | 8,760 | 8,760 | 8,760 | 8,760 | — |
| Percent optimal hours | 100% | 100% | N/A | N/A | N/A |
| Unscheduled downtime hours | 0% | 0% | N/A | N/A | N/A |
| **Total, Facilities**[a] | **$527,000** | **$527,000** | **$575,000** | **$535,000** | **-$40,000** |
| Number of users | 9,900 | 9,900 | 9,900 | 9,900 | — |
| Achieved operating hours | 31,187 | 31,187 | N/A | N/A | N/A |
| Planned operating hours | 31,361 | 31,361 | 31,361 | 31,361 | — |
| Optimal hours | 31,361 | 31,361 | 31,361 | 31,361 | — |
| Percent optimal hours[b] | 99% | 99% | N/A | N/A | N/A |
| Unscheduled downtime hours | 1% | 1% | N/A | N/A | N/A |

[a] ASCR prioritizes operations of the facilities. Annual budget shifts at ASCR facilities are driven by or impact upgrade projects and do not change operating hours.

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

**Advanced Scientific Computing Research**
**Scientific Employment**

| | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|
| Number of permanent Ph.D.'s (FTEs) | 634 | 683 | 783 | +100 |
| Number of postdoctoral associates (FTEs) | 315 | 331 | 350 | +19 |
| Number of graduate students (FTEs) | 407 | 438 | 525 | +87 |
| Other scientific employment (FTEs)[a] | 196 | 212 | 205 | -7 |

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

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

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

**Summary**

The FY 2017 Budget Request included funding to initiate research, development, and computer-system procurements to deliver an exascale ($10^{18}$ operations per second) computing capability by the mid-2020s. This activity, referred to as the Exascale Computing Initiative (ECI), is a partnership between the Office of Science (SC) and the National Nuclear Security Administration (NNSA) and addresses Department of Energy's (DOE) science and national security mission requirements.

In FY 2017, SC initiated the Office of Science Exascale Computing Project (SC-ECP) within Advanced Scientific Computing Research (ASCR) to support a large research and development (R&D) co-design project between domain scientists, application and system software developers, and hardware vendors to develop an exascale ecosystem as part of the ECI. Other activities included in the ECI but not the SC-ECP include $270,000,000 in FY 2021 to support the final site preparations and the start of installation of the exascale systems at both the Argonne and Oak Ridge Leadership Computing Facilities (LCFs). Supporting parallel development at both LCFs will reduce the overall risk of ECI and broaden the range of applications able to utilize this new capability. Procurement costs of exascale systems, which is not included in the SC-ECP, will be funded within the ASCR facility budgets in the outyears. This Project Data Sheet (PDS) is for the SC-ECP only; prior-year activities related to the SC-ECP are also included.

The FY 2021 Request for SC-ECP will support project management; co-design activities between application development, software technologies, and hardware node and system design; continuous integration and testing of ECP-funded application and software tools and technologies onto SC LCF pre-exascale resources; and increased engagement and integration between SC-ECP and the LCFs in readying the ECP software stack and applications via testing and development on early access exascale hardware.

**Significant Changes**

The FY 2021 Request for SC-ECP is $168,945,000. The FY 2021 Request supports investments in the ECP technical focus areas—application development, software technology and hardware and integration—to finalize a capable exascale software ecosystem that supports the successful delivery of the first exascale-capable computer in the calendar year 2021 timeframe. The decrease reflects the completion of vendor partnerships as well as project focus moving more to development and deployment rather than on research.

The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-1/3A, Approve Alternative Selection and Cost Range and Approve Phase One Funding of Hardware and Software Research Projects and Application Development, which was approved on January 3, 2017. The project is scheduled to achieve CD-2 in the second quarter of FY 2020. The estimated Total Project Cost (TPC) range of the SC-ECP is $1.0 billion to $2.7 billion.

**Critical Milestone History**

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3B | D&D Complete | CD-4 |
|---|---|---|---|---|---|---|---|---|
| FY 2017 | 3Q FY 2016 | TBD | TBD | TBD | TBD | TBD | N/A | TBD |
| FY 2018 | 7/28/16 | 2Q FY 2019 | 1/03/17 | 4Q FY 2019 | 3Q FY 2019 | 4Q FY 2019 | N/A | 4Q FY 2023 |
| FY 2019 | 7/28/16 | 2Q FY 2019 | 1/03/17 | 4Q FY 2019 | 3Q FY 2019 | 4Q FY 2019 | N/A | 4Q FY 2023 |

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3B | D&D Complete | CD-4 |
|---|---|---|---|---|---|---|---|---|
| FY 2020 | 7/28/16 | 2Q FY 2019 | 1/03/17 | 1Q FY 2020 | 3Q FY 2019 | 1Q FY 2020 | N/A | 4Q FY 2023 |
| FY 2021 | 7/28/16 | 3/22/16 | 1/03/17 | 2Q FY 2020 | 6/06/19 | 2Q FY 2020 | N/A | 4Q FY 2024 |

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

| Fiscal Year | Performance Baseline Validation | CD-3A |
|---|---|---|
| FY 2017 | TBD | TBD |
| FY 2018 | 4Q FY 2019 | 1/03/17 |
| FY 2019 | 4Q FY 2019 | 1/03/17 |
| FY 2020 | 1Q FY 2020 | 1/03/17 |
| FY 2021 | 1Q FY 2020 | 1/03/17 |

**CD-3A** – Approve Long Lead Time Procurements

**Project Cost History**

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

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC, Except D&D | OPC, D&D | OPC, Total | Total |
|---|---|---|---|---|---|---|---|
| FY 2017 | N/A | TBD | TBD | TBD | N/A | TBD | TBD |
| FY 2018 | N/A | 390,000 | 390,000 | 763,524 | N/A | 763,524 | 1,153,524 |
| FY 2019 | N/A | 426,735 | 426,735 | 807,230 | N/A | 807,230 | 1,233,965 |
| FY 2020 | N/A | 426,735 | 426,735 | 829,650 | N/A | 829,650 | 1,256,385 |
| FY 2021 | N/A | 507,680 | 507,680 | 818,526 | N/A | 818,526 | 1,326,206 |

**2. Project Scope and Justification**

**Scope**

Four well-known challenges[a] are key to requirements and Mission Need of the SC-ECP. These challenges are:

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

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

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

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

**Justification**

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

Key Performance Parameters (KPPs)

The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| Exascale performance improvements for mission-critical challenge problems | 50 percent of selected applications achieve Figure of Merit improvement greater than or equal to 50x | 100 percent of selected applications achieve Figure of Merit improvement greater than or equal to 50x |
| Broaden exascale science and mission capability | 50 percent of the selected applications can execute their challenge problem[a] | 100 percent of selected applications can execute their challenge problem |
| Productive and sustainable software ecosystem | 50 percent of the weighed impact goals are met | 100 percent of the weighted impact goals are met |
| Enrich the HPC Hardware Ecosystem | Vendors meet 80 percent of all the PathForward milestones | Vendors meet 100 percent of all the PathForward milestones |

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

### 3. Financial Schedule

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Construction | | | |
| FY 2020 | 174,735 | 174,735 | 174,735 |
| FY 2021 | 154,945 | 154,945 | 154,945 |
| Outyears | 178,000 | 178,000 | 178,000 |
| **Total, TEC** | **507,680** | **507,680** | **507,680** |
| **Other Project Cost (OPC)** | | | |
| (Research for Application Development, System Software Technology, and Hardware Technology) | | | |
| FY 2016[a] | 146,820 | 146,820 | 2,191 |
| FY 2017 | 164,000 | 164,000 | 90,425 |
| FY 2018 | 205,000 | 205,000 | 177,363 |
| FY 2019 | 232,706 | 232,706 | 216,728 |
| FY 2020 | 14,000 | 14,000 | 136,040 |
| FY 2021 | 14,000 | 14,000 | 153,779 |
| Outyears | 42,000 | 42,000 | 42,000 |
| **Total, OPC** | **818,526** | **818,526** | **818,526** |
| **Total Project Cost (TPC)** | | | |
| FY 2016[a] | 146,820 | 146,820 | 2,191 |
| FY 2017 | 164,000 | 164,000 | 90,425 |
| FY 2018 | 205,000 | 205,000 | 177,363 |
| FY 2019 | 232,706 | 232,706 | 216,728 |
| FY 2020 | 188,735 | 188,735 | 310,775 |
| FY 2021 | 168,945 | 168,945 | 308,724 |
| Outyears | 220,000 | 220,000 | 220,000 |
| **Total, TPC** | **1,326,206** | **1,326,206** | **1,326,206** |

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

### 4. Details of Project Cost Estimate

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

(dollars in thousands)

| | Current Total Estimate[a] | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Application Development | 236,759 | 211,800 | N/A |
| Production Ready Software | 142,661 | 147,190 | N/A |
| Hardware Partnership | 128,260 | 67,745 | N/A |
| **Total, TEC** | **507,680** | **426,735** | **N/A** |
| **Other Project Cost (OPC)** | | | |
| Planning/Project Mgmt | 102,595 | 123,715 | N/A |
| Application Development | 333,568 | 298,824 | N/A |
| Software Research | 199,754 | 167,970 | N/A |
| Hardware Research | 182,609 | 239,141 | N/A |
| **Total, OPC** | **818,526** | **829,650** | **N/A** |
| **Total Project Cost** | **1,326,206** | **1,256,385** | **N/A** |

### 5. Schedule of Appropriations Requests

(dollars in thousands)

| Request Year | Type | Prior Years[b] | FY 2019 | FY 2020 | FY 2021 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| FY 2017 | TEC | — | TBD | TBD | TBD | TBD | TBD |
| | OPC | 311,894 | TBD | TBD | TBD | TBD | TBD |
| | TPC | 311,894 | TBD | TBD | TBD | TBD | TBD |
| FY 2018 | TEC | — | — | 175,000 | — | 215,000 | 390,000 |
| | OPC | 518,524 | 189,000 | 14,000 | — | 42,000 | 763,524 |
| | TPC | 518,524 | 189,000 | 189,000 | — | 257,000 | 1,153,524 |
| FY 2019 | TEC | — | — | 174,735 | — | 252,000 | 426,735 |
| | OPC | 518,524 | 232,706 | 14,000 | — | 42,000 | 807,230 |
| | TPC | 518,524 | 232,706 | 188,735 | — | 294,000 | 1,233,965 |
| FY 2020 | TEC | — | — | 174,735 | — | 252,000 | 426,735 |
| | OPC | 526,944 | 232,706 | 14,000 | — | 56,000 | 829,650 |
| | TPC | 526,944 | 232,706 | 188,735 | — | 308,000 | 1,256,385 |
| FY 2021 | TEC | — | — | 174,735 | 154,945 | 178,000 | 507,680 |
| | OPC | 515,820 | 232,706 | 14,000 | 14,000 | 42,000 | 818,526 |
| | TPC | 515,820 | 232,706 | 188,735 | 168,945 | 220,000 | 1,326,206 |

[a] Estimate includes distribution of contingency funds based on percentage of planned cost; these values will be adjusted as contingency is distributed.
[b] Funding was provided to ASCR in FY 2016 to support the Department's ECI efforts at ANL and ORNL. For completeness, that information is shown here.

## 6. Related Operations and Maintenance Funding Requirements

System procurement activities for the exascale-capable computers are not part of the SC-ECP. The exascale-capable computers will become part of existing facilities and operations and maintenance funds, and will be included in the ASCR facilities' operations or research program's budget. A Baseline Change Proposal (BCP) was executed in March 2018 to reflect this change. In the FY 2021 Budget Request, $270,000,000 is included in the Argonne and Oak Ridge National Laboratories' LCF budgets to begin planning non-recurring engineering and site preparations for the delivery and deployment for the exascale systems. These funds are included in ECI but not in SC-ECP.

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | FY 2022 |
| Expected Useful Life | 5 years |
| Expected Future Start of D&D of this capital asset | 4Q 2030 |

## 7. D&D Information

N/A, no construction.

## 8. Acquisition Approach

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

## Basic Energy Sciences

### Overview

The mission of the Basic Energy Sciences (BES) program is to support fundamental research to understand, predict, and ultimately control matter and energy at the electronic, atomic, and molecular levels in order to provide the foundations for new energy technologies and to support DOE missions in energy, environment, and national security. BES accomplishes its mission through excellence in scientific discovery in the energy sciences, and through stewardship of world-class scientific user facilities that enable cutting-edge research and development.

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

BES scientific user facilities consist of a complementary set of intense x-ray sources, neutron sources, and research centers for nanoscale science. Capabilities at BES facilities probe materials and chemical systems with ultrahigh spatial, temporal, and energy resolutions to investigate the critical functions of matter—transport, reactivity, fields, excitations, and motion—and answer some of the most challenging science questions. The above-noted BESAC report recounts the central role of these shared resources as a key to U.S. scientific and industrial leadership. BES has a long history of delivering major construction projects on time and on budget, and of providing reliable availability and support to users for operating facilities. This record follows from rigorous community-based processes for conceptualization, planning, and execution of projects, and from performance assessment of operating facilities.

Key to exploiting scientific discoveries for future energy systems is the ability to create new materials using sophisticated synthesis and processing techniques, to precisely define the atomic arrangements in matter, and to design chemical processes, which will enable control of physical and chemical transformations and conversions of energy from one form to another. Such materials will need to be more functional than today's energy materials. These new chemical processes will require ever-increasing control to the levels of electrons. These advances are not found in nature; rather they must be designed and fabricated to exacting standards using principles revealed by basic science. Today, BES-supported activities are entering a new era in which materials can be built with atom-by-atom precision, chemical processes at the molecular scale can be controlled with increasing accuracy, and computational models can predict the behavior of materials and chemical processes before they exist. Collectively, these new tools and capabilities convey a significant strategic advantage for the Nation to advance the scientific frontiers while laying the foundation for future innovations and economic prosperity.

### Highlights of the FY 2021 Request

The BES FY 2021 Request of $1,935,673,000 focuses resources toward the highest priorities in early-stage fundamental research, in operation and maintenance of scientific user facilities, and in facility upgrades. Key elements in the FY 2021 Request are summarized below.

<u>Research</u>

The Request continues funding for the Energy Frontier Research Centers (EFRCs), the Batteries and Energy Storage Energy Innovation Hub, and the Fuels from Sunlight Energy Innovation Hub. Core research priorities in the FY 2021 Request include:

- Critical materials: Critical materials, including rare earth elements, are vital to the Nation's security and economic prosperity. In BES, the Request increases support for research to advance our understanding of fundamental properties

[a] https://science.osti.gov/~/media/bes/pdf/BESat40/BES_at_40.pdf

of these materials, identify methodologies to reduce their use and to discover substitutes, and enhance chemical processing and separation science for rare earths.

- Artificial Intelligence (AI) and Machine Learning (ML) for data-driven science: The Request increases investments in AI methods and ML tools to accelerate fundamental research for the discovery of new chemical mechanisms and material systems with exceptional properties and function.
- Exascale computing: The Request continues support for computational materials and chemical sciences to deliver shared software infrastructure to the research communities as part of the Exascale Computing Initiative.
- Microelectronics: BES increases its investment in microelectronics with a focus on materials, chemistry, and fundamental device science. BES will partner with Advanced Scientific Computing Research (ASCR), High Energy Physics (HEP), and Fusion Energy Sciences (FES) to support multi-disciplinary microelectronics research to accelerate the advancement of microelectronic technologies in a co-design innovation ecosystem in which materials, chemistries, devices, systems, architectures, algorithms, and software are developed in a closely integrated fashion.
- Next-generation biology: There is a significant opportunity to cross-fertilize and leverage discoveries and approaches across the biological, physical, and computational sciences to develop bio-inspired, biohybrid and biomimetic systems. Areas of focus include neuromorphic computing, programmable biomaterials and biocatalysts, and next-generation tools for characterization of chemical, biological, biomaterial, and biohybrid systems.
- Polymer upcycling: Fundamental research can provide the foundational knowledge for polymer upcycling, that is, the selective deconstruction of the polymers that constitute plastics, followed by reassembly into high-value chemicals, fuels, or materials in a repeating cycle. Areas of focus include transformative chemistry and biology for polymer upcycling, design of next-generation polymeric materials, and next-generation tools for elucidating chemical and biological mechanisms.
- Quantum information science (QIS): In support of the National Quantum Initiative, SC QIS Center(s) established in FY 2020 will constitute an interdisciplinary partnership among SC programs. This partnership complements a robust core research portfolio stewarded by the individual SC programs to create the ecosystem across universities, national laboratories, and industry that is needed to advance developments in QIS and related technology.
- Strategic accelerator technology: Accelerator R&D is a core capability, which SC stewards for the Nation. Support for this initiative will allow the U.S. to continue to provide the world's most comprehensive and advanced accelerator-based facilities for scientific research, and to continue to attract and train the workforce needed to design and operate these facilities.

Facility Operations

In the Scientific User Facilities subprogram, BES maintains a balanced suite of complementary tools. The Advanced Light Source (ALS), Advanced Photon Source (APS), National Synchrotron Light Source-II (NSLS-II), and the Stanford Synchrotron Radiation Lightsource (SSRL) will continue operations and are supported at approximately 91 percent of optimum. The Linac Coherent Light Source (LCLS) operations continue at 97 percent of optimum. Both BES-supported neutron sources, the Spallation Neutron Source (SNS) and the High Flux Isotope Reactor (HFIR), will be operational in FY 2021 and funded at approximately 91 percent of optimum. The Request provides funding for the five Nanoscale Science Research Centers (NSRCs) for continued QIS-related tools development.

Projects

The Request provides continued support for the Advanced Photon Source Upgrade (APS-U), Advanced Light Source Upgrade (ALS-U), Linac Coherent Light Source-II High Energy (LCLS-II-HE), Proton Power Upgrade (PPU), and Second Target Station (STS) projects. The FY 2021 Request includes one new construction project, the Cryomodule Repair and Maintenance Facility (CRMF). The FY 2021 Request also continues two Major Item of Equipment projects: NSLS-II Experimental Tools-II (NEXT-II) and NSRC Recapitalization.

**FY 2021 Research Initiatives**

Basic Energy Sciences supports the following FY 2021 Research Initiatives.

| | (dollars in thousands) | | | |
|---|---|---|---|---|
| | **FY 2019 Enacted** | **FY 2020 Enacted** | **FY 2021 Request** | **FY 2021 Request vs FY 2020 Enacted** |
| **New Research Initiatives** | | | | |
| Next Generation Biology Initiative | — | — | 3,750 | +3,750 |
| Rare Earth / Separation Science Initiative | — | — | 25,000 | +25,000 |
| Revolutionizing Polymer Upcycling | — | — | 8,250 | +8,250 |
| Strategic Accelerator Technology Initiative | — | — | 6,250 | +6,250 |
| **Total, New Research Initiatives** | **—** | **—** | **43,250** | **+43,250** |
| | | | | |
| **Ongoing Research Initiatives** | | | | |
| Artificial Intelligence and Machine Learning | 3,214 | 10,000 | 20,000 | +10,000 |
| Exascale Computing Initiative | 26,000 | 26,000 | 26,000 | — |
| Microelectronics Innovation | — | 5,000 | 30,000 | +25,000 |
| Quantum Information Science | 49,517 | 72,270 | 72,270 | — |
| **Total, Ongoing Research Initiatives** | **78,731** | **113,270** | **148,270** | **+35,000** |

**Basic Energy Sciences**
**Funding**

(dollars in thousands)

| | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|
| **Materials Sciences and Engineering** | | | | |
| Scattering and Instrumentation Sciences Research | 71,235 | 71,235 | 65,205 | -6,030 |
| Condensed Matter and Materials Physics Research | 132,463 | 144,963 | 166,875 | +21,912 |
| Materials Discovery, Design, and Synthesis Research | 65,443 | 65,443 | 67,489 | +2,046 |
| Established Program to Stimulate Competitive Research (EPSCoR) | 19,270 | 24,088 | 7,001 | -17,087 |
| Energy Frontier Research Centers (EFRCs) | 55,800 | 57,500 | 57,500 | — |
| Energy Innovation Hubs—Batteries and Energy Storage | 24,088 | 24,088 | 24,088 | — |
| Computational Materials Sciences | 13,000 | 13,000 | 13,000 | — |
| SBIR/STTR | 14,445 | 15,165 | 15,197 | +32 |
| **Total, Materials Sciences and Engineering** | **395,744** | **415,482** | **416,355** | **+873** |
| | | | | |
| **Chemical Sciences, Geosciences, and Biosciences** | | | | |
| Fundamental Interactions Research | 89,067 | 101,567 | 99,611 | -1,956 |
| Chemical Transformations Research | 97,836 | 97,836 | 101,385 | +3,549 |
| Photochemistry and Biochemistry Research | 75,724 | 75,724 | 67,413 | -8,311 |
| Energy Frontier Research Centers (EFRCs) | 54,200 | 57,500 | 57,500 | — |
| Energy Innovation Hubs—Fuels from Sunlight | 15,000 | 20,000 | 20,000 | — |
| Computational Chemical Sciences (CCS) | 13,000 | 13,000 | 13,000 | — |
| General Plant Projects (GPP) | 1,000 | 1,000 | 1,000 | — |
| SBIR/STTR | 13,063 | 13,851 | 13,596 | -255 |
| **Total, Chemical Sciences, Geosciences, and Biosciences** | **358,890** | **380,478** | **373,505** | **-6,973** |

(dollars in thousands)

| | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|
| **Scientific User Facilities** | | | | |
| X-Ray Light Sources | 505,000 | 518,791 | 494,830 | -23,961 |
| High-Flux Neutron Sources | 282,000 | 289,701 | 260,088 | -29,613 |
| Nanoscale Science Research Centers (NSRCs) | 135,000 | 138,687 | 129,938 | -8,749 |
| Other Project Costs | 19,100 | 23,000 | 7,000 | -16,000 |
| Major Items of Equipment | — | 10,500 | 2,000 | -8,500 |
| Research | 29,457 | 39,879 | 36,206 | -3,673 |
| SBIR/STTR | 32,509 | 36,482 | 31,751 | -4,731 |
| **Total, Scientific User Facilities** | **1,003,066** | **1,057,040** | **961,813** | **-95,227** |
| **Subtotal, Basic Energy Sciences** | **1,757,700** | **1,853,000** | **1,751,673** | **-101,327** |
| | | | | |
| **Construction** | | | | |
| 21-SC-10 Cryomodule Repair & Maintenace Facility (CRMF) | — | — | 1,000 | +1,000 |
| 19-SC-14 Second Target Station (STS), ORNL | 1,000 | 20,000 | 1,000 | -19,000 |
| 18-SC-10 Advanced Photon Source Upgrade (APS-U), ANL | 130,000 | 170,000 | 150,000 | -20,000 |
| 18-SC-11 Spallation Neutron Source Proton Power Upgrade (PPU), ORNL | 60,000 | 60,000 | 5,000 | -55,000 |
| 18-SC-12 Advanced Light Source Upgrade (ALS-U), LBNL | 60,000 | 60,000 | 13,000 | -47,000 |
| 18-SC-13 Linac Coherent Light Source-II-High Energy (LCLS-II-HE), SLAC | 28,000 | 50,000 | 14,000 | -36,000 |
| 13-SC-10 Linac Coherent Light Source-II (LCLS-II), SLAC | 129,300 | — | — | — |
| **Total, Construction** | **408,300** | **360,000** | **184,000** | **-176,000** |
| **Total, Basic Energy Sciences** | **2,166,000** | **2,213,000** | **1,935,673** | **-277,327** |

SBIR/STTR funding:

- FY 2019 Enacted: SBIR $52,617,000 and STTR $7,400,000
- FY 2020 Enacted: SBIR $57,423,000 and STTR $8,075,000
- FY 2021 Request: SBIR $53,080,000 and STTR $7,464,000

**Basic Energy Sciences**
**Explanation of Major Changes**

| | (dollars in thousands) FY 2021 Request vs FY 2020 Enacted |
|---|---|
| **Materials Sciences and Engineering**<br>Research will continue to support fundamental scientific opportunities, including those identified in recent BESAC and Basic Research Needs workshop reports. Research priorities include critical materials, computational materials sciences, AI/ML for data-driven science, next-generation microelectronics, QIS, and strategic accelerator technology. The Request also includes funding for continued support of the EFRCs and the Batteries and Energy Storage Energy Innovation Hub. | **+873** |
| **Chemical Sciences, Geosciences, and Biosciences**<br>Research will continue to support fundamental scientific opportunities, including those identified in recent BESAC, Basic Research Needs, and Roundtable workshop reports. Research priorities include critical materials, computational chemical sciences, AI/ML for data-driven science, next-generation biology, next-generation microelectronics, polymer upcycling, and QIS. The Request also includes funding for continued support of the EFRCs and the Fuels from Sunlight Energy Innovation Hub. | **-6,973** |
| **Scientific User Facilities**<br>The Advanced Light Source (ALS), Advanced Photon Source (APS), National Synchrotron Light Source-II (NSLS-II), and the Stanford Synchrotron Radiation Lightsource (SSRL) user facilities will operate at approximately 91 percent of optimum. The Linac Coherent Light Source (LCLS) operations continue at 97 percent of optimum. Both BES-supported neutron sources, the Spallation Neutron Source (SNS) and the High Flux Isotope Reactor (HFIR), will operate at approximately 91 percent of optimum. The Request continues to support all five NSRCs, with funding for continued QIS-related tools development. Research priorities include strategic accelerator technology and applications of AI methods and ML techniques to accelerator optimization, control, prognostics, and data analysis. The Request also continues two major items of equipment: the NEXT-II beamline project for NSLS-II and the NSRC recapitalization project. | **-95,227** |
| **Construction**<br>The Request continues support for the Advanced Photon Source-Upgrade (APS-U) project, the Advanced Light Source Upgrade (ALS-U) project, the Linac Coherent Light Source-II High Energy (LCLS-II-HE) project, the Proton Power Upgrade (PPU) project at the Spallation Neutron Source (SNS), and the Second Target Station (STS) project at SNS. The Request includes one new project, a Cryomodule Repair and Maintenance Facility. | **-176,000** |
| **Total, Basic Energy Sciences** | **-277,327** |

**Basic and Applied R&D Coordination**

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

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

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

**Program Accomplishments**

*Harnessing quantum phenomena to accelerate discovery in QIS.*

Novel approaches to exploit quantum mechanical phenomena in quantum devices, such as quantum computers and quantum sensors, hold the promise of providing unprecedented insight into the origins of material functionalities and chemical processes.

- Researchers discovered a new superconductor composed of a single layer of iron selenide on a strontium titanate substrate. Generally, superconductors do not respond to light. However, for this new superconductor, ultrafast laser (or low power, ultra violet) pulses can be used to increase the temperature at which the material becomes superconducting from 24 to 30 Kelvin. This superconducting state persisted for days, but could be reversed by high voltage pulses. This newly discovered, photo-induced superconductivity effect is being explored for novel quantum devices.
- Scientists reported the first demonstration of electrically tunable superconductivity in a device composed of three atomically thin (2D) layers of graphene sandwiched between 2D layers of boron nitride to form a repeating pattern called a moiré superlattice. Application of an electric field changes the electron density in the graphene layers, allowing highly controllable switching between electrically insulating and superconducting states in a single sample. The device can be used to study the interplay between atoms and electrons in exotic new materials with potential use in quantum computation and related electronics.
- A new quantum algorithm for simulating molecules was developed, which reduces quantum hardware requirements by allowing the quantum computer to determine its own circuit automatically and algorithmically customized for each molecule being simulated. This is an important step toward simulating more complicated and larger molecules on today's noisy, intermediate-scale quantum computers.

*Precision science to discover, understand, and control chemical processes and materials.*

Advanced synthesis and characterization techniques are used to explore chemical and physical behaviors to enable understanding and control of their functionality for energy-relevant and information applications.

- Researchers explained how single-atom catalysts affect the stability of reaction intermediates in important energy-relevant transformations, resulting in more efficient and selective catalysts. These recent advances not only validate the utilization of these catalysts for fundamental structure-reactivity relationship studies, but also indicate their untapped potential to manipulate chemical reactions.

- Researchers demonstrated that optically transparent and electrically conductive functional materials can be rapidly fabricated from polymer templates with exquisite microstructural organization using a chemical synthesis technique called sequential infiltration synthesis. Materials synthesized by these methods have been applied to important applications in lithography, oil sorption, protein separations, and optical coatings.
- Resilient and flexible borophene holds promise for fabricating atomically thin electronic devices. However, only nanoscale phase domains had been produced, preventing detailed analyses and device fabrication. Scientists used advanced electron microscopy techniques to directly visualize and verify that use of a copper substrate formed much larger single-crystal domains. The large crystals of this previously unknown borophene phase are expected to allow electrons to move through the structure quickly, which is crucial for developing flexible electronic devices.

*Learning from biology to inspire new approaches to advanced energy technologies.*
The development of energy technologies critically depends on discovery and creation of new chemical processes and high-performance materials with functions and properties exceeding those currently available. Biological systems provide inspiration for new approaches to manipulate matter, energy, entropy, and information across multiple length scales.

- Researchers discovered a new class of material that absorbs and fixes atmospheric carbon dioxide to grow and self-repair using incident sunlight. In a cascade of reactions, the prototype material uses embedded chloroplasts extracted from plants to capture carbon through photosynthetically produced sugars (glucose). Ultimately, these sugars are transformed into a continuously regenerating, expanding, and densifying polymer matrix capable of self-repair.
- In photosynthesis, solar energy is used to extract and use electrons from water and to make energy-dense compounds from carbon dioxide. In plants, the combination of two protein complexes, Photosystems I and II, is required to accomplish this energy-intensive process with high efficiency. Researchers found that these natural membrane-bound proteins can self-assemble with synthetic cobalt or nickel catalysts and use light to make hydrogen gas, suggesting natural/synthetic hybrid systems could be used for solar fuel production.
- Industry relies on high temperature and pressure to convert nitrogen into ammonia, a key component in fertilizers. In nature, the nitrogenase enzyme performs this same chemistry at room temperature and pressure. Replicating this feat at an industrial scale would help reduce energy costs and global carbon emissions. Using computational and experimental methods, scientists discovered that biology couples the production of hydrogen, which releases energy, with cleaving nitrogen, which requires energy, enabling the enzyme to convert nitrogen to ammonia efficiently. These results provide new insights for design of synthetic catalysts for ammonia synthesis.

*Data science to advance discovery in basic energy sciences.*
AI/ML techniques are enabling researchers to identify reaction pathways, predict physical and chemical properties, and design new chemicals and materials. Development and application of machine learning algorithms can be limited by the availability of extensive databases of experimental and simulated data and the throughput by which data can be generated. New, interpretable data models are helping to accelerate scientific discovery.

- Researchers coupled data infrastructure to high throughput experimentation to yield the world's largest database of materials experiments. Using the extensive database, they created a model that predicts the optical absorption spectrum from a material's image and vice versa. Light absorption characteristics of photocatalysts and photoelectrodes have been difficult to predict, but this result advances ML for discovery and characterization of these materials for energy conversion.
- Tectonic faults slip in various manners, ranging from ordinary earthquakes to slow slip events. Using new machine learning techniques trained on laboratory data, researchers discovered a new geophysical signal in the Cascadia subduction zone in the Pacific Northwest. This signal occurs as a continuously broadcasting low-amplitude tremor that precisely relates to the fault displacement rate throughout the slow slip cycle. These insights may prove useful in determining if and how a slow slip may couple to or evolve into a major earthquake.
- The Materials Project at Lawrence Berkeley National Laboratory has been a leader in producing material property databases and is now developing software to evaluate electronic and mechanical properties from such data. Recent applications include calculations of hundreds of electronic surface parameters, the largest database of such properties. Machine learning algorithms were developed to accelerate the optimization of two-dimensional layered materials for next generation electronics. Experimental data and calculations were combined for high throughput screening of transparent conductors for next generation optoelectronics.

*New techniques and capabilities at BES facilities*.

Advances in tools and instruments often drive scientific discovery. Recent developments and upgrades at the scientific user facilities provide users with cutting-edge capabilities for ground-breaking science.

- The Dynamic Diffraction Direct Detector (4D Camera) at the Molecular Foundry achieved an unprecedented 87,000 frames per second. This is 60 times faster than previous high speed electron detectors. The detector enables real-time contrast ptychographic imaging. This new capability is a breakthrough in nanoscale strain mapping and quantification of materials using scanning electron diffraction imaging methods at high resolution.
- An advanced nano-diffraction capability developed at the National Synchrotron Light Source-II is able to obtain strain mapping with a few nanometer resolution for microprocessors with complex 3D structure. This capability is a critical research tool for next-generation microelectronics.
- The upgraded WAND diffractometer at the High Flux Isotope Reactor provides wide angle coverage and high flux, useful for monitoring in-situ material synthesis under complex environment and stroboscopic measurements of ferroelectric switching. This capability will help identify new routes for the synthesis of advanced energy materials that are difficult to synthesize.

*BES user facilities help industry advance the technology frontiers.*

In FY 2019, more than 600 industrial users conducted experiments at the BES scientific user facilities using the advanced instrumentation and methods available to test, probe, and develop their technologies.

- A team of Molecular Foundry scientists and Dow Chemical users developed a method to apply pulsed-electron beams to image a beam-sensitive material with atomic resolution. This is the first time that beam-sensitive and air-sensitive magnesium chloride has been studied with atomic resolution. The new technique could be used to study other soft materials and could aid the development of sustainable plastics.
- Neutron diffraction at SNS provided important information on the chemical reactions during the “batch to glass” (sand, alumina, and additives to glass) process in real time at 1400 degrees Celsius. This information will be useful to build new models that will improve production processes and decrease the amount of time required to bring new and more durable types of glasses for commercial applications (e.g., car windows, screens on electronic devices, etc.) and to improve the efficiency and reliability of the glass manufacturing processes.
- Center for Functional Nanomaterials staff worked with users from the Toyota Research Institute and Michigan State University to study the mechanism of rechargeable batteries with magnesium metal anodes. Experiments revealed that the combination of a highly functional solid electrolyte interphase at the anode and magnesium nanocrystals formed during operation are key to improved performance. Magnesium has five times more volumetric energy storage density compared to graphite anodes used in commercial lithium-ion batteries.

**Basic Energy Sciences**
**Materials Sciences and Engineering**

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

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

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

- **Scattering and Instrumentation Sciences**—Advancing science using new tools and techniques to characterize materials structure and dynamics across multiple length and time scales, including ultrafast science, and to correlate this data with materials performance under real world and extreme conditions.
- **Condensed Matter and Materials Physics**—Understanding the foundations of material functionality and behavior including electronic, thermal, optical, mechanical, and rare-earth properties, the impact of extreme environments, and materials whose properties arise from the effects of quantum mechanics.
- **Materials Discovery, Design, and Synthesis**—Developing the knowledge base and synthesis strategies to design and precisely assemble structures to control properties and enable discovery of new materials with unprecedented functionalities, including approaches learned from biological systems, that limit the use of rare earth and other critical materials, and that enable more effective polymer chemistries.

The portfolio emphasizes understanding of how to direct and control energy flow in materials systems over multiple time (from femtoseconds to seconds) and length (from the nanoscale to mesoscale) scales, and translation of this understanding to prediction of material behavior, transformations, and processes in challenging real-world systems. An example of this research is examination of the transformations that take place in materials with many atomic constituents, complex structures, and a broad range of defects when these materials are exposed to extreme environments, including extremes in temperature, pressure, stress, photon and radiation flux, electromagnetic fields, and chemical exposures – such as those found in fossil energy, nuclear energy, accelerator technologies, and most industrial settings. To maintain leadership in materials discovery, the research that this subprogram supports explores new frontiers of unpredicted, emergent materials behavior; utilization of nanoscale control; and materials systems that are metastable or far from equilibrium. This research includes investigation of the interfaces between physical and biological sciences to explore new approaches to novel materials design. A growing emphasis in materials chemistry is understanding and novel approaches to enable polymer recycling to higher value molecular systems. Also essential is the development of advanced characterization tools, instruments and techniques that can assess a wide range of space and time scales, especially in combination and under dynamic *operando* conditions to analyze non-equilibrium materials, conditions, and excited-state phenomena. Growing research activities in quantum materials highlight the importance and challenges for materials science in understanding and guiding the development of systems that realize unique properties for QIS and can contribute to SC QIS Centers. Materials science for next generation microelectronics will provide the needed advances for future computing, sensors, and detectors that are critical for national priorities in energy and for leadership in advanced research over a wide range of fields. An increasingly important aspect of materials research is the use of AI/ML for data-driven science to enhance the utility of both theoretical and experimental data for predictive design and discovery of materials.

In addition to single-investigator and small-group research, this subprogram supports Computational Materials Sciences, EFRCs, and the Batteries and Energy Storage Hub. The subprogram also supports, in partnership with other SC programs, SC QIS Centers beginning in FY 2020. These research modalities support multi-investigator, multidisciplinary research and focus on forefront scientific challenges that relate to the DOE energy mission. The Computational Materials Sciences activity supports integrated, multidisciplinary teams of theorists and experimentalists who focus on development of validated community codes and the associated databases for predictive design of materials that will take advantage of advanced exascale computing platforms. The EFRCs support teams of investigators to perform basic research to accelerate transformative scientific advances for the most challenging topics in materials sciences. Early stage research in the Batteries and Energy Storage Hub focuses on developing the scientific understanding required to advance next generation energy storage for the grid, transportation, and other national priorities. In support of the National Quantum Initiative, SC QIS Centers will push the current state-of-the-art science and technology toward realizing the full potential of quantum-based applications, from computing to communication to sensing.

The Materials Sciences and Engineering subprogram also includes the DOE Established Program to Stimulate Competitive Research (EPSCoR). The DOE EPSCoR program strengthens investments in early stage energy research for states and U.S. territories that do not historically have large federally-supported academic research programs.

<u>Scattering and Instrumentation Sciences Research</u>

Advanced characterization tools with very high precision in space and time are essential to understand, predict, and ultimately control matter and energy at the electronic, atomic, and nanoscale levels. Research in Scattering and Instrumentation Science supports innovative techniques and instrumentation development for advanced materials science research with scattering, spectroscopy, and imaging using electrons, neutrons, and x-rays, including development of science to understand ultrafast dynamics. These techniques provide precise and complementary information on the relationship among structure, dynamics, and properties. The major advances in materials sciences from DOE's world-leading electron, neutron, and x-ray scattering facilities provide continuing evidence of the importance of this research field. In addition, the BESAC report on transformative opportunities for discovery science identified imaging as one of the pillars for future transformational advances. The use of multimodal platforms to reveal the most critical features of a material has been a finding in several of the Basic Research Needs reports. These tools and techniques are also critical in advancing understanding and discovery of novel quantum materials, including materials for next generation systems to advance QIS and support the work of SC QIS Centers.

The unique interactions of electrons, neutrons, and x-rays with matter enable a range of complementary tools with different sensitivities and resolution for the characterization of materials at length- and time-scales spanning many orders of magnitude. A distinct aspect of this activity is the development of innovative instrumentation and techniques for scattering, spectroscopy, and imaging needed to correlate the microscopic and macroscopic properties of energy materials, including the use of cryogenic environments to evaluate properties only occurring at these temperatures and to learn about processes and interfaces in materials that are damaged by the probes used to characterize them. The use of multiscale and multimodal techniques to extract heretofore unattainable information on multiple length and time scales is a growing aspect of this research. For example, to design transformational new materials for energy-related applications, *operando* experiments contribute to understanding the atomic and nanoscale changes that lead to materials failure in non-equilibrium and extreme environments (temperature, pressure, stress, radiation, magnetic fields, and electrochemical potentials). Information from these characterization tools is the foundation for the creation of new materials that have extraordinary tolerance and can function within an extreme environment without property degradation.

<u>Condensed Matter and Materials Physics Research</u>

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

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

This activity also emphasizes research to understand how materials respond to their environments, including the influence of temperature, electromagnetic fields, radiation, corrosive chemicals, and other extreme conditions. 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. Research in this area will enable the design of materials with superior properties and resistance to change under the influence of radiation. There is a growing emphasis on extending knowledge of radiation effects to enable predictive capabilities for the multiple extreme environments envisioned for future nuclear reactors.

There is a critical need to advance theories used to describe material properties across a broad range of length and time scales, from the atomic scale to the macroscale where the influence of size, shape, and composition is not adequately understood. In addition, current theories fail to describe the time evolution of these properties from femtoseconds to seconds and to much longer time scales. Theoretical research also includes development of advanced computational and data-oriented techniques and predictive theory and modeling for discovery of materials with targeted properties. New techniques for AI/ML for data-driven science are seeing increasing applications in materials science research to extract value from large databases of theoretical calculations and experimental measurements.

Quantum materials research as it relates to QIS is a priority with important connections to national security and energy, including the development of the understanding to enable future generations of sensors, computers, and related technologies. BES is establishing research priorities and its unique role in this critical field through community engagement in roundtable discussions, interactions with other SC programs, and at the interagency level. The research will couple materials expertise in quantum materials, theory for materials discovery, and prototypes of next generation devices. These advances will be key components of the activities of SC QIS Centers. Quantum materials are also important for next-generation microelectronics and accelerator technologies, including magnets, detectors, and sensors.

This activity includes the SC QIS Centers, which promote basic research and early stage development to accelerate the advancement of QIS through vertical integration between systems and theory, and hardware and software. As identified by BES strategic planning reports, including the Basic Research Needs Workshop on Quantum Materials[a] and the Roundtable on Opportunities for Basic Research for Next-Generation Quantum Systems[b], key materials-related technical areas will include fundamental theory of materials and molecular systems for quantum applications; research leading to materials and molecular systems that meet quantum communication, computation, and sensor requirements; fundamental research on device physics for next generation QIS systems, including interface science and modeling of materials performance; and synthesis and fabrication research for quantum materials and processes, including integration in novel device architectures.

[a] https://science.osti.gov/-/media/bes/pdf/reports/2016/BRNQM_rpt_Final_12-09-2016.pdf
[b] https://science.osti.gov/-/media/bes/pdf/reports/2018/Quantum_systems.pdf

In FY 2021, BES, in partnership with other SC programs, will continue support for the multi-disciplinary multi-institutional QIS center(s), selected through a merit review process in FY 2020. The SC QIS centers will focus on a set of QIS applications or cross-cutting topics that collectively cover the development space that may impact SC Programs, including work on sensors, quantum emulators/simulators and enabling technologies that will pave the path to exploit quantum computing in the longer term.

This activity also contributes to microelectronics research, including basic research to accelerate the advancement of microelectronic technologies in a co-design innovation ecosystem. Computing systems encompassing new materials, devices, architectures, algorithms, and software are needed to maintain the continued upward trajectory in performance that Moore's law scaling has historically provided. Optimization must occur at every level of computing and power microelectronics systems, and co-design principles are essential to meet the future needs of SC and the nation. Among the challenges is discovery science that can lead to microelectronics for exascale computers and beyond with a small footprint and low power utilization. Such high performance computation will be necessary for analyzing and managing the vast amount of data that will be generated by future SC facilities to enable new discoveries. Furthermore, transforming power electronics and the electricity grid into a modern, agile, resilient, and energy-efficient system requires advances in new microelectronics materials, and their integration within a co-design framework. In FY 2021, BES will partner with ASCR, HEP, and FES to support multi-disciplinary microelectronics research. Informed by community strategic planning efforts including the Basic Research Needs for Microelectronics report, key technical areas will include materials, chemistry, and fundamental device science; component integration, architecture, and algorithms; and next-generation tools for synthesis, fabrication, and characterization of devices and systems.

Materials Discovery, Design, and Synthesis Research

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

The BESAC report on transformative opportunities for discovery science reinforced the importance of the continued growth of synthesis science, recognizing the transformational opportunity to realize targeted functionality in materials by controlling the synthesis and assembly of hierarchical architectures and beyond equilibrium matter. BES will enhance this program in FY 2021 to expand the application of materials discovery and synthesis research to understand the unique properties of rare earth and other critical materials, with the goal of reducing their use through development of substitutes, reducing the quantities required for specific properties, and developing novel synthesis techniques. New research directions will be inspired by the roundtable report on upcycling of polymers, the molecules that make-up plastics. Understanding of the synthesis process will enable design of new systems that are easier to recycle into similar products with comparable complexity and value.

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

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

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

Annual EPSCoR funding opportunities alternate between a focus on research performed in collaboration with the DOE national laboratories and a focus on implementation awards that facilitate larger team awards for the development of research infrastructure. The FY 2021 program will focus on implementation awards for larger teams and will consider renewals of the FY 2019 awards as well as proposals for new teams. The program supports a small cadre of early career scientists from EPSCoR jurisdictions on an annual basis and provides complementary support for research grants to eligible institutions.

Energy Frontier Research Centers (EFRCs)
The EFRC program is a unique research modality, bringing together the skills and talents of teams of investigators to perform energy-relevant, basic research with a scope and complexity beyond what is possible in standard single-investigator or small-group awards. These multi-investigator, multi-disciplinary centers foster, encourage, and enable transformative scientific advances. They allow experts from a variety of disciplines to collaborate on shared challenges, combining their strengths to uncover new and innovative solutions to the most difficult problems in materials sciences. The EFRCs also support numerous graduate students and postdoctoral researchers, educating and training a scientific workforce for the 21st century economy. The EFRCs supported in this subprogram focus on the following topics: the design, discovery, synthesis, characterization, and understanding of novel, solid-state materials that convert energy into electricity; the understanding of materials and processes that are foundational for electrical energy storage, gas separation, and defect evolution in radiation environments; future nuclear energy; and quantum materials that can optimize the transmission, utilization, and control of energy and information. After ten years of research activity, the program has produced an impressive breadth of scientific accomplishments, including over 11,600 peer-reviewed journal publications.

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

Energy Innovation Hubs—Batteries and Energy Storage
The Joint Center for Energy Storage Research (JCESR) focuses on early stage research to tackle forefront, basic scientific challenges for next-generation electrochemical energy storage. JCESR is a multi-institutional research team led by Argonne National Laboratory (ANL) in collaboration with four other national laboratories, eleven universities, the Army Research Laboratory, and industry. In the initial five-year award (2013-2018), JCESR created a library of fundamental scientific knowledge including: demonstration of a new class of membranes for anode protection and flow batteries; elucidation of the characteristics required for multi-valent intercalation electrodes; understanding the chemical and physical processes that must be controlled in lithium-sulfur batteries to greatly improve cycle life; and computational screening of over 16,000 potential electrolyte compounds using the Electrolyte Genome protocols.

For the current award (2018-2023, pending annual progress reviews and appropriations), JCESR used its past research to identify a number of critical scientific gaps to serve as a foundation for the proposed research. The research directions are consistent with the priorities established in the recent BES workshop report *Basic Research Needs for Next Generation Electrical Energy Storage*[a] including discovery science for exploration of new battery chemistries and materials with novel functionality. It is anticipated that advances will elucidate cross-cutting scientific principles for electrochemical stability; ionic and electronic transport at interfaces/interphases, in bulk materials or membranes; solvation structures and dynamics in electrolytes; nucleation and growth of materials, new phases, or defects; coupling of electrochemical and mechanical processes; and kinetic factors that govern reversible and irreversible reactions. Close coupling of theory, simulation, and experimentation is expected to accelerate scientific progress; to unravel the complex, coupled phenomena of electrochemical energy storage; to bridge gaps in knowledge across length and temporal scales; and to enhance the predictive capability of electrochemical models. In the current research, prototypes will be used to demonstrate the impact of materials advances for specific battery architectures and designs.

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

Computational Materials Sciences

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

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

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

BES manages the computational materials science research activities using the approaches developed for similar large team modalities. Management reviews by a peer review panel are held in the first year of the award, followed by a mid-term

[a] https://science.osti.gov/-/media/bes/pdf/reports/2017/BRN_NGEES_rpt.pdf

peer review to assess scientific progress, with regular teleconferences, annual progress reports, and active management by BES throughout the performance period.

## Activities and Explanation of Changes

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| **Materials Sciences and Engineering** | **$415,482** | **$416,355** | **+$873** |
| Scattering and Instrumentation Sciences Research | $71,235 | $65,205 | -$6,030 |
| Funding continues to emphasize the development and use of forefront characterization tools to address challenges in materials science including understanding of quantum phenomena. The research will explore dynamics across many orders of magnitude in length and time scales to understand the evolution of emergent phenomena and in materials and their properties. Research includes complex quantum behavior and performance in the environments experienced by materials used in energy generation and use. Investments in x-ray science will emphasize hypothesis-driven research using x-ray free electron laser (XFEL) sources, exploiting tailored excitations, and imaging with coherent x-rays. Neutron scattering research will focus on emergent quantum phenomena and soft materials, especially at interfaces. Electron scattering research will focus on innovative techniques to assess quantum phenomena. | | The Request will continue to push the frontiers of instrumentation and techniques needed to understand materials properties and enable materials discovery, including quantum phenomena, materials behavior in extreme energy-related environments, and multidimensional phenomena (requiring simultaneous assessment crossing space, time, and chemical evolution). Investments will emphasize hypothesis driven research with x-ray free electron lasers, imaging with coherent x-rays, advanced neutron scattering probes of interfaces and soft materials, cryogenic electron microscopy probes, and multimodal techniques that combine probes. Research will focus on innovation that will enable assessment of new regimes not amenable to current characterization approaches. | Funding emphasizes forefront R&D of novel techniques to understand quantum phenomena and soft materials, including cryogenic techniques. |

(dollars in thousands)

| FY 2020 Enacted | FY 2021 Request | Explanation of Changes<br>FY 2021 Request vs FY 2020 Enacted |
|---|---|---|
| Condensed Matter and Materials Physics Research $144,963 | $166,875 | +$21,912 |
| Funding continues to focus on forefront experimental and theoretical condensed matter research, emphasizing quantum phenomena including new and emergent behavior for QIS such as spintronics, topological states, and novel 2D materials. Physical behavior research will emphasize innovative science to understand coherent light-matter interactions. Mechanical behavior and radiation effects research will continue to focus on the mechanisms of materials failure due to mechanical strain, corrosion, and radiation environments, including the coupled extremes envisioned for future nuclear reactors. BES will partner with other SC Program Offices to establish at least one multi-disciplinary multi-institutional QIS center, which will be selected through a merit reviewed process conducted in FY 2020. The scope of the SC QIS center will be on a set of QIS applications or cross-cutting topics that collectively cover the development space that may impact SC Programs and include work on sensors, quantum emulators/ simulators and enabling technologies that will pave the path to exploit quantum computing in the longer term. | The Request will continue to support research to understand, better design, and discover new quantum materials, and to advance the theory needed to understand quantum phenomena. Included is a specific focus on research to support QIS and related systems. This activity will provide continued support for the QIS Centers established in FY 2020. The Request will also continue to establish the science base for next generation optical and electronic materials, including a new emphasis on materials for next generation microelectronics and for accelerator magnets, optics, and detectors. The Request increases support to investigate the unique properties associated with rare earth and critical materials to identify opportunities for substitutions and reduced use of these elements in energy relevant technologies. Theory and modeling research will include AI/ML for data-driven science to enhance materials discovery. | Funding emphasizes new tools and approaches to accelerate the discovery of new materials that will reduce or eliminate the use of rare earth elements while retaining their unique functionality for energy relevant technologies. Activities include enhancement of AI/ML techniques to better use data from both experiments and calculations. In addition, the increase will support a new focus on the science needed to provide the materials required for next generation microelectronics and for accelerator magnets, optics, detectors, and sensors. |

(dollars in thousands)

| FY 2020 Enacted | FY 2021 Request | Explanation of Changes<br>FY 2021 Request vs FY 2020 Enacted |
|---|---|---|
| Materials Discovery, Design, and Synthesis Research $65,443 | $67,489 | +$2,046 |
| Funding continues to focus on understanding the fundamentals of predictive design and synthesis of materials across multiple length scales using chemical, physical and bio-inspired techniques. Development of insights on the dynamics of materials structure and chemistry during the early stages of materials synthesis will be stressed, as will research that incorporates both experiment and theory. For complex materials and materials systems, research will focus on the fundamentals of growth kinetics, self-assembly, directed and dissipative assembly, and the role of interfaces and defect management. Discovery of new functional materials and new synthesis and computational techniques to create complex materials with targeted structure and properties will be emphasized. | The Request will continue research on innovative synthesis and discovery of materials through scientific understanding of the basic chemical and physical phenomena, and science-based utilization of biological concepts. Support will be maintained for investigation of fundamental dynamics and kinetics of synthesis and self-assembly over multiple length and timescales, including the role of defects and interfaces. Research will emphasize new approaches to replace or minimize the use of critical and rare earth materials. | The increase will support additional investment in research to better understand synthesis approaches and materials discovery to enable rare earth substitution and reduced use of critical materials, utilizing synthetic advances in related fields and predictive theory, modeling, and data mining/AI to accelerate progress. |
| Established Program to Stimulate Competitive Research (EPSCoR) $24,088 | $7,001 | -$17,087 |
| Funding continues to span science in support of the DOE mission, with emphasis on early stage science that underpins DOE energy technology programs. Following the prior year focus on implementation award investments, the focus for this year will be on broadening EPSCoR jurisdiction-laboratory partnerships, leveraging the DOE national laboratory energy research expertise and user facilities. Investment will continue in early career research faculty from EPSCoR designated jurisdictions and in co-investment with other programs for awards to eligible institutions. | The Request will continue to support early stage science, including research that underpins DOE energy technology programs. Following the previous year's focus on state-lab partnership awards, FY 2021 will emphasize implementation awards, larger multiple principal investigator grants that develop research capabilities in EPSCoR jurisdictions. The FY 2021 funding opportunity will consider both renewals of FY 2019 awards and new proposals. Investment will continue in early career research faculty from EPSCoR designated jurisdictions and in co-investment with other programs for awards to eligible institutions. | Funding focuses on implementation awards that facilitate larger team awards for the development of research capabilities. |

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | | Explanation of Changes FY 2021 Request vs FY 2020 Enacted | |
|---|---|---|---|---|---|
| Energy Frontier Research Centers (EFRCs) | $57,500 | | $57,500 | | $— |
| Funding continues to support four-year EFRC awards that were made in FY 2018. In addition, FY 2020 funds support a solicitation that will recompete the four-year EFRC awards made in FY 2016, which focused on science relevant to DOE's environmental management mission, and make new awards that are responsive to recent BES strategic planning workshop reports, including use-inspired science relevant to advanced microelectronics, QIS, and polymer upcycling. | | The Request will provide the fourth year of support for four-year EFRC awards that were made in FY 2018 and the second year of support for four-year EFRC awards that were made in FY 2020. | | No changes. | |
| Energy Innovation Hubs—Batteries and Energy Storage | $24,088 | | $24,088 | | $— |
| Funding continues to focus on early stage research for next generation electrical energy storage for the grid and vehicles. Research will emphasize understanding the fundamentals of electrochemistry (transport, solvation, evolution of chemistries and materials during charge/ discharge) and discovery science, including close coupling of theory, simulation, and experimentation, to elucidate the impact of coupled phenomena and for predictive design of new materials for batteries. | | The Request will continue the prior year's focus, based on the renewal of the JCESR Hub in FY 2018. Early stage research for next generation electrical energy storage for the grid and vehicles will continue to emphasize understanding the fundamentals of electrochemistry (transport, solvation, evolution of chemistries and materials during charge/ discharge) and discovery of the coupled factors that govern performance. The research will closely integrate theory, simulation, and experimentation to elucidate the impact of coupled phenomena and enable predictive design of new materials for batteries. | | No changes. | |

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| Computational Materials Sciences | $13,000 | $13,000 | $— |
| Funding continues research on current Computational Materials Sciences (CMS) awards that focus on development of research-oriented, open-source, experimentally validated software and the associated databases required to predictively design materials with specific functionality. Software will utilize leadership class computers, and be made available to the broad research community. The codes will also incorporate frameworks suited for future exascale computer systems. Awards that complete their fourth year of research will be considered for renewal in a solicitation that also considers new applications. | | The Request will continue research on current CMS awards that focus on development of research-oriented, open-source, experimentally validated software and the associated databases required to predictively design materials with specific functionality. Software will utilize leadership class computers, and be made available to the broad research community. The codes will incorporate frameworks suited for future exascale computer systems. | No changes. |
| SBIR/STTR | $15,165 | $15,197 | +$32 |
| In FY 2020, SBIR/STTR funding will be set at 3.65 percent of non-capital funding. | | In FY 2021, SBIR/STTR funding will be set at 3.65 percent of non-capital funding. | The SBIR/STTR funding will be consistent with the BES total budget. |

**Description**

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

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

- **Fundamental Interactions**—Discover the factors controlling chemical reactivity and dynamics in the gas phase, condensed phases and at interfaces, based upon a quantum description of the interactions among photons, electrons, atoms, and molecules.
- **Chemical Transformations**—Understand and control the mechanisms of chemical catalysis, synthesis, separation, stabilization and transport in complex chemical systems, from atomic to geologic scales.
- **Photochemistry and Biochemistry**—Elucidate the molecular mechanisms of the capture of light energy and its conversion into electrical and chemical energy through biological and chemical pathways.

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

In addition to single-investigator and small-group research, the subprogram supports multi-investigator, cross-disciplinary teams—through EFRCs, the Fuels from Sunlight Energy Innovation Hub, Computational Chemical Sciences, data science, and QIS—to focus on forefront scientific challenges that relate to the DOE energy mission. The subprogram also supports, in partnership with other SC programs, SC QIS Centers beginning in FY 2020.

The Request continues to focus resources toward the highest priorities in early-stage fundamental research. High priority areas include ultrafast science to probe the dynamics of electrons, atoms, and molecules that underlie photochemical processes, chemical transformations, and energy flow; QIS research to understand the quantum nature of atomic and molecular systems and research to exploit recent advances in quantum computing to address scientific challenges that are beyond the capabilities of classical computers; photo and electrochemical processes associated with the capture of solar energy and conversion to fuels; conversions of increasingly complex chemical systems such as polymers and mixed feedstocks; and the use of AI/ML for data-driven science.

Fundamental Interactions Research

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

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

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

Sciences and the Roundtable on Opportunities for Basic Research for Next-Generation Quantum Systems,[a] key technical areas will include fundamental theory of materials and molecular systems for quantum applications; research leading to materials and molecular systems that meet quantum communication, computation, and sensor requirements; fundamental research on device physics for next generation QIS systems, including interface science; and synthesis and fabrication research for quantum materials and processes, including integration in novel device architectures.

In FY 2021, BES, in partnership with other SC programs, will continue support for the multi-disciplinary multi-institutional QIS center(s), selected through a merit review process in FY 2020. The SC QIS centers will focus on a set of QIS applications or cross-cutting topics that collectively cover the development space that may impact SC Programs, including work on sensors, quantum emulators/simulators and enabling technologies that will pave the path to exploit quantum computing in the longer term.

This activity also supports microelectronics research, including basic research to accelerate the advancement of microelectronic technologies in a co-design innovation ecosystem. Computing systems encompassing new materials, devices, architectures, algorithms, and software will be needed to maintain the continued upward trajectory in performance that Moore's law scaling has historically provided. Optimization must occur at every level of computing and power microelectronics systems, and co-design principles will be essential to meet the future needs of DOE-SC and the nation. Among the challenges is discovery science that can lead to microelectronics for exascale computers and beyond with a small footprint and low power utilization. Such high performance computation will be necessary for analyzing and managing the vast amount of data that will be generated by future DOE-SC facilities to enable new discoveries. Furthermore, advances in new microelectronics materials, and their integration within a co-design framework, are required to transform power electronics and the electricity grid into a modern, agile, resilient, and energy-efficient system. In FY 2021, BES will partner with ASCR, HEP, and FES to support multi-disciplinary microelectronics research. Informed by community strategic planning efforts including the Basic Research Needs for Microelectronics report,[b] key technical areas will include materials, chemistry, and device physics; component integration, architecture, and algorithms; and next-generation tools for synthesis, fabrication, and characterization of devices and systems.

Chemical Transformations Research

This activity advances the knowledge of chemical reactivity, matter transport, and chemical separation and stabilization processes to provide foundational knowledge in core research areas – catalysis science, separation science, heavy element chemistry and geosciences – that are critical for developing the next generation of energy applications. The research uses tools from Ultrafast Chemistry to identify transient species during reactions and refine theories of reactivity; advance understanding of Charge Transport and Reactivity important in electrocatalytic, electroseparations, and geochemical redox processes; explore Chemistry at Complex Interfaces in catalytic, geochemical and separation systems; and develop understanding of Chemistry in Aqueous Environments that play important roles in geochemical transformations and chemical separations, including heavy elements. Reaction Pathways in Diverse Environments represent a major fraction of the research in this activity, particularly focused on achieving predictability and control of catalytic conversions, which are dominated by correlated structural and electronic dynamics under reaction conditions. This activity includes the development and application of theoretical, computational and data analytics methods to achieve a deeper understanding of reaction pathways in complex systems and design new molecules and materials (e.g., catalysts and membranes) that enable control over chemical processes.

Chemical Transformations Research comprises four core areas: Catalysis Science, Separation Science, Heavy Element Chemistry, and Geosciences. Catalysis science research emphasizes understanding of reaction mechanisms, precise synthesis, *operando* characterization and manipulation of catalytic active sites and their environments, and control of reaction conditions for optimized efficiency and selectivity. A primary goal is the molecular-level control of chemical transformations relevant to the sustainable conversion of energy resources, with a focus on thermal and electrochemical conversions of complex feedstocks, including synthetic polymers and mixed hydrocarbons and carbohydrates. Separation science research seeks to understand and ultimately predict and control the atomic and molecular interactions and energy exchanges determining the efficiency of chemical separations. The major focus is to advance discovery of principles driving

[a] https://science.osti.gov/bes/Community-Resources/Reports

[b] https://science.osti.gov/-/media/bes/pdf/reports/2019/BRN_Microelectronics_rpt.pdf

separation processes and predictive design of future chemical separation processes that demand less energy, as well as media with the desired chemical and transport properties. Emphasis is placed on extracting actinides and rare earth elements and efficiently separating gas, liquid, and solid mixtures. Heavy element chemistry provides foundational knowledge on the influence of complex environments, such as liquid-solid and liquid-liquid interfaces, and extreme conditions, such as temperature and radiation, on the dynamic and kinetic behavior of actinide compounds in these environments. A primary goal is to gain an understanding of the unique chemistry of f-electron systems that is required to design new ligands and processes for actinide separations processes, predict the chemical evolution of actinides in nuclear wastes and next-generation reactors, and improve models of actinide environmental transport. Geosciences research provides the fundamental scientific basis underlying the subsurface chemistry and physics of natural substances under extreme conditions of pressure in solid or confined environments (e.g., porous media). Areas of emphasis include the molecular-level understanding of phase equilibria, reaction mechanisms and rates associated with aqueous geochemical processes, and a mechanistic understanding of the origins of subsurface physical properties and the response of earth materials associated with processes such as chemo-mechanical stress corrosion and strain localization. This knowledge will advance abilities to model and predict phenomena such as subsurface migration, mineralization, crack propagation and subsurface fracture that occur over multiple scales of time and space.

This activity supports efforts central to revolutionizing polymer upcycling and to addressing challenges in critical materials, rare earth elements, and separation science. As identified by the BES strategic planning report from the Roundtable on Chemical Upcycling of Polymers,[a] fundamental research can provide the foundational knowledge needed to enable polymer upcycling—the selective deconstruction of polymers that make up plastic followed by reassembly into high-value chemicals, fuels, or materials. Research opportunities include transformative chemistry and biology for chemical conversion and upcycling of polymers, design of next generation polymers and polymeric materials, and next generation tools for determining chemical and biochemical mechanisms with potential benefit for polymer upcycling. Research will build upon this activity's efforts in catalysis science and separation science to develop efficient, selective processes for polymer deconstruction and reconstruction, including the upcycling of complex mixtures of polymeric materials. Rare earth elements provide enhanced performance and new materials functionality based on their rich electronic properties. Research opportunities includes the discovery, design, and synthesis of new materials and processes that limit the use of rare earths, and separation science to enhance recovery of rare earth elements from both minerals and recycled materials. Research will build on this activity's efforts in heavy element chemistry, geosciences, separation science, and catalysis science for understanding the chemistry and physics of f-electron systems to advance the predictive design of controlled molecular and material structures; for understanding the interactions of solutions with interfaces, including mineral interfaces, to provide foundational knowledge needed to advance separations of rare earth elements from critical minerals and recycled materials; and the design of new catalysts that limit the use of rare earths and noble metals.

Photochemistry and Biochemistry Research

This activity supports research on the molecular mechanisms that capture light energy and convert it into electrical and chemical energy in both natural and man-made systems. An important component of this activity is its leadership role in the support of basic research in both solar photochemistry and natural photosynthesis. The fundamental chemical and physical concepts resulting from studies of both natural systems (e.g. photosynthetic and affiliated downstream biological processes) and man-made chemical systems provide crucial foundational knowledge on processes of energy capture, conversion, and storage and can foster the development of bioinspired, biomimetic, and biohybrid energy systems.

Research on the structural and chemical dynamics of energy absorption, transfer, conversion and storage across multiple spatial and temporal scales provides fundamental knowledge of Charge Transport and Reactivity. Efforts target the basic understanding of mechanisms and dynamics of chemical and biochemical processes such as water oxidation, charge transfer, and redox interconversion of small molecules (e.g. carbon dioxide/methane, nitrogen/ammonia, and protons/hydrogen). A breadth of approaches and tools, including those in Ultrafast Chemistry, are used to investigate quantum phenomena in natural and artificial systems; these studies of the potential role and manipulation of photodriven quantum coherence in natural photosynthesis and artificial molecular systems could not only enhance fundamental understanding of energy transfer but also inspire new methods for quantum information processing, potentially in the portfolio of SC QIS Centers. Crosscutting research on the synthesis, dynamics, and function of natural and artificial

[a] https://science.osti.gov/-/media/bes/pdf/BESat40/Polymer_Upcycling_Brochure.pdf

membranes and nano- to meso-scale structures increases knowledge of both Chemistry at Complex Interfaces and Chemistry in Aqueous Environments. Multidisciplinary studies of the structural, functional and mechanistic properties of enzymes, enzyme systems, and energy-relevant biological reactions advance understanding of Reaction Pathways in Diverse Environments and identify principles important for catalyst function, selectivity, and stability.

The biosciences research supported under this activity sits at the interface between chemistry/physics and biology. This multidisciplinary integration enables research in biological systems to provide insights for understanding and enhancing man-made chemical systems while, in a reciprocal manner, studies of chemical (non-biological) systems provide insights into the dynamics and chemical reactivity underlying biochemical processes. Research in natural photosynthesis advances knowledge of biological mechanisms of solar energy capture and conversion and encompasses light harvesting, quantum coherent energy transfer, electron and proton transport, photosynthetic uptake and reduction of carbon dioxide, and mechanisms of self-assembly, self-regulation, and self-repair exhibited by photosynthetic proteins, membranes and cellular compartments. The mechanistic understanding of natural photosynthesis can inspire development of bio-hybrid, biomimetic, and artificial photosynthetic systems for solar fuels production and inform strategies to enhance photosynthetic efficiency in natural systems. Physical science tools are used extensively to probe structural, functional, and mechanistic properties of enzymes, enzyme systems, and reactions and pathways related to energy capture, conversion, and storage in natural systems, including complex multielectron redox reactions, electron transfer and bifurcation, metal uptake and use, and processes beyond primary photosynthesis such as nitrogen reduction and deposition of reduced carbon into energy-dense carbohydrates and lipids. This knowledge of energy conversion and storage in biological systems will identify principles for the design of highly selective and efficient catalysts, for instance, for ammonia synthesis or polymer conversion; the control of electron flow to achieve desired metabolic products; and the design of next-generation energy conversion technologies. Complementary research on solar energy conversion in artificial systems focuses on the elementary steps of light absorption, charge separation, and charge transport within a number of chemical systems. Supported research incorporates organic and inorganic photochemistry, catalysis and photocatalysis, light-driven electron and energy transfer in the condensed phase and across interfaces, photoelectrochemistry, photodriven generation of quantum coherence in artificial molecular systems, and artificial assemblies for charge separation and transport. These studies provide essential foundational knowledge for the use of solar energy for fuel production and electricity generation. Research also addresses the fundamental physical and chemical effects produced by the absorption of energy from ionizing radiation. A common theme is the exploration of radiolytic processes that occur across solid-liquid and solid-gas interfaces, where surface chemistry can be activated and changed by radiolysis. These studies increase fundamental knowledge of the chemical reactions that occur in the extreme environments of nuclear reactors, including in their fuel and coolants, and can provide insights for effective nuclear waste remediation, fuel-cycle separation and design of nuclear reactors.

Research focused on molecular-level understanding of biochemical processes advances SC's Next-Generation Biology initiative. New efforts in this activity will build on BES biochemistry and biophysics research to discover and design chemical processes and complex structures that can enable development of bio-inspired, biohybrid, and biomimetic energy systems with desired functions and properties. Studies will target the molecular-level mechanisms nature uses to control complex chemical conversions, including error-correcting and defect-managing mechanisms, and to manage information and signal transduction in complex hierarchical systems. Research will also continue to develop new approaches for dynamic and in-situ imaging and characterization, including capabilities at SC facilities, and computational tools for understanding complex assembly and other biochemical processes.

Energy Frontier Research Centers (EFRCs)

The EFRC program is a unique research modality, bringing together the skills and talents of teams of investigators to perform energy-relevant, basic research with a scope and complexity beyond what is possible in standard single-investigator or small-group awards. These multi-investigator, multi-disciplinary centers foster, encourage, and accelerate basic research to enable transformative scientific advances. They allow experts from a variety of disciplines to collaborate on shared challenges, combining their strengths to uncover new and innovative solutions to the most difficult problems in chemical sciences, geosciences, and biosciences. The EFRCs also support numerous graduate students and postdoctoral researchers, educating and training a scientific workforce for the 21st century economy. The EFRCs supported in this subprogram focus on the following topics: the design, discovery, characterization, and control of the chemical, biochemical, and geological moieties and processes for the advanced conversion of solar energy into chemical fuels and for improved electrochemical storage of energy; the understanding of catalytic chemistry and biochemistry that are foundational for fuels, chemicals, and separations; interdependent energy-water issues; future nuclear energy; and advanced interrogation and characterization of the earth's subsurface. After ten years of research activity, the program has produced an impressive breadth of scientific accomplishments, including over 11,600 peer-reviewed journal publications.

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

Energy Innovation Hubs—Fuels from Sunlight

Based on competitive merit review, new multi-investigator, cross-disciplinary solar fuels research awards will be initiated in FY 2020 to address both emerging new directions and long-standing challenges in the use of solar energy, water, and carbon dioxide as the only inputs for fuels production. The FY 2021 Request will continue support for this early-stage fundamental research on solar fuels generation that is building on the unique accomplishments of the first Fuels from Sunlight Hub and is addressing key scientific challenges identified by the strategic planning report from the Roundtable on Liquid Solar Fuels.[a]

Computational Chemical Sciences

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

BES launched research awards in FY 2017 to perform computational chemical sciences research that focuses on the creation of computational codes and associated experimental/computational databases for the design of chemical processes and assemblies. Additional awards were initiated in FY 2018. The FY 2017 awards will be recompeted in FY 2021. These research efforts combine the skills of experts in theoretical chemistry, modeling, computation, and applied mathematics. The research includes development of new *ab initio* theory, mining data from both experimental and theoretical databases, and experimental validation of the codes. The computational codes will advance the predictive capability for chemical processes and assemblies, using DOE's scientific user facilities (including both advanced experimental as well as leadership class computational capabilities). This research will result in publicly accessible databases of experimental/computational data and open source, robust, validated, user friendly software that captures the essential physics and chemistry of relevant chemical systems. The ultimate goal is use of these codes/data by the broader research community and by industry to dramatically accelerate chemical research in the U.S.

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

[a] https://science.osti.gov/-/media/bes/pdf/reports/2020/Solar_Fuels_Brochure.pdf

General Plant Projects (GPP)

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

## Activities and Explanation of Changes

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| **Chemical Sciences, Geosciences, and Biosciences** | **$380,478** | **$373,505** | **-$6,973** |
| Fundamental Interactions Research | $101,567 | $99,611 | -$1,956 |
| Funding continues to develop forefront ultrafast approaches to study and control energy flow and bond rearrangements in gas-phase, condensed phase and interfacial chemical phenomena. Gas-phase research continues studies of reaction pathways in heterogeneous environments and expands to examine quantum phenomena in tailored molecules. Research efforts extend to understand and control chemical and quantum phenomena in increasingly complex multiphase environments. Understanding, leading to control of interfacial reactivity, informs the design and synthesis of new materials relevant to microelectronics. This activity continues to develop advanced theoretical and computational approaches, including AI/ML for data-driven science, that will operate on future exascale computers, and to drive advances in the application of quantum computing for molecular calculations. BES will partner with other SC Program Offices to establish at least one multi-disciplinary multi-institutional QIS center, which will be selected through a merit reviewed process conducted in FY 2020. The scope of the SC QIS center will be on a set of QIS applications or cross-cutting topics that collectively cover the development space that may impact SC Programs and include work on sensors, quantum emulators/ simulators and enabling technologies that will pave the path to exploit quantum computing in the longer term. | | The Request will continue to develop forefront ultrafast approaches, with emphasis on the use of x-ray free electron lasers, including LCLS and its upgrades. Gas-phase research will continue studies of how reactive intermediates in heterogeneous environments impact reaction pathways, and quantum phenomena underlying QIS, such as coherence and entanglement, in tailored molecules. Research will extend efforts to understand and control chemical processes and quantum phenomena at the molecular level in increasingly complex aqueous and interfacial systems. Research to understand and control interfacial chemical reactions will increase with the aim of designing and synthesizing new materials relevant to microelectronics. This activity will continue to develop advanced theoretical and computational approaches that can be scaled to operate on exascale computers. Development of AI/ML methods will increase to enable novel data science approaches for knowledge discovery. Research will emphasize efforts to drive advances in the application of quantum information science for understanding and exploiting quantum phenomena in chemical systems. This activity provides continued support for the QIS Centers established in FY 2020. | Funding will emphasize new efforts to understand and control interfacial chemical reactions that can enable new materials for microelectronics and will support research in studies of quantum phenomena important for QIS and the impact of molecular environments on these phenomena. Support will continue the development of advanced theoretical and computational approaches, with increased emphasis on the development and application of AI/ML methods that will enable novel data science approaches for knowledge discovery. |

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| Chemical Transformations Research | $97,836 | $101,385 | +$3,549 |
| Funding continues to support predictive fundamental research on the design and synthesis of novel catalysts to efficiently convert chemical feedstocks, including hydrocarbons, biomass, and synthetic polymers, to high-value fuels and chemicals. Fundamental studies also target the understanding and control of the synthesis and reconstruction of molecular structures with advanced (opto)electronic and spin properties. Fundamental separation science research continues on innovative approaches for separating chemical mixtures with emphasis on the use of computational approaches, including data science tools and multi-scale methods, to investigate molecular recognition at complex interfaces, predict transport and separation in confined environments, and bonding and dynamics. Support continues to understand geochemical and geophysical mechanisms of reaction and transport processes in the subsurface environments, such as nucleation, growth and mineralization, solvation in aqueous environments at extreme conditions, and dynamics at mineral-water interfaces. Heavy element research continues to expand the knowledge of the chemistry of actinide reactivity, bonding, synthesis, and separation, supports training in nuclear chemistry, and advances theoretical methods to accurately describe the chemistry of f-electron systems. | | The Request will continue support for fundamental research to understand mechanisms of catalysis and to predict, design, and synthesize novel catalysts and bioinspired metal complexes with enhanced performance for thermo- and electro-chemical conversions, with an increased emphasis on chemical upcycling of polymers. Separation science research will continue to focus on novel approaches to separate complex chemical mixtures with high efficiency, with a new emphasis on separations processes, including reactive separations that will facilitate the chemical upcycling of polymers. Geosciences research will continue to elucidate subsurface phenomena, such as mineral nucleation, and rock fracture propagation, with an emphasis on the intersection of geochemical and geophysical processes under extreme subsurface conditions. Heavy element research will continue to deepen understanding of actinide speciation and reactivity, fundamental theories of f-electron systems, and approaches to synthesize and separate actinide compounds. New efforts on the chemistry of rare earth elements, including heavy elements such as lanthanides, will focus on understanding their reactivity to limit their use in catalytic processes, their interactions and chemical processes in multiphase systems relevant to separations from complex mixtures, and their behavior in rare-earth containing minerals, particularly the interaction of these minerals with aqueous solutions, that are relevant to extraction in geological environments. | Funding will emphasize atomically precise synthesis and control of new catalytic and chemically active functions; understanding multiscale phenomena in extreme and constrained environments; and developing integrated computational and data science approaches to predict multiscale and multiphysics processes. Support will increase for research on catalysis and separations, including reactive separations, for chemical upcycling of polymers. Increased emphasis on the chemistry of rare earths will include selective separations from solutions, dynamics and reactivity at mineral-water interfaces during extraction and recovery, utilization of the f-electron properties of rare-earth elements, and understanding the promotor properties of rare-earth elements used for catalysis. |

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| Photochemistry and Biochemistry Research | $75,724 | $67,413 | -$8,311 |
| Funding continues to support fundamental research and innovative approaches to understand physical, chemical, and biochemical processes of light energy capture and conversion in chemical and biological systems. Studies of light absorption, energy transfer, charge transport and separation, and photocatalysis continue to be emphasized in both natural and artificial systems to advance foundational knowledge of solar energy capture and conversion with an emphasis on solar fuels generation. Understanding of molecular mechanisms of photon capture and electron transfer advance solar fuels research as well as provide insights into quantum phenomena in energy transfer. Research on biocatalysis continues to focus on a mechanistic understanding of enzyme structure and function with a particular emphasis on multi-electron redox reactions, electron bifurcation, and co-factor tuning. Efforts to understand processes and reactions on ultrafast timescales for energy conversion in natural and artificial systems continue as well as studies of reactivity across complex interfaces, in aqueous environments, and under dynamic conditions. | | The Request will continue to support fundamental research that emphasizes an understanding of the physical, chemical, and biochemical processes of light energy capture and conversion in biological and chemical systems. Studies of light absorption, energy transfer, charge transport and separation, separations processes, and photocatalysis in both natural and artificial systems will provide fundamental knowledge to guide the design of new energy systems. The Request will increase focus on biochemical processes and complex structures that can enable development of bio-inspired, biohybrid, and biomimetic energy systems with desired functions and properties. Research on molecular mechanisms of biocatalysis, revealed by studies of enzyme structure and function, multi-electron redox reactions, and electron bifurcation, will inform bioinspired design of catalysts and reaction pathways, for instance to guide new approaches for polymer upcycling. Research on metal uptake and use by biological systems will inform bio-inspired separation processes. Studies will also increase understanding of how rare elements can be minimized in photo-absorbers and catalysts for solar fuels. Advances in solar fuels will continue via research on molecular mechanisms of photon capture, electron transfer, and product selectivity and separation from non-target molecules. Studies of light energy capture will address the relationship between quantum phenomena and the efficiency and fidelity of energy transfer and conversion. | Funding will emphasize charge transport, energy transfer, light harvesting, separations, photo- and biocatalytic mechanisms, self-assembly/repair of complex structures, and excited-state dynamics of processes important for energy capture and conversion in biological and chemical systems. Such research will place an increased emphasis on fundamental principles for bioinspired design and development of biomimetic and biohybrid energy systems and processes. |

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| Energy Frontier Research Centers (EFRCs) | $57,500 | $57,500 | $ — |
| Funding continues to support four-year EFRC awards that were made in FY 2018. In addition, FY 2020 funds will support a solicitation that will recompete the four-year EFRC awards made in FY 2016, which focused on science relevant to DOE's environmental management mission, and make new awards that are responsive to recent BES strategic planning workshop reports, including use-inspired science relevant to advanced microelectronics, QIS, and polymer upcycling. | | The Request will provide the fourth year of support for four-year EFRC awards that were made in FY 2018 and the second year of support for four-year EFRC awards that were made in FY 2020. | No changes. |
| Energy Innovation Hubs—Fuels from Sunlight | $20,000 | $20,000 | $ — |
| Funding supports early-stage fundamental research on solar fuels generation that builds on the unique capabilities and accomplishments of the Joint Center for Artificial Photosynthesis. New awards of multi-investigator, cross-disciplinary solar fuels research solicited in the FY 2020 recompetition will continue to address emerging new directions as well as long-standing challenges in this transformational area of energy science. Research focuses on tackling forefront, fundamental scientific challenges for generating fuels using only sunlight, carbon dioxide, and water as inputs. Advances in this area also benefit from consideration of photodriven generation of fuels from molecules other than carbon dioxide. The research capitalizes on unique capabilities and accomplishments developed to date to elucidate scientific principles for light energy capture and conversion into chemical bonds by integrating experiment and theory, including coupling high-throughput experimentation with artificial intelligence to accelerate progress. | | The Request will continue to support early-stage fundamental research on solar fuels generation to address both emerging new directions and long-standing scientific challenges in this area of energy science. Research will continue to focus on generating fuels using only sunlight, carbon dioxide, and water as inputs. However, photodriven generation of fuels from molecules other than carbon dioxide can also provide important new insights and may be supported to reveal principles for solar energy capture and conversion into liquid fuels. Efforts that integrate experiment and theory and couple high-throughput experimentation with artificial intelligence will continue to be emphasized. | No changes. |

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| Computational Chemical Sciences | $13,000 | $13,000 | $— |
| Funding continues the Computational Chemical Sciences (CCS) awards made in FY 2017 and FY 2018, with ongoing focus on developing public, open source codes for future exascale computer platforms. | | The Request will continue CCS awards made in FY 2018, with ongoing focus on developing public, open source codes for future exascale computer platforms. In addition, FY 2021 funds will support a recompetition of CCS awards made in FY 2017, and make awards for development of new theoretical and computational approaches and open source codes in areas relevant to directions identified in BES strategic planning workshop reports. | Funding will support priority research areas for CCS awards as identified in BES strategic planning workshop reports |
| General Plant Projects | $1,000 | $1,000 | $ — |
| Funding supports minor facility improvements at Ames Laboratory. | | The Request will support minor facility improvements at Ames Laboratory. | No changes. |
| SBIR/STTR | $13,851 | $13,596 | -$255 |
| In FY 2020, SBIR/STTR funding will be set at 3.65 percent of non-capital funding. | | In FY 2021, SBIR/STTR funding will be set at 3.65 percent of non-capital funding. | The SBIR/STTR funding will be consistent with the BES total budget. |

## Basic Energy Sciences
## Scientific User Facilities

### Description

The Scientific User Facilities subprogram supports the operation of a geographically diverse suite of major research facilities that provide unique tools to thousands of researchers from universities, industry, and government laboratories 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, researchers 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. Keeping BES accelerator-based facilities at the forefront requires continued, transformative advances in accelerator science and technology. Strategic investments in high-brightness electron injectors, superconducting undulators with strong focusing, and high gradient superconducting cavities will have the most impactful benefits. X-ray free electron laser (FEL) oscillators offer the most near-future attainable advances in x-ray science capabilities, requiring additional research efforts in x-ray resonant cavities and high heat-load diamond materials. Research in seeded FEL schemes for full coherent x-rays, and attosecond electron and x-ray pulse generation are critical for multi-terawatt FEL amplifiers required by single-particle imaging.

The twelve BES scientific user facilities provide the nation with the most comprehensive and advanced x-ray, neutron, and electron based experimental tools enabling fundamental discovery science. Hundreds of experiments are conducted simultaneously around the clock generating vast quantities of raw experimental data that must be stored, transported, and then analyzed to convert the raw data into information to unlock the answers to important scientific questions. Managing the collection, transport and analysis of data at the BES facilities is a growing challenge as new facilities come online with expanded scientific capabilities coupled together with advances in detector technology. Over the next decade, the data volume, and the computational power to process the data, is expected to grow by several orders of magnitude. Applications of AI/ML methods and tools are being implemented in new software and hardware to help address these data and information challenges and needs. Challenges include speeding up high-fidelity simulations for online models, fast tuning in high-dimensional space, anomaly/breakout detection, 'virtual diagnostics' that can operate at high repetition rates, and sophisticated compression/rejection data pipelines operating at the 'edge' (next to the detector) to save the highest value data from user experiments.

In FY 2019, more than 16,000 scientists and engineers in many fields of science and technology used BES scientific facilities. These facilities provide unique capabilities to the scientific community and industry and are a critical component of maintaining U.S. leadership in the physical sciences. Collectively, these user facilities and enabling tools contribute to important research results that span the continuum from basic to applied research and embrace the full range of scientific and technological endeavors, including chemistry, physics, geology, materials science, environmental science, biology, and biomedical science. These capabilities enable scientific insights that can lead to the discovery and design of advanced materials and novel chemical processes with broad societal impacts, from energy applications to information technologies and biopharmaceutical discoveries. The advances enabled by these facilities extend from energy-efficient catalysts to spin-based electronics and new drugs for cancer therapy. For approved, peer-reviewed projects, operating time is available at no cost to researchers who intend to publish their results in the open literature.

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

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

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

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

- they have a wavelength similar to the spacing between atoms, allowing atomic resolution studies of structure, and have an energy similar to the elementary excitations of atoms and magnetic spins in materials, thus allowing an investigation of material dynamics;
- they have no charge, allowing deep penetration into a bulk material;
- they are scattered to a similar extent by both light and heavy atoms but differently by different isotopes of the same element, so that different chemical sites can be distinguished via isotope substitution experiments, for example in organic and biological materials;

- they have a magnetic moment, and thus can probe magnetism in condensed matter systems; and
- their scattering cross-section is precisely measurable on an absolute scale, facilitating straightforward comparison with theory and computer modeling.

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

The Spallation Neutron Source (SNS) at ORNL uses another approach for generating neutron beams where an accelerator generates protons that strike a heavy-metal target such as mercury. As a result of the impact, neutrons are produced in a process known as spallation.

The SNS is the world's brightest pulsed neutron facility and presently includes 19 instruments. These world-leading instruments include very high resolution inelastic and quasi-elastic scattering capabilities, powder and single crystal diffraction, polarized and unpolarized beam reflectometry, and spin echo and small angle scattering spectrometers. A full suite of high and low temperature, high magnetic field, and high pressure sample environment equipment is available on each instrument. All the SNS instruments are in high demand by researchers world-wide in a range of disciplines from biology to materials sciences and condensed matter physics.

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

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

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

Other Project Costs

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

Major Items of Equipment

BES supports major item of equipment (MIE) projects to ensure the continual development and upgrade of major scientific instrument capabilities, including fabricating new x-ray and neutron experimental stations, improving core facilities, and providing new stand-alone instruments and capabilities.

Research

This activity supports targeted basic research in accelerator physics, x-ray and neutron detectors, and development 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 manipulations to reduce the cost and complexity and improve performance of next generation FELs, and development of intense laser-based terahertz (THz) sources to study non-equilibrium behavior in complex materials. As the complexity of accelerators and the performance requirements continue to grow the need for more dynamic and adaptive control systems becomes essential. Particle accelerators are complicated interconnected machines and ideal for applications of artificial intelligence and machine learning algorithms to improve performance optimization, rapid recovery of fault conditions, and prognostics to anticipate problems. Detector research is a crucial component to enable the optimal utilization of user facilities, together with the development of innovative optics instrumentation to advance photon-based sciences, and data management techniques. The emphasis of the detector activity is on research leading to new and more efficient photon and neutron detectors. X-ray optics research involves development of systems for time-resolved x-ray science that preserve the spatial, temporal, and spectral properties of x-rays. Research includes studies on creating, manipulating, transporting, and performing diagnostics of ultrahigh brightness beams and developing ultrafast electron diffraction systems that complement the capabilities of x-ray FELs. This activity also includes research in sophisticated data management tools to address the vastly accelerated pace and volume of data generated by faster, higher resolution detectors and brighter light sources. This activity also supports training in the field of particle beams and their associated accelerator technologies.

## Activities and Explanation of Changes

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | | Explanation of Changes FY 2021 Request vs FY 2020 Enacted | |
|---|---|---|---|---|---|
| **Scientific User Facilities** | **$1,057,040** | | **$961,813** | | **-$95,227** |
| X-Ray Light Sources | $518,791 | | $494,830 | | -$23,961 |
| Funding supports LCLS operations, which resume in the third quarter of FY 2020 upon completion of installation of LCLS-II accelerator components. All light source facilities will operate at approximately 100 percent of optimal. | | The Request will support operations at five BES light sources (LCLS, APS, ALS, NSLS-II, and SSRL). | | Funding will support LCLS operations at 97 percent of optimal. The remaining light source facilities will operate at approximately 91 percent of optimal. | |
| High-Flux Neutron Sources | $289,701 | | $260,088 | | -$29,613 |
| Funding supports SNS and HFIR operations. These facilities will operate at 100 percent of optimal. | | The Request will support operations at SNS and HFIR. | | Funding will support operations for SNS and HFIR at approximately 91 percent of optimal. | |
| Nanoscale Science Research Centers | $138,687 | | $129,938 | | -$8,749 |
| Funding supports operations of five NSRCs, with funding for nanoscience, QIS research, and related development of synthesis and characterization tools. | | The Request will provide funding for five NSRCs (CFN, CNM, CNMS, TMF, and CINT). The NSRCs will continue to develop nanoscience and QIS-related research infrastructure and capabilities for materials synthesis, device fabrication, metrology, modeling and simulation. | | Funding will support operations for the five NSRCs as well as QIS-related research infrastructure and capabilities. | |
| Other Project Costs | $23,000 | | $7,000 | | -$16,000 |
| Funding supports Other Project Costs for the LCLS-II-HE project at SLAC National Accelerator Laboratory, ALS-U at Lawrence Berkeley National Laboratory, and the Second Target Station at Oak Ridge National Laboratory. | | The Request will support Other Project Costs for the LCLS-II-HE project at SLAC National Accelerator Laboratory, PPU at Oak Ridge National Laboratory, and the Second Target Station project at Oak Ridge National Laboratory. The Request initiates the Cryomodule Repair and Maintenance Facility (CRMF) project. | | Other Project Costs follow project plans. | |

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| Major Items of Equipment | $10,500 | $2,000 | -$8,500 |
| Funding initiates a beamline project for NSLS-II (NEXT-II) at Brookhaven National Laboratory and will support conceptual designs of new beamlines. The FY 2020 Enacted budget also initiates a recapitalization project for the NSRCs and will support planning and design activities in preparation for CD-1, along with possible procurements. | | The Request will continue the beamline project for NSLS-II (NEXT-II) at Brookhaven National Laboratory. Design work for NEXT-II will continue along with R&D, prototyping, other supporting activities, and possible long lead procurements. The recapitalization project for the NSRCs will also continue with R&D, design, engineering, prototyping, other supporting activities, and possible procurements. | Funding will support the NEXT-II and NSRC Recapitalization MIE projects. |
| Research | $39,879 | $36,206 | -$3,673 |
| Funding supports high-priority research activities for detectors and optics instrumentation and applications of machine learning techniques to accelerator optimization, control, prognostics, and data analysis. | | The Request will support high-priority research activities for advanced seeded FEL schemes that provide several orders of magnitude performance enhancement, detectors and optics instrumentation and applications of machine learning techniques to accelerator optimization, control, prognostics, and data analysis. Research will emphasize transformative advances in accelerator science and technology that lead to significant improvements in very high brightness and high current electron sources and in high intensity proton sources. | Funding will support investment in future accelerator technologies to continue to provide the world's most comprehensive and advanced accelerator-based facilities for scientific research. Funding will also continue the development of AI/ML methods and tools to address data and information challenges at the BES user facilities, including accelerator optimization, control, prognostics, and data analysis. |
| SBIR/STTR | $36,482 | $31,751 | -$4,731 |
| In FY 2020, SBIR/STTR funding will be set at 3.65 percent of non-capital funding. | | In FY 2021, SBIR/STTR funding will be set at 3.65 percent of non-capital funding. | The SBIR/STTR funding will be consistent with the BES total budget. |

## Basic Energy Sciences
## Construction

### Description

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

Advanced Photon Source Upgrade (APS-U)

The APS-U project will provide scientists with an x-ray source possessing world-leading transverse coherence and extreme brightness. The magnetic lattice of the APS storage ring will be upgraded to a multi-bend achromat configuration to provide 100-1000 times increased brightness and coherent flux. APS-U will ensure that the APS remains a world leader in hard x-ray science. The project received approval for CD-3, Approve Start of Construction, on July 25, 2019, with a Total Project Cost (TPC) of $815,000,000 and CD-4, Approve Project Completion, in 2Q FY 2026.

Advanced Light Source Upgrade (ALS-U)

The ALS-U project will upgrade the existing ALS facility by replacing the existing electron storage ring with a new electron storage ring based on a multi-bend achromat lattice design, which will provide a soft x-ray source that is up to 1000 times brighter and with a significantly higher coherent flux fraction. ALS-U will leverage two decades of investments in scientific tools at the ALS by making use of the existing beamlines and infrastructure. ALS-U will ensure that the ALS facility remains a world leader in soft x-ray science. The project received CD-3A, Approve Long Lead Procurements, on December 19, 2019. The current TPC range is $330,000,000 - $495,000,000.

Linac Coherent Light Source-II-HE (LCLS-II-HE)

The LCLS-II-HE project will increase the energy of the superconducting linac currently under construction as part of the LCLS-II project from 4 giga-electronvolts (GeV) to 8 GeV and thereby expand the high repetition rate operation (1 million pulses per second) of this unique facility into the hard x-ray regime (5-12 keV). LCLS-II-HE will add new and upgraded instrumentation to augment existing capabilities and upgrade the facility infrastructure as needed. The LCLS-II-HE project will upgrade and expand the capabilities of the LCLS-II to maintain U.S. leadership in ultrafast x-ray science. The project received CD-1, Approve Alternative Selection and Cost Range, on September 21, 2018. The current TPC range is $290,000,000 - $480,000,000.

Proton Power Upgrade (PPU)

The PPU project will double the proton beam power capability of the Spallation Neutron Source (SNS) from 1.4 megawatts (MW) to 2.8 MW, upgrade the first target station to accommodate beam power up to 2 MW, and deliver a 2 MW qualified target. PPU will fabricate and install seven new superconducting radio frequency (RF) cryomodules, with supporting RF equipment, in the existing linac tunnel and klystron gallery respectively. Equipment will be upgraded to handle the higher beam current. The ring will be upgraded with minor modifications to the injection and extraction areas. The increased beam power of 2 MW to be provided to the first target station will be enabled by the additional cryomodules, and improved target performance will be enabled by the addition of a new target gas injection system and a redesigned mercury target vessel. The project received CD-3B, Approve Long Lead Procurements, on September 3, 2019. The current TPC range is $184,000,000 - $320,000,000.

Second Target Station (STS)

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

Cryomodule Repair and Maintenance Facility (CRMF)

The CRMF project will provide a much needed capability to maintain, repair, and test superconducting radiofrequency (SRF) accelerator components, including SRF cryomodules that make up the new superconducting accelerator being constructed by the LCLS-II and LCLS-II-HE projects. The facility will provide for the full disassembly and repair of the SRF cryomodule; the ability to disassemble, clean, and reassemble the SRF cavities and cavity string; testing capabilities for the full cryomodule; and separate testing capabilities for individual SRF cavities. To accomplish this, the project is envisioned to require a 19,000 to 23,000 gross square foot building to contain the necessary equipment. The building will need a concrete shielded enclosure for cryomodule testing, a control room, vertical test stand area for testing SRF cavities and components, a cryogen distribution box which is connected to a source of liquid helium and will distribute liquid helium within the CRMF building, cryomodule fixtures used to insert and remove the cold mass from the cryomodule vacuum vessel, a cleanroom partitioned into class 10 and class 1000 areas, a loading and cryomodule preparation area, storage areas, and a 15 ton bridge crane for moving equipment from one area to another within the building. The project received CD-0, Approve Mission Need, on December 5, 2019. The current TPC range is $70,000,000 - $98,000,000.

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

## Activities and Explanation of Changes

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| **Construction** | **$360,000** | **$184,000** | **-$176,000** |
| 21-SC-10, Cryomodule Repair and Maintenance Facility (CRMF), SLAC | $— | $1,000 | +$1,000 |
| No funds were requested in FY 2020. | | The Request will support conducting an Analysis of Alternatives to determine the project site and the basic parameters on which to base a conceptual design. Engineering and design activities may begin. | This is the initial request for the CRMF project. |
| 19-SC-14, Second Target Station (STS), ORNL | $20,000 | $1,000 | -$19,000 |
| Funding supports continued planning, targeted R&D and engineering design, and other activities required to advance the STS project. Construction funds will be executed after the appropriate critical decision approvals are received. | | The Request will continue planning, R&D, and engineering activities to assist in maturing the project design, scope, cost, schedule and key performance parameters. | Funding will support the STS project. |
| 18-SC-10, Advanced Photon Source Upgrade (APS-U), ANL | $170,000 | $150,000 | -$20,000 |
| Funding supports targeted R&D, engineering design, equipment prototyping, testing, fabrication, site preparation, installation, long lead and advanced procurements, and other activities required to advance the APS-U project. | | The Request will support advancing the final engineering designs, engineering, prototyping, testing, fabrication, procurement, integration, and installation for the storage ring and experimental facilities, and further site preparation and civil construction associated with the long beamlines. | Funding will support the APS-U project. |

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | | Explanation of Changes FY 2021 Request vs FY 2020 Enacted | |
|---|---|---|---|---|---|
| 18-SC-11, Spallation Neutron Source Proton Power Upgrade (PPU), ORNL | $60,000 | | $5,000 | | -$55,000 |
| Funding supports R&D, engineering, prototyping, preliminary and final design, testing, fabrication, procurement, component integration and installation, and other activities required to advance the PPU project. | | The Request will continue support of R&D, engineering, prototyping, preliminary and final designs, testing, fabrication, procurement, component integration and installation, and civil construction site preparation. Advancing the target R&D, engineering, design, and prototyping in conjunction with SNS operations target improvement plans will be a high priority. | | Funding will support the PPU project. | |
| 18-SC-12, Advanced Light Source Upgrade (ALS-U), LBNL | $60,000 | | $13,000 | | -$47,000 |
| Funding supports planning, engineering, design, R&D, equipment prototyping, testing, and other activities to advance the ALS-U project. | | The Request will continue support of engineering, design, R&D prototyping and long lead procurements of construction items. | | Funding will support the ALS-U project. | |
| 18-SC-13, Linac Coherent Light Source-II High Energy (LCLS-II-HE), SLAC | $50,000 | | $14,000 | | -$36,000 |
| Funding supports planning, engineering, design, R&D, equipment prototyping, testing, and other activities required to advance the LCLS-II-HE project. | | The Request will continue engineering, design, R&D prototyping, and long lead procurements of construction items. | | Funding will support the LCLS-II-HE project. | |

## Basic Energy Sciences
## Capital Summary

(dollars in thousands)

| | Total | Prior Years | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|---|---|
| **Capital Operating Expenses** | | | | | | |
| Capital Equipment | N/A | N/A | 76,610 | 46,825 | 35,325 | -11,500 |
| Minor Construction Activities | | | | | | |
| General Plant Projects (GPP) | N/A | N/A | 3,000 | 1,000 | 1,000 | — |
| Accelerator Improvement Projects (AIP) | N/A | N/A | 48,045 | 10,700 | 56,612 | +45,912 |
| **Total, Capital Operating Expenses** | **N/A** | **N/A** | **127,655** | **58,525** | **92,937** | **+34,412** |

## Capital Equipment

(dollars in thousands)

| | Total | Prior Years | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|---|---|
| **Capital Equipment** | | | | | | |
| Major Items of Equipment | | | | | | |
| *Scientific User Facilities* | | | | | | |
| NSLS-II Experimental Tools-II (NEXT-II), BNL | 80,000 | — | — | 5,500 | 1,000 | -4,500 |
| NSRC Recapitalization | 80,000 | — | — | 5,000 | 1,000 | -4,000 |
| Total, MIEs | N/A | N/A | — | 10,500 | 2,000 | -8,500 |
| Total, Non-MIE Capital Equipment | N/A | N/A | 76,610 | 36,325 | 33,325 | -3,000 |
| **Total, Capital Equipment** | **N/A** | **N/A** | **76,610** | **46,825** | **35,325** | **-11,500** |

**Minor Construction Activities**

(dollars in thousands)

| | Total | Prior Years | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|---|---|
| **General Plant Projects (GPP)** | | | | | | |
| Total GPPs less than $5M[a] | N/A | N/A | 3,000 | 1,000 | 1,000 | — |
| **Total, General Plant Projects (GPP)** | **N/A** | **N/A** | **3,000** | **1,000** | **1,000** | **—** |
| **Accelerator Improvement Projects (AIP)** | | | | | | |
| Greater than or equal to $5M and less than $20M | | | | | | |
| VENUS, Spallation Neutron Source, ORNL | 13,400 | N/A | 13,400 | — | — | — |
| DISCOVER, Spallation Neutron Source, ORNL | 18,500 | N/A | — | — | 18,500 | +18,500 |
| Full Scale SCL Chemistry Upgrade, Spallation Neutron Source, ORNL | 5,000 | N/A | — | — | 5,000 | +5,000 |
| Guide Hall Extension, High Flux Isotope Reactor, ORNL | 9,000 | N/A | — | — | 9,000 | +9,000 |
| Storage Ring HVAC System Upgrade, Advanced Light Source, LBNL | 6,900 | N/A | 650[b] | 6,250[b] | — | -6,250 |
| Copper to Soft Xray, Linac Coherent Light Source, SLAC | 7,664 | N/A | 7,664[b] | — | — | — |
| 3rd Harmonic Cavity, National Synchrotron Light Source-II, BNL | 8,760 | N/A | — | — | 8,760 | +8,760 |
| 3rd RF Cavity, National Synchrotron Light Source-II, BNL | 9,300 | 5,100 | 4,200[b] | — | — | — |
| Total, AIPs (greater than or equal to $5M and less than $20M) | N/A | N/A | 25,914 | 6,250 | 41,260 | +35,010 |
| Total, AIPs less than $5M[c] | N/A | N/A | 22,131 | 4,450 | 15,352 | +10,902 |
| **Total, Accelerator Improvement Projects (AIP)** | **N/A** | **N/A** | **48,045** | **10,700** | **56,612** | **+45,912** |
| **Total, Minor Construction Activities** | **N/A** | **N/A** | **51,045** | **11,700** | **57,612** | **+45,912** |

[a] GPP activities less than $5 million include design and construction for additions and/or improvements to land, buildings, replacements or additions to roads, and general area improvements.
[b] Funding was not previously included in the FY 2020 Request because it was not required to be disclosed as minor construction project.
[c] AIP activities less than $5 million include minor construction at an existing accelerator facility.

**Basic Energy Sciences**
**Major Items of Equipment Description(s)**

Scientific User Facilities MIEs:

*NSLS-II Experimental Tools-II (NEXT-II) Project*

The NEXT-II project proposes to add three world-class beamlines to the NSLS-II Facility as part of a phased buildout of beamlines to provide advances in scientific capabilities for the soft x-ray user community. These beamlines will focus on the techniques of coherent diffraction imaging, soft x-ray spectromicroscopy, and nanoscale probes of electronic excitations. The project received CD-0, Approve Mission Need, on December 19, 2018. The current total project cost range is $40,000,000 to $80,000,000. The FY 2021 Request of $1,000,000 will continue R&D, prototyping, other supporting activities, and possible long lead procurements.

*Nanoscale Science Research Center (NSRC) Recapitalization Project*

The NSRCs started early operations in 2006-2007 and now, a decade later, they need to recapitalize their instrumentation to continue to perform cutting edge science to support and accelerate advances in the fields of nanoscience, materials, chemistry, and biology. The recapitalization will also provide essential support for quantum information science and systems. The project received CD-0, Approve Mission Need, on December 19, 2018. The current total project cost range is $50,000,000 to $90,000,000. The FY 2021 Request of $1,000,000 will continue R&D, design, engineering, prototyping, other supporting activities, and possible procurements.

**Basic Energy Sciences**
**Construction Projects Summary**

(dollars in thousands)

| | Total | Prior Years | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|---|---|
| **21-SC-10, Cryomodule Repair and Maintenance Facility (CRMF)** | | | | | | |
| TEC | 70,000 | — | — | — | 1,000 | +1,000 |
| OPC | 10,000 | — | — | — | 1,000 | +1,000 |
| **TPC** | **80,000** | **—** | **—** | **—** | **2,000** | **+2,000** |
| **19-SC-14, Second Target Station (STS), ORNL** | | | | | | |
| TEC | 1,223,700 | — | 1,000 | 20,000 | 1,000 | -19,000 |
| OPC | 45,300 | 10,805 | 5,000 | 17,000 | 1,000 | -16,000 |
| **TPC** | **1,269,000** | **10,805** | **6,000** | **37,000** | **2,000** | **-35,000** |
| **18-SC-10, Advanced Photon Source Upgrade (APS-U), ANL** | | | | | | |
| TEC | 796,500 | 235,500 | 130,000 | 170,000 | 150,000 | -20,000 |
| OPC | 18,500 | 8,500 | — | — | — | — |
| **TPC** | **815,000** | **244,000**[a] | **130,000** | **170,000** | **150,000** | **-20,000** |
| **18-SC-11, Proton Power Upgrade (PPU), ORNL** | | | | | | |
| TEC | 236,202 | 36,000 | 60,000 | 60,000 | 5,000 | -55,000 |
| OPC | 13,798 | 10,798 | — | — | 3,000 | +3,000 |
| **TPC** | **250,000** | **46,798** | **60,000** | **60,000** | **8,000** | **-52,000** |
| **18-SC-12, Advanced Light Source Upgrade (ALS-U), LBNL** | | | | | | |
| TEC | 380,200 | 16,000 | 60,000 | 60,000 | 13,000 | -47,000 |
| OPC | 30,000 | 24,000 | 2,000 | 2,000 | — | -2,000 |
| **TPC** | **410,200** | **40,000** | **62,000** | **62,000** | **13,000** | **-49,000** |

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

| | (dollars in thousands) | | | | | |
|---|---|---|---|---|---|---|
| | **Total** | **Prior Years** | **FY 2019 Enacted** | **FY 2020 Enacted** | **FY 2021 Request** | **FY 2021 Request vs FY 2020 Enacted** |
| **18-SC-13, Linac Coherent Light Source-II-HE (LCLS-II-HE), SLAC** | | | | | | |
| TEC | 408,000 | 8,000 | 28,000 | 50,000 | 14,000 | -36,000 |
| OPC | 20,000 | 2,000 | 6,000 | 4,000 | 2,000 | -2,000 |
| **TPC** | **428,000** | **10,000** | **34,000** | **54,000** | **16,000** | **-38,000** |
| **13-SC-10, Linac Coherent Light Source-II (LCLS-II), SLAC** | | | | | | |
| TEC | 993,100 | 863,800 | 129,300 | — | — | — |
| OPC | 51,900 | 45,800 | 6,100 | — | — | — |
| **TPC** | **1,045,000** | **909,600**[a] | **135,400** | **—** | **—** | **—** |
| **Total, Construction** | | | | | | |
| **TEC** | **4,107,702** | **1,159,300** | **408,300** | **360,000** | **184,000** | **-176,000** |
| **OPC** | **189,498** | **101,903** | **19,100** | **23,000** | **7,000** | **-16,000** |
| **TPC** | **4,297,200** | **1,261,203** | **427,400** | **383,000** | **191,000** | **-192,000** |

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

**Basic Energy Sciences**
**Funding Summary**

(dollars in thousands)

| | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|
| Research | 815,600 | 871,321 | 856,817 | -14,504 |
| Facility Operations | 922,000 | 947,179 | 884,856 | -62,323 |
| Projects | | | | |
| Major Items of Equipment | — | 10,500 | 2,000 | -8,500 |
| Construction | 427,400 | 383,000 | 191,000 | -192,000 |
| Total, Projects | 427,400 | 393,500 | 193,000 | -200,500 |
| Other[a] | 1,000 | 1,000 | 1,000 | — |
| **Total, Basic Energy Sciences** | **2,166,000** | **2,213,000** | **1,935,673** | **-277,327** |

[a] Includes non-Facility related GPP.

## Basic Energy Sciences
## Scientific User Facility Operations

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

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

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

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

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

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

(dollars in thousands)

| | FY 2019 Enacted | FY 2019 Current | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|---|
| **TYPE A FACILITIES** | | | | | |
| **Advanced Light Source** | **$66,283** | **$66,583** | **$68,093** | **$63,842** | **-$4,251** |
| Number of users | 2,000 | 2,171 | 1,800 | 1,500 | -300 |
| Achieved operating hours | N/A | 4,468 | N/A | N/A | N/A |
| Planned operating hours | 4,700 | 4,700 | 3,880 | 3,750 | -130 |
| Optimal hours | 4,700 | 4,700 | 3,880[a] | 4,100 | +220 |
| Percent optimal hours | 100% | 95.1% | 100% | 91.5% | N/A |
| Unscheduled downtime hours | <10% | <10% | <10% | <10% | N/A |

[a] Optimal hours decreased for maintenance and the PG&E Public Safety Power Shutoffs.

(dollars in thousands)

| | FY 2019 Enacted | FY 2019 Current | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|---|
| **Advanced Photon Source** | **$136,743** | **$138,743** | **$140,477** | **$131,708** | **-$8,769** |
| Number of users | 5,700 | 5,426 | 4,900 | 4,700 | -200 |
| Achieved operating hours | N/A | 4,909 | N/A | N/A | N/A |
| Planned operating hours | 5,000 | 5,000 | 5,000 | 4,550 | -450 |
| Optimal hours | 5,000 | 5,000 | 5,000 | 5,000 | — |
| Percent optimal hours | 100% | 98.2% | 100% | 91.0% | N/A |
| Unscheduled downtime hours | <10% | <10% | <10% | <10% | N/A |
| | | | | | |
| **National Synchrotron Light Source-II, BNL** | **$114,127** | **$114,277** | **117,244** | **$109,925** | **-$7,319** |
| Number of users | 1,600 | 1,755 | 1,700 | 1,500 | -200 |
| Achieved operating hours | N/A | 4,863 | N/A | N/A | N/A |
| Planned operating hours | 5,000 | 5,000 | 5,000 | 4,550 | -450 |
| Optimal hours | 5,000 | 5,000 | 5,000 | 5,000 | — |
| Percent optimal hours | 100% | 97.3% | 100% | 91.0% | N/A |
| Unscheduled downtime hours | <10% | <10% | <10% | <10% | N/A |
| | | | | | |
| **Stanford Synchrotron Radiation Lightsource** | **$42,847** | **$43,497** | **$44,017** | **$41,268** | **-$2,749** |
| Number of users | 1,650 | 1,761 | 1,500 | 1,400 | -100 |
| Achieved operating hours | N/A | 5,004 | N/A | N/A | N/A |
| Planned operating hours | 5,070 | 5,070 | 5,090 | 4,900 | -190 |
| Optimal hours | 5,070 | 5,070 | 5,090 | 5,400 | -310 |
| Percent optimal hours | 100% | 98.7% | 100% | 90.7% | N/A |
| Unscheduled downtime hours | <10% | <10% | <10% | <10% | N/A |
| | | | | | |
| **Linac Coherent Light Source** | **$145,000** | **$150,400** | **$148,960** | **$148,087** | **-$873** |
| Number of users | 300 | 529 | 500 | 800 | +300 |
| Achieved operating hours | N/A | 1,512 | N/A | N/A | N/A |
| Planned operating hours | 1,600 | 1,600 | 2,500 | 4,480 | +1,980 |
| Optimal hours | 1,600[a] | 1,600 | 2,500 | 4,600 | +2,100 |
| Percent optimal hours | 100% | 94.5% | 100% | 97.4% | N/A |
| Unscheduled downtime hours | <10% | <10% | <10% | <10% | N/A |

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

(dollars in thousands)

| | FY 2019 Enacted | FY 2019 Current | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|---|
| **Spallation Neutron Source** | **$205,714** | **$206,214** | **$187,048** | **$165,588** | **-$21,460** |
| Number of users | 800 | 758 | 800 | 730 | -70 |
| Achieved operating hours | N/A | 3,771 | N/A | N/A | N/A |
| Planned operating hours | 4,900 | 4,900 | 4,600 | 4,550 | -50 |
| Optimal hours | 4,900 | 4,900 | 4,600 | 5,000 | +400 |
| Percent optimal hours | 100% | 77.0% | 100% | 91.0% | N/A |
| Unscheduled downtime hours | <10% | <10% | <10% | <10% | N/A |
| | | | | | |
| **High Flux Isotope Reactor** | **$76,286** | **$76,286** | **$102,653** | **$94,500** | **-$8,153** |
| Number of users | 560 | — | 520 | 500 | -20 |
| Achieved operating hours | N/A | 3[a] | N/A | N/A | N/A |
| Planned operating hours | 4,000 | 4,000 | 3,900 | 3,650 | -250 |
| Optimal hours | 4,000 | 4,000 | 3,900 | 4,000 | +100 |
| Percent optimal hours | 100% | 0.1% | 100% | 91.3% | N/A |
| Unscheduled downtime hours | <10% | <10% | <10% | <10% | N/A |
| | | | | | |
| **<u>TYPE B</u> FACILITIES** | | | | | |
| **Center for Nanoscale Materials** | **$27,704** | **$27,704** | **$28,461** | **$26,665** | **-$1,796** |
| Number of users | 600 | 599 | 530 | 500 | -30 |
| | | | | | |
| **Center for Functional Nanomaterials** | **$24,148** | **$24,148** | **$24,807** | **$23,243** | **-$1,564** |
| Number of users | 580 | 593 | 510 | 500 | -10 |
| | | | | | |
| **Molecular Foundry** | **$31,237** | **$31,987** | **$32,090** | **$30,065** | **-$2,025** |
| Number of users | 700 | 1,011 | 800 | 700 | -100 |
| | | | | | |
| **Center for Nanophase Materials Sciences** | **$27,078** | **$27,078** | **$27,818** | **$26,063** | **-$1,755** |
| Number of users | 600 | 653 | 630 | 600 | -30 |
| | | | | | |
| **Center for Integrated Nanotechnologies** | **$24,833** | **$24,833** | **$25,511** | **$23,902** | **-$1,609** |
| Number of users | 600 | 860 | 700 | 600 | -100 |

[a] HFIR was shut down in Q1 FY 2019 due to a fuel element failure. A corrective action plan was implemented and HFIR restarted in November 2019.

(dollars in thousands)

| | FY 2019 Enacted | FY 2019 Current | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|---|
| **Total Facilities** | **$922,000** | **$931,750** | **$947,179** | **$884,856** | **-$62,323** |
| Number of users | 15,690 | 16,116 | 14,890 | 14,030 | -860 |
| Achieved operating hours | N/A | 24,530 | N/A | N/A | N/A |
| Planned operating hours | 30,270 | 30,270 | 29,970 | 30,430 | -460 |
| Optimal hours | 30,270 | 30,270 | 29,970 | 33,100 | +3,130 |
| Percent optimal hours[a] | 100% | 82.2% | 100% | 92.3% | N/A |
| Unscheduled downtime hours | <10% | <10% | <10% | <10% | N/A |

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

## Basic Energy Sciences
## Scientific Employment

| | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|
| Number of permanent Ph.D.'s (FTEs) | 4,800 | 4,950 | 4,680 | -270 |
| Number of postdoctoral associates (FTEs) | 1,310 | 1,370 | 1,310 | -60 |
| Number of graduate students (FTEs) | 2,050 | 2,140 | 2,060 | -80 |
| Other scientific employment (FTEs) [a] | 3,030 | 3,100 | 2,890 | -210 |

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

**21-SC-10, Cryomodule Repair and Maintenance Facility**
**Project is for Design and Construction**

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

### Summary

The FY 2021 Request for the Cryomodule Repair and Maintenance Facility (CRMF) project is $2,000,000, including $1,000,000 in Total Estimated Cost (TEC) funds and $1,000,000 in Other Project Costs (OPC) funds. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-0 (Approve Mission Need), approved on December 5, 2019. The notional Total Project Cost (TPC) range, approved at CD-0 is $70,000,000 - $98,000,000 based on a point estimate of $80,000,000.

### Significant Changes

This a new Construction Project Data Sheet (CPDS) and CRMF is a new start for FY 2021.

In FY 2020, SLAC National Accelerator Laboratory (SLAC) recognized a critical need for a facility capable of repairing and maintaining the cryomodules being installed through the Linac Coherent Light Source-II (LCLS-II) and LCLS-II High Energy (LCLS-II-HE) construction projects. SLAC developed and submitted a proposal for the CRMF to Basic Energy Sciences for consideration. The proposal was sent out to an independent group of experts in the field of superconducting radiofrequency science and superconducting linac construction for review and comment. The proposal was well received by the experts, and based on their support, BES developed a Mission Need Statement document as required to support CD-0, Approve Mission Need. The FY 2021 Request will support conducting an Analysis of Alternatives to determine the project site and the basic design parameters on which to base a conceptual design. Depending on progress and appropriate CD approvals, some of the FY 2021 Request funding may be used for engineering and design activities.

A Federal Project Director will be assigned to this project prior to CD-1.

### Critical Milestone History

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | D&D Complete | CD-4 |
|---|---|---|---|---|---|---|---|---|
| FY 2021[a] | 12/05/2019 | 1Q FY 2021 | 1Q FY 2021 | 1Q FY 2022 | 4Q FY 2022 | 1Q FY 2023 | N/A | 1Q FY 2027 |

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

| Fiscal Year | Performance Baseline Validation | CD-3A |
|---|---|---|
| FY 2021[a] | 4Q FY 2021 | 1Q FY 2022 |

**CD-3A** – Approve Long-Lead Procurements: As the project planning and design matures, long lead procurement may be requested in FY 2022 to mitigate cost and schedule risk to the project.

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

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC, Except D&D | OPC, D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|---|
| FY 2021[a] | 4,000 | 66,000 | 70,000 | 10,000 | N/A | 10,000 | 80,000 |

## 2. Project Scope and Justification

**Scope**

The preliminary scope of the CRMF project is to construct a building to contain the necessary equipment to maintain, repair, and test superconducting radiofrequency (SRF) accelerator components. The building will need a concrete shielded enclosure for cryomodule testing, a control room, vertical test stand area for testing SRF cavities and components, a cryogen distribution box which is connected to a source of liquid helium and will distribute liquid helium within the CRMF building, cryomodule fixtures used to insert and remove the cold mass from the cryomodule vacuum vessel, a cleanroom partitioned into class 10 and class 1000 areas, a loading and cryomodule preparation area, storage areas, and a 15 ton bridge crane for moving equipment from one area to another within the building.

Optional scope to be considered and included in the preliminary scope includes a stand-alone cryoplant that would provide a source of liquid helium (if one is not available at the selected site), a dedicated SRF injector test area which requires extending the envisioned building length by 30 feet, and a 40 mega-electronvolt (MeV) SRF linac to provide the equipment and diagnostics necessary for an integrated injector test stand.

**Justification**

SC, through the two current BES construction projects, LCLS-II and LCLS-II-HE, is making over a $1,400,000,000 capital investment in a SRF linac at SLAC to support the science mission of DOE. The LCLS-II project is providing a 4 GeV SRF-based linear accelerator capable of providing 1 megahertz (MHz) electron pulses to create a free electron, x-ray laser. This machine contains 35 SRF cryomodules to accelerate the electrons to 4 GeV. The LCLS-II-HE will increase the energy of the LCLS-II linac to 8 GeV by providing an additional 20 SRF cryomodules of a similar design to the LCLS-II ones, but operating at a higher accelerating gradient. SLAC has partnered with Fermi National Accelerator Laboratory (FNAL) and the Thomas Jefferson National Accelerator Facility (TJNAF) to provide the accelerating cryomodules. The cryomodules are produced at FNAL and TJNAF making use of specialized fabrication, assembly, and test capabilities available there. To make any repairs, the cryomodules must currently be sent back to either FNAL or TJNAF at an increased risk of damage, cost, and schedule delays.

The initial assumption was that cryomodules could be shipped back to the partner laboratories as needed for maintenance at a rate of 1 to 2 cryomodules per year. However, cryomodules could be damaged during transportation, posing a risk to facility operations. This approach also assumes that either FNAL or TJNAF would have the maintenance capabilities available when needed. Recently, TFNAF has agreed to manufacture cryomodules for an accelerator upgrade to the Spallation Neutron Source linac and the production facilities at FNAL will produce cryomodules for the Proton Improvement Plan-II (PIP-II) linac upgrade at FNAL. At this time, the two partner laboratories have informed SLAC that they will need 6 to 12 months of advance notice to schedule maintenance or repairs to the SLAC hardware.

The proposed CRMF will provide the capability to maintain, repair, and test SRF accelerator components, the primary one being the SRF cryomodules that make up the new superconducting accelerator being constructed by the LCLS-II and LCLS-II-HE construction projects. The facility will provide for the full disassembly and repair of the SRF cryomodule; the ability to disassemble, clean, and reassemble the SRF cavities and cavity string; testing capabilities for the full cryomodule; and separate testing capabilities for individual SRF cavities.

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

The photon energy range for LCLS-II-HE could be extended by lowering the emittance of the electron injector which requires an R&D effort. Progress in this area at SLAC has been hindered by lack of an appropriate research and development facility with testing capabilities. This needed R&D effort is currently being performed at LBNL and ANL in partnership with SLAC. The CRMF project could provide this needed support to SLAC when constructed.

Prior to CD-1, SC will conduct an Analysis of Alternatives that, among other things, will examine the cost benefits of having a dedicated CRMF facility at SLAC versus relying on partner laboratories or others to provide this capability. The risk in schedule and operations in terms of cost of having the facility sited somewhere other than SLAC will be included in this cost analysis. SC will also evaluate the proposed project scope as part of the Analysis of Alternatives required for CD-1 approval.

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

Key Performance Parameters (KPPs)

The Key Performance Parameters (KPPs) are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| Conventional Facilities Building Area | 22,000 gross square feet | 25,000 gross square feet |
| Electron Beam Energy | 50 MeV | 128 MeV |
| Cryogenic Cooling Capacity at 2K | 100 Watts | 250 Watts |

### 3. Financial Schedule

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| FY 2021 | 1,000 | 1,000 | 1,000 |
| Outyears | 3,000 | 3,000 | 3,000 |
| Total, Design | 4,000 | 4,000 | 4,000 |
| Construction | | | |
| Outyears | 66,000 | 66,000 | 66,000 |
| Total, Construction | 66,000 | 66,000 | 66,000 |
| Total Estimated Cost (TEC) | | | |
| FY 2021 | 1,000 | 1,000 | 1,000 |
| Outyears | 69,000 | 69,000 | 69,000 |
| **Total, TEC** | **70,000** | **70,000** | **70,000** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Other Project Cost (OPC)** | | | |
| FY 2021 | 1,000 | 1,000 | 1,000 |
| Outyears | 9,000 | 9,000 | 9,000 |
| **Total, OPC** | **10,000** | **10,000** | **10,000** |
| **Total Project Cost (TPC)** | | | |
| FY 2021 | 2,000 | 2,000 | 2,000 |
| Outyears | 78,000 | 78,000 | 78,000 |
| **Total, TPC[a]** | **80,000** | **80,000** | **80,000** |

**4. Details of Project Cost Estimate**

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| Design | 3,500 | N/A | N/A |
| Contingency | 500 | N/A | N/A |
| Total, Design | 4,000 | N/A | N/A |
| Construction | | | |
| Site Preparation | 1,000 | N/A | N/A |
| Equipment | 35,000 | N/A | N/A |
| Other Construction | 15,500 | N/A | N/A |
| Contingency | 14,500 | N/A | N/A |
| Total, Construction | 66,000 | N/A | N/A |
| **Total, TEC** | **70,000** | **N/A** | **N/A** |
| *Contingency, TEC* | *15,000* | *N/A* | *N/A* |

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

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Other Project Cost (OPC)** | | | |
| OPC except D&D | | | |
| R&D | 1,000 | N/A | N/A |
| Conceptual Planning | 1,000 | N/A | N/A |
| Conceptual Design | 2,000 | N/A | N/A |
| Start-Up | 3,000 | N/A | N/A |
| Contingency | 3,000 | N/A | N/A |
| **Total, OPC** | **10,000** | **N/A** | **N/A** |
| *Contingency, OPC* | *3,000* | *N/A* | *N/A* |
| **Total Project Cost** | **80,000** | **N/A** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***18,000*** | ***N/A*** | ***N/A*** |

**5. Schedule of Appropriations Requests**

(dollars in thousands)

| Request Year | Type | Prior Years | FY 2021 | Outyears | Total |
|---|---|---|---|---|---|
| FY 2021 | TEC | — | 1,000 | 69,000 | 70,000 |
| | OPC | — | 1,000 | 9,000 | 10,000 |
| | TPC | — | 2,000 | 78,000 | 80,000 |

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

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | FY 2027 |
| Expected Useful Life | 25 years |
| Expected Future Start of D&D of this capital asset | FY 2052 |

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | Previous Total Estimate | Current Total Estimate | Previous Total Estimate | Current Total Estimate |
| Operations and Maintenance | N/A | 5,500 | N/A | 286,000 |

Additional operations and maintenance costs are expected above the estimated costs to operate the LCLS-II facility. The estimate will be updated and additional details will be provided after CD-1, Approve Alternate Selection and Cost Range.

**7. D&D Information**

At this stage of project planning and development, SC anticipates that a new 19,000 to 23,000 gsf building may be constructed as part of this project.

## 8. Acquisition Approach

DOE has not determined the site of the CRMF project. If the selected site is a national laboratory, then the project would be acquired under the existing DOE Management and Operations contract for that laboratory.

The selected site will prepare a Conceptual Design Report for the CRMF project and demonstrate that they have the required project management systems in place to execute the project.

The selected organization may partner with other laboratories for design and procurement of key technical subsystem components. Technical system designs will require research and development activities. Preliminary cost estimates for these systems are based on similar facilities at other national laboratories, to the extent practicable. The project will fully exploit recent cost data from similar operating facilities in planning and budgeting. SLAC or partner laboratory staff may assist with completing the design of the technical systems. The selected contractor or subcontracted vendors with the necessary capabilities will fabricate technical equipment. All subcontracts will be competitively bid and awarded based on best value to the government.

Lessons learned from other SC projects and other similar facilities will be exploited fully in planning and executing CRMF.

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

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

### Summary

The FY 2021 Request for Second Target Station (STS) project is $2,000,000, including $1,000,000 in Total Estimated Cost (TEC) funds and $1,000,000 in Other Project Costs (OPC) funds. The most recent DOE O 413.3B approved Critical Decision (CD) is CD-0 (Approve Mission Need), approved on January 7, 2009. The current Total Project Cost (TPC) range is $800,000,000 - $1,500,000,000.

### Significant Changes

This Construction Project Data Sheet (CPDS) is an update of the FY 2020 CPDS and does not include a new start for FY 2021. There are no significant changes.

In FY 2019, the project advanced the planning, research and development (R&D), and conceptual design and conducted technical design reviews for the major systems (target, instruments, controls, accelerator, and conventional facilities). In FY 2020, the project continues planning, R&D, design, engineering, and other activities required to advance the STS project toward CD-1. The focus will be on project planning and initiation activities such as refining the initial cost estimates and refining the scope definitions, key performance parameters, and TPC range. In FY 2021, the project will continue the FY 2020 activities of planning, R&D, and engineering to assist in maturing the project design, scope, cost, schedule and key performance parameters.

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

### Critical Milestone History

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | D&D Complete | CD-4 |
|---|---|---|---|---|---|---|---|---|
| FY 2020 | 1/07/09 | 2Q FY 2022 | 2Q FY 2022 | 2Q FY 2023 | 2Q FY 2025 | 2Q FY 2024 | N/A | 4Q FY 2031 |
| FY 2021[a] | 1/07/09 | 2Q FY 2021 | 2Q FY 2021 | 3Q FY 2024 | 3Q FY 2026 | 3Q FY 2025 | N/A | 2Q FY 2032 |

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

### Project Cost History

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC, Except D&D | OPC, D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|---|
| FY 2020 | 65,500 | 1,138,500 | 1,204,000 | 45,300 | N/A | 45,300 | 1,249,300 |
| FY 2021[a] | 65,500 | 1,158,200 | 1,223,700 | 45,300 | N/A | 45,300 | 1,269,000 |

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

## 2. Project Scope and Justification

**Scope**

To address the gap in advanced neutron sources and instrumentation, the SNS project will design, build, install, and test the equipment necessary to provide the four primary elements of the new SNS facility: the neutron target and moderators; the accelerator systems; the instruments; and the conventional facilities. Costs for acceptance testing, integrated testing, and initial commissioning to demonstrate achievement of the KPPs are included in the STS scope. The STS will be located in unoccupied space east of the existing first target station (FTS). The project requires approximately 380,000 $ft^2$ of new buildings, making conventional facility construction a major contributor to project costs.

**Justification**

The BES mission is to “support fundamental research to understand, predict, and ultimately control matter and energy at the electronic, atomic, and molecular levels in order to provide the foundations for new energy technologies and to support DOE missions in energy, environment, and national security.” BES accomplishes its mission by operation of large-scale user facilities consisting of a complementary set of intense x-rays sources, neutron scattering centers, electron beam characterization capabilities, and research centers for nanoscale science.

In the area of neutron science, the scientific community conducted numerous studies since the 1970’s that have established the scientific justification and need for a very high-intensity pulsed neutron source in the U.S. Since 2007, when it began its user program at ORNL, the SNS has been fulfilling this need. In accordance with the 1996 BESAC (Russell Panel) Report recommendation, SNS has many technical margins built into its systems to facilitate a power upgrade into the 2-4 megawatt (MW) range to maintain its position of scientific leadership in the future.

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

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

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

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

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

Key Performance Parameters (KPPs)

The Key Performance Parameters (KPPs) are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| Beam power on target | 0.25 MW at 1.3 giga-electronvolts (GeV) | 0.7 MW at 1.3 GeV |
| Beam energy | 1.3 GeV | 1.3 GeV |
| Number of operating instruments at CD-4 | 6 | 8 |

### 3. Financial Schedule

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| FY 2019 | 1,000 | 1,000 | — |
| FY 2020 | 20,000 | 20,000 | 2,000 |
| FY 2021 | 1,000 | 1,000 | 17,500 |
| Outyears | 43,500 | 43,500 | 46,000 |
| Total, Design | 65,500 | 65,500 | 65,500 |
| Construction | | | |
| Outyears | 1,158,200 | 1,158,200 | 1,158,200 |
| Total, Construction | 1,158,200 | 1,158,200 | 1,158,200 |
| Total Estimated Cost (TEC) | | | |
| FY 2019 | 1,000 | 1,000 | — |
| FY 2020 | 20,000 | 20,000 | 2,000 |
| FY 2021 | 1,000 | 1,000 | 17,500 |
| Outyears | 1,201,700 | 1,201,700 | 1,204,200 |
| **Total, TEC** | **1,223,700** | **1,223,700** | **1,223,700** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Other Project Cost (OPC)** | | | |
| FY 2016 | 5,941 | 5,941 | 3,069 |
| FY 2017 | 62 | 62 | 2,818 |
| FY 2018 | 4,802 | 4,802 | 250 |
| FY 2019 | 5,000 | 5,000 | 6,262 |
| FY 2020 | 17,000 | 17,000 | 17,400 |
| FY 2021 | 1,000 | 1,000 | 2,950 |
| Outyears | 11,495 | 11,495 | 12,551 |
| **Total, OPC** | **45,300** | **45,300** | **45,300** |
| **Total Project Cost (TPC)** | | | |
| FY 2016 | 5,941 | 5,941 | 3,069 |
| FY 2017 | 62 | 62 | 2,818 |
| FY 2018 | 4,802 | 4,802 | 250 |
| FY 2019 | 6,000 | 6,000 | 6,262 |
| FY 2020 | 37,000 | 37,000 | 19,400 |
| FY 2021 | 2,000 | 2,000 | 20,450 |
| Outyears | 1,213,195 | 1,213,195 | 1,216,751 |
| **Total, TPC**[a] | **1,269,000** | **1,269,000** | **1,269,000** |

**4. Details of Project Cost Estimate**

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| Design | 48,500 | 48,500 | N/A |
| Contingency | 17,000 | 17,000 | N/A |
| Total, Design | 65,500 | 65,500 | N/A |
| Construction | | | |
| Construction | 864,700 | 845,000 | N/A |
| Contingency | 293,500 | 293,500 | N/A |
| Total, Construction | 1,158,200 | 1,138,500 | N/A |
| **Total, TEC** | **1,223,700** | **1,204,000** | **N/A** |
| *Contingency, TEC* | *310,500* | *310,500* | *N/A* |

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

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Other Project Cost (OPC)** | | | |
| OPC except D&D | | | |
| R&D | 4,502 | 1,500 | N/A |
| Conceptual Design | 20,852 | 18,375 | N/A |
| Start-Up | 8,621 | 14,100 | N/A |
| Contingency | 11,325 | 11,325 | N/A |
| **Total, OPC** | **45,300** | **45,300** | **N/A** |
| *Contingency, OPC* | *11,325* | *11,325* | *N/A* |
| **Total Project Cost[a]** | **1,269,000** | **1,249,300** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***321,825*** | ***321,825*** | ***N/A*** |

**5. Schedule of Appropriations Requests**

(dollars in thousands)

| Request Year | Type | Prior Years | FY 2019[b] | FY 2020 | FY 2021 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| FY 2020 | TEC | — | 1,000 | 1,000 | 1,000 | 1,201,000 | 1,204,000 |
| | OPC | 6,500 | 5,000 | — | 1,000 | 32,800 | 45,300 |
| | TPC | 6,500 | 6,000 | 1,000 | 2,000 | 1,233,800 | 1,249,300 |
| FY 2021 | TEC | — | 1,000 | 20,000 | 1,000 | 1,201,700 | 1,223,700 |
| | OPC | 10,805 | 5,000 | 17,000 | 1,000 | 11,495 | 45,300 |
| | TPC | 10,805 | 6,000 | 37,000 | 2,000 | 1,213,195 | 1,269,000 |

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

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 2Q FY 2032 |
| Expected Useful Life | 25 years |
| Expected Future Start of D&D of this capital asset | 2Q FY 2057 |

Related Funding Requirements
(dollars in thousands)

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

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

[a] The project is pre-CD-2; the estimated cost and schedule shown are preliminary. Construction will not be executed without appropriate CD approvals.
[b] While no funding was requested, Congress appropriated $6,000,000 for STS in FY 2019.

### 7. D&D Information

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

| | Square Feet |
|---|---|
| New area being constructed by this project at ORNL | ~380,000 |
| Area of D&D in this project at ORNL | — |
| Area at ORNL to be transferred, sold, and/or D&D outside the project, including area previously "banked" | ~380,000 |
| Area of D&D in this project at other sites | — |
| Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked" | — |
| Total area eliminated | — |

### 8. Acquisition Approach

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

The M&O contractor prepared a Technical Design Report for the STS project and identified key design activities, requirements, and high-risk subsystem components to reduce cost and schedule risk to the project and expedite the startup. The necessary project management systems are fully up-to-date, operating, and are maintained as an ORNL-wide resource.

ORNL will partner with other laboratories for design and procurement of key technical subsystem components. Some technical system designs will require research and development activities. Preliminary cost estimates for these systems are based on operating experience of SNS and vendor quotes. ORNL, partner laboratory staff, and/or vendors will complete design of the technical systems. Vendors and/or partner labs with the necessary capabilities will fabricate the technical equipment. ORNL will competitively bid and award all subcontracts based on best value to the government. The M&O contractor's performance will be evaluated through the annual laboratory performance appraisal process.

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

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

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

### Summary

The FY 2021 Request for the Advanced Photon Source-Upgrade (APS-U) project is $150,000,000. The most recent DOE Order 413.3B approved Critical Decision, CD-3 (Approve Start of Construction), was approved on July 25, 2019, with a Total Project Cost (TPC) of $815,000,000 and CD-4, Approve Project Completion, in 2Q FY 2026.

### Significant Changes

This Construction Project Data Sheet (CPDS) is an update of the FY 2020 CPDS and does not include a new start for FY 2021. There are no significant changes.

In FY 2019, APS-U completed the majority of equipment prototyping and development work and awarded most of the contracts for accelerator magnets, support structures, power supplies, vacuum chambers, experimental systems, front ends, and insertion devices needed to maintain the project schedule. Deliveries of the production first articles are arriving for receiving inspection and are successfully passing acceptance testing. FY 2020 funding enables the advancement of the storage ring and experimental facilities final design, engineering, prototyping, testing, fabrication, procurement, integration and installation, and site preparation for the long beamlines. The project will complete the final design of the long beamline building, lease off-site space for storage, assembly and receiving, and start practicing integrated module assembly. The FY 2021 Request will support ongoing FY 2020 activities to advance the final designs, engineering, prototyping, testing, fabrication, procurement, integration, and installation for the storage ring and experimental facilities. Further site preparation and civil construction associated with the long beamlines will occur. System integration, test, and assembly in preparation for the storage ring removal and installation during the experimental dark time will be a high priority.

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

### Critical Milestone History

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | D&D Complete | CD-4 |
|---|---|---|---|---|---|---|---|---|
| FY 2018 | 4/22/10 | 9/18/15 | 2/04/16 | 1Q FY 2019 | 2Q FY 2020 | 4Q FY 2019 | N/A | 1Q FY 2026 |
| FY 2019 | 4/22/10 | 9/18/15 | 2/04/16 | 2Q FY 2019 | 4Q FY 2021 | 1Q FY 2020 | N/A | 2Q FY 2026 |
| FY 2020 | 4/22/10 | 9/18/15 | 2/04/16 | 12/09/18 | 1Q FY 2022 | 1Q FY 2020 | N/A | 2Q FY 2026 |
| FY 2021 | 4/22/10 | 9/18/15 | 2/04/16 | 12/09/18 | 1Q FY 2022 | 7/25/19 | N/A | 2Q FY 2026 |

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

| Fiscal Year | Performance Baseline Validation | CD-3A | CD-3B |
|---|---|---|---|
| FY 2018 | 1Q FY 2019 | 8/30/12 | 10/06/16 |
| FY 2019 | 2Q FY 2019 | 8/30/12 | 10/06/16 |
| FY 2020 | 12/09/18 | 8/30/12 | 10/06/16 |
| FY 2021 | 12/09/18 | 8/30/12 | 10/06/16 |

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

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC, Except D&D | OPC, D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|---|
| FY 2018 | 157,015 | 561,985 | 719,000 | 51,000 | N/A | 51,000 | 770,000 |
| FY 2019 | 167,000 | 590,100 | 757,100 | 12,900 | N/A | 12,900 | 770,000 |
| FY 2020 | 162,825 | 633,675 | 796,500 | 18,500 | N/A | 18,500 | 815,000 |
| FY 2021 | 190,425 | 606,075 | 796,500 | 18,500 | N/A | 18,500 | 815,000 |

## 2. Project Scope and Justification

**Scope**

The APS-U project will upgrade the existing APS to provide scientists with an x-ray light source possessing world-leading transverse coherence and extreme brightness. The APS-U project's scope includes constructing a new storage ring, incorporating an multi-bend achromat (MBA) lattice utilizing the existing tunnel, new insertion devices optimized for brightness and flux, superconducting undulators for selected beamlines, new or upgraded front-ends, and any required modifications to the linac, booster, and radiofrequency systems. The project will also construct new beamlines and incorporate substantial refurbishment of existing beamlines, along with new optics and detectors that will enable the beamlines to take advantage of the improved accelerator performance. Two best-in-class beamlines require conventional civil construction to extend the beamlines beyond the existing APS Experimental Hall to achieve the desired nano-focused beam spot size.

**Justification**

The BES mission is to "support fundamental research to understand, predict, and ultimately control matter and energy at the electronic, atomic, and molecular levels in order to provide the foundations for new energy technologies and to support DOE missions in energy, environment, and national security." APS-U will provide the nation's researchers with a world-class scientific user facility for mission-focused research and advanced scientific discovery."

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

The APS-U will upgrade the APS, by replacing the existing 20-year-old storage ring with an MBA-based machine, and will provide a beam with a natural emittance that is orders of magnitude lower than what is currently available with third-generation light sources. The MBA lattice will provide 100 to 1000 times increased brightness and coherent flux. With this investment and the current APS infrastructure, the APS-U will position the APS as the leading storage ring-based hard x-ray source in the U.S. for decades to come.

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

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

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

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

Key Performance Parameters (KPPs)
The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs is a prerequisite for approval of CD-4, Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| Storage Ring Energy | > 5.7 GeV, with systems installed for 6 GeV operation | 6 GeV |
| Beam Current | ≥ 25 milliamps (mA)in top-up injection mode with systems installed for 200 mA operation | 200 mA in top-up injection mode |
| Horizontal Emittance | < 130 pm-rad at 25 mA | ≤ 42 pm-rad at 200 mA |
| Brightness @ 20 keV[1] | $> 1 \times 10^{20}$ | $1 \times 10^{22}$ |
| Brightness @ 60 keV[1] | $> 1 \times 10^{19}$ | $1 \times 10^{21}$ |
| New APS-U Beamlines Transitioned to Operations | 7 | ≥ 9 |

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

**3. Financial Schedule**

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| MIE funding | | | |
| FY 2012 | 19,200 | 19,200 | 9,095 |
| FY 2013 | 15,000 | 15,000 | 17,825 |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| FY 2014 | 17,015 | 17,015 | 12,889 |
| FY 2015 | 20,000 | 20,000 | 19,782 |
| FY 2016 | 20,000 | 20,000 | 22,529 |
| FY 2017 | 34,785 | 34,785 | 23,873 |
| FY 2018 | — | — | 15,991 |
| FY 2019 | — | — | 4,016 |
| Total, MIE funding | 126,000 | 126,000 | 126,000 |
| Line item funding | | | |
| FY 2018 | 26,000 | 26,000 | 7,838 |
| FY 2019 | 14,650 | 14,650 | 22,340 |
| FY 2020 | 21,000 | 21,000 | 29,420 |
| FY 2021 | 2,775 | 2,775 | 4,827 |
| Total, Line item funding | 64,425 | 64,425 | 64,425 |
| Total, Design | 190,425 | 190,425 | 190,425 |
| Construction | | | |
| MIE funding | | | |
| FY 2012 | 800 | 800 | — |
| FY 2013 | 5,000 | 5,000 | 3,391 |
| FY 2014 | 2,985 | 2,985 | 4,534 |
| FY 2015 | — | — | 573 |
| FY 2016 | — | — | — |
| FY 2017 | 7,715 | 7,715 | 389 |
| FY 2018 | — | — | 4,222 |
| FY 2019 | — | — | 3,391 |
| Total, MIE funding | 16,500 | 16,500 | 16,500 |
| Line item funding | | | |
| FY 2018 | 67,000 | 67,000 | 2,085 |
| FY 2019 | 115,350 | 115,350 | 18,638 |
| FY 2020 | 149,000 | 149,000 | 153,950 |
| FY 2021 | 147,225 | 147,225 | 217,075 |
| Outyears | 111,000 | 111,000 | 197,827 |
| Total, Line item funding | 589,575 | 589,575 | 589,575 |
| Total, Construction | 606,075 | 606,075 | 606,075 |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| Total Estimated Cost (TEC) | | | |
| MIE funding | | | |
| FY 2012 | 20,000 | 20,000 | 9,095 |
| FY 2013 | 20,000 | 20,000 | 21,216 |
| FY 2014 | 20,000 | 20,000 | 17,423 |
| FY 2015 | 20,000 | 20,000 | 20,355 |
| FY 2016 | 20,000 | 20,000 | 22,529 |
| FY 2017 | 42,500 | 42,500 | 24,262 |
| FY 2018 | — | — | 20,213 |
| FY 2019 | — | — | 7,407 |
| Total, MIE funding | 142,500 | 142,500 | 142,500 |
| Line item funding | | | |
| FY 2018 | 93,000 | 93,000 | 9,923 |
| FY 2019 | 130,000 | 130,000 | 40,978 |
| FY 2020 | 170,000 | 170,000 | 183,370 |
| FY 2021 | 150,000 | 150,000 | 221,902 |
| Outyears | 111,000 | 111,000 | 197,827 |
| Total, Line item funding | 654,000 | 654,000 | 654,000 |
| **Total, TEC** | **796,500** | **796,500** | **796,500** |
| **Other Project Cost (OPC)** | | | |
| OPC except D&D | | | |
| MIE funding | | | |
| FY 2010 | 1,000 | 1,000 | 587 |
| FY 2011 | 7,500 | 7,500 | 3,696 |
| FY 2012 | — | — | 4,217 |
| Total, MIE funding | 8,500 | 8,500 | 8,500 |
| Line item funding | | | |
| Outyears | 10,000 | 10,000 | 10,000 |
| Total, Line item funding | 10,000 | 10,000 | 10,000 |
| **Total, OPC** | **18,500** | **18,500** | **18,500** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Project Cost (TPC)** | | | |
| MIE funding | | | |
| FY 2010 | 1,000 | 1,000 | 587 |
| FY 2011 | 7,500 | 7,500 | 3,696 |
| FY 2012 | 20,000 | 20,000 | 13,312 |
| FY 2013 | 20,000 | 20,000 | 21,216 |
| FY 2014 | 20,000 | 20,000 | 17,423 |
| FY 2015 | 20,000 | 20,000 | 20,355 |
| FY 2016 | 20,000 | 20,000 | 22,529 |
| FY 2017 | 42,500 | 42,500 | 24,262 |
| FY 2018 | — | — | 20,213 |
| FY 2019 | — | — | 7,407 |
| Total, MIE funding | 151,000 | 151,000 | 151,000 |
| Line item funding | | | |
| FY 2018 | 93,000 | 93,000 | 9,923 |
| FY 2019 | 130,000 | 130,000 | 40,978 |
| FY 2020 | 170,000 | 170,000 | 183,370 |
| FY 2021 | 150,000 | 150,000 | 221,902 |
| Outyears | 121,000 | 121,000 | 207,827 |
| Total, Line item funding | 664,000 | 664,000 | 664,000 |
| **Total, TPC** | **815,000** | **815,000** | **815,000** |

**4. Details of Project Cost Estimate**

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| Design | 182,825 | 146,825 | 166,962 |
| Contingency | 7,600 | 16,000 | 9,696 |
| Total, Design | 190,425 | 162,825 | 176,658 |

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| Construction | | | |
| Equipment | 461,675 | 483,575 | 465,180 |
| Other Construction | 17,000 | 15,000 | 17,000 |
| Contingency | 127,400 | 135,100 | 137,662 |
| Total, Construction | 606,075 | 633,675 | 619,842 |
| **Total, TEC** | **796,500** | **796,500** | **796,500** |
| *Contingency, TEC* | *135,000* | *151,100* | *147,358* |
| **Other Project Cost (OPC)** | | | |
| OPC except D&D | | | |
| Conceptual Planning | 1,000 | 1,000 | 1,000 |
| Conceptual Design | 7,500 | 7,500 | 7,500 |
| Start-Up | 7,100 | 7,800 | 7,100 |
| Contingency | 2,900 | 2,200 | 2,900 |
| **Total, OPC** | **18,500** | **18,500** | **18,500** |
| *Contingency, OPC* | *2,900* | *2,200* | *2,900* |
| **Total Project Cost** | **815,000** | **815,000** | **815,000** |
| ***Total, Contingency (TEC+OPC)*** | ***137,900*** | ***153,300*** | ***150,258*** |

**5. Schedule of Appropriations Requests**

(dollars in thousands)

| Request Year | Type | Prior Years | FY 2019 | FY 2020 | FY 2021 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| FY 2018 | TEC | 162,500 | 81,772 | 152,419 | 160,000 | 162,309 | 719,000 |
| | OPC | 8,500 | — | — | 5,000 | 37,500 | 51,000 |
| | TPC | 171,000 | 81,772 | 152,419 | 165,000 | 199,809 | 770,000 |
| FY 2019 | TEC | 162,500 | 60,000 | 150,000 | 159,780 | 224,820 | 757,100 |
| | OPC | 8,500 | — | — | — | 4,400 | 12,900 |
| | TPC | 171,000 | 60,000 | 150,000 | 159,780 | 229,220 | 770,000 |
| FY 2020 | TEC | 235,500 | 130,000 | 150,000 | 160,000 | 121,000 | 796,500 |
| | OPC | 8,500 | — | — | 5,000 | 5,000 | 18,500 |
| | TPC | 244,000 | 130,000 | 150,000 | 165,000 | 126,000 | 815,000 |
| FY 2021 | TEC | 235,500 | 130,000 | 170,000 | 150,000 | 111,000 | 796,500 |
| | OPC | 8,500 | — | — | — | 10,000 | 18,500 |
| | TPC | 244,000 | 130,000 | 170,000 | 150,000 | 121,000 | 815,000 |

## 6. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 2Q FY 2026 |
| Expected Useful Life | 25 years |
| Expected Future Start of D&D of this capital asset | 2Q FY 2051 |

Related Funding Requirements
(dollars in thousands)

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

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

## 7. D&D Information

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

| | Square Feet |
|---|---|
| New area being constructed by this project at ANL | 26,000-28,000 |
| Area of D&D in this project at ANL | — |
| Area at ANL to be transferred, sold, and/or D&D outside the project, including area previously "banked" | 26,000-28,000 |
| Area of D&D in this project at other sites | — |
| Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked" | — |
| Total area eliminated | — |

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

## 8. Acquisition Approach

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

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

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

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

### Summary

The FY 2021 Request for the Proton Power Upgrade (PPU) project is $8,000,000, including $5,000,000 in Total Estimated Cost (TEC) funds and $3,000,000 in Other Project Costs (OPC) funds. The most recent DOE O 413.3B approved Critical Decision (CD) is CD-3B (Approve Long Lead Procurements), approved on September 3, 2019. The preliminary Total Project Cost (TPC) range, based on early concepts under consideration, is $184,000,000 - $320,000,000.

### Significant Changes

This Construction Project Data Sheet (CPDS) is an update of the FY 2020 CPDS and does not include a new start for FY 2021. There are no significant changes.

In FY 2019, the project continued R&D, design, engineering, prototyping, preliminary and final design, long-lead procurement, and activities aimed at further advancing the target performance in coordination with Spallation Neutron Source (SNS) operations target management. Additional long lead procurement authority (CD-3B), approved in late FY 2019 and executed in FY 2020, will advance the klystron gallery buildout, radiofrequency (RF) procurements, and cryomodule hardware procurements and assembly. In FY 2020, the project will continue R&D, engineering, prototyping, preliminary and final design, testing, fabrication, procurement, and component integration and installation. Target R&D, engineering, design, and prototyping to improve performance and reliability will also continue. In FY 2021, the project will prioritize these continuing activities of R&D, engineering, prototyping, preliminary and final design, testing, fabrication, procurement, component integration and installation, and civil construction site preparation. Advancing the target R&D, engineering, design, and prototyping in conjunction with SNS operations target improvement plans will be a high priority.

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

### Critical Milestone History

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | D&D Complete | CD-4 |
|---|---|---|---|---|---|---|---|---|
| FY 2020 | 1/07/09 | 8/01/17 | 4/04/18 | 2Q FY 2021 | 4Q FY 2022 | 3Q FY 2022 | N/A | 3Q FY 2027 |
| FY 2021[a] | 1/07/09 | 8/01/17 | 4/04/18 | 2Q FY 2021 | 4Q FY 2022 | 2Q FY 2021 | N/A | 3Q FY 2027 |

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

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

| Fiscal Year | Performance Baseline Validation | CD-3A | CD-3B |
|---|---|---|---|
| FY 2020 | 2Q FY 2021 | 10/05/18 | 2Q FY 2020 |
| FY 2021[a] | 2Q FY 2021 | 10/05/18 | 9/03/19 |

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

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC, Except D&D | OPC, D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|---|
| FY 2020 | 27,300 | 210,000 | 237,300 | 12,700 | N/A | 12,700 | 250,000 |
| FY 2021[a] | 46,700 | 189,502 | 236,202 | 13,798 | N/A | 13,798 | 250,000 |

## 2. Project Scope and Justification

**Scope**

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

**Justification**

The BES mission is to "support fundamental research to understand, predict, and ultimately control matter and energy at the electronic, atomic, and molecular levels in order to provide the foundations for new energy technologies and to support DOE missions in energy, environment, and national security." BES accomplishes its mission by operating large-scale user facilities consisting of a complementary set of intense x-rays sources, neutron scattering centers, electron beam characterization capabilities, and research centers for nanoscale science.

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

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

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

the critical roles of heterogeneity and interfaces. The uniform conclusion from all workshops was that in the areas of science covered, neutrons play a unique and pivotal role in understanding structure and dynamics in materials required to develop future technologies.

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

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

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

Key Performance Parameters (KPPs)
The Key Performance Parameters (KPPs) are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| Beam power on target | 1.7 MW at 1.25 giga-electronvolts (GeV) | 2.0 MW at 1.3 GeV |
| Beam energy | 1.25 GeV | 1.3 GeV |
| Target operational time without failure | 1,250 hours at 1.7 MW | 1,250 hours at 2.0 MW |
| Stored beam intensity in ring | ≥ $1.6x10^{14}$ protons at 1.25 GeV | ≥ 2.24x1014 protons at 1.3 GeV |
| Number of PPU installed cryomodules | 6 | 7 |

### 3. Financial Schedule

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| FY 2018 | 5,000 | 5,000 | 2,655 |
| FY 2019 | 16,000 | 16,000 | 12,647 |
| FY 2020 | 20,700 | 20,700 | 17,640 |
| FY 2021 | 5,000 | 5,000 | 8,060 |
| Outyears | — | — | 5,698 |
| Total, Design | 46,700 | 46,700 | 46,700 |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| Construction | | | |
| FY 2018 | 31,000 | 31,000 | 1,794 |
| FY 2019 | 44,000 | 44,000 | 8,480 |
| FY 2020 | 39,300 | 39,300 | 86,000 |
| FY 2021 | — | — | 18,026 |
| Outyears | 75,202 | 75,202 | 75,202 |
| Total, Construction | 189,502 | 189,502 | 189,502 |
| Total Estimated Cost (TEC) | | | |
| FY 2018 | 36,000 | 36,000 | 4,449 |
| FY 2019 | 60,000 | 60,000 | 21,127 |
| FY 2020 | 60,000 | 60,000 | 103,640 |
| FY 2021 | 5,000 | 5,000 | 26,086 |
| Outyears | 75,202 | 75,202 | 80,900 |
| **Total, TEC** | **236,202** | **236,202** | **236,202** |
| **Other Project Cost (OPC)** | | | |
| FY 2016 | 4,059 | 4,059 | 1,267 |
| FY 2017 | 6,739 | 6,739 | 3,773 |
| FY 2018 | — | — | 3,004 |
| FY 2019 | — | — | 1,567 |
| FY 2020 | — | — | 1,187 |
| FY 2021 | 3,000 | 3,000 | 1,830 |
| Outyears | — | — | 1,170 |
| **Total, OPC** | **13,798** | **13,798** | **13,798** |
| **Total Project Cost (TPC)** | | | |
| FY 2016 | 4,059 | 4,059 | 1,267 |
| FY 2017 | 6,739 | 6,739 | 3,773 |
| FY 2018 | 36,000 | 36,000 | 7,453 |
| FY 2019 | 60,000 | 60,000 | 22,694 |
| FY 2020 | 60,000 | 60,000 | 104,827 |
| FY 2021 | 8,000 | 8,000 | 27,916 |
| Outyears | 75,202 | 75,202 | 82,070 |
| **Total, TPC** | **250,000** | **250,000** | **250,000** |

## 4. Details of Project Cost Estimate

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| Design | 38,800 | 20,800 | N/A |
| Contingency | 7,900 | 6,500 | N/A |
| Total, Design | 46,700 | 27,300 | N/A |
| Construction | | | |
| Construction | 137,702 | 156,000 | N/A |
| Contingency | 51,800 | 54,000 | N/A |
| Total, Construction | 189,502 | 210,000 | N/A |
| **Total, TEC** | **236,202** | **237,300** | **N/A** |
| *Contingency, TEC* | *59,700* | *60,500* | N/A |
| **Other Project Cost (OPC)** | | | |
| OPC except D&D | | | |
| R&D | 2,800 | 2,500 | N/A |
| Conceptual Design | 6,498 | 5,225 | N/A |
| Other OPC Costs | 1,300 | 1,800 | N/A |
| Contingency | 3,200 | 3,175 | N/A |
| **Total, OPC** | **13,798** | **12,700** | **N/A** |
| *Contingency, OPC* | *3,200* | *3,175* | *N/A* |
| **Total Project Cost** | **250,000** | **250,000** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***62,900*** | ***63,675*** | ***N/A*** |

## 5. Schedule of Appropriations Requests

(dollars in thousands)

| Request Year | Type | Prior Years | FY 2019[a] | FY 2020 | FY 2021 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| FY 2020 | TEC | 36,000 | 60,000 | 5,000 | 30,000 | 106,300 | 237,300 |
| | OPC | 10,300 | — | — | — | 2,400 | 12,700 |
| | TPC | 46,300 | 60,000 | 5,000 | 30,000 | 108,700 | 250,000 |
| FY 2021 | TEC | 36,000 | 60,000 | 60,000 | 5,000 | 75,202 | 236,202 |
| | OPC | 10,798 | — | — | 3,000 | — | 13,798 |
| | TPC | 46,798 | 60,000 | 60,000 | 8,000 | 75,202 | 250,000 |

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

### 6. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 3Q FY 2027 |
| Expected Useful Life | 40 years |
| Expected Future Start of D&D of this capital asset | 3Q FY 2067 |

Related Funding Requirements
(dollars in thousands)

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

### 7. D&D Information

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

| | Square Feet |
|---|---|
| New area being constructed by this project at ORNL ........ | 3,000-4,000 |
| Area of D&D in this project at ORNL ........ | — |
| Area at ORNL to be transferred, sold, and/or D&D outside the project, including area previously “banked” ........ | 3,000-4,000 |
| Area of D&D in this project at other sites ........ | — |
| Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously “banked” ........ | — |
| Total area eliminated ........ | — |

### 8. Acquisition Approach

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

The M&O contractor has completed a Conceptual Design Report for the PPU project and identified key design activities, requirements, and high-risk subsystem components to reduce cost and schedule risk to the project and expedite the startup. The necessary project management systems are fully up-to-date, operating, and are maintained as an ORNL-wide resource.

ORNL will partner with other laboratories for design and procurement of key technical subsystem components. Some technical system designs will require research and development activities. Preliminary cost estimates for these systems are based on operating experience of SNS and vendor quotes. ORNL, partner laboratory staff, and/or vendors will complete the design of the technical systems. Vendors and/or partner labs with the necessary capabilities will fabricate technical equipment. All subcontracts will be competitively bid and awarded based on best value to the government.

Lessons learned from other Office of Science projects and other similar facilities will be exploited fully in planning and executing PPU. The M&O contractor’s performance will be evaluated through the annual laboratory performance appraisal process.

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

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


**Summary**

The FY 2021 Request for the Advanced Light Source Upgrade (ALS-U) project is $13,000,000. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-3A (Approve Long Lead Procurements), approved December 19, 2019. The preliminary Total Project Cost (TPC) range, based on the reviewed conceptual design, is $330,000,000 - $495,000,000.


**Significant Changes**

This Construction Project Data Sheet (CPDS) is an update of the FY 2020 CPDS and does not include a new start for FY 2021.

The project TPC estimate increased to $410,200,000 at the approval of CD-3A and the Project Completion Date (CD-4) remains at 2Q FY 2028. The TPC estimate increase resulted from a maturing design effort for the project which identified additional costs in the project office, accelerator systems, beamlines, and removal and installation elements. Cost increases resulted from the addition of scope to reduce risks, correction of labor estimates, and updating of equipment costs resulting from design improvements.

In FY 2019, the project continued planning, engineering, design, research and development (R&D), and prototyping activities. FY 2020 funding continues the support of planning, engineering, design, and R&D prototyping activities, and initiates long lead procurements. FY 2021 funding will continue support of engineering, design, R&D prototyping, and long lead procurements of construction items. Authorization of full construction activities is anticipated for late in FY 2021 or early FY 2022.

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

**Critical Milestone History**

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | D&D Complete | CD-4 |
|---|---|---|---|---|---|---|---|---|
| FY 2019 | 9/27/16 | 4Q FY 2019 | 4Q FY 2019 | 4Q FY 2020 | 4Q FY 2022 | 4Q FY 2021 | N/A | 4Q FY 2026 |
| FY 2020 | 9/27/16 | 4/30/18 | 9/21/18 | 2Q FY 2021 | 4Q FY 2021 | 1Q FY 2022 | N/A | 2Q FY 2028 |
| FY 2021[a] | 9/27/16 | 4/30/18 | 9/21/18 | 2Q FY 2021 | 4Q FY 2021 | 1Q FY 2022 | N/A | 2Q FY 2028 |

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

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

| Fiscal Year | Performance Baseline Validation | CD-3A |
|---|---|---|
| FY 2019 | 4Q FY 2020 | 4Q FY 2020 |
| FY 2020 | 2Q FY 2021 | 4Q FY 2019 |
| FY 2021[a] | 2Q FY 2021 | 12/19/19 |

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

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC, Except D&D | OPC, D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|---|
| FY 2019 | 39,000 | 243,000 | 282,000 | 38,000 | N/A | 38,000 | 320,000 |
| FY 2020 | 89,750 | 248,250 | 338,000 | 30,000 | N/A | 30,000 | 368,000 |
| FY 2021[a] | 89,750 | 290,450 | 380,200 | 30,000 | N/A | 30,000 | 410,200 |

## 2. Project Scope and Justification

**Scope**

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

**Justification**

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

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

Currently, BES operates advanced ring-based light sources that produce soft x-rays. The NSLS-II, commissioned in 2015, is the brightest soft x-ray source in the U.S. The ALS, completed in 1993, is competitive with NSLS-II for x-rays below 200 eV

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

but not above that. NSLS-II is somewhat lower in brightness than the new Swedish light source, MAX-IV, which is currently under commissioning and represents the first use of a MBA lattice design in a light source facility. Neither NSLS-II nor ALS make use of the newer MBA lattice design. Switzerland's SLS-2 (an MBA-based design in the planning stage) will be a brighter soft x-ray light source than both NSLS-II and MAX-IV when it is built and brought into operation. These international light sources, and those that follow, will present a significant challenge to U.S. light source community to provide competitive x-ray sources to domestic users. Neither NSLS-II nor ALS soft x-ray light sources possess sufficient brightness or coherent flux to provide the capability to meet the mission need in their current configurations.

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

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

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

The existing ALS is a 1.9 GeV storage ring operating at 500 milliamps (mA) of beam current. It is optimized to produce intense beams of soft x-rays, which offer spectroscopic contrast, nanometer-scale resolution, and broad temporal sensitivity. The ALS facility includes an accelerator complex and photon delivery system that are capable of providing the foundations for an upgrade that will achieve world-leading soft x-ray coherent flux. The existing ALS provides a ready-made foundation, including conventional facilities, a $500,000,000 scientific infrastructure investment and a vibrant user community of over 2,500 users per year already attuned to the potential scientific opportunities an upgrade offers. The facility also includes extensive (up to 40) simultaneously operating beamlines and instrumentation, an experimental hall, computing resources, ancillary laboratories, offices, and related infrastructure that will be heavily utilized in an upgrade scenario. Furthermore, the upgrade leverages the ALS staff, who are experts in the scientific and technical aspects of the proposed upgrade.

In summary, the capabilities at our existing x-ray light source facilities are insufficient to develop the next generation of tools that combine high resolution spatial imaging together with precise energy resolving spectroscopic techniques in the soft x-ray range. To enable these cutting edge experimental techniques, it is necessary to possess an ultra-bright source of soft x-ray light that generates the high coherent x-ray flux required to resolve nanometer-scale features and interactions, and to allow the real-time observation and understanding of materials and phenomena as they emerge and evolve. Developing such a light source will ensure the U.S. has the tools to maintain its leadership in soft x-ray science and will significantly accelerate the advancement of the fundamental sciences that underlie a broad range of emerging and future energy applications.

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

Key Performance Parameters (KPPs)
The Key Performance Parameters (KPPs) are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

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

[1]Units = photons/sec/0.1% BW/mm2/mrad2

### 3. Financial Schedule

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| FY 2018 | 16,000 | 16,000 | — |
| FY 2019 | 35,000 | 35,000 | 22,054 |
| FY 2020 | 10,000 | 10,000 | 27,946 |
| FY 2021 | 13,000 | 13,000 | 24,000 |
| Outyears | 15,750 | 15,750 | 15,750 |
| Total, Design | 89,750 | 89,750 | 89,750 |
| Construction | | | |
| FY 2019 | 25,000 | 25,000 | — |
| FY 2020 | 50,000 | 50,000 | 50,000 |
| FY 2021 | — | — | 22,000 |
| Outyears | 215,450 | 215,450 | 218,450 |
| Total, Construction | 290,450 | 290,450 | 290,450 |
| Total Estimated Cost (TEC) | | | |
| FY 2018 | 16,000 | 16,000 | — |
| FY 2019 | 60,000 | 60,000 | 22,054 |
| FY 2020 | 60,000 | 60,000 | 77,946 |
| FY 2021 | 13,000 | 13,000 | 46,000 |
| Outyears | 231,200 | 231,200 | 234,200 |
| **Total, TEC** | **380,200** | **380,200** | **380,200** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Other Project Cost (OPC)** | | | |
| FY 2016 | 5,000 | 5,000 | 1,430 |
| FY 2017 | 5,000 | 5,000 | 5,306 |
| FY 2018 | 14,000 | 14,000 | 11,699 |
| FY 2019 | 2,000 | 2,000 | 1,863 |
| FY 2020 | 2,000 | 2,000 | 5,607 |
| FY 2021 | — | — | — |
| Outyears | 2,000 | 2,000 | 4,095 |
| **Total, OPC** | **30,000** | **30,000** | **30,000** |
| **Total Project Cost (TPC)** | | | |
| FY 2016 | 5,000 | 5,000 | 1,430 |
| FY 2017 | 5,000 | 5,000 | 5,306 |
| FY 2018 | 30,000 | 30,000 | 11,699 |
| FY 2019 | 62,000 | 62,000 | 23,917 |
| FY 2020 | 62,000 | 62,000 | 83,553 |
| FY 2021 | 13,000 | 13,000 | 46,000 |
| Outyears | 233,200 | 233,200 | 238,295 |
| **Total, TPC[a]** | **410,200** | **410,200** | **410,200** |

**4. Details of Project Cost Estimate**

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| Design | 69,800 | 69,800 | N/A |
| Contingency | 19,950 | 19,950 | N/A |
| Total, Design | 89,750 | 89,750 | N/A |

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

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| Construction | | | |
| Site Preparation | — | — | N/A |
| Equipment | 230,400 | 188,500 | N/A |
| Other Construction | — | — | N/A |
| Contingency | 60,050 | 59,750 | N/A |
| Total, Construction | 290,450 | 248,250 | N/A |
| **Total, TEC** | **380,200** | **338,000** | **N/A** |
| *Contingency, TEC* | *80,000* | *79,700* | *N/A* |
| **Other Project Cost (OPC)** | | | |
| OPC except D&D | | | |
| Conceptual Planning | 2,000 | 2,000 | N/A |
| Conceptual Design | 12,100 | 12,100 | N/A |
| Research and Development | 8,000 | 8,000 | N/A |
| Start-Up | 2,000 | 1,200 | N/A |
| Contingency | 5,900 | 6,700 | N/A |
| **Total, OPC** | **30,000** | **30,000** | **N/A** |
| *Contingency, OPC* | *5,900* | *6,700* | *N/A* |
| **Total Project Cost** | **410,200** | **368,000** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***85,900*** | ***86,400*** | ***N/A*** |

## 5. Schedule of Appropriations Requests

(dollars in thousands)

| Request Year | Type | Prior Years | FY 2019 | FY 2020 | FY 2021 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| FY 2019 | TEC | — | 10,000 | 26,540 | 32,640 | 212,820 | 282,000 |
| | OPC | 10,000 | 2,000 | 5,000 | — | 21,000 | 38,000 |
| | TPC | 10,000 | 12,000 | 31,540 | 32,640 | 233,820 | 320,000 |
| FY 2020 | TEC | 16,000 | 60,000 | 13,000 | 68,000 | 181,000 | 338,000 |
| | OPC | 24,000 | 2,000 | 2,000 | — | 2,000 | 30,000 |
| | TPC | 40,000 | 62,000 | 15,000 | 68,000 | 183,000 | 368,000 |
| FY 2021 | TEC | 16,000 | 60,000 | 60,000 | 13,000 | 231,200 | 380,200 |
| | OPC | 24,000 | 2,000 | 2,000 | — | 2,000 | 30,000 |
| | TPC | 40,000 | 62,000 | 62,000 | 13,000 | 233,200 | 410,200 |

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

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 2Q FY 2028 |
| Expected Useful Life | 25 years |
| Expected Future Start of D&D of this capital asset | 2Q FY 2053 |

Related Funding Requirements
(dollars in thousands)

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

**7. D&D Information**

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

**8. Acquisition Approach**

DOE has determined that the Lawrence Berkeley National Laboratory (LBNL) will acquire the ALS-U project under the existing DOE Management and Operations (M&O) contract.

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

LBNL may partner with other laboratories for design and procurement of key technical subsystem components. Technical system designs will require research and development activities. Preliminary cost estimates for these systems are based on ALS actual costs and other similar facilities, to the extent practicable. Planning and budgeting for the project will exploit recent cost data from similar projects. LBNL or partner laboratory staff will complete the design of the technical systems. 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. The M&O contractor’s performance will be evaluated through the annual laboratory performance appraisal process.

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

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

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

### Summary

The FY 2021 Request for the Linac Coherent Light Source-II High Energy (LCLS-II-HE) project is $16,000,000, including $14,000,000 in Total Estimated Cost (TEC) funds and $2,000,000 in Other Project Costs (OPC) funds. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-1 (Approve Alternate Selection and Cost Range), approved on September 21, 2018. The preliminary Total Project Cost (TPC) range based on the reviewed conceptual design is $290,000,000 - $480,000,000.

### Significant Changes

This Construction Project Data Sheet (CPDS) is an update of the FY 2020 CPDS and does not include a new start for FY 2021.

The project underwent a successful Independent Project Review by the Office of Science in November 2019 to request approval of CD-3A, Approve Long Lead Procurements. The CD-3A approval is anticipated in the 2Q FY 2020. The project's Total Project Cost (TPC) estimate increased to $428,000,000 at the time of the CD-3A review. The Project Completion Date (CD-4) remains at 1Q FY 2029. The TPC estimate increase resulted from a maturing design effort that identified additional costs across the project scope and an increase in the project's contingency to address several future risks. Two major risks centered on the ability to operate the LCLS-II cryomodules above their design accelerating gradient and for the LCLS-II-HE cryomodules to meet their design operating gradient which is significantly higher than previously achieved. The R&D program in progress for the LCLS-II-HE cryomodules is showing promise but is not yet complete. The performance of the LCLS-II cryomodules will not be known until sometime in FY 2020 when the LCLS-II project begins the accelerator commissioning. Both risks can be mitigated by adding additional cryomodules to the project.

In FY 2019, the project continued planning, engineering, design, R&D, and prototyping activities. The project initiated an R&D program aimed at further advancing the performance of the superconducting radio frequency (RF) cavities, which has shown promise on meeting the technological goals required. FY 2020 funding continues the support of planning, engineering, design, R&D prototyping, and long lead procurements, as appropriate. FY 2021 funding will continue engineering, design, R&D prototyping, and long lead procurements of construction items.

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

### Critical Milestone History

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | D&D Complete | CD-4 |
|---|---|---|---|---|---|---|---|---|
| FY 2019 | 12/15/16 | 3Q FY 2019 | 1Q FY 2019 | 1Q FY 2021 | 1Q FY 2023 | 2Q FY 2022 | N/A | 2Q FY 2026 |
| FY 2020 | 12/15/16 | 3/23/18 | 9/21/18 | 2Q FY 2023 | 1Q FY 2023 | 2Q FY 2023 | N/A | 1Q FY 2028 |
| FY 2021[a] | 12/15/16 | 3/23/18 | 9/21/18 | 2Q FY 2023 | 1Q FY 2023 | 2Q FY 2023 | N/A | 1Q FY 2029 |

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

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

**D&D Complete** – Completion of D&D work
**CD-4** – Approve Start of Operations or Project Closeout

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

**CD-3A** – Approve Long-Lead Procurements for cryomodule associated parts and equipment.

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC, Except D&D | OPC, D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|---|
| FY 2019 | 34,000 | 266,000 | 300,000 | 20,000 | N/A | 20,000 | 320,000 |
| FY 2020 | 34,000 | 314,000 | 348,000 | 20,000 | N/A | 20,000 | 368,000 |
| FY 2021[a] | 34,000 | 374,000 | 408,000 | 20,000 | N/A | 20,000 | 428,000 |

## 2. Project Scope and Justification

**Scope**

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

**Justification**

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

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

There is also a limited ability to observe and understand the structural dynamics of complex matter at the atomic scale with hard x-rays, at ultrafast time scales, and in operational environments. Overcoming this capability gap is crucial for the design, control and understanding of new advanced materials necessary to develop new energy technologies. To achieve this objective, the Department needs a hard x-ray source capable of producing high energy ultrafast bursts, with full spatial and temporal coherence, at high repetition rates. Possession of a hard x-ray source with a photon energy range from 5 keV

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

to 12 keV and beyond would enable spectroscopic analysis of additional key elements in the periodic table, deeper penetration into materials, and enhanced resolution. This capability cannot be provided by any existing or planned light source.

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

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

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

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

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

Key Performance Parameters (KPPs)

The Key Performance Parameters (KPPs) are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| Superconducting linac electron beam energy | ≥ 7 GeV | ≥ 8 GeV |
| Electron bunch repetition rate | 93 kHz | 929 kHz |
| Superconducting linac charge per bunch | 0.02 nC | 0.1 nC |
| Photon beam energy range | 200 to ≥ 8,000 eV | 200 to ≥ 12,000 eV |
| High repetition rate capable, hard X-ray end stations | ≥ 3 | ≥ 5 |
| FEL photon quantity ($10^{-3}$ BW) | $5x10^8$ (50x spontaneous @ 8 keV) | > $10^{11}$ @ 8 keV (200 μJ) or<br>> $10^{10}$ @ 12.8 keV (20 μJ) |

### 3. Financial Schedule

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| FY 2018 | 2,000 | 2,000 | — |
| FY 2019 | 10,000 | 10,000 | 4,400 |
| FY 2020 | 6,000 | 6,000 | 11,600 |
| FY 2021 | 6,000 | 6,000 | 8,000 |
| Outyears | 10,000 | 10,000 | 10,000 |
| Total, Design | 34,000 | 34,000 | 34,000 |
| Construction | | | |
| FY 2018 | 6,000 | 6,000 | — |
| FY 2019 | 18,000 | 18,000 | — |
| FY 2020 | 44,000 | 44,000 | 64,000 |
| FY 2021 | 8,000 | 8,000 | 12,000 |
| Outyears | 298,000 | 298,000 | 298,000 |
| Total, Construction | 374,000 | 374,000 | 374,000 |
| Total Estimated Cost (TEC) | | | |
| FY 2018 | 8,000 | 8,000 | — |
| FY 2019 | 28,000 | 28,000 | 4,400 |
| FY 2020 | 50,000 | 50,000 | 75,600 |
| FY 2021 | 14,000 | 14,000 | 20,000 |
| Outyears | 308,000 | 308,000 | 308,000 |
| **Total, TEC** | **408,000** | **408,000** | **408,000** |
| **Other Project Cost (OPC)** | | | |
| FY 2018 | 2,000 | 2,000 | 1,191 |
| FY 2019 | 6,000 | 6,000 | 2,041 |
| FY 2020 | 4,000 | 4,000 | 7,959 |
| FY 2021 | 2,000 | 2,000 | 2,809 |
| Outyears | 6,000 | 6,000 | 6,000 |
| **Total, OPC** | **20,000** | **20,000** | **20,000** |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Project Cost (TPC)** | | | |
| FY 2018 | 10,000 | 10,000 | 1,191 |
| FY 2019 | 34,000 | 34,000 | 6,441 |
| FY 2020 | 54,000 | 54,000 | 83,559 |
| FY 2021 | 16,000 | 16,000 | 22,809 |
| Outyears | 314,000 | 314,000 | 314,000 |
| **Total, TPC[a]** | **428,000** | **428,000** | **428,000** |

**4. Details of Project Cost Estimate**

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| Design | 30,500 | 30,500 | N/A |
| Contingency | 3,500 | 3,500 | N/A |
| Total, Design | 34,000 | 34,000 | N/A |
| Construction | | | |
| Site Preparation | 3,000 | 3,000 | N/A |
| Equipment | 250,700 | 236,000 | N/A |
| Other Construction | 9,000 | 9,000 | N/A |
| Contingency | 111,300 | 66,000 | N/A |
| Total, Construction | 374,000 | 314,000 | N/A |
| **Total, TEC** | **408,000** | **348,000** | **N/A** |
| *Contingency, TEC* | *114,800* | *69,500* | *N/A* |

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

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Other Project Cost (OPC)** | | | |
| OPC except D&D | | | |
| R&D | 4,000 | 4,000 | N/A |
| Conceptual Planning | 1,500 | 1,500 | N/A |
| Conceptual Design | 2,000 | 2,000 | N/A |
| Start-Up | 6,500 | 6,500 | N/A |
| Contingency | 6,000 | 6,000 | N/A |
| **Total, OPC** | **20,000** | **20,000** | **N/A** |
| *Contingency, OPC* | *6,000* | *6,000* | *N/A* |
| **Total Project Cost** | **428,000** | **368,000** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***120,800*** | ***75,500*** | ***N/A*** |

**5. Schedule of Appropriations Requests**

(dollars in thousands)

| Request Year | Type | Prior Years[a] | FY 2019 | FY 2020 | FY 2021 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| FY 2019 | TEC | — | 5,000 | 20,060 | 25,000 | 249,940 | 300,000 |
| | OPC | — | 2,000 | 4,000 | — | 14,000 | 20,000 |
| | TPC | — | 7,000 | 24,060 | 25,000 | 263,940 | 320,000 |
| FY 2020 | TEC | 8,000 | 28,000 | 14,000 | 60,000 | 238,000 | 348,000 |
| | OPC | 2,000 | 6,000 | 4,000 | — | 8,000 | 20,000 |
| | TPC | 10,000 | 34,000 | 18,000 | 60,000 | 246,000 | 368,000 |
| FY 2021 | TEC | 8,000 | 28,000 | 50,000 | 14,000 | 308,000 | 408,000 |
| | OPC | 2,000 | 6,000 | 4,000 | 2,000 | 6,000 | 20,000 |
| | TPC | 10,000 | 34,000 | 54,000 | 16,000 | 314,000 | 428,000 |

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

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 1Q FY 2029 |
| Expected Useful Life | 25 years |
| Expected Future Start of D&D of this capital asset | 1Q FY 2054 |

Related Funding Requirements
(dollars in thousands)

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

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

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

**7. D&D Information**

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

**8. Acquisition Approach**

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

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

SLAC will partner with other laboratories for design and procurement of key technical subsystem components. Technical system designs will require research and development activities. Preliminary cost estimates for these systems are based on actual costs from LCLS-II and other similar facilities, to the extent practicable. The M&O contractor will fully exploit recent cost data in planning and budgeting for the project. SLAC or partner laboratory staff will complete the design of the technical systems. SLAC or subcontracted vendors with the necessary capabilities will fabricate the technical equipment. All subcontracts will be competitively bid and awarded based on best value to the government. The M&O contractor's performance will be evaluated through the annual laboratory performance appraisal process.

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

## Biological and Environmental Research

### Overview

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

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

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

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

### Highlights of the FY 2021 Request

The FY 2021 Request for BER is $516,934,000, which directly aligns with the FY 2021 Administration research and development (R&D) Budget Priorities memo[a] issued by OMB and OSTP that identifies five high priority crosscutting actions that span the five R&D budget priorities to ensure that America remains at the forefront of science. BER research on secure biodesign and high-resolution Earth System models aligns with the R&D priority American Security to underpin improving

[a] https://www.whitehouse.gov/wp-content/uploads/2019/08/FY-21-RD-Budget-Priorities.pdf

the security and resilience of the Nation from emerging threats from biological agents and extreme terrestrial events; investments in novel quantum sensors for biological and ecological systems align with the R&D priority American Leadership in Industries of the Future to develop advanced imaging capabilities that leverage and complement the SC QIS Center(s) established in FY 2020 as an interdisciplinary partnership among SC Program Offices' research in support of the National Quantum Initiative; investments in early-stage research and innovative technologies at the four BRC's align with the R&D priority American Health and Bioeconomic Innovation to lead to domestic sources of clean, affordable, and reliable energy; and the BER foundational research on Earth Systems models and environmental systems directly aligns with the R&D priority American Energy and Environmental Leadership with new observations and exascale-capable, high resolution Earth system prediction models to obtain substantial improvements in computational model performance and spatial resolution across all scales. All BER activities work to Build and Leverage a Diverse, Highly Skilled American Workforce; Support Transformative Research of High Risk and Potential High Reward and Build, Strengthen, and Expand Strategic Multisector Partnerships thought the merit review process and interagency coordination. BER research continues to build on the Administration decisions in FY 2018 to prioritize early-stage, innovative research and technologies that show promise in harnessing American energy resources safely and efficiently. This program supports research that advances DOE's core missions while maintaining American leadership in the area of scientific inquiry and discovery. BER's support of basic research today will contribute to a future of stable, reliable, and secure sources of American energy based on transformative science for economic prosperity.

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

Key elements in the FY 2021 Request include:

Research

- Investments in the Biological Systems Science subprogram to provide the fundamental understanding to underpin transformative science in sustainable bioenergy production and to gain a predictive understanding of plant and microbial physiology, microbiomes, and biological systems in support of DOE's energy and environmental missions. Significant new experimental paradigms reflecting the Next-Generation Biology initiative will leverage new tools and approaches across the Office of Science, to move from genomics and biochemistry of biological systems to implementation of this new understanding in bio-inspired, biohybrid and biomimetic systems. The Genomic Sciences activity will prioritize support for the fourth year of the four DOE BRCs, performing new fundamental research underpinning the production of fuels and chemicals from sustainable biomass resources and the building blocks of new technological advances for translation of basic research results to industry. Secure biosystems design activities will be extended to test the fundamental engineering principles that control plant and microbial systems, with a specific goal of enhancing the stability, resilience, and controlled performance of engineered biological systems. New efforts in translating biodesign rules to functional properties of novel biological polymers will be initiated. These fundamental genomic science activities will consolidate and coordinate ongoing environmental genomics efforts on sustainability and microbiomes research in mission-relevant ecosystems and testbeds. Computational Biosciences efforts will integrate prior efforts on microbiome within the DOE Systems Biology Knowledgebase to develop integrated networks and computational models of system dynamics and behavior.

- Biomolecular Characterization and Imaging Science research, which will continue to support structural, spatial, and temporal understanding of functional biomolecules and processes occurring within living cells. Efforts in advanced bioimaging and characterization of QIS and advanced sensors will contribute to a systems-level predictive understanding of biological processes.

- Earth and Environmental Systems Sciences research activities, which will focus on scientific analysis of how physical and biogeochemical processes impact the sensitivity and uncertainty of Earth system predictions. Environmental

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

System Science will integrate terrestrial ecosystem and subsurface sciences to provide a robust and scale-aware predictive understanding of ecosystems. Investments will continue to support, at a slower pace, the Energy Exascale Earth System Model (E3SM) capability tailored to DOE requirements for a variety of scenarios applied to spatial scales resolved to 10 km. The model system will include advanced software for running on numerous processors, flexibility toward future DOE computer architectures, including exascale, and enhanced usability, testing, adaptability, multi-scale treatments, and provenance. In addition to leveraging of existing data from other agencies, modeling efforts will be validated against atmospheric and terrestrial observations.

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

Facility Operations

- The DOE JGI will continue to be an essential component for DOE systems biology efforts, providing high quality genome sequence data and analysis techniques for a wide variety of plants and microbial communities. The JGI will continue to implement its strategic plan[a] to incorporate new capabilities to sequence DNA and also to interpret, manipulate, and synthesize DNA in support of sustainable, renewable bioenergy and bioproducts research, and environmental research. In FY 2021, the JGI will prioritize improved integration with the Systems Biology Knowledgebase.

- ARM investments will continue to provide new observations selected to represent the diversity of environmental conditions necessary to advance Earth System models. ARM prioritizes long-term measurements at fixed sites in Alaska and Oklahoma, while limiting activities at the East North Atlantic (Azores) site. In addition, the Arctic mobile facility deployed at Oliktok Point will be closed and prepared for a future deployment. One mobile facility will be deployed to the Houston, TX area for Tracking Aerosol Convection Interactions Experiment (TRACER). Scientists will use the second generation C-band ARM Scanning Precipitation Radar (CSAPR2), and a small satellite site with radiosonde and aerosol measurements to learn more about cloud and aerosol interactions in deep convection over the Houston area. The ARM user facility will continue to develop and deploy aerial capabilities, including unmanned aerial system (UAS) and manned aircraft. The newly acquired manned aircraft will continue to undergo testing and evaluation.

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

[a] https://jgi.doe.gov/wp-content/uploads/2019/01/2019_JGI-Strategic-Plan.pdf

**FY 2021 Research Initiatives**

Biological and Environmental Research supports the following FY 2021 Research Initiatives.

| | (dollars in thousands) | | | |
|---|---|---|---|---|
| | **FY 2019 Enacted** | **FY 2020 Enacted** | **FY 2021 Request** | **FY 2021 Request vs FY 2020 Enacted** |
| **New Research Initiatives** | | | | |
| Next Generation Biology Initiative | — | — | 6,250 | +6,250 |
| Revolutionizing Polymer Upcycling | — | — | 6,250 | +6,250 |
| **Total, New Research Initiatives** | **—** | **—** | **12,500** | **+12,500** |
| **Ongoing Research Initiatives** | | | | |
| Artificial Intelligence and Machine Learning | — | 3,000 | 3,000 | — |
| Biosecurity | 4,000 | 20,000 | 25,000 | +5,000 |
| Exascale Computing Initiative | 15,000 | 15,000 | 10,000 | -5,000 |
| Quantum Information Science | 4,500 | 12,000 | 12,000 | — |
| **Total, Ongoing Research Initiatives** | **23,500** | **50,000** | **50,000** | **—** |

**Biological and Environmental Research**
**Funding**

(dollars in thousands)

| | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|
| **Biological Systems Science** | | | | |
| Genomic Science | 249,695 | 268,235 | 242,135 | -26,100 |
| *Bioenergy Research Centers (non-add)* | *[100,000]* | *[100,000]* | *[100,000]* | *[–]* |
| Biomolecular Characterization and Imaging Science | 34,908 | 45,000 | 24,908 | -20,092 |
| Biological Systems Facilities and Infrastructure | 70,000 | 77,000 | 60,000 | -17,000 |
| SBIR/STTR | 13,194 | 14,544 | 12,257 | -2,287 |
| **Total, Biological Systems Science** | **367,797** | **404,779** | **339,300** | **-65,479** |
| | | | | |
| **Earth and Environmental Systems Sciences** | | | | |
| Atmospheric System Research | 28,000 | 35,000 | 12,000 | -23,000 |
| Environmental System Science[a] | 62,143 | 77,638 | 19,000 | -58,638 |
| Earth and Environmental Systems Modeling | 97,000 | 97,000 | 37,643 | -59,357 |
| Earth and Environmental Systems Sciences Facilities and Infrastructure | 138,500 | 123,110 | 102,635 | -20,475 |
| SBIR/STTR | 11,560 | 12,473 | 6,356 | -6,117 |
| **Total, Earth and Environmental Systems Sciences** | **337,203** | **345,221** | **177,634** | **-167,587** |
| **Total, Biological and Environmental Research** | **705,000** | **750,000** | **516,934** | **-233,066** |

SBIR/STTR funding:

- FY 2019 Enacted: SBIR $21,702,000 and STTR $3,052,000
- FY 2020 Enacted: SBIR $23,687,000 and STTR $3,330,000
- FY 2021 Request: SBIR $16,318,000 and STTR $2,295,000

[a] New structure change in FY 2021 for Environmental System Science to reflect all previous Terrestrial Ecosystem Science and Subsurface Biogeochemical Research combined.

## Biological and Environmental Research
## Explanation of Major Changes

| | (dollars in thousands) FY 2021 Request vs FY 2020 Enacted |
|---|---|
| **Biological Systems Science**<br>Within Genomic Sciences, the Request prioritizes research activities to continue early-stage core research to understand the complex mechanisms controlling the interplay of microbes and plants within broader organized biological systems, forming the basis for the next generation of biological discovery. Foundational Genomics research supports expanded secure biosystems design research to understand the fundamental genome structure and functional relationships that result in specific, stable and predictable, new, and beneficial traits in model plant and microbial systems. Novel extensions of biodesign and synthetic biology approaches to the design of new plant and microbially-derived polymers have the potential for sparking new biotechnology applications in resource recovery and recycling ventures. Environmental Genomics will limit research to understanding environmentally relevant microbiomes and the interdependencies between plants and microbes in a sustainable and resilient ecosystem. Computational Bioscience will focus on an integrated computational platform for microbiome. The Request fully supports the four DOE BRCs in their fourth year of bioenergy research to underpin efforts to produce innovative biofuels and bioproducts from renewable biomass resources. Development of new bioimaging, measurement and characterization approaches through the Biomolecular Characterization and Imaging Science activity will include expanded integrative imaging and analysis platforms and biosensors, including using QIS materials, to understand the expression, structure, and function of genome information encoded within cells and for real-time measurements in ecosystems and field sites of mission relevance. The JGI will operate with reduced user support. | **-65,479** |
| **Earth and Environmental Systems Sciences**<br>The Request continues to support, at a reduced pace, the development of high-resolution Earth system modeling, analysis, and intercomparison capabilities focused on DOE mission needs for energy and infrastructure resilience and security. Environmental System Science will continue a focus on Arctic field studies and modeling the fate and transport of nutrients. Using observations from the ARM facility, Atmospheric System Research will focus activities to advance knowledge and improve model representations of atmospheric gases, aerosols, and clouds on the Earth's energy balance. One ARM mobile facility will be deployed to the Houston, TX area; operations of the Arctic mobile facility at Oliktok, AK are completed and operations at the East North Atlantic fixed site will be limited. The newly acquired manned aircraft will continue to undergo testing and evaluation. EMSL will focus on biological and environmental molecular science with reduced user support. Data management activities will include applying advanced AI methods to observations and environmental field data. | **-167,587** |
| **Total, Biological and Environmental Research** | **-233,066** |

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

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

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

All Earth systems research activities are specifically coordinated through the interagency U.S. Global Change Research Program. For example, the DOE E3SM has evolved to become the world's highest resolution capability; and the E3SM version 1 released in April 2018 will be updated to a version 2 model that is anticipated to be released in FY 2022. Version 2 will provide numerous universities the ability to conduct much more sophisticated research based on higher resolution. The new version will add advanced capabilities for exploring cryosphere-ocean dynamics' impacts of climate variability on Antarctic ice shelf melting, continental ice sheet evolution and sea level rise, and the effects of changing water cycles on watershed and coastal hydrological systems. Other agencies, e.g., NOAA, NASA, the Navy, and NSF, are following developments in E3SM via the Earth System Prediction Capability forum (led by DOD and NOAA weather services, but with DOE as a member), so that their modeling platforms can adopt the best practices in physics and computing developed by DOE. The National Geospatial-Intelligence Agency has indicated significant interest in E3SM, as a platform to incorporate their data to address national security problems. The E3SM research also provides BER with strong linkages to DOE applied programs and DOE Office of Policy.

**Program Accomplishments**
*Genomic Science conducts fundamental research on a broad range of biological processes with a recent focus on plant-microbe interactions in soil.*
Results from a Lawrence Berkeley National Laboratory (LBNL)-led team examining changes in soil microbial community structure found that plant root exudates exert a strong influence on soil community composition. This mechanistic understanding offers the attractive possibility of altering soil microbiomes for beneficial purposes. Similarly, a research team from the University of Washington, Harvard Medical School, and Oak Ridge National Laboratory (ORNL) investigating plant-microbe processes found a specific plant compound that induces a regulator of gene expression in an associated bacteria. These types of inter-kingdom communication have important implications for mutualistic and antagonistic interactions between plants and microbes and are key to understanding key control points for plant-microbe interactions. These research findings on plant-microbe interactions are complemented by new technologies developed to image metabolic processes in plants and microorganisms.

A team led by Pacific Northwest National Laboratory (PNNL) developed a mass spectrometry-based imaging capability at the DOE EMSL and demonstrated 3-D imaging of cellular metabolites associated with nitrogen fixation in soybean root nodules, a well-known example of a mutualistic plant-microbe interaction. The new technique can be extended to image similar processes in other systems to visualize and test hypotheses of plant-microbe interactions. More broadly, the activity also supports research on CRISPR[a]-based systems.

Recent research from the University of Illinois, Urbana-Champaign, developed a new CRISPR method that can create tens of thousands of yeast mutants with specific genome edits. This new technique enables the rapid editing of targeted genes across an entire genome and adds to a vast array of new and powerful metabolic engineering techniques underpinning a rapidly expanding global biotechnology industry.

*Bioenergy Research Centers' research continues to highlight significant basic science advances underpinning biofuels and bioproduct production from sustainable plant biomass.*
At the Center for Bioenergy Innovation, continued research on switchgrass has led to the identification of a number of genes impacting cell wall recalcitrance to deconstruction and conversion to biofuels. Recent results showed that down-regulation of a pectin biosynthesis gene resulted in a plant with enhanced growth characteristics and increased yield of cellulosic sugars, a major step towards developing dedicated bioenergy crops.

Researchers at the Center for Advanced Bioenergy and Bioproducts Innovation working with the newly sequenced sugarcane genome identified 178 genes associated with nitrogen transport. This is important because sugarcane is notorious for a low nutrient uptake and these identified genes are now genomic targets for improving nutrient use efficiency in sugarcane. At the Joint BioEnergy Institute researchers have developed a new CRISPR-based interference (CRISPRi) technique that silences gene expression in competing pathways within an engineered cell. The technique was used to divert metabolic flux in an engineered E. coli cell towards increased production of isopentenol, an advanced biofuel. Researchers at the Great Lakes BRC engineered a strain of bacteria capable of utilizing aromatic compounds derived from lignin to produce an important chemical precursor for bioplastics. The work sets the stage for developing valuable chemical products from lignin, a major goal of the BRCs and a major bottleneck towards cost effective production of bioenergy and bioproducts from renewable plant biomass.

*Earth and Environmental Systems Sciences conducts research to improve the scale-aware predictability of the Earth system, with particular focus on the interdependencies of the physical, biogeochemical, and human processes that govern variability, change, and the evolution of extreme events.*
Using improved process level understanding based on field observations that combines with advanced modeling concepts and access to DOE's high performance computing, DOE's investments allow Earth System models to more confidently capture changes to the hydrologic cycle, the cryosphere, and extreme weather events. As part of the Next-Generation Ecosystem Experiments Arctic program, Los Alamos National Laboratory and University of Texas at Austin developed a novel machine-learning methodology that quickly delineates tundra (i.e., frozen soil) polygons from digital elevation models, thereby providing an automated method to quantify rates and amounts of change in arctic permafrost.

Researchers at LBNL and Sandia National Laboratory developed a new sub-model to represent saturated and unsaturated hydrologic processes in E3SM. The new sub-model unifies the physics of unsaturated and saturated zones, improving model predictions based on comparison with observations. A large field experiment, known as the Spruce and Peatland Responses Under Changing Environments (SPRUCE) and led by ORNL, demonstrated that increased ambient temperatures prolonged the growing season, but also made ecosystems more vulnerable to late season frost damage and plant growth. Lastly, an international team of scientists, including researchers at PNNL and LBNL, discovered that fungal spores make up as much as 69 percent of airborne salt particles in the Amazon basin; never before have fungal spores been considered a significant source of salt particle formation.

*User Facilities house state-of-the-art tools and expertise to enable the scientific community to address and solve research questions for biological and environmental systems.*

- JGI provides the necessary genome sequencing of plants and microorganisms as a basis for identifying beneficial bioenergy properties and traits. The Eucalyptus family of plants is well known to produce a broad range of terpene compounds which are important biofuel and bioproduct components. The sequencing and analysis of a member of the

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[a] CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats) – advanced genome editing tools with broad potential for biotechnology applications.

Eucalyptus family (*C. Citriodora*) led to the identification of 102 new functional terpene synthase (TPS) genes. The work broadens the known TPS gene family lineage in Eucalyptus species and provides new genomic targets for biofuel and bioproduct development.

- Bioimaging capabilities developed by University of Idaho researchers and the EMSL are providing enhanced capabilities to monitor metabolic processes within single cells. This was recently demonstrated by tracking net lipid (biofuel precursors) production in yeast cells and quantifying the rates of metabolic processes. The work provides a new way to utilize imaging information to calculate rates of metabolism in single cells.
- The ARM user facility used ground-based ARM observations to study how optical depth (i.e., low-cloud reflectivity) changes with warming at three ARM sites. Findings were consistent with satellite measurements, increasing confidence in the data trends and enabling these ARM observations to be used to assess, calibrate, and improve the accuracy of Earth system models.

## Biological and Environmental Research
## Biological Systems Science

### Description

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

Key questions that drive these studies include:

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

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

The subprogram supports the operation of the DOE BRCs and the DOE JGI scientific user facility.

<u>Genomic Science</u>

The Genomic Science activity supports research seeking to reveal the fundamental principles that drive biological systems relevant to DOE missions in energy security and resilience. These principles guide the interpretation of the genetic code into functional proteins, biomolecular complexes, metabolic pathways, and the metabolic/regulatory networks underlying the systems biology of plants, microbes, and communities. Advancing fundamental knowledge of these systems in concert with integrative, collaborative, and open access computational platforms will accelerate next generation of biological research for solutions to clean energy production, breakthroughs in genome-based biotechnology, understanding the role of biological systems in the environment, and adapting biological design paradigms to physical and material systems.

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

Foundational Genomics supports fundamental research on discovery and manipulation of genome structural and regulatory elements and epigenetic controls to scale from genotype to phenotype in microbes and plants. Efforts in biosystems design research build on and complement existing genomics-based research, through development of new secure gene-editing and multi-gene stacking techniques for microbes and plants. The results will yield an increased range of microorganisms and plants as model research organisms to expand and complement available biological systems for bioenergy and biotechnology research. Building on knowledge gained from breaking down plant cell wall polymers for bioenergy, engineered microbial and fungal systems will be explored for polymer recycling. Fungal systems and some bacteria utilize powerful enzymatic machinery to breakdown polymers to monomers for use as substrates. BER's contribution towards understanding and anticipating the convergence of advanced genomics science with other fields is critical for foresight into secure technology development, leveraging scientific communities across biological, physical, and computational science fields with the unique ability to evaluate systems across disciplinary boundaries. All secure biosystems design efforts on plant and microbial systems will be consistent with the National Biodefense Strategy framework.[a]

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

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

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

Biomolecular Characterization and Imaging Science supports approaches to systems biology that focus on translating information encoded in an organism's genome to those traits expressed by the organism. These genotype to phenotype translations are key to gaining a predictive understanding of cellular function under a variety of environmental and bioenergy-relevant conditions. The Biomolecular Characterization and Imaging Science activity will enable development of new bioimaging, measurement, and characterization technologies to visualize the structural, spatial, and temporal relationships of key metabolic processes and critical biomaterials governing phenotypic expression in plants and microbes. The activity will include new efforts to develop QIS materials for imaging and characterization and to advance design of sensors and detectors based on correlated materials for real-time biological and environmental sensing technology. This information is crucial for developing an understanding of the impact of various environmental and/or biosystems designs on whole cell or community function.

<u>Biological Systems Science Facilities and Infrastructure</u>

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

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

[a] https://www.whitehouse.gov/wp-content/uploads/2018/09/National-Biodefense-Strategy.pdf

## Activities and Explanation of Changes

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| **Biological Systems Science** | **$404,779** | **$339,300** | **-$65,479** |
| Genomic Science | $268,235 | $242,135 | -$26,100 |
| Foundational Genomics supports biosystems design techniques to modify microbes and plants for beneficial bioenergy, bioproduct and biotechnology purposes. Complementary efforts increase on genome-modification techniques to identify and predict biosecurity implications for energy and the environment. Environmental Genomics focuses on sustainable plant and microbial community interactions in model and natural microbiomes, and complementary research on plant and microbial physiology for bioenergy and ecosystem purposes. Computational analysis related to low dose radiation exposure is supported. | | Foundational Genomics research will support expanded secure biosystems design research to gain the ability to stably and securely modify microorganisms and plants with specific beneficial traits for renewable bioenergy, bioproduct and biomaterials production with particular emphasis on programmable materials production and provide foundational research for the Next Generation of Biology. New efforts will be initiated in biological-based polymer recycling and upcycling research. Environmental Genomics will focus research to understanding environmentally relevant microbiomes and the interdependencies between plants and microbes in a sustainable and resilient ecosystem. | Funding will support new concepts in biosystems design for programmable production (and/or deconstruction) of organic/inorganic/hybrid materials in modified plants and microorganisms. Building on knowledge gained from breaking down plant cell wall polymers for bioenergy, engineered microbial and fungal systems will be explored for polymer recycling. |
| Computational Bioscience enhances research to merge bioinformatics capabilities within the JGI and the DOE Systems Biology Knowledgebase to produce an open source, integrated computational platform for microbiome and bioenergy-related research. The efforts for the National Microbial Data Collaborative (NMDC) continue. | | Computational Bioscience will support open computational platform development for microbiome science integrative with the JGI and the DOE Systems Biology Knowledgebase for bioenergy, bioproduct and programmable biomaterials design. | Funding will support new computational techniques and design tools to enable programmable organic/inorganic/hybrid materials production in modified plants and microorganisms. |
| The four BRCs continue operations to develop bioenergy crops with enhanced tolerance to environmental stress, biomass deconstruction techniques to breakdown biomass, biotechnology approaches to produce fuels, chemicals and products from lignocellulosic materials, | | The four BRCs will begin their fourth year of operations to develop modified bioenergy crops with expanded traits for bioenergy and bioproduct production and tolerance to a range of environmental stresses, development of biomass deconstruction process | The four BRCs will expand the knowledge needed to develop a range of plants modified with beneficial traits and conversion pathways in microorganisms to sustainably produce a broad |

(dollars in thousands)

| FY 2020 Enacted | FY 2021 Request | Explanation of Changes<br>FY 2021 Request vs FY 2020 Enacted |
|---|---|---|
| and research to understand sustainable regional-scale bioenergy crop production. | streams, design of new engineered pathways in microbes to convert biomass components to a range of fuels, chemicals and bioproducts, and new analysis concepts for sustainable production of bioenergy crops on marginal lands. | spectrum of fuel components, bioproducts and biomaterials from renewable biomass. |
| Biomolecular Characterization and Imaging Science $45,000 | $24,908 | -$20,092 |
| Biomolecular Characterization and Imaging Science supports new multi-modal imaging, visualization and structural characterization of biomolecular processes occurring in plants and microbes in support of systems biology research, including the use of neutrons. Investments in electron cryomicroscopy instrumentation at SC light sources are underway and will be completed. Research funding continues support for new imaging, characterization and/or sensor techniques that take advantage of quantum-enabled science concepts, with an emphasis on improvements in quantifying nutrient and metabolite flows in situ in field environments. | Development of new bioimaging, measurement and characterization approaches through the Biomolecular Characterization and Imaging Science activity will include expanded integrative imaging and analysis platforms and biosensors, including quantum science-enabled techniques, to understand and validate hypotheses of cellular metabolism and/or pathway design relevant to bioenergy, bioproduct and biomaterials production in plants and microorganisms. | Funding will support the exploration of new quantum science-based concepts for bioimaging and/or measurement and characterization capabilities for analyses of biological processes relevant to bioenergy/bioproduct/biomaterials research. |

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|
| Biological Systems Science Facilities and Infrastructure | $77,000 | | $60,000 | -$17,000 |
| JGI serves as a central source for genome sequence production capabilities for plants, microbes and microbial communities. These services are crucial to BER programs, such as the BRCs, and are also available to the larger research community. JGI is enhancing efforts on metagenomics efforts to support microbiome research, and production of complex plant, fungal and microbial genomes supporting systems biology research within the BRCs and the BER portfolio. The resulting data and analyses are closely coupled with KBase for open access on an integrated bioinformatics platform. JGI and KBase move to Integrative Genomics Building on the LBNL campus. | | JGI will provide users with expanded analysis capabilities in a more integrative computational platform for microbiome science through the NMDC and within the DOE Systems Biology Knowledgebase. New capabilities for natural product identification will be explored in concert with expanded metagenomic datasets and analysis techniques. | | Integrative computational platforms among JGI, the NMDC, and KBase will allow the research community to conduct large scale metagenomics and microbiome analyses in a collaborative and reproducible manner facilitating BER's larger efforts in bioenergy, bioproduct and biomaterials research. |
| SBIR/STTR | $14,544 | | $12,257 | -$2,287 |
| In FY 2020, SBIR/STTR funding is set at 3.65 percent of non-capital funding | | In FY 2021, SBIR/STTR funding is set at 3.65 percent of non-capital funding. | | The SBIR/STTR funding will be consistent with the BER total budget. |

## Biological and Environmental Research
## Earth and Environmental Systems Sciences

### Description

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

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

Atmospheric System Research

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

Environmental System Science

Environmental System Science supports research to provide an integrated, robust and scale-aware predictive understanding of environmental systems, including the role of hydro-biogeochemistry from the subsurface to the top of the vegetative canopy that considers effects of seasonal to interannual variability and change, and short-term extreme events that act on spatial scales that span from molecular to global. Multi-scale new data and understanding are essential to advance Earth system modeling that can and is being 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 and environmental stewardship. The vision for this activity is to develop a unified predictive capability that integrates scale-aware process understanding with unique characteristics of watersheds, coastal zones, and terrestrial-aquatic interfaces that are present in, e.g., the Arctic, boreal zone, and the Tropics, including the Great Lakes.

Using decadal-scale investments such as the Next Generation Ecosystem Experiment (NGEE) to study the variety of time scales and processes associated with ecological change, Environmental System Science research focuses on understanding, observing, and modeling the processes controlling exchange flows between the atmosphere and the terrestrial biosphere, and improving and validating the representation of environmental systems in coupled Earth system models. Research supports the integration of observations with process modeling from molecular to field scales, to improve understanding of hydrological, and biogeochemical processes that affect terrestrial environments.

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

Earth and Environmental Systems Modeling

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

Earth and Environmental Systems Sciences Facilities and Infrastructure

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

ARM is a multi-laboratory, multi-platform, multi-site, national scientific user facility, providing the world's most comprehensive, continuous, and precise observations of clouds, aerosols, and related meteorological information. These observations provide new data to address the main source of uncertainty in Earth system models: the interdependence of clouds, atmospheric aerosols, and precipitation that in turn influences the radiation balance. In addition to supporting interdisciplinary science challenges, extreme events represented in DOE's Earth system model are used to inform plans for designs and deployment of future energy infrastructures. ARM currently consists of three fixed, long-term measurement facility sites (in Oklahoma, Alaska, and the Azores), three mobile observatories, and an airborne research capability that operates at sites selected by the scientific community. In FY 2021, ARM will continue operations at the three fixed sites. One mobile facility will be deployed to the Houston, TX area for Tracking Aerosol Convection Interactions Experiment (TRACER). Scientists will use the second-generation C-band ARM Scanning Precipitation Radar (CSAPR2), and a small satellite site with radiosonde and aerosol measurements to learn more about cloud and aerosol interactions in deep convection over the Houston area. ARM investigators study the impact of evolving clouds, aerosols, and precipitation on the Earth's radiative balance and rate of Earth system change, addressing the most significant scientific uncertainties in predictability research. ARM will continue to incorporate very high-resolution Large Eddy Simulations at the fixed Oklahoma site during specific campaigns requested by the scientific community. BER is also maintaining the exponentially increasing data archive to support enhanced analyses and model development. The data extracted from the archive are used to improve atmospheric process representations at higher resolution, greater sophistication and robustness of ultra-high-resolution atmospheric models. Besides supporting BER atmospheric sciences and Earth system modeling research, the ARM facility freely provides key information to other agencies that are engaged in, e.g., calibration and validation of space-borne sensors.

BER-supported scientists require high-quality and well-characterized in situ aircraft observations of aerosol and cloud microphysical properties and coincident dynamical and thermodynamic properties in order to continue to improve fundamental understanding of the physical and chemical processes that control the formation, life cycle, and radiative impacts of cloud and aerosol particles. To meet these needs, the ARM user facility will continue to develop the aerial capabilities, including unmanned aerial system (UAS) and manned aircraft. In FY 2021, the newly acquired manned aircraft will continue to undergo testing and evaluation, including modifications to the air frame as needed to install numerous existing and new atmospheric aerosol, cloud, turbulence, and other sensors.

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, catalysts and materials, and interfacial and surface (including aerosol) science relevant to energy and environmental challenges facing DOE and the Nation. This research informs the development of advanced biofuels and bioproducts, the design of novel methods to accelerate environmental cleanup, and an improved understanding of Arctic infrastructure vulnerability due to biogenic processes that govern permafrost thaw. EMSL will address a more focused set of scientific topics that continue to exploit High Resolution and Mass Accuracy Capability (HRMAC), live cell imaging, and more extensive utilization of other EMSL instrumentation into process and systems models and simulations to address challenging problems in the biological and environmental system sciences.

Data sets generated by ARM, other DOE and Federal Earth observing activities, and Earth system modeling activities are enormous. The new science derived from Earth observations and model-generated data can be used to achieve broad benefits ranging from informing the design of robust resilient infrastructures to risk analysis involving natural disaster impact mitigation to commercial supply chain management to natural resource management and environmental stewardship. Accessibility and usage of these data sets are fundamental to supporting decision-making, scientific discovery, technological innovation, and national security.

The BER Data Management activity will focus efforts on archiving scientifically useful data from the Earth System Grid Federation, ARM, Ameriflux, NGEE field experiments, SPRUCE site observations, and long- term DOE investments to understand watershed systems.

## Activities and Explanation of Changes

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| **Earth and Environmental Systems Sciences** | **$345,221** | **$177,634** | **-$167,587** |
| Atmospheric System Research (ASR) | $35,000 | $12,000 | -$23,000 |
| ASR accelerates research on clouds, aerosols, and thermodynamic processes, with a focus on data from the Oklahoma and Alaska fixed sites and using data from prior and ongoing field campaigns in Argentina, Norway, and the Southern Ocean. Initial data from the Arctic campaign is included in the analyses. ASR continues to make use of data generated by Large Eddy Simulations at the ARM Oklahoma site. | | The Request for ASR will continue limited research on clouds, aerosols, and thermodynamic processes, with a focus on data from the ARM fixed sites as well as recent field campaigns conducted in the Arctic during FY 2020. ASR will continue to make use of data generated by Large Eddy Simulations at the ARM Oklahoma site. | Reduced research will focus on using the new observations from ARM field studies to inform Earth system model development. |
| Environmental System Science (ESS) | $77,638 | $19,000 | -$58,638 |
| The ESS activity focuses research on permafrost and continues investments in studies of boreal ecology and modeling hydrobiogeochemistry of watersheds and terrestrial-aquatic interfaces, including the Great Lakes. Research on tropical ecology and subsurface biogeochemistry research on radionuclides and mercury continues. | | The Request for ESS will focus research on permafrost and will maintain limited investments in studies of boreal ecology and modeling hydrobiogeochemistry of watersheds and terrestrial-aquatic interfaces, with a focus on the coastal zones encompassed by the Delaware and Susquehanna watersheds and the Great Lakes. | Funding for ESS will support investment in modeling activities associated with the terrestrial-aquatic project located in the mid-Atlantic and Great Lakes region. |

(dollars in thousands)

| FY 2020 Enacted | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|
| Earth and Environmental Systems Modeling $97,000 | $37,643 | -$59,357 |
| Earth and Environmental Systems Modeling investments focus on further refinement of the science underpinning non-hydrostatic modeling and incorporating the necessary software for deployment of the model onto exascale computing architectures. The research continues to support activities on the modeling of extreme phenomena (e.g., hurricanes), improved representation of biogeochemistry, and a better understanding of the water cycle. | The Request for Earth and Environmental Systems Modeling will focus investments on further refinement of the science underpinning non-hydrostatic adaptive mesh modeling and incorporating the necessary software for deployment of the model onto exascale computing architectures. The E3SM version 1 release in April 2018 will be updated to a version 2 model that is anticipated to be released in FY 2022. Version 2 will enable more sophisticated research based on higher model resolution, and the new version will add advanced capabilities for exploring cryosphere-ocean dynamics' impacts of climate variability on Antarctic ice shelf melting, continental ice sheet evolution and sea level rise, and the effects of changing water cycles on watershed and coastal hydrological systems. | Funding will support development of Version 2 of E3SM, with a planned release in FY 2022 to the scientific community in support of broad-based basic research as well as to energy sector stakeholders who require projections. |
| Core research continues to support model intercomparisons and diagnostics. In addition, research focuses on understanding the fine scale physics and dynamics that govern interactions between the Arctic and midlatitudes. | The Request will focus on core research in model intercomparisons and diagnostics. In addition, research will incorporate limited fine scale physics and dynamics that can be applied to metrics that can be applied to coastal zones and mid-latitude-Arctic interactions. | Funding will support research with a shift in emphasis from the science of just Arctic-midlatitude interactions to examine boundary regions that also include coastal zones. |

(dollars in thousands)

| FY 2020 Enacted | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|
| Earth and Environmental Systems Sciences Facilities and Infrastructure $123,110 | $102,635 | -$20,475 |
| ARM activities continue to provide new observations, through long term measurements at fixed sites in Alaska and Oklahoma and the Eastern North Atlantic. The ARM continues the seasonal mobile facility deployment at the Oliktok site. The research prioritizes all ARM activities for critical observations needed to improve the E3SM model. ARM is deploying the third mobile facility to northern Norway. Furthermore, ARM is completing a major multi-agency and multi-national campaign in the Arctic. Testing continues on the new aircraft acquired in FY 2019 to evaluate performance. | The Request for ARM will continue to provide new observations through long term measurements at fixed sites in Alaska and Oklahoma, while limiting active operations at the Eastern North Atlantic site. ARM will complete a long-term deployment of its Oliktok, AK, mobile facility in preparation for a new location in the southeastern U.S. in FY 2022. The Request prioritizes all ARM activities for critical observations needed to improve the E3SM model. ARM will initiate deployment of its second mobile facility to Houston, TX. The newly acquired aircraft will continue to undergo testing and evaluation, including modifications to the air frame as needed to install numerous existing and new atmospheric aerosol, cloud, turbulence, and other sensors. | Funding will support limited ARM Eastern North Atlantic site operations, and the mobile facility at Oliktok, Alaska will complete its deployment. |
| EMSL continues to focus on science that exploits unique capabilities of mass spectrometry (e.g., the HRMAC and nuclear magnetic resonance), live cell imaging, Quiet Wing, and high-performance computing. EMSL continues to build the Dynamic Transmission Electron Microscope, in support of BER science. | The Request for EMSL will continue to focus on science that exploits unique capabilities of mass spectrometry (e.g., the HRMAC and nuclear magnetic resonance), live cell imaging, Quiet Wing, and high-performance computing. EMSL will complete construction of the Dynamic Transmission Electron Microscope (DTEM) and provide some new capabilities in support of BER science. | Funding will support the multiple experimental capabilities of the new DTEM and a reduced number of users. |

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | | Explanation of Changes<br>FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|
| The Earth and Environmental Sciences Data Management activity continues to maintain existing critical software and data archives in support of ongoing experimental and modeling research. Essential data archiving and storing protocols, capacity is maintained. New analytical methodologies are being explored to advance scientific insight based on the fusion of model generated and observed data. | | The Request for the Earth and Environmental Sciences Data Management activity will provide support to maintain existing critical software and data archives in support of ongoing experimental and modeling research. Essential data archiving and storing protocols, capacity, and provenance will be maintained. Advanced analytical methodologies such as Machine Learning (ML) will be used to improve the predictability of extreme events more rapidly using Earth system models. | | Funding will support new analytical methodologies to advance scientific insight based on the fusion of model generated and observed data. |
| SBIR/STTR | $12,473 | | $6,356 | -$6,117 |
| In FY 2020, SBIR/STTR funding is set at 3.65 percent of non-capital funding. | | In FY 2021, SBIR/STTR funding is set at 3.65 percent of non-capital funding. | | The SBIR/STTR funding will be consistent with the BER total budget. |

## Biological and Environmental Research
## Capital Summary

(dollars in thousands)

| | Total | Prior Years | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|---|---|
| **Capital Operating Expenses** | | | | | | |
| Capital Equipment | N/A | N/A | 26,800 | 9,800 | 7,000 | -2,800 |
| **Total, Capital Operating Expenses** | **N/A** | **N/A** | **26,800** | **9,800** | **7,000** | **-2,800** |

## Capital Equipment

(dollars in thousands)

| | Total | Prior Years | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|---|---|
| **Capital Equipment** | | | | | | |
| Major Items of Equipment[a] | | | | | | |
| *Earth and Environmental Systems Sciences* | | | | | | |
| Atmospheric Radiation Measurement Research Facility (ARM) – ARM Aircraft project | 17,700 | 200[b] | 17,500 | — | — | — |
| Total, MIEs | N/A | N/A | 17,500 | — | — | — |
| Total, Non-MIE Capital Equipment | N/A | N/A | 9,300 | 9,800 | 7,000 | -2,800 |
| **Total, Capital Equipment** | **N/A** | **N/A** | **26,800** | **9,800** | **7,000** | **-2,800** |

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

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

Earth and Environmental Systems Sciences Facilities and Infrastructure MIE(s):

*Atmospheric Radiation Measurement Research Facility (ARM) – ARM Aircraft project*

BER-supported scientists require high-quality and well-characterized in situ aircraft observations of aerosol and cloud microphysical properties and coincident dynamical and thermodynamic properties to continue to improve fundamental understanding of the physical and chemical processes that control the formation, life cycle, and radiative impacts of cloud and aerosol particles. To meet these needs, the ARM user facility has been using a dedicated large twin-turboprop Gulfstream-159 (G-1) aircraft to conduct weeks- to months-long intensive observational campaigns over a range of meteorological conditions and locations around the world. The G-1 aircraft used by ARM was built in 1961, was one of only 10 G-1s that remained in service worldwide and was at the end of its service life. BER initiated retirement and replacement of the aircraft in FY 2019. The FY 2019 Enacted budget included funding to replace the Battelle-owned G-1 aircraft that supported airborne data collection as part of ARM field campaigns. The FY 2020 Enacted budget and the FY 2021 Request will support continued testing and evaluation of the newly acquired DOE-owned Bombardier Challenger 850 Regional Jet aircraft. This includes supporting modifications to the air frame as needed to install numerous existing and new atmospheric aerosol, cloud, turbulence, and other sensors. This aircraft will allow for observations that will provide new data to address the main source of uncertainty in Earth system models: the interdependence of clouds, atmospheric aerosols, and precipitation that in turn influences the radiation balance. Earth system modeling, simulation, and analysis tools that will be enabled through this capability are essential for informing energy infrastructure investment decisions that have the future potential for large-scale deployment that in turn benefit national security.

**Biological and Environmental Research**
**Funding Summary**

(dollars in thousands)

| | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|
| Research | 516,858 | 570,500 | 367,684 | -202,816 |
| Facility Operations | 170,642[a] | 179,500 | 149,250 | -30,250 |
| Projects | | | | |
| Major Items of Equipment | 17,500 | — | — | — |
| Construction | — | — | — | — |
| Total, Projects | 17,500 | — | — | — |
| **Total, Biological and Environmental Research** | **705,000** | **750,000** | **516,934** | **-233,066** |

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

**Biological and Environmental Research**
**Scientific User Facility Operations**

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

(dollars in thousands)

| | FY 2019 Enacted | FY 2019 Current | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|---|
| **TYPE B FACILITIES** | | | | | |
| **Atmospheric Radiation Measurement Research Facility (ARM)** | **$85,500**[a] | **$85,500**[a] | **$70,110** | **$54,500** | **-$15,610** |
| Number of users | 980 | 980 | 1,100 | 900 | -200 |
| **Joint Genome Institute** | **$70,000** | **$70,000** | **$77,000** | **$60,000** | **-$17,000** |
| Number of users | 1,933 | 1,933 | 1,925 | 1,550 | -375 |
| **Environmental Molecular Sciences Laboratory** | **$45,000** | **$45,000** | **$45,000** | **$43,500** | **-$1,500** |
| Number of users | 577 | 577 | 577 | 525 | -52 |
| **Total Facilities** | **$200,500** | **$200,500** | **$192,110** | **$158,000** | **-34,110** |
| Number of users | 3,490 | 3,490 | 3,602 | 2,975 | -627 |

[a] Includes Air-ARM MIE - replacement aircraft.

**Biological and Environmental Research**
**Scientific Employment**

| | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|
| Number of permanent Ph.D.'s (FTEs) | 1,425 | 1,500 | 1,250 | -250 |
| Number of postdoctoral associates (FTEs) | 350 | 370 | 280 | -90 |
| Number of graduate students (FTEs) | 490 | 520 | 400 | -120 |
| Other scientific employment (FTEs)[a] | 350 | 370 | 280 | -90 |

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

## Fusion Energy Sciences

### Overview

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

Plasma science is wide-ranging, with various types comprising 99 percent of the visible universe. It is the state of matter in the sun's center, corona, and solar flares. Plasma dynamics are at the heart of the formation of galactic jets and accretion of stellar material around black holes. On Earth it is the substance of lightning and flames. Plasma physics describes the processes giving rise to the aurora that illuminates the far northern and southern nighttime skies. Practical applications of plasmas are found in various forms of lighting and semiconductor manufacturing. High-temperature fusion plasmas at hundreds of millions of degrees occur in national security applications, albeit for very short times. The same fusion plasmas may be exploited in the laboratory in a controlled fashion to become the basis for a future clean nuclear power source, which could provide domestic energy independence and security. This is a large driver for the FES subprograms focused on the scientific study of "burning plasma." In the burning plasma state of matter, the nuclear fusion process itself provides the dominant heat source for sustaining the plasma temperature. Such a self-heated plasma can continue to undergo fusion reactions that produce energy without requiring the input of heating power from the outside, and thus resulting in a large net energy yield.

In the FES program, foundational science for burning plasmas is obtained by investigating the behavior of laboratory fusion plasmas confined with strong magnetic fields. The DIII-D National Fusion Facility and the National Spherical Torus Experiment-Upgrade (NSTX-U), the latter of which is currently down for recovery and repair, are world-leading Office of Science (SC) user facilities for experimental research, available to and used by scientists from national laboratories, universities, and industry research groups.

Complementing these experimental activities is a significant effort in fusion theory and simulation to predict and interpret the complex behavior of plasmas as self-organized systems. As part of this effort, FES supports several Scientific Discovery through Advanced Computing (SciDAC) centers, in partnership with the Advanced Scientific Computing Research (ASCR) program. FES also investigates the behavior of plasmas that are confined near steady state. U.S. scientists take advantage of international partnerships to conduct research on superconducting tokamaks and stellarators with long-duration capabilities. In addition, the development of novel materials, a research area of high interest to many scientific fields, is especially important for fusion energy sciences since fusion plasmas create an environment of high-energy neutrons and huge heat fluxes that impinge on and damage the material structures containing the plasmas.

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

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

The FES program addresses several of the Administration's research and development (R&D) budget priorities[a]. Research in fusion has the potential to contribute to American energy dominance by making a clean energy technology that relies on widely available and virtually inexhaustible fuel sources available to the American people. Research in plasma science, within and beyond fusion, will contribute to American prosperity through the tremendous potential for spinoff applications

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

(described in a report by the Fusion Energy Sciences Advisory Committee [FESAC][a] ) as well as targeted investments (e.g., in early-stage low temperature plasma research) that can lead to the development of transformative technologies. Investments in SC's major fusion facilities and smaller-scale experiments will help maintain and modernize the research infrastructure necessary to conduct world-leading research. Established partnerships within and outside DOE maximize, leverage, and increase the cost effectiveness of FES research activities. Also, FES partnerships with industry through the Innovation Network for Fusion Energy (INFUSE) program will propagate scientific discoveries that could transition into the private sector. Investments in transformational technologies such as artificial intelligence and machine learning (AI/ML), quantum information science (QIS), microelectronics, and high-performance strategic computing could accelerate progress in several mission areas. Finally, the unique scientific challenges and rigor of fusion and plasma physics research lead to the development of a well-trained STEM workforce, which will contribute to maintaining and advancing U.S. competitiveness and world-leadership in key areas of future technological and economic importance, as well as national security.

**Highlights of the FY 2021 Request**
The FY 2021 Request is $425,151,000. The priorities described in "The Office of Science's Fusion Energy Sciences Program: A Ten-Year Perspective,"[b] the research opportunities identified in a series of community engagement workshops held in 2015,[c] and the FY 2017 FESAC report on the potential for transformative developments in fusion science and technology[d] informed the strategic choices in this Request. Priorities include keeping SC fusion user facilities world-leading, investing in high-performance computing and preparing for exascale, exploring the potential of QIS and machine learning, supporting high-impact research in fusion materials, strengthening partnerships for access to international facilities with unique capabilities, learning how to predict and control transient events in fusion plasmas, continuing stewardship of discovery plasma science (e.g., via intermediate-scale facilities), and continuing to seek opportunities with private-public partnerships. Furthermore, the 2018 report[e] of the National Academies of Sciences, Engineering, and Medicine burning plasma study commissioned by FES also informs the research priorities for burning plasma science.

Key elements in the FY 2021 Request include:

<u>Research</u>

- DIII-D research: DIII-D research will focus on assessing the reactor potential of current-drive systems to inform the design of next-step devices, integrating core and edge plasma solutions that extrapolate to future fusion reactors, and advancing the understanding of power exhaust strategies.
- NSTX-U research: The NSTX-U research budget will fund a focused effort on physics topics that directly support the recovery of robust NSTX-U plasma operations, as well as collaborative research at other facilities to support NSTX-U research program priorities.
- Partnerships with private fusion efforts: Private-public collaborations through the INFUSE program will leverage opportunities in critical fusion research areas (e.g., diagnostics, theory and simulation, materials science, and magnet technology).
- Enabling technology, fusion nuclear science, and materials: Research will continue on high-temperature superconductors and additive manufacturing. FES will continue to explore options for a neutron source that will test materials in fusion-relevant environments.
- Scientific Discovery through Advanced Computing: SciDAC projects will continue development of an integrated whole-device modeling capability, in partnership with the ASCR program, and pursue transformative approaches such as machine learning and QIS.
- Long-pulse tokamak and stellarator research: Long-pulse tokamak research enables U.S. scientists to work on superconducting tokamaks with world-leading capabilities. Long-pulse stellarator research will allow U.S. teams to take full advantage of U.S. hardware investments on the Wendelstein 7-X (W7-X) stellarator and enhance the scientific output on this device.

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[a] https://science.osti.gov/~/media/fes/fesac/pdf/2015/2101507/FINAL_FES_NonFusionAppReport_090215.pdf
[b] https://science.osti.gov/-/media/fes/pdf/workshop-reports/2016/FES_A_Ten-Year_Perspective_2015-2025.pdf
[c] https://science.osti.gov/fes/Community-Resources/Workshop-Reports
[d] https://science.osti.gov/-/media/fes/fesac/pdf/2018/TEC_Report_15Feb2018.pdf
[e] https://www.nap.edu/catalog/25331/final-report-of-the-committee-on-a-strategic-plan-for-us-burning-plasma-research

- Discovery plasma science: Research continues to support small- and intermediate scale basic plasma science and HEDLP facilities, and also future fusion design studies. FES will partner with ASCR, Basic Energy Sciences (BES), and High Energy Physics (HEP) to support multi-disciplinary microelectronics research that will promote basic research to accelerate the advancement of microelectronic technologies in a co-design innovation ecosystem in which materials, chemistries, devices, systems, architectures, algorithms, and software are developed in a closely integrated fashion.
- QIS: In support of the National Quantum Initiative, the Request continues support for the SC QIS Center(s) established in FY 2020. These centers constitute an interdisciplinary partnership among SC Program Offices. This partnership complements a robust core research portfolio stewarded by the individual SC programs to create the ecosystem across universities, national laboratories, and industry that is needed to advance developments in QIS and related technology.

Facility Operations

- DIII-D operations: The funding will allow 13 weeks of facility operations, along with machine and infrastructure refurbishments and improvements for new research capabilities.
- NSTX-U recovery activities: The NSTX-U facility is down for recovery and repair, which will continue through FY 2021. The NSTX-U Operations budget will support high-priority activities to implement repairs and corrective actions required to achieve research operations, as well as to increase machine reliability.

Projects

- Continued U.S. hardware development and delivery to ITER: The FY 2021 Request will support the continued design and fabrication of the highest-priority in-kind hardware systems. This includes continued fabrication of the Central Solenoid magnet system, which consists of seven superconducting modules, structural components, and assembly tooling. The U.S. will also continue design and fabrication efforts for other hardware systems.
- High energy density laboratory plasmas: FES will support design activities for a significant upgrade to the MEC instrument on the LCLS facility at SLAC.
- Major Item of Equipment (MIE) project for world-leading fusion materials research: The Materials Plasma Exposure eXperiment (MPEX) MIE project will be a world-leading facility for steady-state, high-heat-flux testing of fusion materials. The project is expected to achieve Critical Decision (CD) 1 in FY 2020. FY 2021 funding will maintain required detailed design and R&D activities, develop the performance baseline, and allow for initiation of long-lead major procurements for the device.

Other

- GPP/GPE: Funding is provided for General Plant Projects/General Purpose Equipment, to support Princeton Plasma Physics Laboratory (PPPL) infrastructure improvements and repairs.

**FY 2021 Research Initiatives**

Fusion Energy Sciences supports the following FY 2021 Research Initiatives

| | (dollars in thousands) | | | |
|---|---|---|---|---|
| | **FY 2019 Enacted** | **FY 2020 Enacted** | **FY 2021 Request** | **FY 2021 Request vs FY 2020 Enacted** |
| **Ongoing Research Initiatives** | | | | |
| Artificial Intelligence and Machine Learning | — | 7,000 | 7,000 | — |
| Microelectronics Innovation | 4,000 | — | 5,000 | +5,000 |
| Quantum Information Science | — | 7,520 | 9,520 | +2,000 |
| U.S. Fusion Program Acceleration program[a][b] | 2,000 | 4,000 | 5,000 | +1,000 |
| **Total, Ongoing Research Initiatives** | **6,000** | **18,520** | **26,520** | **+8,000** |

[a] In FY 2021, the U.S. Fusion Program Acceleration initiative focuses on strengthening fusion research within the United States. This initiative includes the INFUSE program ($4 million) and a study to determine the needs for a future fusion facility ($1 million).

[b] In FY 2019, INFUSE funding was included under Science Discovery through Advanced Computing (SciDAC) and High Energy Density Laboratory Plasmas (HEDLP) activities. Starting in FY 2020, INFUSE is identified as a separate activity.

## Fusion Energy Sciences
## Funding

| | (dollars in thousands) | | | |
|---|---|---|---|---|
| | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
| **Burning Plasma Science: Foundations** | | | | |
| Advanced Tokamak | 130,500 | 123,500 | 92,500 | -31,000 |
| Spherical Tokamak | 96,000 | 101,000 | 72,500 | -28,500 |
| Theory & Simulation | 50,000 | 44,000 | 51,000 | +7,000 |
| GPE/GPP/Infrastructure | 10,204 | 7,000 | 1,000 | -6,000 |
| Innovation Network for Fusion Energy (INFUSE) program[a] | — | 4,000 | 4,000 | — |
| **Total, Burning Plasma Science: Foundations** | **286,704** | **279,500** | **221,000** | **-58,500** |
| | | | | |
| **Burning Plasma Science: Long Pulse** | | | | |
| Long Pulse: Tokamak | 14,000 | 14,000 | 8,000 | -6,000 |
| Long Pulse: Stellarators | 8,500 | 8,500 | 7,500 | -1,000 |
| Materials & Fusion Nuclear Science | 38,746 | 47,500 | 33,500 | -14,000 |
| **Total, Burning Plasma Science: Long Pulse** | **61,246** | **70,000** | **49,000** | **-21,000** |
| | | | | |
| **Discovery Plasma Science** | | | | |
| Plasma Science Frontiers | 52,050 | 42,500 | 25,000 | -17,500 |
| Measurement Innovation | 8,000 | 3,000 | 3,000 | — |
| SBIR/STTR & Other | 24,000 | 19,000 | 15,151 | -3,849 |
| **Total, Discovery Plasma Science** | **84,050** | **64,500** | **43,151** | **-21,349** |
| **Subtotal, Fusion Energy Sciences** | **432,000** | **414,000** | **313,151** | **-100,849** |

[a] In FY 2019, INFUSE funding was included under Science Discovery through Advanced Computing (SciDAC) and High Energy Density Laboratory Plasmas (HEDLP) activities. Starting in FY 2020, INFUSE is identified as a separate activity.

| | (dollars in thousands) | | | |
|---|---|---|---|---|
| | **FY 2019 Enacted** | **FY 2020 Enacted** | **FY 2021 Request** | **FY 2021 Request vs FY 2020 Enacted** |
| **Construction** | | | | |
| 20-SC-61, Matter in Extreme Conditions Petawatt Upgrade | — | 15,000 | 5,000 | -10,000 |
| 14-SC-60, U.S. Contributions to ITER | 132,000 | 242,000 | 107,000 | -135,000 |
| **Total, Construction** | **132,000** | **257,000** | **112,000** | **-145,000** |
| **Total, Fusion Energy Sciences** | **564,000** | **671,000** | **425,151** | **-245,849** |

SBIR/STTR funding:

- FY 2019 Enacted: SBIR $12,992,000 and STTR $1,827,000
- FY 2020 Enacted: SBIR $12,348,000 and STTR $1,737,000
- FY 2021 Request: SBIR $8,469,000 and STTR $1,191,000

## Fusion Energy Sciences
## Explanation of Major Changes

| | (dollars in thousands) FY 2021 Request vs FY 2020 Enacted |
|---|---|
| **Burning Plasma Science: Foundations**<br>The Request for DIII-D supports the transition to extended shift operations to allow increased utilization of the facility, with 13 weeks of research operations, as well as some continued facility enhancements to ensure the world-leading status of the facility. Funding for the NSTX-U program will support the completion of the NSTX-U Recovery project and initiation of machine commissioning, and maintain collaborative research at other facilities to support NSTX-U research program priorities. SciDAC continues to make progress toward whole-device modeling; this subprogram will also continue exploring transformative approaches to fusion science, such as machine learning and QIS. Enabling R&D will focus attention on high-temperature superconductor development. Funding is provided for General Plant Projects/General Purpose Equipment (GPP/GPE) to support critical infrastructure improvements and repairs at PPPL and other DOE laboratories where fusion research is conducted. Private-public partnership collaborations through the INFUSE program will continue. | **-58,500** |
| **Burning Plasma Science: Long Pulse**<br>The Request will continue to provide support for high-priority international collaboration activities, both for tokamaks and stellarators. Materials research and fusion nuclear science research programs are focused on high priorities, such as advanced plasma-facing and structural materials. The Request supports design and R&D activities for the MPEX MIE project, expected to be baselined in FY 2021, and initiates long-lead major procurements. | **-21,000** |
| **Discovery Plasma Science**<br>For General Plasma Science, the Request emphasizes user research on collaborative research facilities at universities and national laboratories and participation in the NSF-DOE Partnership. For High Energy Density Laboratory Plasmas, the focus remains on supporting research utilizing the Matter in Extreme Conditions (MEC) instrument of the LCLS user facility at SLAC, supporting research on medium-scale laser facilities through the LaserNetUS network, and exploring research opportunities of QIS. | **-21,349** |
| **Construction**<br>FES will support design activities for a significant upgrade to the MEC instrument. The U.S. Contributions to ITER project will continue design, fabrication, and delivery of highest-priority First Plasma hardware. | **-145,000** |
| **Total, Fusion Energy Sciences** | **-245,849** |

**Basic and Applied R&D Coordination**

FES participates in coordinated intra- and inter-agency initiatives within DOE and with other federal agencies on science and technology issues related to fusion and plasma science. Within SC, FES operates the MEC instrument at the SLAC LCLS user facility operated by BES, and supports high-performance computing research with ASCR. Within DOE, FES operates a joint program with NNSA in HEDLP physics and, in FY 2020, conducted joint solicitations with the Advanced Research Projects Agency-Energy (ARPA-E). FESAC provides technical and programmatic advice to FES and NNSA for the joint HEDLP program. Outside DOE, FES carries out a discovery-driven plasma science research program in partnership with NSF. Research supported through this joint program extends to a wide range of natural phenomena, including the origin of magnetic fields in the universe and the nature of plasma turbulence. The joint programs with NNSA and NSF involve coordination of solicitations, peer reviews, and workshops.

**Program Accomplishments**

*The need for a new fusion materials irradiation capability.*

The FES sponsored U.S. Virtual Laboratory for Technology (VLT) organized a workshop to discuss the need for a fusion prototypic neutron source (FPNS) and to determine the parameters required to fill this need. The workshop reached the unanimous conclusion that a near term, moderate cost FPNS would significantly advance the scientific understanding of materials degradation in the intense fusion neutron environment and would be a major asset to the U.S. fusion program. A FPNS is a potential intermediate step to next generation sources such as the International Fusion Materials Irradiation Facility (IFMIF) being pursued by the EU and Japan if it becomes available near-term. Achieving this role requires start of construction within about three years.

*The Innovation Network for Fusion Energy (INFUSE) pilot program.*

Recognizing the surge in interest and investments by the private sector in the development of fusion energy, FES launched a pilot program to accelerate progress in fusion energy by establishing research partnerships with the private sector. These private-public research partnerships enable applicants to access and leverage the world-class expertise and capabilities in fusion science available at the DOE national laboratories. This new FES program is modeled after the successful Gateway for Accelerated Innovation in Nuclear (GAIN) Nuclear Energy Voucher program established by the Office of Nuclear Energy.

*Machine learning allows NSTX-U to accurately model external heating during plasma discharges.*

Neutral beam injectors are an effective source of heating for fusion experimental plasmas, but understanding this power tends to be a slow, analysis intensive process requiring many discharges. Recently, researchers at the Princeton Plasma Physics Laboratory (PPPL) were able to develop a new model of neutral beam injection that is fast and accurate enough to be useful in controlling discharges as they evolve. The scientists used neural networks and trained the model using a database of NSTX-U discharges. If this new model is used to control the plasma, it is expected that the optimization of plasma performance scenarios could be achieved many times faster than is typical.

*Establishment of LaserNetUS.*

FES established a network of laser facilities in the U.S. that includes nine institutions: the University of Texas at Austin, The Ohio State University, Colorado State University, The University of Michigan, University of Nebraska- Lincoln, University of Rochester, SLAC National Accelerator Laboratory, Lawrence Berkeley National Laboratory, and Lawrence Livermore National Laboratory. LaserNetUS will provide scientists with access to these facilities, promote networking and collaboration, develop next generation workforce for DOE laboratories, and help the U.S. regain the recently lost leadership in high intensity laser science.

*U.S. diagnostic is key to Wendelstein 7-X (W7-X) stellarator world record.*

W7-X attained the stellarator world record for the fusion triple product of ion temperature, plasma density, and energy confinement. This represents further progress towards achieving the reactor values needed to ignite a plasma. This value of the fusion triple product is excellent for a device of this size, achieved under realistic conditions, i.e. at a high temperature of the plasma ions. The temperature was measured by the x-ray imaging crystal spectrometer, built and operated by PPPL. The record could not have been confirmed without the crucial spectrometer measurement.

*Never-before-seen Parker spiral created in the Laboratory.*
The Sun is a spinning ball of plasma that generates its own magnetic field. Fueled by the nuclear fusion in its core, the Sun spews plasma out into the solar system forming the solar wind. The solar wind sweeps away the Sun's magnetic field. As the Sun rotates, the magnetic field bends into a spiral structure known as the Parker spiral. For the very first time, researchers recreated the Parker spiral in the laboratory by forcing a helium plasma to rotate in the plasma confinement vessel. Once the plasma spun fast enough, its magnetic field formed a spiral. Although the Parker spiral is far more complex and expansive than its laboratory equivalent, this laboratory plasma model accurately reproduces the structure of the Sun's magnetic field. The results can be used to further examine the origin and evolution of the solar wind.

*Plasma syntheses of nanoparticles.*
Exact mechanisms of nanoparticle growth in an arc discharge are not fully understood because it is difficult to make in situ measurements of nanoparticles. For the first time, spatially-resolved measurements with a planar laser-induced incandescence technique, and simulations were performed to identify the plasma parameters and location where nanoparticles form and grow in an atmospheric pressure carbon arc. The measurements revealed that large clouds of nanoparticles have formed in the arc periphery bordering the region with a high density of diatomic carbon molecules. Two-dimensional fluid simulations of the arc combined with thermodynamic modeling show that the nanoparticle cloud shape is determined by the convection flow pattern, and nanoparticle size is determined by the rate of the condensation of carbon molecular species and particle agglomeration. These results will contribute to the development of more accurate models for the growth of nanoparticles and nanotubes in plasma environments.

*Several key DIII-D facility enhancements completed.*
In May, 2018, the DIII-D National Fusion Facility began an extended shutdown period in order to implement several major facility enhancements that could not be completed while the facility was operating. This work was completed on schedule in April 2019, and research operations resumed as planned in June. The enhancements to the facility will give DIII-D researchers several new world-unique tools to investigate the physics of advanced tokamak fusion plasmas. The new heating and current drive capabilities, as well as improvements to DIII-D's interior structure and diagnostic systems, have already been commissioned and are being used in experiments. These new resources will help DIII-D scientists to further optimize the advanced tokamak as a fusion energy source.

*Building the world's largest pulsed electromagnet*.
ITER's giant central solenoid was designed to induce a powerful current in the ITER plasma and maintain it during long pulses. The ITER project intends to demonstrate that through magnetically confined super-hot plasma, more energy will be given off than what it took to make the fusion reaction for a sustained period of time. The implications of a successful demonstration are world changing and may eventually lead to fusion energy power plants. One of the critical systems the U.S. is providing is the central solenoid (CS), which serves as the backbone of the ITER Magnet System. The CS consists of six independent coil modules held together by a vertical pre-compression structure. The U.S. is responsible for the six modules, an additional spare module, the structure that connects them together, and the required assembly tooling. When installed, the CS will be able to generate 6.4 Gigajoules of stored magnetic energy. The manufacturing process takes approximately 22 to 24 months per module plus an additional five to six months of testing. In April 2019, the first of seven modules successfully passed the first round of extensive testing. Six modules are currently in various stages of production and the first will be ready in early 2020 for shipment.

**Fusion Energy Sciences**
**Burning Plasma Science: Foundations**

**Description**
The Burning Plasma Science: Foundations subprogram advances the predictive understanding of plasma confinement, dynamics, and interactions with surrounding materials.

Among the activities supported by this subprogram are:

- Research at major experimental facilities aimed at resolving fundamental advanced tokamak and spherical tokamak science issues.
- Research on small-scale magnetic confinement experiments to elucidate physics principles underlying toroidal confinement and to validate theoretical models and simulation codes.
- Theoretical work on the fundamental description of magnetically confined plasmas and the development of advanced simulation codes on current and emerging high-performance computers.
- Research on technologies needed to support the continued improvement of the experimental program and facilities.
- Support for infrastructure improvements at Princeton Plasma Physics Laboratory (PPPL) and other DOE laboratories where fusion research is ongoing.
- Support for private-public partnerships through the INFUSE program.

Research in the Burning Plasma Science: Foundations area in FY 2021 will focus on high-priority scientific issues and opportunities in the areas of transients in tokamaks, plasma-material interactions, and whole-device modeling, as identified by basic research needs workshops and other community-led studies. It will also support new transformational approaches, such as machine learning, QIS, and other SC-wide initiatives.

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

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

Versatile, university-led, small-scale advanced tokamak research is complementary to the efforts at the major user facilities, providing rapid and cost-effective development of new techniques and exploration of new concepts. These activities are often the first step in a multi-stage approach toward the extension of the scientific basis for advanced tokamaks. Recent efforts are focused on improving fusion plasma control physics for advanced tokamaks through application of modern digital tokamak control theory and validation of fundamental plasma stability theory.

<u>Spherical Tokamak</u>
The NSTX-U user facility at PPPL is designed to explore the physics of plasmas confined in a spherical tokamak (ST) configuration, characterized by a compact (apple-like) shape. If the predicted ST energy confinement improvements are experimentally realized in NSTX-U, then the ST might provide a more compact fusion reactor than other plasma confinement geometries. In FY 2021, NSTX-U recovery activities will continue with component fabrication and installation, as well as addressing corrective actions that will ensure reliable plasma operations.

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

Theory and Simulation

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

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

The FES SciDAC element, a component of the SC-wide SciDAC program, is aimed at accelerating scientific discovery in fusion plasma science by capitalizing on SC investments in leadership-class computing systems and associated advances in computational science. The portfolio that emerged from the FY 2017 SC-wide SciDAC-4 re-competition and follow-up targeted reviews in FY 2018 consists of nine multi-institutional interdisciplinary partnerships, seven of which are jointly supported by FES and ASCR, and addresses the high-priority research directions identified in recent community workshops. The current portfolio emphasizes increased integration and whole-device modeling, as well as synergy with the fusion-relevant projects of the SC Exascale Computing Project (SC-ECP) to increase the readiness of the fusion community for the upcoming Exascale era.

Additional objectives of this element include the support of emerging computational approaches, such as ML and other data-centric technologies and the support of longer-term transformative research opportunities such as computing aspects of QIS, as identified in the 2018 FES Roundtable on QIS[a].

GPE/GPP/Infrastructure

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

Innovation Network for Fusion Energy Program

The Innovation Network for Fusion Energy (INFUSE) program provides private-sector fusion companies with access to the expertise and facilities of DOE's national laboratories to overcome critical scientific and technological hurdles in pursuing development of fusion energy systems. Initiated in FY 2019, this private-public research partnership program, the first of its kind in SC, is modeled after the successful Gateway for Accelerated Innovation in Nuclear (GAIN) Nuclear Energy Voucher program. The INFUSE program does not provide funding directly to the private companies, but instead provides support to DOE laboratories to enable them to collaborate with their industrial partners. Among the areas supported by INFUSE are the development of fusion technologies, such as new and improved magnets; materials science, including engineered materials, testing and qualification; plasma diagnostic development; modeling and simulation; and access to magnetic fusion experimental capabilities.

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

**Activities and Explanation of Changes**

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| **Burning Plasma Science: Foundations** | **$279,500** | **$221,000** | **-$58,500** |
| Advanced Tokamak | $123,500 | $92,500 | -$31,000 |
| *DIII-D Research* | *$56,000* | *$40,500* | *-$15,500* |
| *DIII-D Operations* | *$60,500* | *$49,000* | *-$11,500* |
| Funding supports 20 weeks of research at the DIII-D facility. The facility begins a transition to an extended shift mode of operation to support optimal facility operations levels for DIII-D. Facility improvements to increase auxiliary heating power, current drive, and 3D magnetic field shaping capabilities are supported. Research utilizes new heating and current drive systems to access steady-state tokamak plasma scenarios at high pressure and low rotation, further refine techniques to avoid and mitigate transients in tokamaks, and exploits new diagnostics to improve the understanding of divertor material erosion and transport. Specific research goals aim at resolution of predictive burning plasma physics, validation of impurity transport models, and integration of core and edge plasma solutions that extrapolate to future fusion reactors. | | The Request will support 13 weeks of operations at the DIII-D facility. Research will utilize newly installed capabilities including innovative current drive systems, tungsten tiles to study the transport of metal impurities, and new diagnostics to study pedestal and power exhaust physics. A new helium liquifier system will be installed and operated to improve availability of the facility. Specific research goals will aim at assessing the reactor potential of current-drive systems to inform the design of next-step devices, integrating core and edge plasma solutions that extrapolate to future fusion reactors, and advancing the understanding of power exhaust strategies. | Funding will support research and operations. Progress will continue on several high-priority facility enhancement projects aimed at ensuring the world-leading status of the facility. |

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes<br>FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| *Enabling R&D* | *$6,000* | *$2,000* | *-$4,000* |
| Funding supports research in high-temperature superconducting magnet technology and plasma fueling and heating technologies. Developing high-field magnet cable testing capabilities, in collaboration with the HEP continues. | | The Request will support continuing research in high-temperature superconducting magnet technology and plasma fueling and heating technologies. | Funding will focus on high-temperature superconducting magnet technology and heating and fueling technologies. |
| *Small-scale Experimental Research* | *$1,000* | *$1,000* | $— |
| Funding supports university-led experiments in developing innovative strategies to improve the performance of advanced tokamaks. | | The Request will continue university-led experiments to develop new optical-based tokamak control schemes, measure boundary and wall current dynamics during plasma disruptions, and refine scrape-off layer current control methods. | Support for research activities will continue at the same level of effort. |
| Spherical Tokamak | $101,000 | $72,500 | -$28,500 |
| *NSTX-U Research* | *$30,000* | *$27,000* | *-$3,000* |
| *NSTX-U Operations* | *$68,000* | *$43,500* | *-$24,500* |
| Funding supports continual recovery procurements and fabrication activities that are necessary to realize robust research operations. Research supports analysis and modeling efforts at other facilities that support NSTX-U research program priorities and the installation of high-priority diagnostic instruments on the device continues. | | The Request for operations funding will continue to support recovery procurements, fabrication, and machine reassembly activities that are necessary to resume robust research operations. Research efforts will focus on analysis and modeling activities at other facilities that support NSTX-U program priorities. | Operations funding will continue to support the NSTX-U Recovery activity as PPPL continues machine reassembly activities and prepares for machine commissioning and plasma start-up. Research funding will be dedicated to the highest-priority scientific objectives of NSTX-U. |

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| *Small-scale Experimental Research* | *$3,000* | *$2,000* | *-$1,000* |
| Funding supports studies and experiments focus on exploring operational scenarios without a central solenoid and model validation and detailed core turbulent transport mechanisms that elucidate experimental observations of improved confinement when the plasma is surrounded by liquid lithium. | | The Request will continue to support studies and experiments focused on exploring operational scenarios without a central solenoid, model validation, and detailed core turbulent transport mechanisms observed in plasmas with low recycling liquid lithium walls. | Research efforts will focus on the highest-priority activities. |
| Theory & Simulation | $44,000 | $51,000 | +$7,000 |
| *Theory* | *$19,000* | *$21,000* | *+$2,000* |
| Funding supports the foundational problems in the science of magnetic confinement. Emphasis is placed on research that maximizes synergy with large-scale simulation efforts and addresses recommendations from community workshops. | | The Request will continue to support theory and modeling efforts focusing on advancing the scientific understanding of the fundamental physical processes governing the behavior of magnetically confined plasmas. The activity will emphasize research that addresses critical burning plasma challenges, including plasma disruptions, runaway electrons, three-dimensional and non-axisymmetric effects, and the physics of the plasma boundary. | The increase in funding will strengthen efforts that address the needs of large-scale simulation projects. |
| *SciDAC* | *$25,000* | *$30,000* | *+$5,000* |
| Funding supports nine FES SciDAC partnerships to address challenges in burning plasma science, with emphasis on integration and whole-device modeling, as well as Exascale readiness. Progress in plasma disruptions accelerates following the addition of a partnership focusing on runaway electron physics in FY 2018. Validation of the simulation codes against experimental data is also emphasized. Research efforts focusing on emerging technologies with transformational potential, such as machine learning and computing aspects of QIS, continues. | | The Request will continue to support the nine FES SciDAC partnerships, now in their fifth and final year. Emphasis on whole-device modeling and Exascale readiness will continue. The Request will also support research on fusion-relevant quantum computing, machine learning, and artificial intelligence. | SciDAC partnerships will continue at the same level of effort. Additional funding will support new efforts in QIS and fusion-relevant AI/ML applications. |

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | | Explanation of Changes<br>FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|
| GPE/GPP/Infrastructure | $7,000 | | $1,000 | -$6,000 |
| Funding supports PPPL infrastructure improvements, repair, maintenance and environmental monitoring. In addition, a study of FES infrastructure needs at ORNL continues. | | The Request will support PPPL infrastructure improvements, repair, maintenance and environmental monitoring. | | Funding efforts will focus on the highest-priority activities. |
| Innovation Network for Fusion Energy (INFUSE) program | $4,000 | | $4,000 | — |
| Funding enables more awards, allows the participation of additional DOE laboratories in the program, and expands the eligibility requirements to include foreign companies, provided their participation in this activity is in the economic interest of the U.S. | | The Request will enable the INFUSE program to continue to provide funding opportunities for partnerships with the private sector through DOE laboratories in multiple research areas. | | The INFUSE program will continue at the same level of effort. |

**Fusion Energy Sciences**
**Burning Plasma Science: Long Pulse**

**Description**

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

Long Pulse: Tokamak

This program supports interdisciplinary teams from multiple U.S. institutions for collaborative research aimed at advancing the scientific and technology basis for sustained long-pulse burning plasma operation in tokamaks. Bilateral research on international facilities with capabilities not available in the U.S. targets critical topical areas identified in recent FESAC reports and detailed community workshop reports, including prediction and avoidance of transient events in fusion reactors, advanced algorithms such as AI/ML, plasma-material interactions, and integrated simulations. Research on overseas superconducting tokamaks, conducted onsite and also via fully remote facility operation, leverages progress made in domestic experimental facilities and provides access to model validation platforms for mission critical applications supported through the FES/ASCR partnership within the SciDAC portfolio. Efforts are augmented by research on non-superconducting tokamaks with access to burning plasma scenarios and mature diagnostic suites.

Long Pulse: Stellarator

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

U.S. domestic compact stellarator research is focused on improvement of the stellarator magnetic confinement concept through quasi-symmetric shaping of the toroidal magnetic field. Quasi-symmetric shaping, invented in the U.S., offers an improved solution for stable, well confined, steady-state stellarator plasmas.

Materials and Fusion Nuclear Science

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

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

**Activities and Explanation of Changes**

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| **Burning Plasma Science: Long Pulse** | **$70,000** | **$49,000** | **-$21,000** |
| Long Pulse: Tokamak | $14,000 | $8,000 | -$6,000 |
| Funding supports research on overseas superconducting tokamaks to integrate new diagnostics and control tools to improve the performance and duration of a wide-range of steady-state, long-pulse plasma scenarios in collaboration with international partners. Research goals support the pursuit of robust disruption and runaway mitigation solutions, validation of theoretical tools for plasma scenario development and optimization, and refinement of power exhaust control solutions that are consistent with transient-free plasma operation. | | The Request will support U.S. teams to develop prediction, avoidance, and mitigation strategies for potentially damaging transient events in large tokamaks, validate computational tools for integrated simulation of burning plasmas, and assess the potential of solid metal walls as the main plasma facing material in long-pulse tokamak facilities. | Research efforts will focus on high-priority topics aimed at resolving critical design issues for large long-pulse tokamaks such as ITER, and validation of predictive models that support facility and plasma control design frameworks. |
| Long Pulse: Stellarators | $8,500 | $7,500 | -$1,000 |
| *Superconducting Stellarator Research* | *$6,000* | *$5,000* | *-$1,000* |
| Funding supports U.S. scientist to complete fabrication and installation of a continuous high-speed pellet system to provide fueling for quasi-steady-state plasma experiments; develop a complete set of powder droppers for boron powder injection to enable steady-state wall conditioning; examine the effect of plasma turbulence and coherent modes on energy and particle transport; and explore edge radiative cooling with an island divertor, including 3D equilibrium effects. | | The Request will support U.S. scientists to utilize the continuous pellet fueling system, which was installed on W7-X, to understand optimum profiles for turbulence suppression. This U.S.-built system, which is critical for long-pulse operation, will help address a number of scientific issues involved with quasi-steady-state operation for the stellarator configuration. | Research efforts will focus on the highest-priority activities. |

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| *Compact Stellarator Research* | *$2,500* | *$2,500* | *$—* |
| Funding supports research on experiments that are providing data in regimes relevant to mainline stellarator confinement and experimental validation of models and codes. | | The Request will support experiments in regimes relevant to the mainline stellarator magnetic confinement efforts and help confirm theoretical models and simulation codes to support the development of an experimentally-validated predictive capability for magnetically-confined fusion plasmas. | Research efforts will continue at the same level of support. |
| Materials & Fusion Nuclear Science | $47,500 | $33,500 | -$14,000 |
| *Fusion Nuclear Science* | *$11,000* | *$8,500* | *-$2,500* |
| Funding supports research to focus on the core areas of plasma-facing components, safety, tritium fuel cycle, and breeder blanket technologies. Opportunities are pursued for expansion into other novel technologies as identified by the FESAC report on Transformative Enabling Capabilities. In addition, FES continues to evaluate options for a near-term fusion-relevant neutron source. | | The Request will continue to focus on the core research areas of tritium fuel cycle, breeder blanket technologies, safety, and plasma-facing components. The program will continue expanding efforts into the areas of novel fusion blanket and tritium fuel cycle research. In addition, FES will continue to evaluate options for a near-term neutron source to test materials in fusion-relevant environments. | Research efforts will focus on the highest-priority areas across the entire fusion nuclear science technology portfolio to balance the core programs and expansion into new areas. |
| *Materials Research* | *$15,500* | *$13,000* | *-$2,500* |
| Funding supports research efforts to focus on the development of materials that can withstand the extreme fusion environment. Working toward opportunities for expansion into high-priority research in advanced materials and manufacturing. | | The Request will continue to focus research on the development of materials that can withstand the extreme fusion environment, including further expansion into the high impact topics of advanced materials and manufacturing. | Research efforts will focus on high-priority activities in fusion materials research. |
| *Projects* | *$21,000* | *$12,000* | *-$9,000* |
| Funding supports the MPEX MIE project and enables engineering design activities and preparation for baseline approval and long-lead procurements. | | The Request will continue to support the MPEX MIE project. Activities will include the establishment of the project performance baseline and the initiation of long-lead procurement items. | Funding will continue to support critical activities required to develop a cost, schedule, and scope baseline and initiate long-lead procurements for the MPEX MIE project. |

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

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

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

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

- General Plasma Science: Research at the frontiers of basic and low temperature plasma science, including dynamical processes in laboratory, space, and astrophysical plasmas, such as magnetic reconnection, dynamo, shocks, turbulence cascade, structures, waves, flows and their interactions; behavior of dusty plasmas, non-neutral, single-component matter or antimatter plasmas, and ultra-cold neutral plasmas; plasma chemistry and processes in low-temperature plasma, interfacial plasma, synthesis of nanomaterials, and interaction of plasma with surfaces, materials or biomaterials. In addition, this portfolio supports microelectronics and QIS research opportunities.
- High Energy Density Laboratory Plasmas: Research directed at exploring the behavior of matter at extreme conditions of temperature, density, and pressure, including laboratory astrophysics and planetary science, structure and dynamic of matter at the atomic scale, laser-plasma interactions and relativistic optics, magnetohydrodynamics and magnetized plasmas, and plasma atomic physics and radiation transport. In addition, this portfolio supports QIS research opportunities.
- Exploratory Magnetized Plasma: Basic research involving the creation, control, and manipulation of magnetically confined plasmas to increase the understanding of terrestrial, space, and astrophysical phenomena or applications.

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

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

programs at major fusion facilities. In addition, this portfolio supports new QIS research opportunities on fusion-relevant quantum sensing applications.

SBIR/STTR & Other

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

**Activities and Explanation of Changes**

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| **Discovery Plasma Science** | **$64,500** | **$43,151** | **-$21,349** |
| Plasma Science Frontiers | $42,500 | $25,000 | -$17,500 |
| *General Plasma Science* | *$18,000* | *$13,000* | *-$5,000* |
| Funding supports core research areas focused on basic plasma science and low-temperature plasma collaborative research facilities, including support for users of these facilities. | | The Request supports core research activities in basic and low temperature plasma science focused on supporting user research on collaborative research facilities at universities and national laboratories. | Research efforts will focus on highest-priority science issues in both basic and low temperature plasmas. |
| *High Energy Density Laboratory Plasmas* | *$20,000* | *$12,000* | *-$8,000* |
| Funding supports research with an emphasis on utilization of the Matter in Extreme Conditions (MEC) instrument at the LCLS at SLAC. Support continues for the MEC beam-line science team and the LaserNetUS initiative. Application of HEDLP to advance QIS is supported. | | The Request will emphasize research utilizing the MEC, LaserNetUS, and QIS. | Research efforts will focus on the highest-priority science issues. |
| *Projects* | *$4,500* | *$—* | *-$4,500* |
| Funding continues to support the conceptual design of the MEC Petawatt Upgrade. | | No funding is requested. | No funding is requested. |
| Measurement Innovation | $3,000 | $3,000 | $— |
| Funding supports the development of transformative and innovative diagnostics for plasma transient instabilities, plasma-materials interactions, modeling validation, and basic plasma science identified in the community workshops as well as for partnership opportunities with the private sector. | | The Request will continue to support the development of transformative and innovative diagnostics for plasma transient instabilities, plasma-material interactions, modeling validation, QIS research activities, and basic plasma science identified in the community engagement workshops. | Research efforts will focus on highest-priority activities. |

(dollars in thousands)

| FY 2020 Enacted | FY 2021 Request | Explanation of Changes<br>FY 2021 Request vs FY 2020 Enacted |
|---|---|---|
| SBIR/STTR & Other $19,000 | $15,151 | -$3,849 |
| Funding supports USBPO activities, HBCUs, peer reviews for solicitations, outreach programs, and FESAC. SBIR/STTR funding is statutorily set at 3.65 percent of noncapital funding in FY 2020. | The Request will continue to support USBPO activities, HBCUs, peer reviews for solicitations, outreach programs, and FESAC. In addition, the Request will support the initiation of a study for a future fusion facility complex that will support both public and private activities. SBIR/STTR is statutorily set at 3.65 percent of noncapital funding in FY 2021. | The study effort on a future fusion facility complex is a new activity for this program element. The SBIR/STTR funding will be consistent with the FES total budget. |

## Fusion Energy Sciences
## Construction

### Description

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

Matter in Extreme Conditions (MEC) Petawatt Upgrade

The National Academies of Sciences, Engineering, and Medicine (NAS) 2017 report "Opportunities in Intense Ultrafast Lasers: Reaching for the Brightest Light[a]" recommended that "The Department of Energy should plan for at least one large-scale open-access high-intensity laser facility that leverages other major science infrastructure in the Department of Energy complex". The MEC Petawatt Upgrade project was a new start in FY 2020 and is an upgrade to the existing MEC facility. This project is aimed at providing an experimental collaborative National User Facility for High-Energy-Density Science that will address this NAS recommendation as well as maintain U.S. leadership in this important field of study. MEC is an experimental research end-station that utilizes SLAC's Linac Coherent Light Source. The project received CD-0, "Approve Mission Need" on January, 4, 2019. The FY 2021 Request of $5,000,000 will support conceptual design of the MEC Petawatt Upgrade. The estimated total project cost is $50,000,000 to $200,000,000.

ITER

The ITER facility, currently under construction in St. Paul-lez-Durance, France, and more than 65 percent complete for First Plasma, is designed to provide fusion power output approaching reactor levels of hundreds of megawatts, for hundreds of seconds. Construction of ITER is a collaboration among the United States, European Union, Russia, Japan, India, Republic of Korea, and China, governed by an international agreement (the "ITER Joint Implementing Agreement"), through which the U.S. contributes in-kind-hardware components, personnel, and also a financial contribution, e.g. for the installation and assembly of the components provided by the U.S. and other Members to the ITER Organization (IO). An independent review of CD-2, "Approve Performance Baseline" for the First Plasma subproject was completed in November 2016 and then subsequently approved by the Project Management Executive (PME) on January 13, 2017, with a total project cost of $2.5 billion. The FY 2021 Request of $107,000,000 will support the highest priority activities. The estimated total project cost is $4,700,000,000 to $6,500,000,000.

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

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

## Activities and Explanation of Changes

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| **Construction** | **$257,000** | **$112,000** | **-$145,000** |
| Matter in Extreme Conditions (MEC) Petawatt Upgrade | $15,000 | $5,000 | -$10,000 |
| Funding supports design activities for this project to achieve CD-1. | | The Request will support design activities, preparation for developing a project baseline, and long-lead procurements for an upgrade to MEC. | Funding will support critical activities required to develop a cost, schedule, and scope baseline and initiate long-lead procurements for the MEC upgrade project. |
| U.S. Contributions to ITER | $242,000 | $107,000 | -$135,000 |
| Funding supports continuing design and fabrication of the highest priority “in-kind” hardware systems. | | The Request will support continued design and fabrication of in-kind hardware systems for the First Plasma subproject (SP-1). | Funding will continue to focus on the highest-priority SP-1 activities. |

## Fusion Energy Sciences
## Capital Summary

(dollars in thousands)

| | Total | Prior Years | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|---|---|
| **Capital Operating Expenses** | | | | | | |
| Capital Equipment | N/A | N/A | 16,874 | 21,760 | 48,112 | +26,352 |
| Minor Construction Activities | | | | | | |
| General Plant Projects (GPP) | N/A | N/A | 9,134 | 6,350 | 380 | -5,970 |
| **Total, Capital Operating Expenses** | **N/A** | **N/A** | **26,008** | **28,110** | **48,492** | **+20,382** |

### Capital Equipment

(dollars in thousands)

| | Total | Prior Years | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|---|---|
| **Capital Equipment** | | | | | | |
| Major Items of Equipment[a] | | | | | | |
| *Burning Plasma Science: Long Pulse* | | | | | | |
| Materials Plasma Exposure eXperiment (MPEX) | 86,000-175,000 | — | 14,746 | 21,000 | 12,000 | -9,000 |
| Total, Non-MIE Capital Equipment | N/A | N/A | 2,128 | 760 | 36,112 | +35,352 |
| **Total, Capital Equipment** | **N/A** | **N/A** | **16,874** | **21,760** | **48,112** | **+26,352** |

### Minor Construction Activities

(dollars in thousands)

| | Total | Prior Years | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|---|---|
| **General Plant Projects (GPP)** | | | | | | |
| Total GPPs less than $5M[b] | N/A | N/A | 9,134 | 6,350 | 380 | -5,970 |

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

## Major Items of Equipment Description(s)

Burning Plasma Science: Long Pulse MIE:

*Materials Plasma Exposure eXperiment (MPEX)*

FES has conducted substantial research and development over the past five years to identify and develop an innovative, linear, high-intensity plasma source capable of producing the extreme plasma parameters required to simulate a burning plasma environment. FES is now building on this research to develop a first-of-a-kind, world-leading experimental capability that will be used to explore solutions to the plasma-materials interactions challenge. MPEX, which will be located at ORNL, will allow dedicated studies of reactor-relevant heat and particle loads on neutron-irradiated materials. The overall motivation is to gain entry into a new class of fusion materials science wherein the combined effects of fusion-relevant heat, particle, and neutron fluxes can be studied for the first time anywhere in the world. The project is expected to be baselined in FY 2021. The proposed funding will allow for the project to obtain baseline performance approval in FY 2021 and initiate long-lead time procurements for the device. Following conceptual design completion, the preliminary cost range is between $86,000,000 –$175,000,000.

## Fusion Energy Sciences
## Construction Projects Summary

(dollars in thousands)

| | Total | Prior Years | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|---|---|
| **20-SC-61, Matter in Extreme Conditions (MEC) Petawatt Upgrade** | | | | | | |
| TEC | TBD | — | — | 15,000 | 5,000 | -10,000 |
| OPC | TBD | — | 1,600 | 4,500 | — | -4,500 |
| **TPC** | **TBD** | **—** | **1,600** | **19,500** | **5,000** | **-14,500** |
| **14-SC-60, U.S. Contributions to ITER** | | | | | | |
| TEC | TBD | 1,239,617 | 132,000 | 242,000 | 107,000 | -135,000 |
| OPC | TBD | 70,302 | — | — | — | — |
| **TPC** | **TBD** | **1,309,919** | **132,000** | **242,000** | **107,000** | **-135,000** |
| **Total, Construction** | | | | | | |
| **TEC** | **TBD** | **1,239,617** | **132,000** | **257,000** | **112,000** | **-145,000** |
| **OPC** | **TBD** | **70,302** | **1,600** | **4,500** | **—** | **-4,500** |
| **TPC** | **TBD** | **1,309,919** | **133,600** | **261,500** | **112,000** | **-149,500** |

## Fusion Energy Sciences
## Funding Summary

(dollars in thousands)

| | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|
| Research | 261,950 | 253,000 | 207,651 | -45,349 |
| Facility Operations | 143,500 | 128,500 | 92,500 | -36,000 |
| Projects | | | | |
| Major Items of Equipment | 14,746 | 21,000 | 12,000 | -9,000 |
| Construction | 133,600 | 261,500 | 112,000 | -149,500 |
| Total, Projects | 148,346 | 282,500 | 124,000 | -158,500 |
| Other | 10,204 | 7,000 | 1,000 | -6,000 |
| **Total, Fusion Energy Sciences** | **564,000** | **671,000** | **425,151** | **-245,849** |

**Fusion Energy Sciences**
**Scientific User Facility Operations**

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

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

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

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

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

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

(dollars in thousands)

| | FY 2019 Enacted | FY 2019 Current | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|---|
| **TYPE A FACILITIES** | | | | | |
| **DIII-D National Fusion Facility** | **$121,500** | **$121,443** | **$116,500** | **$89,500** | **-27,000** |
| Number of users | 673 | 718 | 718 | 600 | -118 |
| Achieved operating hours | N/A | 480 | N/A | N/A | N/A |
| Planned operating hours | 480 | 480 | 800 | 520 | -280 |
| Optimal hours | 480 | 480 | 960 | 960 | — |
| Percent optimal hours | 100% | 100% | 83% | 54% | -29.2% |
| Unscheduled downtime hours | N/A | N/A | N/A | N/A | N/A |

(dollars in thousands)

| | FY 2019 Enacted | FY 2019 Current | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|---|
| **National Spherical Tours Experimental—Upgrade** | **$93,000** | **$92,250** | **$98,000** | **$70,500** | **-27,500** |
| Number of users | 385 | 308 | 326 | 320 | -6 |
| Achieved operating hours | N/A | N/A | N/A | N/A | N/A |
| Planned operating hours | — | — | — | — | — |
| Optimal hours | — | — | — | — | — |
| Percent optimal hours | N/A | N/A | N/A | N/A | N/A |
| Unscheduled downtime hours | N/A | N/A | N/A | N/A | N/A |
| **Total Facilities** | **$214,500** | **$213,693** | **$214,500** | **160,000** | **-54,500** |
| Number of users | 1,058 | 1,026 | 1,044 | 920 | -124 |
| Achieved operating hours | N/A | 480 | N/A | N/A | N/A |
| Planned operating hours | 480 | 480 | 800 | 520 | -280 |
| Optimal hours | 480 | 480 | 960 | 960 | — |
| Percent optimal hours[a] | 100% | 100% | 83% | 54% | -29.2% |
| Unscheduled downtime hours | N/A | N/A | N/A | N/A | N/A |

**Fusion Energy Sciences**
**Scientific Employment**

| | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|
| Number of permanent Ph.D.'s (FTEs) | 932 | 859 | 646 | -213 |
| Number of postdoctoral associates (FTEs) | 114 | 106 | 79 | -27 |
| Number of graduate students (FTEs) | 310 | 287 | 216 | -71 |
| Other scientific employment (FTEs)[b] | 1,390 | 1,284 | 964 | -320 |

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

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

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

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


**Summary**

The FY 2021 Request for the Matter in Extreme Conditions (MEC) Petawatt Upgrade project is $5,000,000. The MEC is an experimental research end-station that utilizes the Linac Coherent Light Source (LCLS) SC User Facility at the SLAC National Accelerator Laboratory. The preliminary estimated Total Project Cost (TPC) range for the MEC Petawatt Upgrade is $50,000,000 to $200,000,000. SC plans for the project to achieve Critical Decision-1 (CD-1), "Approve Alternative Selection and Cost Range" in FY 2020.

SLAC is developing options with wide-ranging cost and schedule implications. In the 2nd quarter of FY 2020, FES will select the option that considers how best to achieve and maintain world leading fusion discovery science. The best option will include a large-scale, open-access, high-intensity laser facility that is co-located with hard X-ray laser-probing capabilities (i.e., with an X-ray wavelength that allows atomic resolution).


**Significant Changes**

The project achieved CD-0, "Approve Mission Need" on January, 4, 2019. Other Project Costs funding in FY 2020 will support preliminary design of the civil infrastructure and technical hardware. When the project achieves CD-1, "Approve Alternative Selection and Cost Range", which is planned for FY 2020, SC will then initiate TEC design efforts. A Federal Project Director has been assigned to the MEC Petawatt Upgrade project.

**Critical Milestone History**

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | D&D Complete | CD-4 |
|---|---|---|---|---|---|---|---|---|
| FY 2020 | 1/04/19 | 3Q FY 2019 | 1Q FY 2020 | TBD | TBD | TBD | TBD | TBD |
| FY 2021 | 1/04/19 | 4Q FY 2020 | 4Q FY 2020 | 3Q FY 2022[a] | 4Q FY 2021[a] | 3Q FY 2023[a] | FY 2040[a] | 1Q FY 2028[a] |

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

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC, Except D&D | OPC, D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|---|
| FY 2020 | 1,000 | — | 1,000 | 1,600 | — | 1,600 | 2,600 |
| FY 2021 | 20,000 | 170,400 | 190,400 | 9,600 | — | 9,600 | 200,000[a] |

[a] This project is pre-CD-2; therefore, funding and schedule estimates are preliminary.

## 2. Project Scope and Justification

**Scope**

The scope of the MEC Petawatt Facility project includes the development of a facility that couples high-energy and high-intensity drive lasers, including a system with at least a range of 1 to 10 pettawatt (PW) peak power, to an X-ray source capable of producing ultrafast, high-peak-brightness pulses. The laser will be placed in a dedicated MEC experimental hall (located at the end of the LCLS-II Far Experimental hall), comprised of a new access tunnel with a range of 100 to 500 feet in length, a new cavern with 6,000 to 10,000 square feet, and associated safety systems and infrastructure.

**Justification**

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

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

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

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

The project will be conducted utilizing the project management principles described in DOE O 413.3B*, Program and Project Management for the Acquisition of Capital Assets*.

Key Performance Parameters (KPPs)

The Key Performance Parameters (KPPs) are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project

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

must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion. The project is in conceptual design phase and the KPPs reflect the types of parameters being considered and are notional at this stage; the preliminary KPPs will be developed in coordination with FES and proposed for the Project Management Executive (PME) consideration and approval at CD-1.

| Performance Measure | Threshold | Objective |
|---|---|---|
| Radiation shielded experiment cavern | 0.5 PW at 1 Hertz (Hz) | 1.0 PW at 10 Hz |

### 3. Financial Schedule

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| FY 2020 | 15,000 | 15,000 | 15,000 |
| FY 2021 | 5,000 | 5,000 | 5,000 |
| Outyears | — | — | — |
| Total, Design | 20,000 | 20,000 | 20,000 |
| Construction | | | |
| FY 2020 | — | — | — |
| FY 2021 | — | — | — |
| Outyears | 170,400 | 170,400 | 170,400 |
| Total, Construction | 170,400 | 170,400 | 170,400 |
| Total Estimated Cost (TEC) | | | |
| FY 2020 | 15,000 | 15,000 | 15,000 |
| FY 2021 | 5,000 | 5,000 | 5,000 |
| Outyears | 170,400 | 170,400 | 170,400 |
| **Total, TEC** | **190,400** | **190,400** | **190,400** |
| **Other Project Cost (OPC)** | | | |
| FY 2019 | 1,600 | 1,600 | 280 |
| FY 2020 | 4,500 | 4,500 | 5,820 |
| FY 2021 | — | — | — |
| Outyears | 3,500 | 3,500 | 3,500 |
| **Total, OPC** | **9,600** | **9,600** | **9,600** |
| **Total Project Cost (TPC)** | | | |
| FY 2019 | 1,600 | 1,600 | 280 |
| FY 2020 | 19,500 | 19,500 | 20,820 |
| FY 2021 | 5,000 | 5,000 | 5,000 |
| Outyears | 173,900 | 173,900 | 173,900 |
| **Total, TPC** | **200,000**[a] | **200,000** | **200,000** |

[a] This project is pre-CD-2; therefore, funding and schedule estimates are preliminary.

## 4. Details of Project Cost Estimate

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| Design | 17,000 | TBD | TBD |
| Contingency | 3,000 | TBD | TBD |
| Total, Design | 20,000 | TBD | TBD |
| Construction | | | |
| Site Work | — | TBD | TBD |
| Equipment | 60,800 | TBD | TBD |
| Construction | 70,000 | TBD | TBD |
| Other, as needed | — | TBD | TBD |
| Contingency | 39,600 | TBD | TBD |
| Total, Construction | 170,400 | TBD | TBD |
| Other TEC | | | |
| Cold Startup | — | TBD | TBD |
| Contingency | — | TBD | TBD |
| Total, Other TEC | — | TBD | TBD |
| **Total, TEC** | **190,400** | **TBD** | **TBD** |
| *Contingency, TEC* | 42,600 | TBD | TBD |
| **Other Project Cost (OPC)** | | | |
| OPC except D&D | | | |
| R&D | 350 | TBD | TBD |
| Conceptual Planning | 850 | TBD | TBD |
| Conceptual Design | 1,900 | TBD | TBD |
| Other OPC Costs | 3,500 | TBD | TBD |
| Contingency | 3,000 | TBD | TBD |
| **Total, OPC** | **9,600** | **TBD** | **TBD** |
| *Contingency, OPC* | 3,000 | TBD | TBD |
| **Total Project Cost** | **200,000** | **TBD** | **TBD** |
| ***Total, Contingency (TEC+OPC)*** | **45,600** | **TBD** | **TBD** |

## 5. Schedule of Appropriations Requests

(dollars in thousands)

| Request Year | Type | Prior Years | FY 2019 | FY 2020 | FY 2021 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| FY 2020 | TEC | N/A | — | 1,000 | — | TBD | TBD |
| | OPC | N/A | 1,600 | — | — | TBD | TBD |
| | TPC | N/A | 1,600 | 1,000 | — | TBD | TBD |
| FY 2021 | TEC | N/A | — | 15,000 | 5,000 | 170,400 | 190,400 |
| | OPC | N/A | 1,600 | 4,500 | — | 3,500 | 9,600 |
| | TPC | N/A | 1,600 | 19,500 | 5,000 | 173,900 | 200,000[a] |

## 6. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 1Q FY 2028 |
| Expected Useful Life | TBD |
| Expected Future Start of D&D of this capital asset | TBD |

Related Funding Requirements
(dollars in thousands)

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

## 7. D&D Information

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

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

## 8. Acquisition Approach

As part of the DOE Order 413.3B CD-1 process, an Acquisition Strategy will be prepared for review and approval of the PME at CD-1.

[a] This project is pre-CD-2; therefore, funding and schedule estimates are preliminary.

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

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

**Summary**

The FY 2021 Request for the U.S. ITER project is $107,000,000. ITER is a major fusion research facility being constructed in Saint-Paul-lez-Durance, France by an international partnership of seven Members or Domestic Agencies, specifically the U.S., China, the European Union, India, the Republic of Korea, Japan, and the Russian Federation. These Members or Domestic Agencies are comprised of 34 countries. Since it will not result in a facility owned by the U.S. or located in the U.S., the U.S. ITER project is not classified as a Capital Asset Project but is classified as a Major System Project. U.S. ITER is a DOE project to provide the U.S. share of ITER construction, classified as in-kind hardware (i.e., subsystems, equipment, and components), as well as financial resources to support the ITER Organization (IO), as delineated in the Joint Implementation Agreement (JIA). Sections of this Construction Project Data Sheet (CPDS) have been tailored accordingly to reflect the unique nature of the U.S. ITER project.

As outlined in the May 2016 Secretary of Energy's Report to Congress, DOE was to baseline the "First Plasma" portion of the U.S. ITER project. As such, DOE divided the U.S. ITER project hardware scope into two distinct subprojects, which represent the two phases of the project: the First Plasma (FP) subproject (SP-1), and the Post-FP subproject (SP-2). An independent review of CD-2, "Approve Performance Baseline" for the SP-1 was completed in November 2016 and then subsequently approved by the PME on January 13, 2017, with a total project cost of $2.5 billion, and a CD-4, "Project Completion" date of December 2027. In addition, the PME also approved CD-3, "Approve the Start of Construction" for the SP-1 on January 13, 2017. This CPDS focuses on the FP subproject (SP-1) activities.

SP-2 is the second element of the U.S. ITER project, and includes the remainder of U.S. hardware contributions for Post-FP operations leading up to Deuterium-Tritium Operations. SP-2 is planned for baselining in the future.

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

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

**Significant Changes**

This CPDS is an update of the FY 2020 CPDS and does not include a new start for FY 2021 SP-1, which includes fabrication and delivery of all hardware required for FP and the completion of design for all U.S. hardware contributions, is more than 60 percent complete.

The FY 2021 Request of $107,000,000 will support the continued design and fabrication of highest-priority "in-kind" hardware systems. This includes continued fabrication of the Central Solenoid (CS) magnet system, which consists of seven superconducting magnet modules, structural components, and assembly tooling. In FY 2020, the U.S. will deliver the first CS magnet module (Module 1) to the ITER site, as well as continue design and fabrication efforts associated with other "in-kind" hardware systems. The U.S. ITER project has obligated $1.2 billion through the end of FY 2019 to U.S. industry, universities, and DOE laboratories.

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

**Critical Milestone History**

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | D&D Complete | CD-4 |
|---|---|---|---|---|---|---|---|---|
| FY 2006 | 7/05/05 | | TBD | TBD | | TBD | N/A | TBD |
| FY 2007 | 7/05/05 | | TBD | TBD | | TBD | N/A | 2017 |
| FY 2008 | 7/05/05 | | 1/25/08 | 4Q FY 2008 | | TBD | N/A | 2017 |
| FY 2009 | 7/05/05 | 9/30/09[a] | 1/25/08 | 4Q FY 2010 | | TBD | N/A | 2018 |
| FY 2010 | 7/05/05 | 7/27/10[b] | 1/25/08 | 4Q FY 2011 | | TBD | N/A | 2019 |
| FY 2011 | 7/05/05 | 5/30/11[c] | 1/25/08 | 4Q FY 2011 | 4/12/11[d] | TBD | N/A | 2024 |
| FY 2012 | 7/05/05 | 7/10/12[e] | 1/25/08 | 3Q FY 2012 | 5/02/12[f] | TBD | N/A | 2028 |
| FY 2013 | 7/05/05 | 12/11/12[g] | 1/25/08 | TBD[h] | 4/10/13[i] | TBD | N/A | 2033 |
| FY 2014 | 7/05/05 | | 1/25/08 | TBD | 12/10/13[j] | TBD | N/A | 2034 |
| FY 2015 | 7/05/05 | | 1/25/08 | TBD | | TBD | N/A | 2036 |
| FY 2016[k] | 7/05/05 | | 1/25/08 | TBD | | TBD | N/A | TBD |
| FY 2017[l] | 7/05/05 | | 1/25/08 | TBD | | TBD | N/A | TBD |

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

| Fiscal Year | Performance Baseline Validation | CD-1 Cost Range Update | CD-2/3 | | CD-4 | |
|---|---|---|---|---|---|---|
| | | | CD-3B | SP-2 | SP-1 | SP-2 |
| FY 2018[m] | 7/05/05 | 1/13/17 | 1/13/17 | 2019 | 1Q FY 2027 | 2034-2038 |
| FY 2019 | 7/05/05 | 1/13/17 | 1/13/17 | 2019 | 1Q FY 2027 | 2034-2038 |

[a] Electron Cyclotron Heating (ECH) Transmission lines (TL) (06/22/2009); Tokamak Cooling Water System (07/21/2009); CS Modules, Structures, and Assembly Tooling (AT) (09/30/2009).
[b] Ion Cyclotron Heating Transmission Lines (ICH) (10/14/2009); Tokamak Exhaust Processing (TEP) (05/17/2010); Diagnostics: Residual Gas Analyzer (RGA) (07/14/2010), Upper Visible Infrared Cameras (VIR) (07/27/2010).
[c] Vacuum Auxiliary System (VAS) – Main Piping (12/13/2010); Diagnostics Low-Field-Side Reflectometer (LFS) (05/30/2011).
[d] Cooling Water Drain Tanks (04/12/2011).
[e] Diagnostics: Upper Port (10/03/2011), Electron Cyclotron Emission (ECE) (12/06/2011), Equatorial Port E-9 and Toroidal Interferometer Polarimeter (TIP) (01/02/2012), Equatorial Port E-3 (07/10/2012).
[f] Steady State Electrical Network (05/02/2012).
[g] VAS Supply (11/13/2012); Disruption Mitigation (12/11/2012); Pellet Injection (04/29/2013); Diagnostics: Motional Stark Effect Polarimeter (MSE) (05/29/2013), Core Imaging X-ray Spectrometer (CIXS) (06/01/2013).
[h] The CD-2 date will be determined upon acceptable resolution of issues related to development of a high-confidence ITER Project Schedule and establishment of an approved funding profile.
[i] RGA Divertor Sampling Tube (07/28/14); CS AT, Early Items (09/17/14).
[j] CS Modules and Structures (11/18/2013); VAS Main Piping B-2, L-1, L-2 (12/10/2013).
[k] CS AT Remaining Items (12/02/2015).
[l] Roughing Pumps (03/2017); VAS 03 Supply (07/2017); Roughing Pumps I&C (04/2017); VAS 03 Supply I&C (07/2017); CS AT Bus Bar Alignment and Coaxial Heater (04/2017); VAS Main Piping L3/L4 (03/2017); VAS 02 CGVS (&C Part 1 (06/2017).
[m] VAS 02 Supply Part 1 (05/2018); ICH RF Building and I&C (11/2017); TCWS Captive Piping and First Plasma (11/2017); ICH RF components supporting INDA/IO testing (01/2018).

| Fiscal Year | Performance Baseline Validation | CD-1 Cost Range Update | CD-2/3 | | CD-4 | |
|---|---|---|---|---|---|---|
| | | | CD-3B | SP-2 | SP-1 | SP-2 |
| FY 2020 | 7/05/05 | 1/13/17 | 1/13/17 | 2021/2022 | 1Q FY 2028 | 2034-2038 |
| FY 2021 | 7/05/05 | 1/13/17 | 1/13/17 | 2021/2022 | 1Q FY 2028 | 2034-2038 |

**Project Cost History**

At the time of CD-1 approval in January 2008, the preliminary cost range was $1.45 billion to $2.2 billion. Until 2016, however, it was not possible to confidently baseline the project due to prior delays in the international ITER construction schedule. Various factors (e.g., schedule delays, design and scope changes, funding constraints, regulatory requirements, risk mitigation, and inadequate project management and leadership issues in the ITER Organization at that time) affected the project cost and schedule. Shortly after Director General Bigot's appointment in March 2015, the ITER Project was baselined for cost and schedule.

In response to a 2013 Congressional request, a DOE SC Independent Project Review (IPR) Committee assessed the project and determined that the existing cost range estimate of $4.0 billion to $6.5 billion would likely encompass the final total TPC. This range, recommended in 2013, was included in subsequent President's Budget Requests. In May 2016, DOE provided a "Report on the Continued U.S. Participation in the ITER Project" to Congress, which stated that the FP part of the U.S. ITER project would be baselined in FY 2017. In preparation for baselining SP-1, based on the results of the IPR, the acting Director for the Office of Science updated the lower end of this range to reflect updated cost estimates resulting in the current approved CD-1R range of $4.7 billion to $6.5 billion. This updated CD-1R range incorporates increases in the projects hardware estimate that have occurred since August 2013. The SP-1 TPC is now baselined at $2.5 billion.

**Subproject 1 (First Plasma Hardware for U.S. ITER)**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC, Except D&D | OPC, D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|---|
| FY 2017[a] | 696,025 | 1,723,334 | 2,419,359 | 80,641 | N/A | 80,641 | 2,500,000 |
| FY 2018 | 696,025 | 1,723,334 | 2,419,359 | 80,641 | N/A | 80,641 | 2,500,000 |
| FY 2019 | 696,025 | 1,723,334 | 2,419,359 | 80,641 | N/A | 80,641 | 2,500,000 |
| FY 2020 | 696,025 | 1,733,673 | 2,429,698 | 70,302 | N/A | 70,302 | 2,500,000 |
| FY 2021 | 696,025 | 1,733,673 | 2,429,698 | 70,302 | N/A | 70,302 | 2,500,000 |

**2. Project Scope and Justification**

**Introduction**

ITER is an international partnership among seven Members (China, the European Union, India, Japan, the Republic of Korea, the Russian Federation, and the U.S.) designed to demonstrate 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 percent) of the ITER facility's construction cost, while the other six Members, including the U.S., will each support one-eleventh (9.09 percent) 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. and Japan will contribute a 13 percent share; the EU will provide 34 percent and the other Members will each provide 10 percent. Operation, Deactivation, and Decommissioning are not part of the U.S. ITER project funding.

[a] Prior to FY2017 the TPC for U.S. ITER was reported as "TBD"; estimates reported beginning in FY 2017 represent the validated baseline values for Subproject 1 First Plasma Hardware. These values for the SP-1 baseline have not been updated to reflect impacts from FY 2017 and FY 2018 funding reductions and allocations.

Responsibility for ITER integration, management, design, licensing, installation, and operation rests with the IO, which is an international legal entity located in France.

**Scope**

U.S. Contributions to ITER – Construction Project Scope

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

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

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

- Tokamak Cooling Water System (TCWS): manages the thermal energy generated during the operation of the tokamak. (58 percent of system for SP-1)
- 15 percent of ITER Diagnostics: provides the measurements necessary to control, evaluate, and optimize plasma performance and to further the understanding of plasma physics. (6 percent for SP-1)
- Disruption Mitigation (DM) Systems: limits the impact of plasma disruptions to the tokamak vacuum vessel, blankets, and other components. All of DM design is done in SP-1.
- Electron Cyclotron Heating (ECH) Transmission Lines: brings additional power to the plasma and deposits power in specific areas of the plasma to minimize instabilities and optimize performance. (55 percent for SP-1)
- Tokamak Exhaust Processing (TEP) System: separates hydrogen isotopes from tokamak exhaust. (All of TEP design is done in SP-1)
- Tokamak Fueling System (Pellet Injection): injects fusion fuels in the form of deuterium-tritium ice pellets into the vacuum chamber. (9 percent for SP-1)
- Ion Cyclotron Heating (ICH) Transmission Lines: bring additional power to the plasma. (15 percent for SP-1)
- Central Solenoid (CS) Magnet System: confines, shapes and controls the plasma inside the vacuum vessel. All CS workscope is SP-1.
- 8 percent of Toroidal Field (TF) Conductor: component of the TF magnet that confines, shapes, and controls the plasma. All TF work scope was completed in FY 2017.
- 75 percent of the Steady-State Electrical Network (SSEN): supplies the electricity needed to operate the entire plant, including offices and the operational facilities. All SSEN work scope was completed in FY 2017.
- Vacuum Auxiliary System (VAS): creates and maintains low gas densities in the vacuum vessel and connected vacuum components. (85 percent for SP-1)
- Roughing Pumps: evacuate the tokamak, cryostat, and auxiliary vacuum chambers prior to and during operations. (56 percent for SP-1)

**Justification**

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

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

Key Performance Parameters (KPPs)

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

**Table 1. SP-1 In-Kind Hardware Description**

| System/Subsystem | Threshold |
|---|---|
| Central Solenoid Magnet System | Provide 7 (including spare) independent coil packs made of superconducting niobium-tin providing 13 Tesla at 45 kilo Amps (kA), the vertical pre- compression structure, and assembly tooling. |
| Toroidal Field Magnet Conductor | Provide 9 active lengths (~765m), 1 dummy length (~765m) for winding trials and 2 active lengths (~100m each) for superconducting qualification. |
| Steady State Electrical Network | Provide components for a large AC power distribution system (transformers, switches, circuit breakers, etc.) at high-voltage (400kV) and medium-voltage (22kV) levels. |
| Tokamak Cooling Water System | Provide Final Designs for major industrial components (heat exchangers, pumps, valves, pressurizers, etc.) capable of removing 1 gigawatt (GW) of heat. Among those components, also fabricate and deliver certain IO-designated items. |
| Diagnostics | Provide Final Designs for 4 diagnostic port plugs and 7 instrumentation systems (Core Imaging X-ray Spectrometer, Electron Cyclotron Emission Radiometer, Low Field Side Reflectometer, Motional Stark Effect Polarimeter, Residual Gas Analyzer, Toroidal Interferometer/Polarimeter, and Upper IR/Visible Cameras). Among those components, also fabricate and deliver certain IO-designated items. |
| Electron Cyclotron Heating Transmission Lines | Provide Final Designs for approximately 4 kilometers (km) of aluminum waveguide lines (24 lines) capable of transmitting up to 1.5 megawatts (MW) per line. Among those components, also fabricate and deliver certain IO-designated items. |
| Ion Cyclotron Heating Transmission Lines | Provide Final Designs for approximately 1.5 km of coaxial transmission lines (8 lines) capable of transmitting up to 6 MW per line. Among those components, also fabricate and deliver certain IO-designated items. |
| Pellet Injection System | Provide Final Designs for injector system capable of delivering deuterium/tritium fuel pellets up to 16 times per second. Among those components, also fabricate and deliver certain IO-designated items. |
| Vacuum Roughing Pumps | Provide Final Designs for a matrix of pump trains consisting of approximately 400 vacuum pumps. Among those components, also fabricate and deliver certain IO-designated items. |
| Vacuum Auxiliary Systems | Provide Final Designs for vacuum system components (valves, pipe manifolds, auxiliary pumps, etc.) and approximately 6 km of vacuum piping. Among those components, also fabricate and deliver certain IO-designated items. |
| Tokamak Exhaust Processing System | Provide Final Designs for an exhaust separation system for hydrogen isotopes and non-hydrogen gases. |
| Disruption Mitigation System | Provide design, and research and development (R&D) (up to a limit of $25,000,000[a]) for a system to mitigate plasma disruptions that could cause damage to the tokamak inner walls and components. |

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

### 3. Financial Schedule

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Estimated Cost (TEC)** [a] | | | |
| Hardware | | | |
| FY 2006 | 13,754 | 13,754 | 6,169 |
| FY 2007 | 36,588 | 36,588 | 24,238 |
| FY 2008 | 23,500 | 23,500 | 24,121 |
| FY 2009 | 85,401 | 85,401 | 26,278 |
| FY 2010 | 85,266 | 85,266 | 46,052 |
| FY 2011 | 63,875 | 63,875 | 84,321 |
| FY 2012[b] | 91,453 | 91,441 | 99,249 |
| FY 2013 | 107,635 | 107,669 | 110,074 |
| FY 2014[c] | 166,605 | 166,605 | 153,995 |
| FY 2015 | 134,043 | 134,043 | 114,129 |
| FY 2016[d] | 115,000 | 115,000 | 106,519 |
| FY 2017 | 50,000 | 50,000 | 123,117 |
| FY 2018 | 122,000 | 122,000 | 98,185 |
| FY 2019 | 102,000 | 102,000 | 126,726 |
| FY 2020 | 157,000 | 157,000 | 167,182 |
| FY 2021 | 107,000 | 107,000 | 100,348 |
| Outyears | TBD | TBD | TBD |
| Subtotal | 1,461,120 | 1,461,142 | 1,410,703 |
| Total, Hardware | TBD | TBD | TBD |
| Cash Contributions[e] | | | |
| FY 2006 | 2,112 | 2,112 | 2,112 |
| FY 2007 | 7,412 | 7,412 | 7,412 |
| FY 2008 | 2,644 | 2,644 | 2,644 |
| FY 2009 | 23,599 | 23,599 | 23,599 |
| FY 2010 | 29,734 | 29,734 | 29,734 |
| FY 2011 | 3,125 | 3,125 | 3,125 |
| FY 2012[f] | 13,214 | 13,214 | 13,214 |
| FY 2013 | 13,805 | 13,805 | 13,805 |

[a] Costs through FY 2019 reflect actual costs; costs for FY 2020 and the outyears are estimates.
[b] Prior actuals adjusted to incorporate project funds utilized at PPPL and DOE. Obligation adjusted to reflect year-end PPPL settlement funding.
[c] Appropriations prior to FY 2014 reflect major item of equipment funding. Starting in FY 2014, this project is funded as a Congressional control point.
[d] FY 2016 funding for taxes and tax support is included in the FY 2017 Hardware funding amount.
[e] Includes cash payments, secondees, taxes and tax support.
[f] Prior actuals adjusted to incorporate project funds utilized at PPPL and DOE. Obligation adjusted to reflect year-end PPPL settlement funding.

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| FY 2014[a] | 32,895 | 32,895 | 32,895 |
| FY 2015 | 15,957 | 15,957 | 15,957 |
| FY 2016 | — | — | — |
| FY 2017 | — | — | — |
| FY 2018 | — | — | — |
| FY 2019 | 30,000 | 30,000 | 30,000 |
| FY 2020 | 85,000 | 85,000 | 85,000 |
| FY 2021[b] | TBD | TBD | TBD |
| Outyears | TBD | TBD | TBD |
| Subtotal | 259,497 | 259,497 | 259,497 |
| Total, Cash Contributions | TBD | TBD | TBD |
| Hardware and Cash Contributions | | | |
| FY 2006 | 15,866 | 15,866 | 8,281 |
| FY 2007 | 44,000 | 44,000 | 31,650 |
| FY 2008 | 26,144 | 26,144 | 26,765 |
| FY 2009 | 109,000 | 109,000 | 49,877 |
| FY 2010 | 115,000 | 115,000 | 75,786 |
| FY 2011 | 67,000 | 67,000 | 87,446 |
| FY 2012[c] | 104,667 | 104,655 | 112,463 |
| FY 2013 | 121,440 | 121,474 | 123,879 |
| FY 2014[d] | 199,500 | 199,500 | 186,890 |
| FY 2015 | 150,000 | 150,000 | 130,086 |
| FY 2016 | 115,000 | 115,000 | 106,519 |
| FY 2017 | 50,000 | 50,000 | 123,117 |
| FY 2018 | 122,000 | 122,000 | 98,185 |
| FY 2019 | 132,000 | 132,000 | 156,726 |
| FY 2020 | 242,000 | 242,000 | 252,182 |
| FY 2021 | 107,000 | 107,000 | 100,348 |
| Outyears | TBD | TBD | TBD |
| Subtotal | 1,720,617 | 1,720,639 | 1,670,200 |
| **Total, TEC** | **TBD** | **TBD** | **TBD** |

[a] Appropriations prior to FY 2014 reflect major item of equipment funding. Starting in FY 2014, this project is funded as a Congressional control point.
[b] From within total ITER funding, in kind contribution and cash payment will be decided during the execution year.
[c] Prior actuals adjusted to incorporate project funds utilized at PPPL and DOE. Obligation adjusted to reflect year-end PPPL settlement funding.
[d] 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)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Other Project Cost (OPC)** | | | |
| FY 2006 | 3,449 | 3,449 | 1,110 |
| FY 2007 | 16,000 | 16,000 | 7,606 |
| FY 2008 | -74 | -74 | 7,513 |
| FY 2009 | 15,000 | 15,000 | 5,072 |
| FY 2010 | 20,000 | 20,000 | 7,754 |
| FY 2011 | 13,000 | 13,000 | 10,032 |
| FY 2012[a] | 333 | 311 | 22,302 |
| FY 2013 | 2,560 | 2,560 | 5,984 |
| FY 2014[b] | — | — | 2,090 |
| FY 2015 | — | — | 600 |
| FY 2016 | 34 | 34 | — |
| FY 2017 | — | -50 | 58 |
| FY 2018 | — | — | 2 |
| FY 2019 | — | — | 107 |
| Subtotal | 70,302 | 70,230 | 70,230 |
| **Total, OPC** | **TBD** | **TBD** | **TBD** |
| **Total Project Cost (TPC)[c]** | | | |
| FY 2006 | 19,315 | 19,315 | 9,391 |
| FY 2007 | 60,000 | 60,000 | 39,256 |
| FY 2008 | 26,070 | 26,070 | 34,278 |
| FY 2009 | 124,000 | 124,000 | 54,949 |
| FY 2010 | 135,000 | 135,000 | 83,540 |
| FY 2011 | 80,000 | 80,000 | 97,478 |
| FY 2012[a] | 105,000 | 104,966 | 134,765 |
| FY 2013 | 124,000 | 124,034 | 129,863 |
| FY 2014[d] | 199,500 | 199,500 | 188,980 |
| FY 2015 | 150,000 | 150,000 | 130,686 |
| FY 2016 | 115,034 | 115,034 | 106,519 |
| FY 2017 | 50,000 | 49,950 | 123,175 |

[a] Prior actuals adjusted to incorporate project funds utilized at PPPL and DOE. Obligation adjusted to reflect year-end PPPL settlement funding.
[b] Appropriations prior to FY 2014 reflect major item of equipment funding. Starting in FY 2014, this project is funded as a Congressional control point.
[c] Costs through FY 2019 reflect actual costs; costs for FY 2020 and the outyears are estimates.
[d] 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)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| FY 2018 | 122,000 | 122,000 | 98,187 |
| FY 2019 | 132,000 | 132,000 | 156,726 |
| FY 2020 | 242,000 | 242,000 | 252,182 |
| FY 2021 | 107,000 | 107,000 | 100,348 |
| Outyears | TBD | TBD | TBD |
| Subtotal | 1,790,919 | 1,790,869 | 1,740,323 |
| **Total, TPC** | **TBD** | **TBD** | **TBD** |

**4. Details of Project Cost Estimate**

The project has an approved updated CD-1 Cost Range, and DOE has chosen to divide the project hardware scope into two distinct subprojects (FP SP-1, and Post-FP SP-2). The baseline for SP-1 was approved in January 2017. Baselining of SP-2 will follow when the Administration has made a decision on the U.S. commitment to ITER. No procurements for SP-2 scope are anticipated until FY 2022 at the earliest. An IPR of U.S. ITER was conducted on November 14–17, 2016, to consider the project's readiness for CD-2 (Performance Baseline) and CD-3 (Begin/Continue Fabrication) for SP-1, as well as for the proposed updated CD-1 Cost Range. Outcomes from the IPR indicated that the project was ready for approval of SP-1 CD-2/3 following a reassessment of contingency to account for risk in the areas of escalation and currency exchange. This recommendation has been addressed. In addition, the IPR committee found no compelling reason to deviate from the cost range identified in the May 2016 Report to Congress ($4.0 billion to $6.5 billion) and recommended that this range be adopted and approved as the Updated CD-1 cost range. However, as noted above, in preparation for baselining SP-1 and based on the outcome of the IPR, a decision was made to update the lower end of this range to reflect updated cost estimates resulting in the current approved CD-1R range of $4.7 billion to $6.5 billion.

**Subproject – 1 First Plasma Hardware Only**
(dollars in thousands)

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

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

**Subproject – 1 First Plasma Hardware Only**
(dollars in thousands)

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

**5. Schedule of Appropriations Requests**

(dollars in thousands)

| Request Year | Type | Prior Years | FY 2019 | FY 2020 | FY 2021 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| FY 2006 | TEC | 1,038,000 | — | — | — | — | 1,038,000 |
| | OPC | 84,000 | — | — | — | — | 84,000 |
| | TPC | 1,122,000 | — | — | — | — | 1,122,000 |
| FY 2007 | TEC | 1,077,051 | — | — | — | — | 1,077,051 |
| | OPC | 44,949 | — | — | — | — | 44,949 |
| | TPC | 1,122,000 | — | — | — | — | 1,122,000 |
| FY 2008 | TEC | 1,078,230 | — | — | — | — | 1,078,230 |
| | OPC | 43,770 | — | — | — | — | 43,770 |
| | TPC | 1,122,000 | — | — | — | — | 1,122,000 |
| FY 2009[b] | TEC | 266,366 | — | — | — | — | TBD |
| | OPC | 38,075 | — | — | — | — | TBD |
| | TPC | 304,441 | — | — | — | — | TBD |
| FY 2010 | TEC | 294,366 | — | — | — | — | TBD |
| | OPC | 70,019 | — | — | — | — | TBD |
| | TPC | 364,385 | — | — | — | — | TBD |
| FY 2011 | TEC | 379,366 | — | — | — | — | TBD |
| | OPC | 65,019 | — | — | — | — | TBD |
| | TPC | 444,385 | — | — | — | — | TBD |

[a] The TPC reported here is only for Subproject 1 (and does not include Subproject 2 or cash contributions estimates), prior to FY 2017 the Total Project Cost for U.S. ITER was identified as "TBD".
[b] The Prior Years column for FY 2009 through FY 2012 reflects the total of appropriations and funding requests only through the year of that row. Thus, for example, in the FY 2010 row, it reflects only funding from FY 2006 to FY 2012.

(dollars in thousands)

| Request Year | Type | Prior Years | FY 2019 | FY 2020 | FY 2021 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| FY 2012[a] | TEC | 394,366 | — | — | — | — | TBD |
| | OPC | 75,019 | — | — | — | — | TBD |
| | TPC | 469,385 | — | — | — | — | TBD |
| FY 2013[b] | TEC | 617,261 | — | — | — | — | TBD |
| | OPC | 82,124 | — | — | — | — | TBD |
| | TPC | 699,385 | — | — | — | — | TBD |
| FY 2014[c] | TEC | 806,868 | — | — | — | — | TBD |
| | OPC | 73,159 | — | — | — | — | TBD |
| | TPC | 880,027 | — | — | — | — | TBD |
| FY 2015 | TEC | 942,578 | — | — | — | — | TBD |
| | OPC | 80,341 | — | — | — | — | TBD |
| | TPC | 1,022,919 | — | — | — | — | TBD |
| FY 2016 | TEC | 1,092,544 | — | — | — | — | TBD |
| | OPC | 80,341 | — | — | — | — | TBD |
| | TPC | 1,172,885 | — | — | — | — | TBD |
| FY 2017 | TEC | 1,182,578 | — | — | — | — | TBD |
| | OPC | 80,341 | — | — | — | — | TBD |
| | TPC | 1,262,919 | — | — | — | — | TBD |
| FY 2018 | TEC | 1,170,244 | — | — | — | — | TBD |
| | OPC | 80,641 | — | — | — | — | TBD |
| | TPC | 1,250,885 | — | — | — | — | TBD |
| FY 2019 | TEC | 1,170,244 | 75,000 | — | — | — | TBD |
| | OPC | 80,641 | — | — | — | — | TBD |
| | TPC | 1,250,885 | 75,000 | — | — | — | TBD |
| FY 2020 | TEC | 1,239,617 | 132,000 | 107,000 | — | — | TBD |
| | OPC | 70,302 | — | — | — | — | TBD |
| | TPC | 1,309,919 | 132,000 | 107,000 | — | — | TBD |
| FY 2021 | TEC | 1,239,617 | 132,000 | 242,000 | 107,000 | — | TBD |
| | OPC | 70,302 | — | — | — | — | TBD |
| | TPC | 1,309,919 | 132,000 | 242,000 | 107,000 | — | TBD |

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

### 6. Related Operations and Maintenance Funding Requirements

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

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 12/2025 |
| Expected Useful Life | 15–25 years |
| Expected Future Start of D&D of this capital asset | TBD |

### 7. D&D Information

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

The U.S. Contributions to ITER decommissioning are assumed to begin when operations commence and continue for a period of 20 years. The U.S. 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 decommissioning and deactivation cost.

### 8. Acquisition Approach

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

## High Energy Physics

### Overview

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

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

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

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

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

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

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

may glimpse the dark matter passing through Earth. Observations of the cosmic frontier may reveal a universe far stranger than ever thought possible.

HEP's Theoretical, Computational, and Interdisciplinary Physics and Advanced Technology Research and Development (R&D) subprograms formulate and enable scientific discovery. The Theoretical, Computational, and Interdisciplinary Physics subprogram provides the framework to explain experimental observations and gain a deeper understanding of nature. Theoretical physicists take the lead in the interpretation of a broad range of experimental results and synthesize new ideas as they search for deep connections and develop testable models. Computational Physics provides advanced computing tools and simulations that are necessary for designing, operating, and interpreting experiments across the frontiers, and enables discovery research via new techniques in high performance computing. Artificial Intelligence (AI)/Machine Learning (ML) supports research to tackle the challenges of managing the increasingly high volumes and complexity of experimental and simulated data across the HEP experimental frontiers, theory, and technology thrusts, and to address cross-cutting challenges across the HEP program as part of Administration initiative in coordination with DOE investments in exascale computing and associated AI efforts. Quantum Information Science (QIS) is a rapidly-developing, inter-disciplinary field, and HEP QIS efforts are aligned with the National Quantum Initiative and DOE priorities in this area. The HEP QIS research program promotes the co-development of quantum information, theory, and technology with the science drivers and opens prospects for new capabilities in sensing, simulation, and computing. In support of the National Quantum Initiative, the National QIS Research Centers constitute an interdisciplinary partnership between HEP and other SC programs. This partnership complements a robust core research portfolio that the individual SC programs, including HEP, steward to create the ecosystem across universities, national laboratories, and industry that is needed to advance developments in QIS and related technology.

The Advanced Technology R&D subprogram fosters fundamental research into particle acceleration and detection techniques and instrumentation. These enabling technologies and new research methods advance scientific knowledge in high energy physics and a broad range of related fields, advancing DOE's strategic goals for science.

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

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

**Highlights of the FY 2021 Request**

The FY 2021 Request for $818,131,000 focuses resources toward the highest priorities in fundamental research, operation and maintenance of scientific user facilities, facility upgrades, and projects identified in the P5 report.

Key elements in the FY 2021 Request include:

<u>Research</u>

Support for university and laboratory researchers to preserve critical core competencies, enable high priority theoretical and experimental activities in pursuit of discovery science, explore the potential of QIS and AI/ML, and invest in high-performance computing, including preparations for exascale, as well as world-leading R&D that requires long-term investments. This includes:

- LHC Support: U.S. responsibilities and leadership roles in the A Toroidal LHC Apparatus (ATLAS) and Compact Muon Solenoid (CMS) experiments at the LHC. To prepare for a ramp up to higher particle collision energy, the installation and commissioning of the upgrades to the ATLAS and CMS detectors will continue during the scheduled two-year long LHC technical stop from January 2019 to December 2020;

- Fermi National Accelerator Laboratory: U.S.-hosted, world-leading neutrino and muon physics experiments at Fermi National Accelerator Laboratory (FNAL), consisting of the Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment (LBNF/DUNE), the related Short-Baseline Neutrino (SBN) program, the NOvA neutrino oscillation experiment, Muon g-2, and the Muon to Electron Conversion Experiment (Mu2e);
- Cosmic Frontier: U.S. responsibilities and leadership roles in world-leading, next-generation experiments to advance the understanding of the nature of dark energy and cosmic acceleration during inflation in the early universe, and the search for dark matter particles;
- Theoretical Research: Intertwining the physics of the Higgs boson, neutrino masses, the dark universe, and exploring the unknown;
- QIS: R&D to accelerate discovery in particle physics while advancing the national effort;
- QIS Research Centers: HEP, in partnership with other SC programs, will continue support for multi-disciplinary QIS Centers initiated in FY 2020 to accelerate the advancement of QIS through vertical integration between systems and theory, and hardware and software. QIS Center scope includes work relating to sensors, quantum computing, emulators/simulators, and enabling technologies that will pave the path to accelerate and exploit QISassociated technologies in the longer term;
- AI/ML: Research to tackle the challenges of managing increasingly high volumes and complexity of experimental and simulated data across the HEP experimental frontiers, theory, and technology thrusts, and to address cross-cutting challenges across the HEP program in coordination with DOE investments in exascale computing and associated AI efforts;
- Microelectronics: HEP will work together with Advanced Scientific Computing Research (ASCR), Basic Energy Sciences (BES), and Fusion Energy Sciences (FES) programs to support multi-disciplinary microelectronics research to accelerate the advancement of microelectronic technologies;
- Advanced Technology R&D: World-leading Advanced Technology R&D that will enable transformative technology for the next-generation of accelerators and particle detectors and the training of experts who build them. The HEP General Accelerator R&D (GARD) activity will increase support for the Traineeship Program for Accelerator Science and Technology to revitalize graduate level training and innovation in the physics of particle accelerators for the benefit of HEP and other SC programs that rely on these enabling technologies;
- Accelerator Stewardship: Develop the fundamental building blocks of new technological advances in accelerator technology, to empower the private sector to accelerate research discoveries from the laboratory to the marketplace, and to support the mission of other federal agencies; and
- Technology R&D and pre-conceptual design studies: Research support for small projects searching for dark matter in new areas, new concepts for neutrino experiments in the DUNE era, or for next-generation dark energy experiments.

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

- Fermilab Accelerator Complex: Operation of the Fermilab Accelerator Complex for 4,580 hours (80 percent of optimal); long-deferred infrastructure maintenance and improvements; the procurement of new computing hardware, software, and storage systems; and the hiring and training of highly-skilled accelerator and instrumentation experts;
- Accelerator Test Facility (ATF): Operation of the Brookhaven National Laboratory (BNL) ATF for 2,150 hours (86 percent of optimal);
- Facility for Advanced Accelerator Experimental Tests II (FACET-II): Commissioning, installation, and 2,500 hours of operation (83 percent of optimal) for FACET-II;
- Sanford Underground Research Facility (SURF): Support services to enable operations of the Large Underground Xenon (LUX)-ZonED Proportional Scintillation in Liquid Noble gases (Zeplin) (LUX-ZEPLIN) (LZ) dark matter experiment, to continue operations of the neutrino-less double beta decay Majorana Demonstrator, and support investments to enhance SURF infrastructure;

- Vera C. Rubin Observatory: Commissioning and facility pre-operations activities for the Vera C. Rubin Observatory in Chile; (formerly known as the Large Synoptic Survey Telescope (LSST) project and facility[a]); and
- Cosmic Frontier Operations: Science operations of the Dark Energy Spectroscopic Instrument (DESI), installed on the Mayall telescope in Arizona, LZ at SURF, and the Super Cryogenic Dark Matter Search at Sudbury Neutrino Observatory Laboratory (SuperCDMS-SNOLAB) dark matter experiment in the Creighton Mine near Sudbury, Ontario, Canada.

Projects

Funding for Construction and Major Items of Equipment (MIEs) includes:

- HL-LHC Projects: Continued investments in the LHC by contributing to the U.S. share of the High-Luminosity (HL-LHC) Accelerator Upgrade Project and the HL-LHC ATLAS and CMS Detector Upgrade Projects to increase the particle collision rate by a factor of three to explore new physics beyond its current reach;
- LBNF/DUNE: Support will enable the Critical Decision (CD)-3B approved scope for the activities: the Far Site excavation of the underground equipment caverns and connecting drifts (tunnels); design and procurement activities for the Far Site cryogenics systems; LBNF Near Site (FNAL) beamline and conventional facilities design; and a site-preparation construction subcontract at the Near Site for relocation of existing service roads and utilities, including communications, power and water systems;
- Proton Improvement Plan II (PIP II): Support will enable engineering design work for conventional facilities and technical systems, continuation of site-preparation activities, initiation of construction for cryogenic plant support systems, and continued fabrication of prototype accelerator system components; and
- Cosmic Microwave Background Stage 4 (CMB-S4): Support for a new start MIE. CMB-S4 is the remaining P5-recommended MIE to commence. Currently operating CMB Stage 3 (CMB-S3) experiments were being built at the time of the P5 report. While these CMB-S3 experiments will provide valuable information on cosmological properties, the sensitivity necessary to directly investigate the inflationary era of the early universe will require designing the next generation project. CMB-S4 will also provide information about the nature of dark energy and neutrino properties.

## FY 2021 Research Initiatives

High Energy Physics supports the following FY 2021 Research Initiatives.

(dollars in thousands)

| | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|
| **New Research Initiatives** | | | | |
| Strategic Accelerator Technology Initiative | — | — | 6,250 | +6,250 |
| **Total, New Research Initiatives** | **—** | **—** | **6,250** | **+6,250** |
| | | | | |
| **Ongoing Research Initiatives** | | | | |
| Artificial Intelligence and Machine Learning | 3,750 | 15,000 | 34,500 | +19,500 |
| Microelectronics Innovation | — | — | 5,000 | +5,000 |
| Quantum Information Science | 27,500 | 38,500 | 43,809 | +5,309 |
| **Total, Ongoing Research Initiatives** | **31,250** | **53,500** | **83,309** | **+29,809** |

[a] The Vera C. Rubin Observatory Designation Act (H.R. 3196) was signed into law on December 20, 2019.

**High Energy Physics**
**Funding**

(dollars in thousands)

| | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|
| **Energy Frontier Experimental Physics** | | | | |
| Research | 76,530 | 71,125 | 50,050 | -21,075 |
| Facility Operations and Experimental Support | 52,000 | 52,650 | 48,480 | -4,170 |
| Projects | 105,000 | 100,000 | 78,000 | -22,000 |
| SBIR/STTR | 5,390 | 4,663 | 3,674 | -989 |
| **Total, Energy Frontier Experimental Physics** | **238,920** | **228,438** | **180,204** | **-48,234** |
| | | | | |
| **Intensity Frontier Experimental Physics** | | | | |
| Research | 61,646 | 58,871 | 35,520 | -23,351 |
| Facility Operations and Experimental Support | 155,035 | 177,122 | 157,445 | -19,677 |
| Projects | 16,000 | 5,494 | 4,000 | -1,494 |
| SBIR/STTR | 8,299 | 8,747 | 7,570 | -1,177 |
| **Total, Intensity Frontier Experimental Physics** | **240,980** | **250,234** | **204,535** | **-45,699** |
| | | | | |
| **Cosmic Frontier Experimental Physics** | | | | |
| Research | 50,741 | 48,072 | 29,220 | -18,852 |
| Facility Operations and Experimental Support | 20,076 | 41,358 | 37,400 | -3,958 |
| Projects | 27,350 | 2,000 | 1,000 | -1,000 |
| SBIR/STTR | 2,869 | 3,471 | 2,300 | -1,171 |
| **Total, Cosmic Frontier Experimental Physics** | **101,036** | **94,901** | **69,920** | **-24,981** |
| | | | | |
| **Theoretical, Computational, and Interdisciplinary Physics** | | | | |
| Research | | | | |
| Theory | 45,760 | 48,504 | 29,480 | -19,024 |
| Computational HEP | 13,351 | 9,430 | 11,440 | +2,010 |
| Quantum Information Science | 27,500 | 38,500 | 43,809 | +5,309 |
| Artificial Intelligence and Machine Learning | — | 15,000 | 34,500 | +19,500 |
| Total, Research | 86,611 | 111,434 | 119,229 | +7,795 |
| SBIR/STTR | 3,223 | 4,093 | 3,412 | -681 |
| **Total, Theoretical, Computational, and Interdisciplinary Physics** | **89,834** | **115,527** | **122,641** | **+7,114** |

(dollars in thousands)

| | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|
| **Advanced Technology R&D** | | | | |
| Research | | | | |
| HEP General Accelerator R&D | 48,447 | 43,454 | 45,606 | +2,152 |
| Detector R&D | 23,694 | 20,937 | 19,450 | -1,487 |
| Total, Research | 72,141 | 64,391 | 65,056 | +665 |
| Facility Operations and Experimental Support | 27,625 | 39,232 | 37,200 | -2,032 |
| Projects | 10,000 | — | — | — |
| SBIR/STTR | 3,740 | 3,783 | 3,846 | +63 |
| **Total, Advanced Technology R&D** | **113,506** | **107,406** | **106,102** | **-1,304** |
| | | | | |
| **Accelerator Stewardship** | | | | |
| Research | 9,083 | 10,788 | 8,510 | -2,278 |
| Facility Operations and Experimental Support | 6,067 | 6,067 | 5,200 | -867 |
| SBIR/STTR | 574 | 639 | 519 | -120 |
| **Total, Accelerator Stewardship** | **15,724** | **17,494** | **14,229** | **-3,265** |
| **Subtotal, High Energy Physics** | **800,000** | **814,000** | **697,631** | **-116,369** |
| | | | | |
| **Construction** | | | | |
| 18-SC-42 Proton Improvement Plan II, FNAL | 20,000 | 60,000 | 20,000 | -40,000 |
| 11-SC-40, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment, FNAL | 130,000 | 171,000 | 100,500 | -70,500 |
| 11-SC-41, Muon to Electron Conversion Experiment, FNAL | 30,000 | — | — | — |
| **Total, Construction** | **180,000** | **231,000** | **120,500** | **-110,500** |
| **Total, High Energy Physics** | **980,000** | **1,045,000** | **818,131** | **-226,869** |

SBIR/STTR funding:

- FY 2019 Enacted: SBIR $21,124,000 and STTR $2,971,000
- FY 2020 Enacted: SBIR $22,265,000 and STTR $3,131,000
- FY 2021 Request: SBIR $18,763,000 and STTR $2,558,000

## High Energy Physics
## Explanation of Major Changes

| | (dollars in thousands) FY 2021 Request vs FY 2020 Enacted |
|---|---|
| **Energy Frontier Experimental Physics**<br>The Request will focus support on LHC data analysis activities that are prioritized through a competitive peer review process and which are based on highest scientific merit and potential impact. Efforts associated with the HL-LHC ATLAS and HL-LHC CMS Detector upgrade activities will continue as researchers prepare for project baselining. The Request will support detector operations activities and associated U.S.-based computing infrastructure and resources needed to process the large volume of data anticipated when the LHC resumes running in Q3 of FY 2021. Support for HL-LHC Accelerator Upgrade and HL-LHC ATLAS and HL-LHC CMS Detector Upgrade Projects decreases and funding will support critical path activities to best maintain synchronization with the international HL-LHC schedule. Support for lower priority research, as determined by the FY 2018 HEPAP portfolio review, will ramp down. | **-48,234** |
| **Intensity Frontier Experimental Physics**<br>The Request will focus research support towards NOvA, the SBN program, Mu2e, and LBNF/DUNE. Support for lower priority small- to mid-scale neutrino experiments, as determined by the FY 2018 HEPAP portfolio review, will ramp down. The Request will support the Fermilab Accelerator Complex and the neutrino and muon experiments at 80 percent of optimal operations. Support for GPP funding is reduced as the Kautz Road Sub-Station Radial Feed Electrical Upgrade, and the cleanroom consolidation and construction in Industrial Building 4 in support of cryomodule assembly will be fully funded in FY 2020. The Request includes an increase of R&D for the PIP-II injector prototype, which is offset by the decrease for LBNF/DUNE OPC as the pre-excavation construction work approaches completion and is ramping down. | **-45,699** |
| **Cosmic Frontier Experimental Physics**<br>The Request will support increased research on the experiments that have recently started and a new MIE start for CMB-S4, while support for the Dark Energy Survey (DES) and research on lower priority experiments, as determined by the FY 2018 HEPAP portfolio review, will ramp down. The Request supports a ramp up in detector and facility operations and data processing for the suite of next generation dark matter and dark energy experiments, while ramping down operations for lower priority experiments. | **-24,981** |
| **Theoretical, Computational, and Interdisciplinary Physics**<br>The Request will increase support for AI/ML to address cross-cutting challenges in AI/ML that will advance the mission of the HEP program. The Request will prioritize theoretical support of the HEP experimental program and the highest-impact theoretical research as determined by competitive peer review. The Request supports transformative computational science, high performance computing, and exploratory research on adapting software workflows and testing hardware to make efficient use of Exascale architecture. The Request will support increases for interdisciplinary HEP-QIS consortia for focused research on foundational HEP-QIS including novel experiments, quantum computing, and quantum research technology and SC QIS Center activity in partnership with other SC programs. | **+7,114** |

| | (dollars in thousands) |
|---|---|
| | FY 2021 Request vs FY 2020 Enacted |
| **Advanced Technology R&D**<br>The Request will capitalize on the science opportunities at the newly completed FACET-II facility and increase the operational hours to 2,500 (83 percent of optimal), grow the Traineeship Program, begin the Strategic Accelerator Technology Initiative to bolster efforts in superconducting Magnet Development, accelerate ultrafast laser R&D, upgrade superconducting radio frequency (SRF) facilities and expand capabilities, and co-fund a multi-office R&D initiative in superconducting materials. Detector R&D support will be prioritized at universities and national laboratories, which enhance collaborative opportunities in support of new directions in HEP discovery science programs, and strengthen new technology developments and capabilities to align with the FY 2020 Basic Research Needs workshop priorities. The Request will support Microelectronics initiative through collaboration with ASCR, BES, and FES to conduct R&D for detector materials, devices, advances in front-end electronics, integrated sensor/processor architectures, and support multi-disciplinary microelectronics research. | **-1,304** |
| **Accelerator Stewardship**<br>The Request will enable the start of the Strategic Accelerator Technology Initiative to advance accelerator technologies that define the U.S. competitive advantage in physical sciences research. The ATF at BNL will operate at 86 percent of optimal. Support for accelerator technologies for industrial, medical and security uses, and advanced laser technology R&D will ramp down. | **-3,265** |
| **Construction**<br>The Request will continue support for LBNF/DUNE completion of the Far Site civil construction activities for pre-excavation and the beginning of excavation activities for the underground equipment caverns and connecting drifts (tunnels), as well as design and procurement activities for Far Site cryogenics systems. The Request will also support Near Site (FNAL) beamline and conventional facilities design and continuation of a site-preparation construction subcontract at the Near Site for relocation of existing service roads and utilities. Also, the Request will support the continuation of construction and fabrication for technical systems including contributions to the DUNE detectors, when design is final and authorized by CD-3. The Request will continue support for PIP-II completion of civil engineering design for the conventional facilities, and technical design and prototyping for the accelerator components. | **-110,500** |
| **Total, High Energy Physics** | **-226,869** |

**Basic and Applied R&D Coordination**

Accelerator Stewardship provides the fundamental building blocks of new technological advances in accelerator applications, including advanced proton and ion beams for the treatment of cancer, in coordination with the National Institutes of Health (NIH). HEP developed the Accelerator Stewardship subprogram based on input from accelerator R&D experts drawn from other federal agencies, universities, national laboratories, and the private sector to help identify specific research areas and infrastructure gaps where HEP investments would have sizable impacts beyond the SC research mission. This subprogram is closely coordinated with BES, FES, and Nuclear Physics (NP) programs and partner agencies to ensure federal stakeholders have input in crafting funding opportunity announcements, reviewing applications, and evaluating the efficacy and impact of funded activities. Use-inspired accelerator R&D for medical applications has been closely coordinated with the NIH/National Cancer Institute (NCI); ultrafast laser technology R&D with the Department of Defense (DOD) and the National Aeronautics and Space Administration (NASA); and microwave and high power accelerator R&D coordinated with the DOD, the Department of Homeland Security's Domestic Nuclear Detection Office in the Countering Weapons of Mass Destruction Office (DHS/CWMD), the NSF/Chemical, Bioengineering, Environmental and Transport (CBET) Systems Division; and the DOE's Office of Environmental Management (EM). Discussions with the National Nuclear Security Administration (NNSA) on mission needs and R&D coordination in laser technology, radioactive source replacement, and particle detector technologies have led to a Basic Research Needs Workshop on Compact Accelerators for Security and Medicine[a] that was held in May 2019 to establish research priorities for accelerator R&D in this critical area.

Ensuring that the Accelerator Stewardship subprogram's use-inspired basic R&D investments result in high-impact applications requires close coordination with other agencies who will carry on the later-stage development. The implementation strategy is to work with applied R&D agencies to jointly define priority research directions at Basic Research Needs Workshops, and then guide R&D and facility investments through joint participation of applied agencies in merit reviews and in the operations review of the BNL ATF. Where an eventual marketable use is envisioned, R&D collaborations are expected to involve a U.S. company to guide the early-stage R&D.

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

The HEP QIS research program has coordinated partnerships with the DOD Office of Basic Research (DOD/OBR) as well as the Air Force's Office of Scientific Research (AFOSR) on synergistic research connecting cosmic black holes with quantum error correction in qubit devices, and a partnership with the Department of Commerce's National Institute of Standards and Technology on quantum metrology and quantum sensor development for experimental discovery along HEP science drivers and for better understanding of fundamental constants. Furthermore, the SC QIS Center effort is a partnership across the HEP, ASCR, and BES programs and engages industry to inform use-inspired research and connect to applied and development activities. These interdisciplinary QIS efforts are aligned with the National Quantum Initiative and SC QIS priorities.

**Program Accomplishments**

*LHC data enables sensitive studies of the Higgs boson and searches for the dark matter particle production (Energy Frontier Experimental Physics).*

Using data collected during the record-setting operations of the LHC through 2018, scientists from the ATLAS and CMS collaborations continued their studies of Higgs boson interactions and searched for signs of dark matter being created in high energy particle collisions. Using AI/ML techniques to enhance their sensitivity, the CMS collaboration used the Higgs boson as a tool for discovery by searching for evidence of it being produced in association with dark matter particles. This sensitive search is the first to combine five Higgs boson decay channels, including some used in searches for the first time.

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[a] https://science.osti.gov/-/media/hep/pdf/Reports/2020/CASM_WorkshopReport.pdf

The ATLAS collaboration applied AI/ML techniques to the search for the Higgs boson decaying to pairs of muons, providing the most sensitive analysis to date. While this challenging decay channel is predicted by the standard model at a low rate, the analysis suggests that observation will be possible in the future era of the HL-LHC. These analyses demonstrate the potential for discovery as the LHC will resume operations in 2021 after a scheduled two-year technical stop for accelerator and detector upgrades.

*Precision Reactor Oscillation and Spectrum Experiment (PROSPECT) produces first results in reactor based search for sterile neutrinos (Intensity Frontier Experimental Physics).*
One major unresolved question about neutrinos is whether there are additional types beyond the three that are known. The known neutrinos change their type as they travel, a phenomenon known as neutrino oscillation, and is it possible that this process allows neutrinos to change into "sterile" types that do not interact directly with other matter. Nuclear reactors provide an intense source of neutrinos that can be used to search for signs of additional neutrino types through oscillations over a few meters of distance. Using data collected during 33 live-days of reactor operation at the High Flux Isotope Reactor (HFIR), scientists on the PROSPECT experiment produced first results their search for sterile neutrinos. The results significantly constrain the favored region for sterile neutrinos from previous experiments, and will continue to improve as more data is recorded.

*Dark Energy Survey completes observations and delivers first combined dark energy constraints from several cosmological probes (Cosmic Frontier Experimental Physics).*
The Dark Energy Survey (DES) aims to understand why the universe is accelerating in its expansion. If Einstein's theory of general relativity is correct, then the dark energy that drives this expansion accounts for nearly 70 percent of the total energy in the universe. However, precise measurements of the history of this expansion may reveal that new dynamic forces are in play. DES successfully completed an extended six years of observations in January 2019, reaching its goal of a deep, uniform survey of a large portion of the southern sky. The rich data have already led to over 200 scientific publications, including detailed cosmology results from the first year of observations. In early 2019, the DES collaboration combined several cosmological probes for the first time in order to constrain the properties of dark energy. These combined constraints are competitive with previous experiments and in early 2020 the release of results from three years of observational data will continue to improve our knowledge.

*Dark matter experiment produces world's most sensitive search for axions (Cosmic Frontier Experimental Physics).*
The Axion Dark-Matter eXperiment Generation 2 (ADMX-G2), successfully continued the world's most sensitive search for a candidate dark matter particle known as the axion. Axions are hypothetical dark matter particles with a very low mass, almost a trillion times lighter than an electron, that would also solve a known issue in the theoretical framework of the standard model of particle physics. The ADMX-G2 experiment sweeps through regions of potential axion mass by tuning a radiofrequency cavity through different frequency bands, and major steps in the scan require swapping the cavity. After producing the world's most sensitive search for axions in the frequency range of 680 MHz to 800 MHz in 2018, the ADMX collaboration continued their search in frequencies up to 1,020 MHz in 2019. ADMX will continue operations in up to three more configurations to eventually reach 2,000 MHz and span an important region of interest in the search for dark matter axions.

*Scrambling of quantum information successfully verified in experiment (Theoretical, Computational, and Interdisciplinary Physics).*
Quantum systems provide experimental testbeds for understanding the universe in new ways. In quantum simulations, the correlations and flow of information between quantum bits (qubits) in a laboratory experiment may provide insight into difficult problems in many other areas including black holes. A major challenge is understanding how information from one qubit is dispersed, or "scrambled," into correlations with entangled qubits over the course of an experiment and distinguishing scrambling from external effects that introduce noise in the quantum information. Using trapped atomic ions as qubits, experimenters successfully measured aspects of quantum information scrambling in an entangled multi-body system and provably distinguished it from external noise. The experimental validation of this process opens new doors for exploring the quantum world and related problems through quantum simulation.

*World record magnetic field strength achieved for a superconducting accelerator magnet (Advanced Technology R&D).*
In high-energy circular colliders, strong magnetic fields are needed to steer particle beams so they can be brought into collision at the interaction points. Future particle colliders will require stronger magnets in order to push the frontiers of discovery science. Stroger magnets reduce the ring size needed for a given particle energy or enable higher energies within the same sized ring. In 2019, scientists at FNAL announced the achievement of the highest magnetic field strength ever recorded for an accelerator magnet. The world record field strength of 14.1 teslas was achieved with the advanced superconducting material niobium-tin at a magnet temperature of 4.5 kelvins (minus 450 degrees Fahrenheit). Efforts are underway to push the performance of the accelerator magnet to even higher fields.

*Fermi National Accelerator Laboratory breaks ground on new heart of accelerator complex (Line Item Construction).*
On March 15, 2019, FNAL held the groundbreaking ceremony for a major new accelerator project, the Proton Improvement Plan II (PIP-II), which will provide a powerful beam for the future experiments served by the Fermilab Accelerator Complex. As an innovative application of cutting-edge superconducting technology, PIP-II has attracted the attention of accelerator experts from around the world and the project will benefit from significant contributions from international partners including France, India, Italy, and the UK. The PIP-II accelerator will play a key role in the future Long Baseline Neutrino Facility hosted by FNAL, enabling it to provide the world's most intense neutrino beam to giant particle detectors in a re-purposed mine a mile beneath the Black Hills of South Dakota. Over a thousand scientists from around the world are collaborating to build the international Deep Underground Neutrino Experiment in order to precisely measure properties of the ghostly neutrino, which may in turn help us understand why the universe today is made of matter instead of antimatter.

## High Energy Physics
## Energy Frontier Experimental Physics

### Description

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

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

<u>Research</u>

The Energy Frontier Experimental Physics subprogram's Research activity supports groups at U.S. academic and research institutions and physicists from national laboratories. These groups, as part of the ATLAS and CMS collaborations, typically have a broad portfolio of responsibilities and leadership roles in support of R&D, experimental design, fabrication, commissioning, operations, and maintenance, and they perform scientific simulations and physics data analyses. DOE selects research efforts with the highest scientific impact and potential based on a competitive peer-review process. In FY 2018, HEPAP evaluated the currently operating portfolio of experiments in the Energy Frontier and assessed the priority of their science output in the context of the science drivers. The findings from this review, in combination with input on strategic directions from regular, open community workshops will inform funding decisions in subsequent years. The activity also supports long-term development to efficiently analyze large datasets anticipated during future LHC operations. The next external peer review of the Energy Frontier laboratory research groups is planned for Q4 of FY 2020.

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

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

<u>Projects</u>

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

## Activities and Explanation of Changes

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| **Energy Frontier Experimental Physics** | **$228,438** | **$180,204** | **-$48,234** |
| Research | $71,125 | $50,050 | -$21,075 |
| Funding supports U.S. scientists leading high profile analysis topics using the large datasets collected by the ATLAS and CMS experiments. | | The Request will support U.S. leadership roles in all aspects of the ATLAS and CMS experimental programs, including the analysis of the large datasets during the next LHC run, which begins in Q3 of FY 2021. | Funding will support LHC data analysis activities that are prioritized through a competitive peer review process and are based on highest scientific merit and potential impact. Efforts associated with the HL-LHC ATLAS and HL-LHC CMS Detector upgrade activities continue in order to prepare for project baselining. |
| Facility Operations and Experimental Support | $52,650 | $48,480 | -$4,170 |
| Funding supports ATLAS and CMS detector maintenance and operations at CERN; the U.S.-based computing infrastructure and resources necessary to store and analyze LHC data; and commissioning activities of U.S.-built detector components. | | The Request will support ATLAS and CMS detector maintenance and operations at CERN and the U.S.-based computing infrastructure and resources used by U.S. scientists to store and analyze the large volume of LHC data acquired during the next LHC run starting in Q3 of FY 2021. | Funding will support additional compute nodes and data storage needs that are anticipated as a result of the higher demand placed on the U.S.-based computing infrastructure during the next LHC running period that resumes in Q3 of FY 2021. Support for commissioning activities of the U.S.-built detector components installed in prior years will ramp down. |
| Projects | $100,000 | $78,000 | -$22,000 |
| Funding supports baselining the detector upgrades projects, and continues procurement of components for the HL-LHC ATLAS and HL-LHC CMS Detector Upgrades, and production of focusing magnets and radio-frequency cavities for the HL-LHC Accelerator Upgrade Project. | | The Request will continue support for the critical path items in the production of quadrupole magnets and crab cavities for the HL-LHC Accelerator Upgrade, and continue critical path items and procurements for the Detector upgrades. | Support will focus on critical path items to best maintain synchronization with the international LHC and HL-LHC schedules. |

(dollars in thousands)

| FY 2020 Enacted | FY 2021 Request | Explanation of Changes<br>FY 2021 Request vs FY 2020 Enacted |
|---|---|---|
| SBIR/STTR $4,663 | $3,674 | -$989 |
| In FY 2020, SBIR/STTR funding is at 3.65 percent of non-capital funding. | In FY 2021, SBIR/STTR funding will be at 3.65 percent of non-capital funding. | The SBIR/STTR funding will be consistent with the HEP total budget. |

**High Energy Physics**
**Intensity Frontier Experimental Physics**

**Description**

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

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

Research

The Intensity Frontier Experimental Physics subprogram's Research activity supports groups at U.S. academic and research institutions and national laboratories. These groups, as part of scientific collaborations, typically have a broad portfolio of responsibilities and leadership roles in support of R&D, experimental design, fabrication, commissioning, operations, and maintenance, as well as performing scientific simulations and physics data analyses on the experiments. DOE selects research efforts with the highest scientific merit and potential impact based on a competitive peer review process. An external peer review of the Intensity Frontier laboratory research groups was conducted in FY 2018; the next review is planned for FY 2023. In FY 2018, HEPAP evaluated the currently operating portfolio of experiments on the Intensity Frontier and assessed the priority of their science output in the context of the science drivers. In early FY 2019, HEP conducted a Basic Research Needs[a] workshop to assess the science landscape and new opportunities for dark matter particle searches and to identify which areas would be suitable for small projects in the HEP program. The findings from these reviews, in combination with input on strategic directions from regular, open community workshops will inform funding decisions in subsequent years.

The largest component of the Intensity Frontier subprogram is the support for research in accelerator-based neutrino physics centered at FNAL with multiple experiments running concurrently in two separate neutrino beams with different beam energies. The flagship NuMI Off-Axis ve Appearance (NOvA) experiment uses the Neutrinos at the Main Injector (NuMI) beam. The Booster Neutrino Beam (BNB) is used by the Short-Baseline Neutrino (SBN) program, which includes a

[a] The "Basic Research Needs for Dark Matter Small Projects New Initiatives" report can be found at: https://science.osti.gov/hep/Community-Resources/Reports

Near Detector (SBN-ND) and a Far Detector (SBN-FD) separated by about 1,600 feet, to definitively address hints of additional neutrinos types beyond the three currently described in the Standard Model. LBNF/DUNE will be the centerpiece of a U.S.-hosted world-leading neutrino research activities, using the world's most intense neutrino beam and large, sensitive underground detectors to make transformative discoveries.

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

Facility Operations and Experimental Support

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

HEP has a cooperative agreement with the South Dakota Science and Technology Authority, an agency of the State of South Dakota, for the operation of the (SURF. Experiments supported by DOE, NSF, and private entities are conducted there. The Nuclear Physics-supported Majorana Demonstrator is currently operating and the HEP-supported LZ experiment is being installed by the LZ collaboration at SURF. Lawrence Berkeley National Laboratory (LBNL) is the lead lab for the LZ collaboration. SURF will be the home of the DUNE far site detectors being built by the LBNF/DUNE project. All costs associated with LBNF and DUNE at SURF are supported by the project and not the cooperative agreement supporting SURF.

Projects

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

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

**Activities and Explanation of Changes**

(dollars in thousands)

| FY 2020 Enacted | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|
| **Intensity Frontier Experimental Physics $250,234** | **$204,535** | **-$45,699** |
| Research $58,871 | $35,520 | -$23,351 |
| Funding prioritizes support for world-leading research efforts on short- and long-baseline neutrino experiments, muon experiments, and technology studies and science planning for LBNF/DUNE. The SBN program is expected to produce its first physics data. The Muon g-2 experiment will achieve the world's most sensitive measurement of the anomalous magnetic dipole moment of a muon. Updated results from NOvA on the neutrino mass ordering and matter-antimatter asymmetry are expected. | The Request will support world-leading research efforts on short- and long-baseline neutrino experiments, muon experiments, and technology studies and science planning for LBNF/DUNE. The FNAL SBN program will move into full operations with all detectors, and the Muon g-2 experiment completes planned data taking. The MicroBoone collaboration will report on their key analyses of the neutrino spectrum anomalies. First joint analyses combining NOvA and T2K data are planned. The Request also will support completion of final analyses on data taken by the Daya Bay and MINERvA neutrino experiments. | Funding will focus research support towards NOvA, the SBN program, Mu2e, and LBNF/DUNE. Support for research on lower priority small- to mid-scale neutrino experiments, as determined by the FY 2018 HEPAP portfolio review, will ramp down. |

(dollars in thousands)

| FY 2020 Enacted | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|
| Facility Operations and Experimental Support $177,122 | $157,445 | -$19,677 |
| Funding supports the Fermilab Accelerator Complex and the neutrino and muon experiments at 85 percent of optimal operations. The Kautz Road Sub-Station Radial Feed Electrical Upgrade GPP will begin as will the Industrial Building 4 cleanroom consolidation and construction GPP in support of cryomodule fabrication. SURF operations will continue to enable operation of the LZ experiment and Majorana Demonstrator. Funding also supports additional investments to enhance SURF infrastructure for reliable and efficient operation of the facility during the construction of LBNF/DUNE. | The Request will support the Fermilab Accelerator Complex and the neutrino and muon experiments at 80 percent of optimal operations; the modernization, repairs, or addition of redundant equipment to help mitigate the risk of slowing down programs and projects; and SURF operations and investments to enhance SURF infrastructure. | Funding will focus support on delivering particle beams at peak power and providing detector and computing operations for ongoing (e.g., NOvA, Muon g-2) and new experiments (e.g., SBN). Overall operations of the Fermilab Accelerator Complex will decrease from 85 to 80 percent of optimal. Support for SURF infrastructure improvements will continue, but at a slightly lower amount. |
| Projects $5,494 | $4,000 | -$1,494 |
| Funding supports OPC for R&D related to the PIP-II Injector Test Facility; a prototype for the front-end injector; for plant support costs at SURF during LBNF/DUNE construction; and an MIE to upgrade the control system of the accelerator system which will allow the Fermilab Accelerator Complex to operate more precisely and efficiently, resulting in better performance and lower operating cost. | The Request will support OPC for developing additional PIP-II project scope necessary for upgrading the existing Booster, Recycler, and Main Injector synchrotrons (downstream from the new linac) to accept the increased beam intensity enabled by the new linac. OPC will continue plant support costs at SURF during LBNF/DUNE construction. Also, the Request will continue OPC for the Fermilab Accelerator Control System MIE. | The funding will decrease for the PIP-II injector prototype and plant support costs at SURF for LBNF/DUNE as the pre-excavation construction work approaches completion and is ramping down. |
| SBIR/STTR $8,747 | $7,570 | -$1,177 |
| In FY 2020, SBIR/STTR funding is at 3.65 percent of non-capital funding. | In FY 2021, SBIR/STTR funding will be at 3.65 percent of non-capital funding. | The SBIR/STTR funding will be consistent with the HEP total budget. |

## High Energy Physics
## Cosmic Frontier Experimental Physics

**Description**

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

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

Research

The Cosmic Frontier Experimental Physics subprogram's Research activity supports groups at U.S. academic and research institutions and national laboratories who perform experiments using instruments on the surface, deep underground, and in space. These groups, as part of scientific collaborations, typically have a broad portfolio of responsibilities and leadership roles in support of R&D, experimental design, fabrication, commissioning, operations, and maintenance, as well as perform scientific simulations and physics data analyses on the experiments in the subprogram. DOE selects research efforts with the highest scientific merit and potential impact based on a competitive peer-review process. HEP conducted an external peer review of the Cosmic Frontier laboratory research groups in FY 2016; the next review is planned for Q4 of FY 2020. In FY 2018, HEPAP evaluated the currently operating portfolio of experiments in the Cosmic Frontier and assessed the priority of their science output in the context of the science drivers. In early FY 2019, HEP conducted a Basic Research Needs[a]

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[a] The "Basic Research Needs for Dark Matter Small Projects New Initiatives" report can be found at: https://science.osti.gov/hep/Community-Resources/Reports

workshop to assess the science landscape and new opportunities for dark matter particle searches and to identify which areas would be suitable for small projects in the HEP program. The findings from these reviews, in combination with input on strategic directions from regular, open community workshops, are informing funding decisions in subsequent years.

The Research activity supports collaborations that enable all phases of experiments, from conceptual design through fabrication and operations, in order to ensure delivery of Cosmic Frontier science. The largest investments support scientific efforts to understand cosmic acceleration, from dark energy and inflation, and to search for dark matter produced in nature. The activity also supports R&D efforts to investigate the motivation and feasibility for possible future projects to enhance dark energy and dark matter studies with projects complementary to the current suite, as well as those using potential new methods or opportunities.

Two complementary next-generation experiments will provide greatly increased precision in measuring the history of the expansion of the universe in order to determine the nature of dark energy. The Vera C. Rubin Observatory (previously called the Large Synoptic Survey Telescope) will carry out a 10-year wide-field, ground-based optical and near-infrared imaging Legacy Survey of Space and Time (LSST), which will be used by the Dark Energy Science Collaboration (DESC). The Dark Energy Spectrographic Instrument (DESI) is carrying out a five-year survey to make light-spectrum measurements of 30 million galaxies and quasars that span over two-thirds of the history of the universe. The current generation of complementary dark energy experiments, Dark Energy Survey (DES) and extended Baryon Oscillation Spectroscopic Survey (eBOSS) completed operations in FY 2019 and continue to provide insight into the nature of dark energy as scientists continue to explore the data and develop innovative analysis techniques. The next-generation Cosmic Microwave Background-Stage 4 (CMB-S4) experiment will have unprecedented sensitivity and precision in measurements of the temperature fluctuations of the early universe. It will allow us to peer directly into the inflationary era in the early moments of the universe for the first time, at a time scale unreachable by other types of experiments.

The activity supports a portfolio of experiments to probe the most promising avenues in the search for the particle nature of dark matter. Two next-generation dark matter search experiments will use complementary technologies to search for weakly interacting massive particles (WIMP) over a wide range of masses, with LZ searching for heavier WIMPs and SuperCDMS-SNOLAB sensitive to lighter WIMPs. The Axion Dark-Matter eXperiment Generation 2 (ADMX-G2) searches for another theoretical dark matter candidate, the axion. Recent advancements in particle theory and sensor technology have created new opportunities to search for dark matter in previously unexplored mass ranges using small, targeted experiments.

In addition, recent new theoretical ideas have underscored that both candidates for Dark Matter, weakly interacting massive particles (WIMPs) and axions, are special cases of a broader theoretical framework that have many of the same attractive features and provide strong motivation for research and development support on possible future project(s) in Dark Matter parameter space beyond HEP's current program’s sensitivity.

Facility Operations and Experimental Support

This activity supports the DOE share of expenses necessary for the successful pre-operations planning activities and maintenance, operations, and data collection and processing during the operating phase of Cosmic Frontier experiments. These experiments are typically not sited at national laboratories, but at telescopes and observatories that are ground-based, in space, or deep underground. The activity provides support for the experiments currently operating as well as for planning and pre-operations activities for the next-generation experiments in the design or fabrication phase. HEP continues to carry out a series of planning reviews to ensure readiness as each experiment transitions from project fabrication to the science operations phase.

The DESI instrumentation is mounted and operating on the NSF’s Mayall Telescope at Kitt Peak National Observatory, with operations of the instrumentation and telescope supported by DOE. The Vera C. Rubin Observatory, which includes the DOE-provided camera, is being commissioned in Chile. DOE and NSF are partnering in observatory operations, with planning activities in process. The DESC continues its pre-operations activities to prepare for the initation of the 10-year survey.

The LZ dark matter detector is located underground and operating in the Sanford Underground Research Facility (SURF) in Lead, South Dakota, and the SuperCDMS-SNOLAB dark matter detector is located at Sudbury Neutrino Observatory in Canada. The ADMX-G2 experiment is carrying out ultra-sensitive searches for axion dark matter particles at the University of Washington.

Projects

The next-generation CMB-S4 experiment is planned as a joint DOE and NSF project and will consist of an array of small and large telescopes working in concert at sites in the South Pole and Chile with 500,000 ultra-sensitive sensors and associated readout system.

**Activities and Explanation of Changes**

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| **Cosmic Frontier Experimental Physics** | **$94,901** | **$69,920** | **-$24,981** |
| Research | $48,072 | $29,220 | -$18,852 |
| Funding prioritizes support for world-leading research efforts on all phases of dark matter and dark energy experiments, as well as technology studies and planning for a CMB-S4 experiment. The Dark Energy Survey (DES) imaging experiment will release all its data from its 5-year survey. | | The Request will support core research efforts in all phases of experiments. The collaborations expect to finish data analyses on ADMX-G2 Run 1D, DES year 3 data, and the full data set for eBOSS. Researchers will participate in data planning, collection, and analysis for LZ, SuperCDMS-SNOLAB, and DESI. Researchers will participate in commissioning of the Vera C. Rubin Observatory and the DESC will continue planning for the subsequent LSST. The Request also includes funding for CMB-S4, Dark Matter and Dark Energy planning as well as technology R&D for the future. | Research support will prioritize efforts for the experiments that have recently started and physics studies for CMB-S4. Research on recently completed and lower priority experiments, as determined by the FY 2018 HEPAP portfolio review, will ramp down. |
| Facility Operations and Experimental Support | $41,358 | $37,400 | -$3,958 |
| Funding supports experiments in various phases: DESI and LZ will start and ADMX-G2 will continue full science operations; effort will continue on the Vera C. Rubin Observatory, including its associated Legacy Survey of Space and Time (LSST) camera, to carry out commissioning activities and a ramp up of pre-operations planning; and SuperCDMS-SNOLAB will continue commissioning and pre-operations activities. | | The Request will support continued science operations on DESI, LZ, ADMX-G2, and partial science operations on SuperCDMS-SNOLAB. The Vera C. Rubin Observatory will continue commissioning and pre-operations efforts. | Support will prioritize the detector and observatory operations and data processing for the next generation dark matter and dark energy experiments, while ramping down operations for lower priority experiments. |

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | | Explanation of Changes FY 2021 Request vs FY 2020 Enacted | |
|---|---|---|---|---|---|
| Projects | $2,000 | | $1,000 | | -$1,000 |
| Funding supports OPC for technology R&D and planning for the CMB-S4 project. | | The Request will support a new MIE start for CMB-S4 as it completes conceptual design and begins preliminary design activities and starts long lead procurements for sensors and cryostats. | | The budget will transition support from OPC to preliminary design activities for CMB-S4. | |
| SBIR/STTR | $3,471 | | $2,300 | | -$1,171 |
| In FY 2020, SBIR/STTR funding is at 3.65 percent of non-capital funding. | | In FY 2021, SBIR/STTR funding will be at 3.65 percent of non-capital funding. | | The SBIR/STTR funding will be consistent with the HEP total budget. | |

## High Energy Physics
## Theoretical, Computational, and Interdisciplinary Physics

**Description**

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

Theory

The HEP theory activity supports world-leading research groups at U.S. academic and research institutions and national laboratories. Both university and laboratory research groups play important roles in addressing the leading research areas discussed above. Laboratory groups are typically more focused on data-driven theoretical investigations and precise calculations of experimentally observable quantities. University groups usually focus on building models of physics beyond the Standard Model and studying their phenomenology, as well as on formal and mathematical theory. DOE selects research efforts with the highest scientific impact and potential based on a competitive peer-review process. HEP conducted an external peer review of the Theory laboratory research groups in FY 2018; the next review is planned for FY 2022. The findings from this review, in combination with input on strategic directions from regular, open community workshops as well as a planned, future Basic Research Needs workshop, will inform funding decisions in subsequent years.

Computational HEP

The Computational HEP activity supports advanced simulations and computational science that extends the boundaries of scientific discovery to regions not directly accessible by experiments, observations, or traditional theory. Computation is necessary at all stages of HEP experiments—from planning and constructing accelerators and detectors, to theoretical modeling, to supporting computationally intensive experimental research and large-scale data analysis for scientific discovery in HEP. Computational HEP priorities are to promote computing research for HEP future needs across the program, by exploiting the latest architectures like massively-parallel high performance computing platforms and future exascale computer systems. Computational HEP partners with the Advanced Scientific Computing Research (ASCR) program, including via the Scientific Discovery through Advanced Computing (SciDAC) activity, and with ASCR facilities and projects to optimize the HEP computing ecosystem for the near and long term future.

Quantum Information Science (QIS)

The HEP QIS activity supports the 'science first' goal of the national QIS strategic plan and advances both HEP and QIS research. Key sub topics include: foundational research on connections between physics of the cosmos and qubit systems, quantum gauge theory techniques, quantum computing for HEP experiments, precision quantum sensors that may yield information on fundamental physics beyond the Standard Model, and applications of HEP research to advance QIS including specialized quantum controls and decoherence. QIS Centers, jointly supported across SC programs, apply concepts and technology from the relevant foundational core research in the corresponding programs and foster partnerships in support of the SC mission. The HEP QIS research activity is part of a broader SC initiative that is conducted in coordination with SC programs, other federal agencies, and the private sector where relevant.

Artificial Intelligence and Machine Learning

The HEP AI/ML activity supports research to tackle the challenges of managing increasingly high volumes and complexity of experimental and simulated data across the HEP experimental frontiers, theory, and technology thrusts. This activity also addresses cross-cutting challenges across the HEP program in coordination with DOE investments in exascale computing and associated AI efforts. Priorities include advancing AI/ML capabilities to provide more efficient processing of large data sets, modeling and mitigation of systematic uncertainties, high-throughput data selection, real-time data classification, and improved operations of particle accelerators and detectors. The activity routinely seeks input on key strategic directions in HEP AI/ML best aligned to support programmatic priorities from open community workshops and relevant federal advisory committees. The HEP AI/ML research activity is part of a broader Administration initiative that is conducted in coordination with DOE and SC programs, other federal agencies, and the private sector, where relevant.

**Activities and Explanation of Changes**

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| **Theoretical, Computational, and Interdisciplinary Physics** | **$115,527** | **$122,641** | **+$7,114** |
| Theory | $48,504 | $29,480 | -$19,024 |
| Funding supports world-leading research that addresses the neutrino mass, the interpretation of experimental results, the development of new ideas for future projects, and the advancement of the theoretical understanding of nature. | | The Request will support world-leading research that addresses the interactions of neutrinos with matter, the interpretation of experimental results, the development of new ideas for future projects, and the advancement of the theoretical understanding of nature. | Funding will prioritize theoretical support of the HEP experimental program and the highest-impact theoretical research as determined by competitive peer review. |
| Computational HEP | $9,430 | $11,440 | +$2,010 |
| Funding supports transformative computational science, high performance computing, and SciDAC 4 activities to provide crosscut computational science tools for HEP science. | | The Request will support transformative computational science, high performance computing, and SciDAC 4 activities; cross cut computational science tools for HEP science and computational science driven discovery; and exploratory research on adapting software workflows and testing hardware to make efficient use of the Exascale architecture. | Funding will support increased focus on high performance computing for particle physics and for computational science driven discovery. |
| Quantum Information Science | $38,500 | $43,809 | +$5,309 |
| Funding supports interdisciplinary HEP-QIS consortia and exploratory Pioneering Pilots to strengthen foundational HEP-QIS research, quantum computing and quantum research technology. Funding also supports up to five new QIS Centers in partnership with other SC program offices. | | The Request will support interdisciplinary HEP-QIS consortia for focused research on foundational HEP-QIS including novel experiments, quantum computing, and quantum research technology. The Request will also continue support for QIS Centers in partnership with other SC program offices. | Increased funding will support quantum simulation experiments and QIS Centers. |

(dollars in thousands)

| FY 2020 Enacted | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|
| Artificial Intelligence and Machine Learning $15,000 | $34,500 | +$19,500 |
| Funding supports new and existing AI/ML research to explore how DOE high performance computing resources can scale up the optimization, performance, and validation studies of AI/ML tracking models, use pattern recognition to develop production-quality tracking for online triggering systems for HEP experiments, and use statistics and AI/ML to better analyze simulated data. | The Request will support AI/ML research to tackle challenges across the HEP program, including new techniques to support the analysis of the large datasets that will be produced in the next LHC run; further enhancements to the science output of data-intensive experiments through improved pattern recognition, anomaly detection, and background rejection; increased operations automation of large detectors and accelerators; and more sophisticated production of large simulated data sets to reduce steeply growing computational demands. | Funding will support cross-cutting challenges in AI/ML that will advance the HEP program. Science community input and programmatic priorities will inform key investment strategies. HEP will select research efforts with the highest scientific impact and potential based on a competitive peer-review process. |
| SBIR/STTR $4,093 | $3,412 | -$681 |
| In FY 2020, SBIR/STTR funding is at 3.65 percent of non-capital funding. | In FY 2021, SBIR/STTR funding will be at 3.65 percent of non-capital funding. | The SBIR/STTR funding will be consistent with the HEP total budget. |

**Description**

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

<u>HEP General Accelerator R&D</u>

The HEP General Accelerator R&D (GARD) activity supports the science underlying the technologies used in particle accelerators and storage rings, as well as the fundamental physics of charged particle beams. Long-term research goals include developing technologies to enable breakthroughs in particle accelerator size, cost, beam intensity, and control. The GARD activity supports groups at U.S. academic and research institutions and national laboratories performing research activity categorized into five areas: accelerator and beam physics; advanced acceleration concepts; particle sources and targetry; radio-frequency acceleration technology; and superconducting magnet and materials. DOE selects research efforts with the highest scientific impact and potential based on a competitive peer-review process. HEP conducted an external peer review of the GARD laboratory research groups in FY 2018; the next review is planned for FY 2022. The findings from this review, in combination with input on strategic directions from regular, open community workshops as well as future Basic Research Needs workshops, will inform funding decisions in subsequent years.

The state-of-the-art SC facilities attract the world's leading researchers, bringing knowledge and ideas that enhance U.S. science and create high technology jobs. As competing accelerator-based facilities are built abroad, they are beginning to draw away scientific and technical talent. Sustaining world-class accelerator-based SC facilities requires continued, transformative advances in accelerator science and technology, and a workforce capable of performing leading accelerator research for future application. The SC Strategic Accelerator Technology Initiative will address these needs by reinforcing high-risk, high-reward accelerator R&D that will invest in SC facilities to stay at the global forefront, and develop a world-leading workforce to build and operate future generations of facilities. HEP, BES, FES, NP, and ASCR will enhance coordination and jointly pursue accelerator R&D topics that will have a strong impact on the scientific capabilities of SC facilities.

In addition to providing support for the highly successful U.S. Particle Accelerator School, the GARD activity also supports the Traineeship Program for Accelerator Science and Technology to revitalize education, training, and innovation in the physics of particle accelerators for the benefit of HEP and other SC programs that rely on these enabling technologies. The Traineeship Program is aimed at university and national laboratory consortia to provide the academic training and research experience needed to meet DOE's anticipated workforce needs. HEP holds a competition for traineeship awards for graduate level students to increase workforce development in areas of critical need. These traineeships leverage existing GARD research activities as well as the capabilities and assets of DOE laboratories.

<u>Detector R&D</u>

The Detector R&D activity supports the development of the next generation instrumentation and particle detectors necessary to maintain U.S. scientific leadership in a worldwide experimental endeavor that is broadening into new research areas. To meet this challenge, HEP aims to foster an appropriate balance between evolutionary, near-term, low-risk detector R&D and revolutionary, long-term, high-risk detector R&D, while training the next generation of experts. The Detector R&D activity consists of groups at U.S. academic and research institutions and national laboratories performing research into the fundamental physics underlying the interactions of particles and radiation in detector materials. This activity also supports technology development that turns these insights into working detectors. DOE selects research efforts with the highest scientific impact and potential based on a competitive peer-review process. HEP conducted an external peer review of the Detector R&D laboratory research groups in FY 2016; the next review is planned for FY 2021. In FY 2020, HEP conducted a Basic Research Needs workshop to assess the science landscape and new opportunities for potentially transformative detector technologies, and to identify which R&D areas would be most suitable for new investments in the HEP program. The findings from this workshop, in combination with input on strategic directions from regular, open community workshops will inform funding decisions in subsequent years.

The Detector R&D activity, as well as the GARD activity, supports the Traineeship Program for Accelerator Science and Technology to revitalize education, training, and innovation in the physics of particle detectors and next generation instrumentation for the benefit of HEP and other SC programs that rely on these enabling technologies. The Traineeship Program is aimed at university and national laboratory consortia to provide the academic training and research experience needed to meet DOE's anticipated workforce needs. HEP holds a competition for traineeship awards for graduate level students to increase workforce development in areas of critical need. These traineeships leverage existing Detector R&D research activities as well as the capabilities and assets of DOE laboratories.

SC is in a unique position to both play a critical role in the advancement of microelectronic technologies over the coming decades, and also to benefit from the resultant capabilities in detection, computing, and communications. Four SC programs – ASCR, BES, FES, and HEP – will work together to advance Microelectronics technologies . While there is a significant emphasis across the Federal government on (QIS, including quantum computing, this initiative is intentionally focused on establishing the foundational knowledge base for future microelectronics and computing technologies that are complementary to quantum computing. Radiation and particle detection specifically will benefit from detector materials R&D, device R&D, advances in front-end electronics, and integrated sensor/processor architectures.

Facility Operations and Experimental Support

This activity supports GARD laboratory experimental and test facilities: Berkeley Lab Laser Accelerator (BELLA), the laser-driven plasma wakefield acceleration facility at LBNL; FACET-II, the beam-driven plasma wakefield acceleration facility at SLAC National Accelerator Laboratory (SLAC); and superconducting radio-frequency accelerator and magnet facilities at FNAL. This activity supports the test beam at FNAL, and detector test and fabrication facilities such as the Microsystems Laboratory at LBNL and the Silicon Detector Facility at FNAL. Accelerator Improvement Projects (AIP) support improvements to GARD facilities.

Projects

The Advanced Technology R&D subprogram supports the development of new tools for particle physics through the development of more advanced accelerators and detectors. Plasma wakefield accelerators may have a transformative impact on the size, capabilities, and cost of future machines. FACET-II will be the world's premier beam driven plasma wakefield acceleration facility and provide intense ultra-short electron beams for other applications in accelerator and related sciences. The FY 2019 Appropriation provided sufficient funds to complete all remaining deliverables. In FY 2020, the project will be completing its Accelerator Readiness Review and final checks of its electronic control systems in anticipation of receiving final CD-4 approval.

## High Energy Physics
## Advanced Technology R&D

### Activities and Explanation of Changes

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| **Advanced Technology R&D** | **$107,406** | **$106,102** | **-$1,304** |
| HEP General Accelerator R&D | $43,454 | $45,606 | +$2,152 |
| Funding supports world-leading General Accelerator R&D that will enable transformative technologies for the next-generation of accelerators for High Energy Physics. Funding also provides support for the Traineeship Program for Accelerator Science and Technology. | | The Request will support world-leading research activities in the areas of accelerator and beam physics, advanced acceleration concepts, particle sources and targetry, radio-frequency acceleration technology and superconducting magnet and materials. The Request will also support the Traineeship Program for Accelerator Science and Technology, and will initiate support for the Strategic Accelerator Technology Initiative. | Funding will support capitalization on the science opportunities at the newly completed FACET-II facility, grow the Traineeship Program, begin the Strategic Accelerator Technology Initiative to bolster efforts in superconducting Magnet Development, accelerate ultrafast laser R&D, upgrade SRF facilities and expand capabilities, and co-fund a multi-program R&D initiative in superconducting materials. |
| Detector R&D | $20,937 | $19,450 | -$1,487 |
| Funding supports cutting-edge Detector R&D activities at universities and national laboratories, targeted at the most promising, high-impact directions led by U.S. efforts. | | The Request will support world-leading Detector R&D activities at universities and national laboratories, with increased emphasis on long-term, high-risk, and high potential impact R&D efforts, informed by the findings of the FY 2020 Basic Research Needs study on HEP Detector R&D. HEP will collaborate with ASCR, BES, and FES to advance Microelectronics technologies. The Request will also expand the Traineeship Program to Detector R&D. | Funding will support efforts toward the Microelectronic initiative and the Traineeship program, while ongoing Detector R&D support will be prioritized at universities and national laboratories that enhance collaborative opportunities in support of new directions in HEP discovery science programs and strengthen new technology developments and capabilities that address priorities identified in the FY 2020 Basic Research Needs study. |

(dollars in thousands)

| FY 2020 Enacted | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|
| Facility Operations and Experimental Support $39,232 | $37,200 | -$2,032 |
| Funding supports the operation of accelerator, test beam, and detector facilities at FNAL, LBNL, and SLAC and improvements to superconducting radio-frequency facilities. Funding also supports final commissioning, installation, and 1,500 hours (50 percent of optimal) of initial operations for FACET-II. | The Request will support the operation of accelerator, test beam, and detector facilities at FNAL, LBNL, and SLAC and improvements to superconducting radio-frequency and magnet test facilities. The Request also includes support for 2,700 hours (90 percent of optimal) facility operations for FACET-II. | Funding will support FACET-II for additional beam time for experiments and to improve its capabilities. The increase will be offset by a decrease at the facilities at ANL, FNAL, LBNL, and SLAC, which will be guided by recent comparative reviews of the laboratory programs. |
| SBIR/STTR $3,783 | $3,846 | +$63 |
| In FY 2020, SBIR/STTR funding is at 3.65 percent of non-capital funding. | In FY 2021, SBIR/STTR funding will be at 3.65 percent of non-capital funding. | The SBIR/STTR funding will be consistent with the HEP total budget. |

## High Energy Physics
## Accelerator Stewardship

**Description**
The Accelerator Stewardship subprogram has three principal activities: facilitating access to unique state-of-the-art SC accelerator R&D infrastructure for the private sector and other users; supporting innovative early-stage applied research to adapt accelerator technology for medical, industrial, security, and defense applications; and driving a limited number of specific accelerator applications towards practical, testable prototypes in a five to seven year timeframe. HEP manages this subprogram as a coordinated interagency initiative, consulting with other SC programs, principally BES, FES, NP; other DOE program offices, principally EM; and other federal stakeholders[a] of accelerator technology. Ongoing interagency consultation guides research and development (R&D) investments, ensuring agency priorities are addressed, exploiting synergies where possible, and identifying new cross-cutting areas of research.

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

The state-of-the-art SC facilities attract the world's leading researchers, bringing knowledge and ideas that enhance U.S. science and create high technology jobs. As competing accelerator-based facilities are built abroad they are beginning to draw away scientific and technical talent. Sustaining world-class accelerator-based SC facilities requires continued, transformative advances in accelerator science and technology, and a workforce capable of performing leading accelerator research for future application. SC's Strategic Accelerator Technology Initiative will address these needs by reinforcing high-risk, high-reward accelerator R&D that will invest in SC facilities to stay at the global forefront, and develop a world-leading workforce to build and operate future generations of facilities. HEP, BES, FES, NP, and ASCR will enhance coordination and jointly pursue accelerator R&D topics that will have a strong impact on the scientific capabilities of SC facilities.

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

[a] Partner agencies for the Accelerator Stewardship subprogram currently are: the National Nuclear Security Administration; National Institutes of Health's National Cancer Institute; the Department of Defense's Office of Naval Research, the Air Force Office of Scientific Research, and the Defense Advanced Research Projects Agency; the NSF's Physics Division; Department of Homeland Security's Countering Weapons of Mass Destruction office.

**Activities and Explanation of Changes**

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| **Accelerator Stewardship** | **$17,494** | **$14,229** | **-$3,265** |
| Research | $10,788 | $8,510 | -$2,278 |
| Funding supports new research activities at laboratories, universities, and in the private sector for technology R&D areas such as accelerator technology for industrial, medical and security uses, and advanced laser technology R&D. | | The Request will support new research activities at laboratories, universities, and in the private sector for technology R&D areas such as accelerator technology for industrial, medical and security uses, and advanced laser technology R&D. The Request will initiate funding for the Strategic Accelerator Technology Initiative. | Funding will enable the start of the Strategic Accelerator Technology Initiative to advance accelerator technologies that define the U.S. competitive advantage in physical sciences research. There will be an offsetting decrease in R&D on accelerator technologies for industrial, medical and security uses, and advanced laser technology R&D. |
| Facility Operations and Experimental Support | $6,067 | $5,200 | -$867 |
| Funding supports the BNL ATF operations at 100 percent of optimal levels and supports facility refurbishments to provide increased reliability and expanded capability to users. | | The Request will support the BNL ATF operations at 86 percent of optimal levels. | Operating hours will be decreased to 86 percent of optimal levels. |
| SBIR/STTR | $639 | $519 | -$120 |
| In FY 2020, SBIR/STTR funding is at 3.65 percent of non-capital funding. | | In FY 2021, SBIR/STTR funding will be at 3.65 percent of non-capital funding. | The SBIR/STTR funding will be consistent with the HEP total budget. |

## Description

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

Proton Improvement Plan II (PIP-II)

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

The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-1 (Approve Alternative Selection and Cost Range), approved on July 23, 2018. The TPC cost range is $653,000,000 to $928,000,000. The funding profile supports the currently estimated TPC of $888,000,000. The CD-4 milestone is Q1 FY 2030.

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

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

The LBNF/DUNE project is a national flagship particle physics initiative. LBNF/DUNE will be the first-ever large-scale, international science facility hosted by the U.S. The LBNF/DUNE project consists of two multinational collaborative efforts. LBNF is responsible for the beamline at FNAL and other experimental and civil infrastructure at FNAL and at the SURF in South Dakota. DUNE is an international scientific collaboration responsible for defining the scientific goals and technical requirements for the beam and detectors, as well as the design, construction and commissioning of the detectors and subsequent research.

DOE's High Energy Physics program manages both activities as a single, line-item construction project—LBNF/DUNE. LBNF, with DOE/FNAL leadership and minority participation by a small number of international partners including CERN, will construct a megawatt-class neutrino source and related facilities at FNAL (the "Near Site"), as well as underground caverns and cryogenic facilities in South Dakota (the "Far Site") needed to house the DUNE detectors. DUNE has international leadership and participation by about 1,160 scientists and engineers from 175 institutions in 32 countries. DOE will fund less than a third of DUNE.

The most recent approved DOE Order 413.3B Critical Decision is CD-3A, approval for Initial Far Site Construction. This approval initiated excavation and construction for the LBNF Far Site conventional facilities in order to mitigate risks and minimize delays for providing a facility ready to accept detectors for installation. The preliminary Total Project Cost (TPC) range is $1,260,000,000 to $1,860,000,000, as approved on September 1, 2016, with a preliminary CD-4 date of Q4 FY 2030. Updated planning and analysis has the TPC point estimate for LBNF/DUNE at $2,600,000,000. The cost estimate increased for two reasons. The first is due to the cost of the excavation. The excavation contractor is now on site and has identified deficiencies in the greater than 100 year old infrastructure that will need to be repaired to support the large volume of rock removal. In addition, the time required to complete the excavation was previously underestimated. An independent cost estimator employed by the project and the design firm verified these new findings. The second reason for the increased cost estimate is that contributions from international partners have been lower than expected. DOE and the laboratory are continuing engagement with potential partners. Scope reductions will be considered to reduce the TPC by the time of baseline.

**Activities and Explanation of Changes**

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| **Construction** | **$231,000** | **$120,500** | **-$110,500** |
| 18-SC-42, Proton Improvement Plan II, FNAL | $60,000 | $20,000 | -$40,000 |
| Funding supports engineering design work for conventional facilities and technical systems, continuation of site-preparation activities and initiation of construction for cryogenic plant support systems, as well as continued procurement of prototype accelerator system components. | | The Request will support completion of civil engineering design for the conventional facilities, technical design and prototyping for the accelerator components, and initiation of construction and procurement for technical systems when design is final and construction is authorized by CD-3. | Support will continue completion of the design phase of PIP-II, including the fabrication of prototypes. |
| 11-SC-40, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment, FNAL | $171,000 | $100,500 | -$70,500 |
| Funding supports the continuation of pre-construction activities to support the Far Site cavern excavation; design and procurement activities for Far Site cryogenics systems; and beamline and conventional facilities design and site preparation at the Near Site. Funding also supports the start of construction and fabrication for technical systems where design is final and authorized by CD-3, including U.S. contributions to the DUNE detectors. | | The Request will support completion of the Far Site civil construction activities for pre-excavation and the beginning of excavation activities for the underground equipment caverns and connecting drifts (tunnels), as well as design and procurement activities for Far Site cryogenics systems. The Request will also support Near Site (FNAL) beamline and conventional facilities design and continuation of a site-preparation construction subcontract at the Near Site for relocation of existing service roads and utilities. The Request supports the continuation of construction and fabrication for technical systems including contributions to the DUNE detectors, when design is final and construction authorized by CD-3. | Support will continue for the transition of Far Site construction work from preexcavation to excavation and the ramp-up of design effort on the Near Site facilities. |

## High Energy Physics
## Capital Summary

(dollars in thousands)

| | Total | Prior Years | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|---|---|
| **Capital Operating Expenses** | | | | | | |
| Capital Equipment | N/A | N/A | 125,260 | 105,350 | 84,700 | -20,650 |
| Minor Construction Activities | | | | | | |
| General Plant Projects (GPP) | N/A | N/A | 8,000 | 10,900 | 1,000 | -9,900 |
| Accelerator Improvement Projects (AIP) | N/A | N/A | 5,600 | — | — | — |
| **Total, Capital Operating Expenses** | **N/A** | **N/A** | **138,860** | **116,250** | **85,700** | **-30,550** |

## Capital Equipment

(dollars in thousands)

| | Total | Prior Years | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|---|---|
| **Capital Equipment** | | | | | | |
| Major Items of Equipment[a] | | | | | | |
| *Energy Frontier Experimental Physics* | | | | | | |
| HL-LHC Accelerator Upgrade Project[b] | 236,672 | 21,572 | 50,000 | 52,025 | 43,000 | -9,025 |
| HL-LHC ATLAS Detector Upgrade[c] | 136,000 | — | 27,500 | 24,500 | 17,500 | -7,000 |
| HL-LHC CMS Detector Upgrade[d] | 121,800 | — | 13,750 | 23,475 | 17,500 | -5,975 |

[a] Each MIE located at a DOE facility Total Estimated Cost (TEC) > $5M and each MIE not located at a DOE facility TEC > $2M.
[b] Critical Decision CD-2/3b for HL-LHC Accelerator Upgrade project was approved on February 11, 2019. The TPC is $242,720,000.
[c] Critical Decision CD-1 for HL-LHC ATLAS Detector Upgrade Project was approved September 21, 2018. The estimated cost range was $149,000,000 to $181,000,000. Critical Decision CD-3a was approved October 16, 2019.
[d] Critical Decision CD-1 for HL-LHC CMS Detector Upgrade Project was approved December 19, 2019. The estimated cost range was $144,100,000 to $183,000,000.

| | (dollars in thousands) | | | | | |
|---|---|---|---|---|---|---|
| | Total | Prior Years | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
| *Cosmic Frontier Experimental Physics* | | | | | | |
| Dark Energy Spectroscopic Instrument[a] (DESI) | 45,250 | 39,800 | 5,450 | — | — | — |
| LUX-ZEPLIN[b] (LZ) | 52,050 | 37,600 | 14,450 | — | — | — |
| Super CDMS-SNOLAB[c] | 15,725 | 13,175 | 2,550 | — | — | — |
| CMB-S4[d] | 350,000 | — | — | — | 1,000 | +1,000 |
| *Advanced Technology R&D* | | | | | | |
| FACET II[e] | 20,500 | 10,500 | 10,000 | — | — | — |
| Total, MIEs | N/A | N/A | 123,700 | 100,000 | 79,000 | -21,000 |
| Total, Non-MIE Capital Equipment | N/A | N/A | 1,560 | 5,350 | 5,700 | +350 |
| **Total, Capital Equipment** | **N/A** | **N/A** | **125,260** | **105,350** | **84,700** | **-20,650** |

**Minor Construction Activities**

| | (dollars in thousands) | | | | | |
|---|---|---|---|---|---|---|
| | Total | Prior Years | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
| **General Plant Projects (GPP)** | | | | | | |
| Greater than or equal to $5M and less than $20M | | | | | | |
| Utility Corridor | 8,000 | — | 8,000 | — | — | — |
| Kautz Road Sub-Station | 7,500 | — | — | 7,500 | — | -7,500 |
| Total GPPs (greater than or equal to $5M and less than $20M) | N/A | N/A | 8,000 | 7,500 | — | -7,500 |
| Total GPPs less than $5M[f] | N/A | N/A | — | 3,400 | 1,000 | -2,400 |
| **Total, General Plant Projects (GPP)** | **N/A** | **N/A** | **8,000** | **10,900** | **1,000** | **-9,900** |

[a] Critical Decision CD-3 for DESI project was approved on June 22, 2016. The TPC is $56,328,000.
[b] Critical Decision CD-3 for LZ project was approved February 9, 2017. The TPC is $55,500,000.
[c] Critical Decisions CD-2/3 for SuperCDMS-SNOLAB project were approved May 2, 2018. The TPC is $18,600,000.
[d] Critical Decision CD-0 for CMB-S4 was approved July 25, 2019. The estimated cost range was $320,000,000 to $395,000,000.
[e] Critical Decisions CD-2/3 for FACET-II project were approved June 8, 2018. The TPC is $25,600,000.
[f] GPP activities less than $5M include design and construction for additions and/or improvements to land, buildings, replacements or additions to roads, and general area improvements.

| | (dollars in thousands) | | | | | |
|---|---|---|---|---|---|---|
| | **Total** | **Prior Years** | **FY 2019 Enacted** | **FY 2020 Enacted** | **FY 2021 Request** | **FY 2021 Request vs FY 2020 Enacted** |
| **Accelerator Improvement Projects (AIP)** | | | | | | |
| Greater than or equal to $5M and less than $20M | | | | | | |
| NuMI Target Systems | 5,600 | — | 5,600 | — | — | — |
| Total, AIPs (greater than or equal to $5M and less than $20M) | N/A | N/A | 5,600 | — | — | — |
| Total, AIPs less than $5M[a] | N/A | N/A | — | — | — | — |
| **Total, Accelerator Improvement Projects (AIP)** | **N/A** | **N/A** | **5,600** | **—** | **—** | **—** |
| **Total, Minor Construction Activities** | **N/A** | **N/A** | **13,600** | **10,900** | **1,000** | **-9,900** |

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

## High Energy Physics
## Major Items of Equipment Description(s)

Energy Frontier Experimental Physics MIEs:

*High Luminosity Large Hadron Collider Accelerator Upgrade Project (HL-LHC Accelerator Upgrade Project)*

The High Luminosity Large Hadron Collider Accelerator Upgrade Project (HL-LHC Accelerator Upgrade Project) received CD-2/3b approval on February 11, 2019 with a TPC of $242,720,000. Following the major upgrade, the CERN LHC machine will further increase the particle collision rate by a factor of three to explore new physics beyond its current reach. This project will deliver components for which U.S. scientists have critical expertise: interaction region focusing quadrupole magnets, and special superconducting RF crab cavities that are capable of generating transverse electric fields. The magnets will be assembled at LBNL, BNL, and FNAL, exploiting special expertise and unique capabilities at each laboratory. The FY 2021 Request of TEC funding of $43,000,000 will focus support on critical path items in the production of quadrupole magnets and crab cavities to best maintain international schedule synchronization.

*High Luminosity Large Hadron Collider ATLAS Detector Upgrade Project (HL-LHC ATLAS)*

The High Luminosity Large Hadron Collider ATLAS Detector Upgrade Project (HL-LHC ATLAS) received CD-1 approval on September 21, 2018 with an estimated cost range of $149,000,000 to $181,000,000 and received CD-3a approval on October 16, 2019. CD-2 is planned for FY 2021. The ATLAS detector will integrate a factor of ten higher amount of data per run, compared to the period prior to the HL-LHC upgrades, making the physical conditions in which the detectors run very challenging. To operate for an additional decade in these new conditions, the ATLAS detector will require upgrades to the silicon pixel and strip tracker detectors, the muon detector systems, the calorimeter detectors and associated electronics, and the trigger and data acquisition systems. The National Science Foundation (NSF) begins support for a Major Research Equipment and Facility Construction (MREFC) Project in FY 2020 to provide different scope to the HL-LHC ATLAS detector. DOE and NSF are coordinating their contributions to avoid duplication. The FY 2021 Request of TEC funding of $17,500,000 will focus support on critical path items to best maintain international schedule synchronization.

*High Luminosity Large Hadron Collider CMS Detector Upgrade Project (HL-LHC CMS)*

The High Luminosity Large Hadron Collider CMS Detector Upgrade Project (HL-LHC CMS) received CD-1 approval on December 19, 2019, with an estimated cost range of $144,100,000 to $183,000,000. The project is planning CD-3a approval of long lead procurements in spring 2020, with CD-2 planned for FY 2021. The CMS detector will integrate a factor of ten higher amount of data per run, compared to the period prior to the HL-LHC upgrades, making the physical conditions in which the detectors run very challenging. To operate for an additional decade in these new conditions, the CMS detector will require upgrades to the silicon pixel tracker detectors, outer tracker detector, the muon detector systems, the calorimeter detectors and associated electronics, the trigger and data acquisition systems and the addition of a novel timing detector. NSF begins support for a MREFC Project in FY 2020 to provide different scope to the HL-LHC CMS detector. DOE and NSF are coordinating their contributions to avoid duplication. The FY 2021 Request of TEC funding of $17,500,000 will focus support on critical path items to best maintain international schedule synchronization.

Cosmic Frontier Experimental Physics MIEs:

*Dark Energy Spectroscopic Instrument (DESI)*

The Dark Energy Spectroscopic Instrument (DESI) project received CD-2 approval on September 17, 2015 with a TPC of $56,328,000. CD-3 was approved on June 22, 2016. DESI fabricated a next-generation, fiber-fed, ten-arm spectrograph for operation on NSF's Mayall 4-meter telescope at Kitt Peak National Observatory in Arizona, with operations of the telescope supported by DOE. DESI will measure the effects of dark energy on the expansion of the universe using dedicated spectroscopic measurements and will provide a strong complement to the imaging Legacy Survey of Space and Time carried out by the Vera C. Rubin Observatory. The FY 2019 Appropriation for DESI provided sufficient funds to complete all remaining project deliverables. In FY 2020, the project completed all deliverables, including the installation and commissioning of all ten spectrographs and associated systems, and starts full science operations. CD-4 approval is expected in FY 2020.

*LUX-ZEPLIN (LZ)*

The LUX-ZEPLIN (LZ) project received CD-2 approval on August 8, 2016 with a TPC of $55,500,000, and a project completion date in FY 2022. CD-3 was approved on February 9, 2017. LZ is one of two MIEs selected to meet the Dark Matter Second

Generation Mission Need and the concept for the experiment was developed by a merger of the LUX and ZEPLIN collaborations from the U.S. and the U.K. respectively. The project will fabricate a detector using seven tons of liquid xenon inside a time projection chamber to search for xenon nuclei that recoil in response to collisions with an impinging flux of dark matter particles known as Weakly Interacting Massive Particles (WIMPs). The detector will be located 4,850 feet deep in the Sanford Underground Research Facility (SURF) in Lead, South Dakota. The FY 2019 Appropriation for LZ provided sufficient funds to complete all remaining project deliverables. In FY 2020, the project will finish underground installation, functional testing, and filling of the detector's chambers with liquid xenon, liquid scintillator, and water, and will start full science operations. CD-4 approval is expected in FY 2020.

*Super Cryogenic Dark Matter Search at Sudbury Neutrino Observatory Laboratory (SuperCDMS-SNOLAB)*
The Super Cryogenic Dark Matter Search at Sudbury Neutrino Observatory Laboratory (SuperCDMS-SNOLAB) project received CD-2/3 approval on May 2, 2018 with a TPC of $18,600,000 and a project completion date at the end of FY 2021. SuperCDMS-SNOLAB is one of the two MIEs selected to meet the Dark Matter Second Generation Mission Need. The project will fabricate instrumentation that uses ultra-clean, cryogenically-cooled silicon (Si) and germanium (Ge) detectors to search for Si or Ge nuclei recoiling in response to collisions with WIMPs, and will optimize to detect low mass WIMPs to cover a range of masses complementary to that of LZ's sensitivity. The detector will be located 2 km deep in the SNOLAB facility in Sudbury, Ontario, Canada. The FY 2019 Appropriation for SuperCDMS-SNOLAB provided sufficient funds to complete all remaining project deliverables in FY 2021, including installation of the seismic platform and assembly of the shielding, cryostat, and calibration system.

*Cosmic Microwave Background Stage 4 (CMB-S4)*
The *Cosmic Microwave Background Stage 4 (CMB-S4) project* received CD-0 approval on July 25, 2019, with an estimated cost range of $320,000,000 to $395,000,000. The project is expected to be carried out as a partnership with NSF, with DOE as the lead agency and a distribution of scope determined by FY 2021. The project consists of fabricating an array of small and large telescopes at two locations: the NSF Amundsen-Scott South Pole Station and the Atacama high desert in Chile. It will include 500,000 ultra-sensitive sensors with associated readout systems. The project is expected to obtain CD-1 approval in mid FY 2021, along with CD-3a approval of long lead procurements at the same time. In FY 2021, plans for the sensors and readout systems as well as the conceptual design will be completed and the preliminary design and pre-production efforts will start. The FY 2021 Request of TEC funding of $1,000,000 will enable long lead procurement for sensor production and testing, as well as associated systems and infrastructure.

<u>Advanced Technology R&D MIE:</u>
*Facility for Accelerator and Experimental Tests II (FACET-II)*
The Facility for Accelerator and Experimental Tests II (FACET-II) project received CD-2/3 on June 8, 2018 with a TPC of $25,600,000. FACET-II will be the world's premier beam driven plasma wakefield acceleration facility. FACET-II is being designed to deliver beams using only one third of the SLAC linear accelerator. FACET-II installation and commissioning work in the SLAC accelerator housing will be constrained by the installation of the Linac Coherent Light Source II (LCLS-II). The FY 2019 Appropriation provided sufficient funds to complete all remaining deliverables. In FY 2020, the project will be completing its Accelerator Readiness Review and final checks of its electronic control systems and receive final CD-4 approval.

## High Energy Physics
## Construction Projects Summary

(dollars in thousands)

| | Total | Prior Years | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|---|---|
| **18-SC-42, Proton Improvement Plan II, FNAL** | | | | | | |
| TEC | 801,200 | 1,000 | 20,000 | 60,000 | 20,000 | -40,000 |
| OPC | 86,800 | 57,035 | 15,000 | 494 | 2,000 | +1,506 |
| **TPC** | **888,000** | **58,035** | **35,000** | **60,494** | **22,000** | **-38,494** |
| **11-SC-40, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment, FNAL** | | | | | | |
| TEC | 2,476,375 | 206,781 | 130,000 | 171,000 | 100,500 | -70,500 |
| OPC | 123,625 | 86,625 | 1,000 | 4,000 | 1,000 | -3,000 |
| **TPC** | **2,600,000** | **293,406** | **131,000** | **175,000** | **101,500** | **-73,500** |
| **11-SC-41, Muon to Electron Conversion Experiment, FNAL** | | | | | | |
| TEC | 250,000 | 220,000 | 30,000 | — | — | — |
| OPC | 23,677 | 23,677 | — | — | — | — |
| **TPC** | **273,677** | **243,677** | **30,000** | **—** | **—** | **—** |
| **Total, Construction** | | | | | | |
| **TEC** | **N/A** | **N/A** | **180,000** | **231,000** | **120,500** | **-110,500** |
| **OPC** | **N/A** | **N/A** | **16,000** | **4,494** | **3,000** | **-1,494** |
| **TPC** | **N/A** | **N/A** | **196,000** | **235,494** | **123,500** | **-111,994** |

**High Energy Physics**
**Funding Summary**

| | (dollars in thousands) | | | |
|---|---|---|---|---|
| | **FY 2019 Enacted** | **FY 2020 Enacted** | **FY 2021 Request** | **FY 2021 Request vs FY 2020 Enacted** |
| Research | 380,847 | 390,077 | 328,906 | -61,171 |
| Facility Operations | 260,803 | 316,429 | 285,725 | -30,704 |
| Projects | | | | |
| Major Items of Equipment | 141,350 | 103,000 | 80,000 | -23,000 |
| Construction | 196,000 | 235,494 | 123,500 | -111,994 |
| Other Projects | 1,000 | – | – | – |
| Total, Projects | 338,350 | 338,494 | 203,500 | -134,994 |
| **Total, High Energy Physics** | **980,000** | **1,045,000** | **818,131** | **-226,869** |

**High Energy Physics**
**Scientific User Facility Operations**

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

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

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

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

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

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

(dollars in thousands)

| | FY 2019 Enacted | FY 2019 Current | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|---|
| **TYPE A FACILITIES** | | | | | |
| **Fermilab Accelerator Complex** | **$132,650** | **$133,585** | **$141,520** | **$126,440** | **-$15,080** |
| Number of users | 2,489 | 2,610 | 2,450 | 2,280 | -170 |
| Achieved operating hours | N/A | 4,911 | N/A | N/A | N/A |
| Planned operating hours | 5,740 | 5,740 | 4,900 | 4,580 | -320 |
| Optimal hours | 5,740 | 5,740 | 5,740 | 5,740 | — |
| Percent optimal hours | 100.0% | 85.6% | 85.4% | 79.8% | -5.6% |
| Unscheduled downtime hours | N/A | 829 | N/A | N/A | N/A |

(dollars in thousands)

| | FY 2019 Enacted | FY 2019 Current | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|---|
| **Accelerator Test Facility (BNL)** | **$6,067** | **$4,812** | **$6,067** | **$5,200** | **-$867** |
| Number of users | 118 | 127 | 127 | 101 | -26 |
| Achieved operating hours | N/A | 2,274 | N/A | N/A | N/A |
| Planned operating hours | 2,500 | 2,020 | 2,500 | 2,150 | -350 |
| Optimal hours | 2,500 | 2,500 | 2,500 | 2,500 | — |
| Percent optimal hours | 100.0% | 91.0% | 100.0% | 86.0% | -14.0% |
| Unscheduled downtime hours | N/A | 388 | N/A | N/A | N/A |
| **FACET-II (SLAC)** | **$1,000** | **$1,300** | **$6,000** | **$10,000** | **+$4,000** |
| Number of users | N/A | N/A | 200 | 250 | +50 |
| Achieved operating hours | N/A | N/A | N/A | N/A | N/A |
| Planned operating hours | N/A | N/A | 1,500 | 2,500 | +1,000 |
| Optimal hours | N/A | N/A | 3,000 | 3,000 | — |
| Percent optimal hours | N/A | N/A | 50.0% | 83.3% | +33.3% |
| Unscheduled downtime hours | N/A | N/A | N/A | N/A | N/A |
| **Total Facilities** | **$139,717** | **$139,697** | **$153,587** | **$141,640** | **-$11,947** |
| Number of users | 2,607 | 2,737 | 2,777 | 2,631 | -146 |
| Achieved operating hours | N/A | 7,185 | N/A | N/A | N/A |
| Planned operating hours | 8,240 | 7,760 | 8,900 | 9,230 | +330 |
| Optimal hours | 8,240 | 8,240 | 11,240 | 11,240 | — |
| Percent optimal hours[a] | 100.0% | 85.7% | 84.6% | 80.3% | -4.3% |
| Unscheduled downtime hours | N/A | N/A | N/A | N/A | N/A |

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

**High Energy Physics**
**Scientific Employment**

| | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|
| Number of permanent Ph.D.'s (FTEs) | 830 | 788 | 648 | -140 |
| Number of postdoctoral associates (FTEs) | 340 | 361 | 295 | -66 |
| Number of graduate students (FTEs) | 500 | 486 | 390 | -96 |
| Other scientific employment (FTEs)[a] | 1,745 | 1,625 | 1,379 | -246 |

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

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

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

### Summary

The FY 2021 Request for the Proton Improvement Project II (PIP-II) is $20,000,000. Initial construction funding was provided in FY 2018 through the Consolidated Appropriations Act. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-1 (Approve Alternative Selection and Cost Range), approved on July 23, 2018, with a preliminary Total Project Cost (TPC) range of $653,000,000 to $928,000,000. The current point estimate is $888,000,000.

### Significant Changes

This Construction Project Data Sheet (CPDS) is an update of the FY 2020 CPDS. This project was initiated with Total Estimated Cost (TEC) funds in FY 2018.

The estimated TPC was increased during design work in FY 2019 as the project plan was revised to incorporate a combination of:

- Upgrades to the Fermi National Accelerator Laboratory (FNAL) Booster, Recycler and Main Injector synchrotrons, downstream from the new linear accelerator (Linac), enabling the accelerator complex to achieve the ultimate beam intensity goal of 1.2 megawatts to be delivered for experimental physics;
- Better cost estimates enabled by more mature designs;
- Improved risk analysis;
- Additional prototyping plans to reduce technical risk; and
- Budgeting for spares.

FY 2021 funds will support completion of civil engineering design for the conventional facilities, technical design and prototyping for the accelerator components, and initiation of construction and procurement for technical systems when design is final, and construction is authorized by CD-3.

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

### Critical Milestone History

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | D&D Complete | CD-4 |
|---|---|---|---|---|---|---|---|---|
| FY 2020 | 11/12/15 | 7/23/18 | 7/23/18 | 3Q FY 2020 | 4Q FY 2021 | 4Q FY 2021 | TBD | 1Q FY 2030 |
| FY 2021 | 11/12/15 | 7/23/18 | 7/23/18 | 3Q FY 2020 | 4Q FY 2025 | 4Q FY 2021 | N/A | 1Q FY 2030 |

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

| Fiscal Year | Performance Baseline Validation | CD-3A |
|---|---|---|
| FY 2020 | 2Q FY 2020 | 3Q FY 2020 |
| FY 2021 | 2Q FY 2020 | 3Q FY 2020 |

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

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC, Except D&D | OPC, D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|---|
| FY 2020 | 91,000 | 547,965 | 638,965 | 82,035 | N/A | 82,035 | 721,000 |
| FY 2021[a] | 184,000 | 617,200 | 801,200 | 86,800 | N/A | 86,800 | 888,000 |

### 2. Project Scope and Justification

**Scope**

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

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

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

b) Cryoplant with storage and distribution system to support SRF Linac operation. The cryoplant is an in-kind contribution by the India DAE Labs that is similar to the cryoplant being designed and constructed for a high-intensity superconducting proton accelerator project in India.[b]

c) Beam Transfer Line from the Linac to the Booster Synchrotron, including accommodation of a beam dump and future delivery of beam to the FNAL Muon Campus.

d) Modification of the Booster, Recycler and Main Injector synchrotrons to accommodate a 50 percent increase in beam intensity and construction of a new injection area in the Booster to accommodate 800-megaelectronvolt (MeV) injection.

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

[a] The project is Pre-CD-2 and has not been baselined. All estimates are preliminary. The preliminary TPC range at CD-1 is $653,000,000 to $928,000,000. The TPC point estimate is $888,000,000.

[b] See Section 8.

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

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

| Components | Quan-tity | Freq. (MHz) | SRF Cavities | Responsibility for Cavity Fabrication | Responsibility for Module Assembly | Responsibility for RF Amplifiers | Cryogenic Cooling Source |
|---|---|---|---|---|---|---|---|
| RFQ | 1 | 162.5 | N/A | N/A | U.S. DOE (LBNL) | U.S. DOE (FNAL) | N/A |
| HWR Cryomodule | 1 | 162.5 | 8 | U.S. DOE (ANL) | U.S. DOE (ANL) | U.S. DOE (FNAL) | India DAE Labs |
| SSR1 Cryomodule | 2 | 325 | 16 | U.S. DOE (FNAL), India DAE Labs | U.S. DOE (FNAL) | India DAE Labs | India DAE Labs |
| SSR2 Cryomodule | 7 | 325 | 35 | France CNRS (IN2P3 Lab) | U.S. DOE (FNAL) | India DAE Labs | India DAE Labs |
| LB-650 Cryomodule | 9 | 650 | 36 | Italy INFN (LASA) | France CEA (Saclay Lab) | India DAE Labs | India DAE Labs |
| HB-650 Cryomodule | 4 | 650 | 24 | UK STFC Labs | UK STFC Labs, U.S. DOE (FNAL) | India DAE Labs | India DAE Labs |

**Justification**

The PIP-II project will enhance the Fermilab Accelerator Complex by providing the capability to deliver higher-power proton beams to the neutrino-generating target that serves the LBNF/DUNE program[a] for groundbreaking discovery in neutrino physics, a major field of fundamental research in high energy particle physics. Increasing the neutrino beam intensity requires increasing the proton beam power on target. The higher proton beam power will come from a 1.2-megawatt (MW) beam on target over an energy range of 60-120 GeV, a significant increase of beam power beyond the current proton beam capability. The PIP-II project will provide more flexibility for future science-driven upgrades to the entire accelerator complex and increase the systems overall reliability by addressing some of the accelerator complex's elements that are far beyond their design life.

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

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

[a] LBNF/DUNE is the DOE Long Baseline Neutrino Facility / Deep Underground Neutrino Experiment.
[b] "Building for Discovery: Strategic Plan for U.S. Particle Physics in the Global Context," HEPAP, 2014.

Key Performance Parameters (KPPs)

The Key Performance Parameters (KPPs) are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

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

### 3. Financial Schedule

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs[a] |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| FY 2018 | 1,000 | 1,000 | — |
| FY 2019 | 20,000 | 20,000 | 17,812[b] |
| FY 2020 | 51,000 | 51,000 | 51,000 |
| FY 2021 | 10,000 | 10,000 | 10,000 |
| Outyears | 102,000 | 102,000 | 105,188 |
| Total, Design | 184,000 | 184,000 | 184,000 |
| Construction | | | |
| FY 2020 | 9,000 | 9,000 | 9,000 |
| FY 2021 | 10,000 | 10,000 | 10,000 |
| Outyears | 598,200 | 598,200 | 598,200 |
| Total, Construction | 617,200 | 617,200 | 617,200 |

[a] Costs through FY 2019 reflect actual costs; costs for FY 2020 and the outyears are estimates.

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

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs[a] |
|---|---|---|---|
| Total Estimated Cost (TEC) | | | |
| FY 2018 | 1,000 | 1,000 | — |
| FY 2019 | 20,000 | 20,000 | 17,812 |
| FY 2020 | 60,000 | 60,000 | 60,000[a] |
| FY 2021 | 20,000 | 20,000 | 20,000 |
| Outyears | 700,200 | 700,200 | 703,388 |
| **Total, TEC** | **801,200** | **801,200** | **801,200** |
| **Other Project Cost (OPC)** | | | |
| FY 2016 | 18,715 | 18,715 | 12,724 |
| FY 2017 | 15,220 | 14,155 | 17,494 |
| FY 2018 | 23,100 | 24,165[b] | 22,214 |
| FY 2019 | 15,000 | 15,000 | 15,000 |
| FY 2020 | 494 | 494 | 494 |
| FY 2021 | 2,000 | 2,000 | 6,603 |
| Outyears | 12,271 | 12,271 | 12,271 |
| **Total, OPC** | **86,800** | **86,800** | **86,800** |
| **Total Project Cost (TPC)** | | | |
| FY 2016 | 18,715 | 18,715 | 12,724 |
| FY 2017 | 15,220 | 14,155 | 17,494 |
| FY 2018 | 24,100 | 25,165 | 22,214 |
| FY 2019 | 35,000 | 35,000 | 32,812 |
| FY 2020 | 60,494 | 60,494 | 60,494 |
| FY 2021 | 22,000 | 22,000 | 26,603 |
| Outyears | 712,471 | 712,471 | 715,659 |
| **Total, TPC** | **888,000** | **888,000** | **888,000** |

[a] Planned TEC activities are completion of site preparation and initiation of procurement for the cryoplant housing and the cryomodules.
[b] $1,065,000 of FY 2017 funding was attributed towards the Other Project Costs activities in FY 2018.

## 4. Details of Project Cost Estimate

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| Design | 170,000 | 76,000 | — |
| Contingency | 14,000 | 15,000 | — |
| Total, Design | 184,000 | 91,000 | — |
| Construction | | | |
| Site Work | 18,000 | 20,000 | — |
| Civil Construction | 145,000 | 81,000 | — |
| Technical Equipment | 245,000 | 246,965 | — |
| Contingency | 209,200 | 200,000 | — |
| Total, Construction | 617,200 | 547,965 | — |
| **Total, TEC** | **801,200** | **638,965** | **—** |
| *Contingency, TEC* | 223,200 | 215,000 | — |
| **Other Project Cost (OPC)** | | | |
| OPC except D&D | | | |
| R&D | 67,700 | 50,935 | — |
| Conceptual Planning | 9,000 | 15,000 | — |
| Conceptual Design | 4,000 | 4,000 | — |
| Contingency | 6,100 | 12,100 | — |
| **Total, OPC** | **86,800** | **82,035** | **—** |
| *Contingency, OPC* | *6,100* | *12,100* | — |
| **Total Project Cost** | **888,000** | **721,000** | **—** |
| ***Total, Contingency (TEC+OPC)*** | **229,300** | **227,100** | **—** |

## 5. Schedule of Appropriations Requests

(dollars in thousands)

| Request Year | Type | Prior Years | FY 2019 | FY 2020 | FY 2021 | Outyears[a] | Total |
|---|---|---|---|---|---|---|---|
| FY 2020 | TEC | 1,000 | 20,000 | 20,000 | — | 597,965 | 638,965 |
| | OPC | 57,035 | 15,000 | 5,000 | — | 5,000 | 82,035 |
| | TPC | 58,035 | 35,000 | 25,000 | — | 602,965 | 721,000 |

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

(dollars in thousands)

| Request Year | Type | Prior Years | FY 2019 | FY 2020 | FY 2021 | Outyears[a] | Total |
|---|---|---|---|---|---|---|---|
| FY 2021[a] | TEC | 1,000 | 20,000 | 60,000 | 20,000 | 700,200 | 801,200 |
| | OPC | 57,035 | 15,000 | 494 | 2,000 | 12,271 | 86,800 |
| | TPC | 58,035 | 35,000 | 60,494 | 22,000 | 712,471 | 888,000 |

**6. 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 |

FNAL will operate the PIP-II Linac as an integral part of the entire Fermilab Accelerator Complex. Related funding estimates for operations, utilities, maintenance and repairs are incremental to the balance of the FNAL accelerator complex for which the present cost of operation, utilities, maintenance and repairs is approximately $100,000,000 annually.

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | Previous Total Estimate | Current Total Estimate | Previous Total Estimate | Current Total Estimate |
| Operations | 4,000 | 4,000 | 80,000 | 80,000 |
| Utilities | 3,000 | 3,000 | 60,000 | 60,000 |
| Maintenance and Repair | 2,000 | 2,000 | 40,000 | 40,000 |
| Total, Operations and Maintenance | 9,000 | 9,000 | 180,000 | 180,000 |

**7. D&D Information**

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

| | Square Feet |
|---|---|
| New area being constructed by this project at FNAL | 127,540 |
| Area of D&D in this project at FNAL | — |
| Area at FNAL to be transferred, sold, and/or D&D outside the project, including area previously "banked" | — |
| Area of D&D in this project at other sites | — |
| Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked" | 127,540 |
| Total area eliminated | — |

[a] The project is Pre-CD-2 and has not been baselined. All estimates are preliminary. The preliminary TPC range at CD-1 is $653,000,000 to $928,000,000. The TPC point estimate is $888,000,000.

The one-for-one replacement will be met through banked space. A waiver from the one-for-one requirement to eliminate excess space at FNAL to offset PIP-II and other projects was approved by DOE Headquarters on November 12, 2009. The waiver identified and transferred to FNAL 575,104 square feet of excess space to accommodate new facilities including Mu2e, LBNF, DUNE, and other facilities, as-yet unbuilt, from space that was banked at other DOE facilities. The PIP-II Project is following all current DOE procedures for tracking and reporting space utilization.

**8. Acquisition Approach**

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

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

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

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

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

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

Domestic engineering and construction subcontractors will perform the civil construction at FNAL. FNAL is utilizing a firm fixed-price contract for architectural-engineering services to complete all remaining designs for conventional facilities with an option for construction support. The general construction subcontract will be placed on a firm-fixed-price basis.

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

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

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

### Summary

The FY 2021 Request for Long Baseline Neutrino Facility (LBNF)/Deep Underground Neutrino Experiment (DUNE) is $100,500,000. The most recent approved DOE Order 413.3B critical decision is CD-3A, approval for Initial Far Site Construction: initiating excavation and construction for the LBNF Far Site conventional facilities in order to mitigate risks and minimize delays for providing a facility ready to accept detectors for installation. The preliminary Total Project Cost (TPC) has been revised to $2,600,000,000 which exceeds by 40 percent the top of the cost range of $1,260,000,000 to $1,860,000,000 that was approved for CD-1(R) on November 5, 2015. (If the top end of the original approved CD-1 cost range grows by more than 50 percent as the project proceeds toward CD-2 then the Program, in coordination with the Project Management Executive, must reassess the alternative selection process.[a]) The TPC range includes the full cost of the DOE contribution to the LBNF host facility and the DUNE experimental apparatus excluding foreign contributions. The preliminary CD-4 date is 4Q FY 2033.

### Significant Changes

This Construction Project Data Sheet (CPDS) is an update of the FY 2020 CPDS. This project was initiated with TEC funds in FY 2012.

Updated planning and analysis in FY 2019 have increased the TPC point estimate for the LBNF/DUNE project to $2,600,000,000 which exceeds by 40 percent[b] the upper end of the Cost Range of $1,260,000,000 to $1,860,000,000 that was approved for CD-1(R) on November 5, 2015. The cost estimate increased for two reasons. The first is due to the cost of the excavation. The excavation contractor is now on site and has identified deficiencies in the greater than 100 year old infrastructure that will need to be repaired to support the large volume of rock removal. In addition, the time required to complete the excavation was underestimated. The independent cost estimator employed by the project and the design firm verified these findings. The second reason for the increased cost is that contributions from international partners have been lower than expected. DOE and the laboratory are continuing engagement with potential partners. Scope reductions will be considered to reduce the TPC by the time of baseline. The increased estimates will be reviewed by Independent Cost Review (ICR) and Independent Project Review (IPR) in FY 2020.

A Baseline Change Proposal (BCP) has been submitted to DOE for approval. It seeks approval to reduce the approved scope and authorized expenditures related to work previously approved by CD-3A. The BCP was triggered by higher cost estimates for the scope approved by CD-3A. The baseline change transfers some of the scope that had been advanced by CD-3A back to CD-3B, where it will be executed in regular order following CD-2 in FY 2021.

The FY 2021 Request will support completion of the Far Site civil construction activities for pre-excavation and the beginning of excavation activities for the underground equipment caverns and connecting drifts (tunnels), as well as design and procurement activities for Far Site cryogenics systems. The Request will also support Near Site (FNAL) beamline and conventional facilities design and continuation of a site-preparation construction subcontract at the Near Site for relocation of existing service roads and utilities. The Request supports the continuation of construction and fabrication for technical systems, including contributions to the DUNE detectors, when design is final and construction authorized by CD-3

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

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[a]Per DOE Order 413.3B, Appendix A-6, 11/29/2010.

[b] If the top end of the original approved CD-1 cost range grows by more than 50% as the project proceeds toward CD-2, the Program, in coordination with the AE, must reassess the alternative selection process. (From DOE Order 413.3B, Appendix A-6, 11/29/2010.)

**Critical Milestone History**

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | D&D Complete | CD-4 |
|---|---|---|---|---|---|---|---|---|
| FY 2011 | 1/08/10 | | 1Q FY 2011 | TBD | 4Q FY 2013 | TBD | TBD | TBD |
| FY 2012 | 1/08/10 | | 2Q FY 2012 | TBD | 2Q FY 2015 | TBD | TBD | TBD |
| FY 2016[a] | 1/08/10 | 12/10/12 | 12/10/12 | 4Q FY 2017 | 4Q FY 2019 | 4Q FY 2019 | N/A | 4Q FY 2027 |
| FY 2017 | 1/08/10 | 11/05/15[b] | 11/05/15[b] | 4Q FY 2017 | 4Q FY 2019 | 4Q FY 2019 | N/A | 4Q FY 2030 |
| FY 2018 | 1/08/10 | 11/05/15[b] | 11/05/15[b] | 1Q FY 2021 | 1Q FY 2022 | 1Q FY 2022 | N/A | 4Q FY 2030 |
| FY 2019 | 1/08/10 | 11/05/15[b] | 11/05/15[b] | 1Q FY 2021 | 1Q FY 2022 | 1Q FY 2022 | N/A | 4Q FY 2030 |
| FY 2020 | 1/08/10 | 11/05/15[b] | 11/05/15[b] | 1Q FY 2021 | 1Q FY 2022 | 1Q FY 2022 | N/A | 4Q FY 2030 |
| FY 2021 | 1/08/10 | 11/05/15[b] | 11/05/15[b] | 1Q FY 2021 | 4Q FY 2023 | 4Q FY 2023 | N/A | 4Q FY 2033 |

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

| Fiscal Year | Performance Baseline Validation | CD-1R | CD-3A | CD-3B | CD-3(C) |
|---|---|---|---|---|---|
| FY 2017 | 1Q FY 2020 | 11/05/15 | 2Q FY 2016 | 3Q FY 2018 | 1Q FY 2020 |
| FY 2018 | 1Q FY 2021 | 11/05/15 | 9/01/16 | 1Q FY 2021 | 1Q FY 2022 |
| FY 2019 | 1Q FY 2021 | 11/05/15 | 9/01/16 | 1Q FY 2021 | 1Q FY 2022 |
| FY 2020 | 1Q FY 2021 | 11/05/15 | 9/01/16 | 1Q FY 2021 | 1Q FY 2022 |
| FY 2021 | 1Q FY 2021 | 11/05/15 | 9/01/16 | 1Q FY 2021 | 4Q FY 2023 |

**CD-1R** – Refresh of CD-1 approval for the new Conceptual Design.
**CD-3A** – Approve Initial Far Site Construction: initiating excavation and construction for the LBNF Far Site conventional facilities in order to mitigate risks and minimize delays for providing a facility ready to accept detectors for installation.
**CD-3B** – Approve Start of Far Site Construction: procurement of the remaining Far Site scope for conventional facilities, cryogenic systems and detectors.
**CD-3C** – Approve Start of Near Site Construction: procurement of Near Site scope and any remaining LBNF/DUNE scope. (Same as CD-3.)

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

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC, Except D&D | OPC, D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|---|
| FY 2011 | 102,000 | TBD | TBD | 22,180 | TBD | TBD | TBD |
| FY 2012 | 133,000 | TBD | TBD | 42,621 | TBD | TBD | TBD |
| FY 2016[a] | 127,781 | 655,612 | 783,393 | 89,539 | N/A | 89,539 | 872,932 |
| FY 2017 | 123,781 | 1,290,680 | 1,414,461 | 89,539 | N/A | 85,539 | 1,500,000 |
| FY 2018 | 234,375 | 1,199,000 | 1,433,375 | 102,625 | N/A | 102,625 | 1,536,000 |
| FY 2019 | 231,000 | 1,234,000 | 1,465,000 | 95,000 | N/A | 95,000 | 1,560,000 |
| FY 2020 | 259,000 | 1,496,000 | 1,755,000 | 95,000 | N/A | 95,000 | 1,850,000 |
| FY 2021[b,c] | 300,000 | 2,176,375 | 2,476,375 | 123,625 | — | 123,625 | 2,600,000 |

**2. Project Scope and Justification**

**Scope**

LBNF/DUNE will be composed of a neutrino beam created by new construction as well as modifications to the existing Fermilab Accelerator Complex, massive neutrino detectors (at least 40,000 tons in total) and associated cryogenics infrastructure located in one or more large underground caverns to be excavated at least 800 miles "downstream" from the neutrino source, and a much smaller neutrino detector at FNAL for monitoring the neutrino beam near its source. A primary beam of protons will produce a neutrino beam directed into a target for converting the protons into a secondary beam of particles (pi mesons and muons) that decay into neutrinos, followed by a decay tunnel hundreds of meters long where the decay neutrinos will emerge and travel through the earth to the massive detector. The Neutrinos at the Main Injector (NuMI) beam at FNAL 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.[d]

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

**Justification**

Recent international progress in neutrino physics, celebrated by the Nobel Prizes for Physics in 1988, 1995, 2002, and 2015, provides the basis for further discovery opportunities. Determining relative masses and mass ordering of the three known neutrinos will give guidance and constraints to theories beyond the Standard Model of particle physics. The study and observation of the different behavior of neutrinos and antineutrinos will offer insight into the dominance of matter over antimatter in our universe and, therefore, the very structure of our universe. The only other source of the matter-antimatter asymmetry, in the quark sector, is too small to account for the observed matter dominance.

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[a] No CPDS was submitted for FY 2013, FY 2014 or FY 2015 because no TEC funds were requested; however, design funds were provided in each year's appropriation.

[b] The project is Pre-CD-2 and has not been baselined. All estimates are preliminary. The preliminary TPC range at CD-1 was $1,260,000,000 to $1,860,000,000. The TPC estimate has increased to $2,600,000,000 and will be reviewed by Independent Cost Review (ICR) and Independent Project Review (IPR) in FY 2020.

[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.

[d] Detailed analyses of alternatives compared the NuMI beam to a new, lower-energy neutrino beam directed toward SURF in South Dakota, and also compared different neutrino detection technologies for the DUNE detector.

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

The LBNF/DUNE project comprises a national flagship particle physics initiative. LBNF/DUNE will be the first-ever large-scale international science facility hosted by the United States. As part of implementation of High Energy Physics Advisory Panel (HEPAP)-Particle Physics Project Prioritization Panel (P5) recommendations, the LBNF/DUNE project consists of two multinational collaborative efforts:

- LBNF is responsible for the beamline and other experimental and civil infrastructure at FNAL and at the Sanford Underground Research Facility (SURF) in South Dakota. It is currently operated by the South Dakota Science and Technology Authority (SDSTA), an agency of the State of South Dakota, and hosts experiments supported by DOE, the National Science Foundation, and major research universities.

- DUNE is an international scientific collaboration responsible for defining the scientific goals and technical requirements for the beam and detectors, as well as the design, construction and commissioning of the detectors and subsequent research program.

DOE's High Energy Physics program manages both activities as a single, line-item construction project—LBNF/DUNE. LBNF, with DOE/FNAL leadership and minority participation by a small number of international partners including CERN, will construct a megawatt-class neutrino source and related facilities at FNAL (the "Near Site"), as well as underground caverns and cryogenic facilities in South Dakota (the "Far Site") needed to house the DUNE detectors. DUNE has international leadership and participation of over 1,000 scientists and engineers from over 170 institutions in over 30 countries. DOE will fund less than a third of DUNE. DOE continues to refine the development of the design and cost estimates as the U.S. DOE contributions to the multinational effort are now better understood. FNAL continues to identify and incorporate additional design activities and prototypes into the project design.

FNAL and DOE have confirmed contributions documented in international agreements from CERN and the UK to LBNF. Discussions are ongoing with several other countries for additional contributions. For the DUNE detectors, the collaboration put in place a process to complete a technical design of the detectors and divide the work of building the detectors between the collaborating institutions. The review of the detector design with a complete set of funding responsibilities by the Long Baseline Neutrino Committee began in 2019, and development of the set of funding responsibilities continues progress. SC will manage all DOE contributions to the facility and the detectors according to DOE Order 413.3B, and FNAL will provide unified project management reporting.

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

<u>Key Performance Parameters (KPPs)</u>
The Key Performance Parameters (KPPs) are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

The preliminary Key Performance Parameters (KPPs) for project completion that were approved by CD-1 in FY 2015 include the primary beam and neutrino beam production systems as well as underground caverns excavated for four separate, 10 kiloton detectors (of liquid-argon, time-projection detectors) at the SURF site, 1000-1500 kilometers (km) from the neutrino source. The DOE contribution for DUNE will include technical components for two of the four detectors, which will be installed and tested with cosmic rays, and components of the cryogenic systems for the detectors, which will be installed and pressure tested.

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

[a] Fiducial detector mass pertains to the mass of the interior volume of the detection medium (liquid argon) that excludes the external portion of the detection medium where most background events would occur.

### 3. Financial Schedule[a]

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs[b] |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design[c] | | | |
| FY 2012 | 4,000 | 4,000 | —[d] |
| FY 2013 | 3,781 | 3,781 | 801 |
| FY 2014 | 16,000 | 16,000 | 7,109 |
| FY 2015 | 12,000 | 12,000 | 15,791 |
| FY 2016 | 26,000 | 26,000 | 26,436[e] |
| FY 2017 | 48,585 | 48,585 | 36,924 |
| FY 2018 | 25,000 | 25,000 | 44,749[f] |
| FY 2019 | 70,000 | 70,000 | 53,841 |
| FY 2020 | 20,000 | 20,000 | 20,000 |
| FY 2021 | 10,000 | 10,000 | 10,000 |
| Outyears | 64,634 | 64,634 | 84,349 |
| Total, Design | 300,000 | 300,000 | 300,000 |
| Construction | | | |
| FY 2017 | 1,415 | 1,415 | 333 |
| FY 2018 | 70,000 | 70,000 | 1,427[g] |
| FY 2019 | 60,000 | 60,000 | 25,865 |
| FY 2020 | 151,000 | 151,000 | 151,000[h] |
| FY 2021 | 90,500 | 90,500 | 90,500 |
| Outyears | 1,803,460 | 1,803,460 | 1,907,250 |
| Total, Construction | 2,176,375 | 2,176,375 | 2,176,375 |

[a] The project is Pre-CD-2 and has not been baselined. All estimates are preliminary. The preliminary TPC range at CD-1 is $1,260,000,000 to $1,860,000,000. Design and international collaboration plans are currently being developed; outyears are preliminary. An Independent Project Review was held January 8-10, 2019.
[b] Costs through FY 2019 reflect actual costs; costs for FY 2019 and the outyears are estimates.
[c] Design Only CPDS was prepared in FY 2012; no CPDS was prepared FY 2013-2015. Funding amounts shown for traceability. FY 2016 and onward CPDS prepared as Design and Construction.
[d] $1,078,000 was erroneously costed to this project in FY 2012, the accounting records were adjusted in early FY 2013.
[e] Costs were for starting Far Site preparation including safety and reliability refurbishment of the underground infrastructure, which was needed prior to initiating excavation of the equipment caverns.
[f] Costs were for continuing project engineering design in preparation for CD-2.
[g] Costs were for initiating excavation of the equipment caverns at the Far Site as approved by CD-3A.
[h] Estimated costs are for the Far Site civil construction excavation activities as well as design and procurement for Far Site cryogenics systems. Also will support beamline and conventional facilities design and a site-preparation construction subcontract at the Near Site (FNAL).

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs[b] |
|---|---|---|---|
| Total Estimated Cost (TEC) | | | |
| FY 2012 | 4,000 | 4,000 | — |
| FY 2013 | 3,781 | 3,781 | 801 |
| FY 2014 | 16,000 | 16,000 | 7,109 |
| FY 2015 | 12,000 | 12,000 | 15,791 |
| FY 2016 | 26,000 | 26,000 | 26,436 |
| FY 2017 | 50,000 | 50,000 | 37,257 |
| FY 2018 | 95,000 | 95,000 | 46,176 |
| FY 2019 | 130,000 | 130,000 | 79,706 |
| FY 2020 | 171,000 | 171,000 | 171,000 |
| FY 2021 | 100,500 | 100,500 | 100,500 |
| Outyears | 1,868,094 | 1,868,094 | 1,991,599 |
| **Total, TEC** | **2,476,375** | **2,476,375** | **2,476,375** |
| **Other Project Cost (OPC)** | | | |
| FY 2009[a] | 12,486 | 12,486 | — |
| FY 2010 | 14,178 | 14,178 | 11,032 |
| FY 2011 | 7,768 | 7,750 | 18,554 |
| FY 2012 | 17,000 | 17,018[b] | 18,497 |
| FY 2013 | 14,107 | 14,107 | 13,389 |
| FY 2014 | 10,000 | 10,000 | 11,348 |
| FY 2015 | 10,000 | 10,000 | 10,079 |
| FY 2016 | 86 | 86 | 2,284 |
| FY 2017 | — | — | 120 |
| FY 2018 | 1,000 | 1,000 | 86 |
| FY 2019 | 1,000 | 1,000 | 347 |
| FY 2020 | 4,000 | 4,000 | 4,000 |
| FY 2021 | 1,000 | 1,000 | 1,000 |
| Outyears | 31,000 | 31,000 | 32,889 |
| **Total, OPC** | **123,625** | **123,625** | **123,625** |
| **Total Project Cost (TPC)** | | | |
| FY 2009 | 12,486 | 12,486 | — |
| FY 2010 | 14,178 | 14,178 | 11,032 |

[a] $13,000,000 of Recovery Act funding was originally planned for the conceptual design, although $12,486,000 was attributed to the project from recategorization for pre-conceptual design activities ($511,000) and closeout of expired funds ($3,000) in subsequent years.

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

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs[b] |
|---|---|---|---|
| FY 2011 | 7,768 | 7,750 | 18,554 |
| FY 2012 | 21,000 | 21,018 | 18,497 |
| FY 2013 | 17,888 | 17,888 | 14,190 |
| FY 2014 | 26,000 | 26,000 | 18,457 |
| FY 2015 | 22,000 | 22,000 | 25,870 |
| FY 2016 | 26,086 | 26,086 | 28,720 |
| FY 2017 | 50,000 | 50,000 | 37,377 |
| FY 2018 | 96,000 | 96,000 | 46,262 |
| FY 2019 | 131,000 | 131,000 | 80,053 |
| FY 2020 | 175,000 | 175,000 | 175,000 |
| FY 2021 | 101,500 | 101,500 | 101,500 |
| Outyears | 1,899,094 | 1,899,094 | 2,024,488 |
| **Total, TPC** | **2,600,000** | **2,600,000** | **2,600,000** |

## 4. Details of Project Cost Estimate

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| Design | 270,000 | 234,000 | N/A |
| Contingency | 30,000 | 25,000 | N/A |
| Total, Design | 300,000 | 259,000 | N/A |
| Construction | | | |
| Construction[a] | 1,146,000 | 891,000 | N/A |
| Equipment[b] | 381,000 | 308,000 | N/A |
| Contingency | 649,375 | 297,000 | N/A |
| Total, Construction | 2,176,375 | 1,496,000 | N/A |
| **Total, TEC** | **2,476,375** | **1,755,000** | **N/A** |
| *Contingency, TEC* | *679,375* | *322,000* | *N/A* |

[a] Construction involves excavation of caverns at SURF, 4850 ft. below the surface, for technical equipment including particle detectors and cryogenic systems and construction of the housing for the neutrino-production beam line and the near detector.
[b] Technical equipment in the DOE scope, estimated here, will be supplemented by in-kind contributions of additional technical equipment, for the accelerator beam and particle detectors, from non-DOE partners as described in Section 1.

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Other Project Cost (OPC)** | | | |
| OPC except D&D | | | |
| R&D | 20,625 | 20,625 | N/A |
| Conceptual Planning | 30,000 | 30,000 | N/A |
| Conceptual Design | 35,000 | 35,000 | N/A |
| Other OPC Costs | 38,000 | 9,375 | N/A |
| Contingency | — | — | N/A |
| **Total, OPC** | **123,625** | **95,000** | **N/A** |
| *Contingency, OPC* | — | — | *N/A* |
| **Total Project Cost** | **2,600,000** | **1,850,000** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***679,375*** | ***322,000*** | ***N/A*** |

### 5. Schedule of Appropriations Requests

(dollars in thousands)

| Request Year | Type | Prior Years | FY 2019 | FY 2020 | FY 2021 | Outyears[a] | Total |
|---|---|---|---|---|---|---|---|
| FY 2011 | TEC | 102,000 | — | — | — | — | 102,000 |
| | OPC | 22,180 | — | — | — | — | 22,180 |
| | TPC | 124,180 | — | — | — | — | 124,180 |
| FY 2012 | TEC | 133,000 | — | — | — | — | 133,000 |
| | OPC | 42,621 | — | — | — | — | 42,621 |
| | TPC | 175,621 | — | — | — | — | 175,621 |
| FY 2016 | TEC | 51,781 | — | — | — | 731,612 | 783,393 |
| | OPC | 89,539 | — | — | — | — | 89,539 |
| | TPC | 141,320 | — | — | — | 731,612 | 872,932 |
| FY 2017 | TEC | 106,802 | — | — | — | 1,307,659 | 1,414,461 |
| | OPC | 85,539 | — | — | — | — | 85,539 |
| | TPC | 192,341 | — | — | — | 1,307,659 | 1,500,000 |
| FY 2018 | TEC | 166,681 | — | — | — | 1,266,694 | 1,433,375 |
| | OPC | 85,725 | — | — | — | 16,900 | 102,625 |
| | TPC | 252,406 | — | — | — | 1,283,594 | 1,536,000 |
| FY 2019 | TEC | 166,681 | 113,000 | — | — | 1,185,319 | 1,465,000 |
| | OPC | 85,725 | 1,000 | — | — | 8,275 | 95,000 |
| | TPC | 252,406 | 114,000 | — | — | 1,193,594 | 1,560,000 |

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

(dollars in thousands)

| Request Year | Type | Prior Years | FY 2019 | FY 2020 | FY 2021 | Outyears[a] | Total |
|---|---|---|---|---|---|---|---|
| FY 2020[a] | TEC | 206,781 | 130,000 | 100,000 | — | 1,318,219 | 1,755,000 |
| | OPC | 86,625 | 1,000 | 4,000 | — | 3,375 | 95,000 |
| | TPC | 293,406 | 131,000 | 104,000 | — | 1,321,594 | 1,850,000 |
| FY 2021 | TEC | 206,781 | 130,000 | 171,000 | 100,500 | 1,868,094 | 2,476,375 |
| | OPC | 86,625 | 1,000 | 4,000 | 1,000 | 31,000 | 123,625 |
| | TPC | 293,406 | 131,000 | 175,000 | 101,500 | 1,899,094 | 2,600,000 |

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

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

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

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | **Previous Total Estimate** | **Current Total Estimate** | **Previous Total Estimate** | **Current Total Estimate** |
| Operations | 9,000 | 9,000 | 180,000 | 180,000 |
| Utilities | 8,000 | 8,000 | 160,000 | 160,000 |
| Maintenance and Repair | 1,000 | 1,000 | 20,000 | 20,000 |
| Total, Operations and Maintenance | 18,000 | 18,000 | 360,000 | 360,000 |

**7. D&D Information**

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

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

[a] The project is Pre-CD-2 and has not been baselined. All estimates are preliminary. The preliminary TPC range at CD-1 was $1,260,000,000 to $1,860,000,000. An Independent Project Review was held January 8-10, 2019.

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

**8. Acquisition Approach**

The Acquisition Strategy, approved as part of CD-1, documents the acquisition approach. DOE is acquiring design, construction, fabrication, and operation of LBNF through the M&O contractor responsible for FNAL, Fermi Research Alliance (FRA). FRA and FNAL, through the LBNF Project based at FNAL, is responsible to DOE to manage and complete construction of LBNF at both the near and remote site locations. FRA and FNAL 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:

- FNAL 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.
- FNAL 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 FNAL.
- FNAL 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.
- FNAL 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.
- FNAL, through the LBNF Project, has established a close working relationship with SURF and the South Dakota Science and Technology Authority (SDSTA), organizations that manage and operate the remote site for the far detector in Lead, SD;
- FNAL has extensive experience with management and participation in international projects and international collaborations, including most recently the LHC and CMS projects at CERN, as well as in the increasingly international neutrino experiments and program.

The LBNF/DUNE construction project is a federal, state, private and international partnership. Leading the LBNF/DUNE Project, FNAL will collaborate and work with many institutions, including other DOE national laboratories (e.g. BNL, LBNL and SLAC), dozens of universities, foreign research institutions, and the SDSTA. FNAL will be responsible for overall project management, Near Site conventional facilities, and the beamline. FNAL will work with SDSTA to complete the conventional facilities construction at the remote site needed to house and outfit the DUNE far detector. With the DUNE collaboration, FNAL 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.

DOE will provide funding for the LBNF/DUNE Project directly to FNAL and collaborating DOE national laboratories via approved financial plans, and under management control of the LBNF/DUNE-U.S. Project Office at FNAL, which will also manage and control DOE funding to the combination of university subcontracts and direct fixed-price vendor procurements that are anticipated for the design, fabrication and installation of LBNF and DUNE technical components. All actions will perform in accordance with DOE approved procurement policies and procedures.

FNAL staff, or by subcontract, temporary staff working directly with FNAL personnel will perform much of the neutrino beamline component design, fabrication, assembly, and installation. The acquisition approach includes both new procurements based on existing designs, and re-purposed equipment from the Fermilab Accelerator Complex. For some highly specialized components, FNAL will have the Rutherford Appleton Laboratory (RAL) in the United Kingdom design and fabricate the components. RAL is a long-standing FNAL collaborator who has proven experience with such components.

FNAL has chosen the Construction Manager/General Contractor (CM/GC) model to execute the delivery of LBNF conventional facilities at the SURF Far Site. The Laboratory is contracting with an architect/engineer (A/E) firm for design of LBNF Far Site conventional facilities at SURF and with a CM/GC subcontractor to manage the construction of LBNF Far Site facilities. FNAL selected this strategy to reduce risk, enhance quality and safety performance, provide a more collaborative approach to construction, and offer the opportunity for reduced cost and shortened construction schedules, via options for the CM/GC to self-perform or competitively bid subcontract award packages.

For the LBNF Near Site conventional facilities at FNAL, the laboratory will subcontract with an A/E firm for design, and has initially planned for a CM/GC subcontractor to manage construction of LBNF Near Site facilities. The Laboratory re-evaluated this strategy based on a gap that developed between when Near Site conventional facilities design would be completed and construction could start based on funding constraints. This resulted in selection of a design-bid-build traditional construction method supported by additional procurements for preconstruction and construction phase services.

For the LBNF Far Site conventional facilities at SURF, DOE entered into a land lease with SDSTA on May 20, 2016 covering the area on which the DOE-funded facilities housing and supporting the LBNF and DUNE detector will be built. The lease and related realty actions provides the framework for DOE and FNAL to construct federally-funded buildings and facilities on non-federal land, and to establish a long-term (multi-decade) arrangement for DOE and FNAL to use SDSTA space to host the DUNE experiment. Modifications, repairs, and improvements to the SDSTA infrastructure to support the LBNF/DUNE project are costed to the project. Repairs and improvements for the overall facility are costed to the cooperative agreement that HEP has with SDSTA for operation of the facility. Protections for DOE's real property interests in these infrastructure tasks are acquired through the lease with SDSTA, contracts and other agreements such as easements. DOE plans for FNAL to have responsibility for managing and operating the LBNF and DUNE far detector and facilities for a useful lifetime of 20 years, and may contract with SDSTA for day-to-day management and maintenance services. At the end of useful life, federal regulations permit transfer of ownership to SDSTA, which is willing to accept ownership as a condition for the lease. FNAL developed an appropriate decommissioning plan prior to lease signing.

## Nuclear Physics

### Overview

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

Nuclear physics addresses three broad, yet tightly interrelated, scientific thrusts: **Quantum Chromodynamics (QCD); Nuclei and Nuclear Astrophysics**; and **Fundamental Symmetries**:

- **QCD** seeks to develop a complete understanding of how the fundamental particles that compose nuclear matter, the quarks and gluons, assemble themselves into composite nuclear particles such as protons and neutrons; how nuclear forces arise between these composite particles that lead to nuclei; and how novel forms of bulk, strongly interacting matter behave, such as the quark-gluon plasma that formed in the early universe.
- **Nuclei and Nuclear Astrophysics** seeks to understand how protons and neutrons combine to form atomic nuclei, including some now being observed for the first time, and how these nuclei have arisen during the 13.8 billion years since the birth of the cosmos.
- **Fundamental Symmetries** seeks to develop a better understanding of fundamental particle interactions by studying the properties of neutrons and by performing targeted, single focus experiments using nuclei to study whether the neutrino is its own anti-particle. Neutrinos are very light, nearly undetectable fundamental particles produced during interactions involving the weak force, through which they were first indirectly observed in nuclear beta decay experiments.

The quest to understand the properties of different forms of nuclear matter requires long-term support for both theoretical and experimental research efforts within the NP portfolio. Theoretical approaches are based on calculations of the interactions of quarks and gluons described by the theory of QCD using today's most advanced computers. Quantum computing holds great potential for obtaining solutions to many-body QCD problems that are intractable with today's computers. Other theoretical research that models the forces between nucleons seeks to understand and predict the structure of nuclear matter. Most experimental approaches in nuclear physics use large accelerators that collide particles at nearly the speed of light, producing short-lived forms of matter for investigation. Nuclear physics also uses low-energy, precision nuclear experiments, many enabled by new quantum sensors to search for a deeper understanding of fundamental symmetries and nuclear interactions. Comparing experimental observations and theoretical predictions tests the limits of our understanding of nuclear matter and suggests new directions for experimental and theoretical research.

Highly trained scientists who conceive, plan, execute, and interpret transformative experiments are at the heart of the NP program. NP supports these university and national laboratory scientists, and U.S. participation in select international collaborations, resulting in an average of approximately 90 Ph.D. degrees awarded annually to students for research supported by the program. DOE NP is the steward of the nation's fundamental nuclear physics research portfolio; in FY 2019, DOE provided over 91 percent and the National Science Foundation (NSF) less than 9 percent of the total investment in the U.S. nuclear physics basic research portfolio. As documented in the 2015 Nuclear Science Advisory Committee (NSAC) Long Range Plan (LRP) for Nuclear Science, Reaching for the Horizon[a], over 40 percent of the scientists who receive Ph.D.'s in nuclear science find careers in sectors other than academia and DOE research laboratories, serving national needs in defense, computing, cutting-edge technology, government, and industry. DOE's mission and priorities guide NP research, which in turn develop the core competencies and expertise needed to achieve the goals of the NP

[a] "*Reaching for the Horizon: The 2015 Long Range Plan for Nuclear Science*." Nuclear Science Advisory Committee, October 2015 (https://science.osti.gov/~/media/np/nsac/pdf/2015LRP/2015_LRPNS_091815.pdf).

program and train the next generation of nuclear scientists. National laboratory scientists work and collaborate with academic scientists and other national laboratory experimental and theoretical researchers to acquire and analyze large volumes of data, and to construct, support, and maintain the advanced instrumentation and world-class accelerator facilities used in experiments. The national laboratories 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 trained scientists to design and build next-generation NP accelerator facilities, and is relevant to machines being developed by other domestic and international programs. The technologies developed to simulate, sense, collect, and analyze nuclear physics data have synergy with quantum information science (QIS), artificial intelligence (AI), machine learning (ML), microelectronics, isotope production science, and data integration.

The world-class scientific user facilities and associated instrumentation necessary to advance the U.S. nuclear science program are large and complex, and account for a significant portion of the NP budget. NP supports three scientific user facilities: the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL); the Continuous Electron Beam Accelerator Facility (CEBAF) at Thomas Jefferson National Accelerator Facility (TJNAF); and the Argonne Tandem Linac Accelerator System (ATLAS) at Argonne National Laboratory (ANL). Each of these facilities has unique capabilities that advance the scientific thrusts outlined in the 2015 LRP. In FY 2021, these facilities will provide particle beams for an international user community of almost 2,000 research scientists. Approximately 35 percent of these researchers are from institutions outside of the U.S., and they provide very significant benefits including leveraging the U.S. program through contributed capital, human capital, and experimental equipment, as well as intellectual contributions. Researchers supported by other SC programs such as High Energy Physics (HEP) and Basic Energy Sciences (BES); other DOE offices such as the National Nuclear Security Administration (NNSA) and Nuclear Energy (NE); other Federal agencies such as NSF, the National Aeronautics and Space Administration (NASA), and the Department of Defense (DOD); and industries, use NP scientific user facilities and core competencies to carry out research programs important for their respective missions. Construction of the Facility for Rare Isotope Beams (FRIB), a world-class nuclear physics scientific user facility with unique capabilities in nuclear structure and astrophysics, is nearing completion at Michigan State University (MSU), according to the baseline cost and schedule. This project is over 92 percent complete and will provide exciting new capabilities in nuclear structure and astrophysics to better understand the landscape of the periodic table of elements. In FY 2021, FRIB will transition to operations as a DOE SC User Facility for nuclear physics.

The 2015 NSAC LRP for Nuclear Science recommended a high-energy, high-luminosity polarized Electron-Ion Collider (EIC) as the highest priority for new facility construction. Consistent with that vision, in 2016 NP commissioned a National Academy of Sciences (NAS) study by an independent panel of external experts to assess the uniqueness and scientific merit of such a facility. The report[a], released in July 2018, strongly supports the scientific case for building a U.S.-based EIC, documenting that an EIC will advance the understanding of the origins of nucleon mass, the origin of the spin properties of nucleons, and the behavior of gluons. Subsequently, DOE determined that the construction of an EIC is the highest priority for new facility construction in the U.S. Nuclear Physics Program to maintain U.S. leadership in nuclear physics and accelerator science. The EIC will enable scientists to investigate and answer questions about the basic building blocks of nuclei and how quarks and gluons, the particles inside neutrons and protons, interact dynamically via the strong force to generate the fundamental properties of neutrons and protons, such as mass and spin.

The Secretary of Energy approved Critical Decision-0, Approve Mission Need*,* on December 19, 2019, with a rough order of magnitude cost range of $1.6 billion to $4.2 billion. An Independent Cost Review, conducted by the DOE Office of Project Management as is required for projects of this magnitude, determined the cost range for CD-0. DOE conducted an Independent Site Selection Assessment and selected BNL to host the EIC facility for the Nation. This selection establishes a cost range of $1.6 billion to $2.6 billion for the EIC. Both BNL and TJNAF will have essential and major roles in both the construction of the EIC and the realization of the facility's full scientific opportunities.

Involving students in the development and construction of NP facilities and advanced instrumentation, as well as accelerator technology and computational techniques, helps to develop the highly trained workforce needed in the field of nuclear science. In addition to significant advances in discovery science, these facilities and techniques provide collateral

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

benefits such as the creation of new technologies with broad-based applications in industry and society, such as AI/ML , QIS, and computational and data infrastructure . NP supports cutting-edge accelerator R&D that is specific to the programmatic needs of its current and planned facilities. In the process, transformative technological advances and core competencies in accelerator science that are developed by NP are also often relevant to other applications and other SC programs. For example, superconducting radio frequency (SRF) particle acceleration developed for NP programmatic missions has provided technological advances for a broad range of applications including materials research, cancer therapy, food safety, bio-threat mitigation, national defense, waste treatment, and commercial fabrication. NP coordinates closely with other SC accelerator R&D activities to exploit synergies and avoid duplication of efforts.

**Highlights of the FY 2021 Request**

The FY 2021 Request for $653,327,000 supports the highest priority efforts and capabilities in nuclear science to optimize scientific productivity and impact on national priorities. World-class experimental user facilities and theoretical and experimental nuclear physics research will continue to enable advances in science. Core research groups will be re-organized and to target select scientific opportunities to promote U.S. competitiveness in nuclear physics. NP will prioritize increasing operations of scientific user facilities and participation in administration research priorities. Supported instrumentation, facilities and construction projects closely align to guidance from NAS studies and the NSAC LRP, and promote U.S. leadership in nuclear science. The Request will continue support for world-class discovery science research and R&D integration to facilitate the development of state-of-the-art applications for medicine, commerce, and national security. The Request continues support for the EIC at BNL, with partnership of TJNAF andother national labs essential to its success.

The Request places an emphasis on Administration research priorities, with increased participation of NP in coordinated SC initiatives, including QIS and AI/ML. The Request also prioritizes research to support the DOE Isotope Initiative, and NP participation in the Strategic Accelerator Technology Initiative. FY 2021 will be the first year of support for the Strategic Accelerator Technology Initiative and the first year of NP support for AI/ML. A community roundtable discussion in FY 2020 on the role of NP in AI/ML highlighted how the NP community could best incorporate AI/ML research, for example by using ML to facilitate effective accelerator operations. Initial funding for the Strategic Accelerator Technology Initiative will enable the pursuit of transformative accelerator R&D initiatives, including next generation electron ion source developments and advanced approaches in SRF technology. There are strong synergies between these different activities and the unique needs and core competencies of the nuclear physics community.

The Request also increases support for the DOE Isotope Program (DOE IP), a DOE priority, to introduce new medical isotopes to the community for clinical trials and cancer therapy, and create isotope harvesting capability at FRIB. The Request supports development of isotope processing core competencies and capabilities at universities and laboratories to increase isotope availability for a suite of applications, including industrial radiography, medical isotope production feedstock, and explosives detection. New stable isotope enrichment capabilities replenish U.S. inventory and reduce foreign dependence on isotopes of strategic importance for the Nation. The Request continues funding for the U.S. Stable Isotope Production and Research Center (U.S. SIPRC). U.S. SIPRC's objective is to mitigate U.S. dependence on foreign sources of enriched stable isotopes for research and applications. DOE continues its focus on an isotope initiative that will expand and develop core competencies and technology critical for long-term U.S. leadership and independence in isotope production.

The Request supports research activities in Nuclear Structure and Astrophysics described separately from the Fundamental Symmetries activities within the Low Energy Subprogram, in an effort to better articulate the breadth of the program and capture the growing effort in fundamental symmetries of nuclear physics. Limited fundamental symmetries research supported in the Medium Energy Subprogram, primarily those efforts associated with the Moller Experiment that will operate at TJNAF, are moved into the Fundamental Symmetries Subprogram to promote consistency between the scientific focus of the MOLLER experiment and the intellectual thrust of the Fundamental Symmetries portfolio.

<u>Research</u>

The Request for Research supports key university and laboratory researchers to nurture critical core competencies and enable the highest priority theoretical and experimental activities to target compelling scientific opportunities at the frontier of nuclear science, and in concert with guidance from the NAS and the NSAC. Research funding is also provided for QIS, AI/ML, transformative accelerator R&D, and isotope production R&D. The Request supports world-class research in all scientific thrusts of nuclear science including:

- Experimental and theoretical research aimed at unravelling the mechanism of quark confinement with the upgraded 12 gigaelectronvolt (GeV) CEBAF.
- Discovery research at RHIC, the nation's only remaining collider, to search for a critical point in the phase diagram of QCD matter and further characterize the quark-gluon plasma (QGP), a form of matter discovered at RHIC that last existed at the beginning of the cosmos.
- Targeted collaboration in the heavy ion program at the CERN Large Hadron Collider (LHC) to provide U.S. researchers the opportunity to investigate states of matter under substantially different initial conditions than those provided by RHIC, providing complementary information regarding the matter that existed during the infant universe.
- Challenging new experiments at ATLAS to study nuclear structure and nuclear reactions occurring under extreme conditions in the cosmos that are conjectured to play a central role in the synthesis of heavy elements.
- Pioneering R&D in the search for neutrino-less double beta decay, a process that if observed would prove that the neutrino is its own anti-particle is supported.
- Continuation of the High Rigidity Spectrometer (HRS) instrumentation for FRIB, which will enable the most sensitive experiments across the entire span of known nuclei, thereby enabling experiments with the most neutron-rich nuclei available at FRIB.
- Research delving into the nature of the neutron at the Fundamental Neutron Physics Beamline at the Spallation Neutron Source (SNS), and the continued development of the high-risk, high-discovery potential Neutron Electric Dipole Moment (nEDM) experiment, that could shed light on why there is more matter than anti-matter in the universe.
- Other Project Cost (OPC) activities including accelerator and detector R&D for the EIC.
- Continuation of funding for the SC QIS Center(s) that will be established in FY 2020 and which will be an interdisciplinary partnership among SC programs in support of the National Quantum Initiative. This partnership complements a robust core research portfolio stewarded by the individual SC programs to create the ecosystem across universities, national laboratories, and industry that is needed to advance developments in QIS and related technology. Innovative NP research in QIS enables precision nuclear physics measurements, quantum simulations with trapped ions, quantum computing solutions to otherwise intractable QCD challenges, development of quantum sensors based on atomic-nuclear interactions and quantum control (coherent control) techniques, and the production of stable isotopes for next generation QIS.
- Accelerator R&D , which is a core capability SC stewards for the Nation. Sustained investment is needed for the U.S. to continue to provide the world's most comprehensive and advanced accelerator-based facilities for scientific research, and to continue to attract and train the workforce needed to design and operate these facilities. NP will support high priority accelerator R&D of relevance to NP next-generation machines and optimal performance of existing machines.
- Targeted cutting-edge techniques based on AI/ML of relevance to nuclear science research, accelerator facility operations, and automated machine operations within the DOE IP.
- Forefront isotope R&D to develop new production methods for critical isotopes in high demand for the Nation, including isotopes for medicine that could revolutionize therapy for metastasized cancer, and the development of enriched stable isotope production capabilities to reduce dependence on foreign supplies and produce isotopes for quantum computing.
- Support for core competencies in developing and operating a broad array of isotope enrichment technologies, critical for research and applications, through research in support of the initiation of the DOE Isotope Initiative.

<u>Facility Operations</u>
The Request for Facility Operations includes funding for the operations of the NP scientific user facilities. Requested funding directs efforts to operations of the facilities to enable world-class science and the optimization of existing capabilities including:

- Support for RHIC to operate for 2,580 hours (100 percent optimal) in FY 2021. Operating hours are capped in FY 2021 due to planned installation requirements. Planned operations with the completed Low Energy RHIC e-Cooler (LEReC) will further increase luminosity to carry out a definitive search for a critical point in the phase diagram of QCD matter. Investments in accelerator improvement projects and capital equipment maintain robust operations and upgrades of the RHIC Access Control System continue.

- Support for CEBAF to operate for 3,010 hours (68 percent optimal) in FY 2021, enabling the highest priority experiments of the 12 GeV science program. Targeted investments in accelerator improvement projects and capital equipment modernize SRF equipment.
- Support for ATLAS to operate as the world's premiere stable ion beam facility for 2,980 hours (44 percent optimal) to enable the most compelling experiments in nuclear structure and astrophysics. Investments in high priority accelerator improvement projects and capital equipment focus on new scientific instrumentation and the Multi-User Upgrade.
- Operations funding for FRIB in FY 2021, which partially supports a transition from a construction project to operations of a scientific user facility, including the movement of key operational staff from the project to the facility operations budget.
- Support for the experimental physics University Centers of Excellence including the Center for Experimental Nuclear Physics and Applications (CENPA) at the University of Washington, the Research and Engineering Center at the Massachusetts Institute for Technology (MIT), the High Intensity Gamma Source (HIGS) at Duke University, and the Texas A&M Cyclotron Institute at the Texas A&M University . These centers provide niche capabilities and unique "hands-on" experiences in nuclear science.
- Funding to fully support mission readiness and nurture critical core competencies at the isotope production facilities. These facilities produce isotopes in short supply that are critical to the nation's federal complex, research enterprise and industry. University isotope production capabilities are increased and networked into the DOE IP for the production of high priority short-lived isotopes. Operation of the Enriched Stable Isotope Prototype Plant (ESIPP) increases to replenish U.S. inventory, reduce dependence on foreign suppliers for research quantities of stable isotopes, and produce isotopes for quantum systems. Investments are made to enhance processing capabilities to keep pace with the growing portfolio of radioisotopes, generate inventories of isotopes in short supply, increase helium-3 supply, continue the FRIB Isotope Harvesting accelerator project, develop electromagnetic separation capabilities for the enrichment of radio-isotopes and heavy stable isotopes, and extract valuable isotopes from the legacy Mark 18a targets, in coordination with NNSA.

<u>Projects</u>
The Request for Construction and Major Items of Equipment (MIEs) includes:

- The final year of construction funding for the Facility for Rare Isotope Beams (FRIB), which will provide world-leading capabilities for nuclear structure and nuclear astrophysics. The project continues to make impressive progress and is over 92 percent complete. Construction funding continues according to the baselined profile.
- Continuation of design efforts and Project Engineering Design (PED) activities for the EIC. The FY 2018 NAS confirmed the importance of a domestic EIC to sustain U.S. world leadership in nuclear science and accelerator R&D core competencies. The Secretary of Energy approved CD-0, Approve Mission Need, in December 2019.
- Continuation of engineering design and long lead procurements for U.S. SIPRC to significantly increase the domestic production capabilities of stable isotopes for scientific, industrial, national security and medical uses. U.S. SIPRC will mitigate. U.S. dependency on foreign supply of stable isotopes.
- Continuation of the Gamma-Ray Energy Tracking Array (GRETA) MIE, which will enable provision of advanced, high resolution gamma ray detection capabilities for FRIB.
- Continuation of the super Pioneering High Energy Nuclear Interaction eXperiment (sPHENIX) MIE, which will have enhanced capabilities that will further RHIC's scientific mission by studying high rate jet production. This project is implemented with funding from within the RHIC facility operations budget.
- Continuation of the Measurement of a Lepton-Lepton Electroweak Reaction (MOLLER) MIE, which will measure the parity-violating asymmetry in polarized electron-electron scattering with the 12 GeV CEBAF machine. This experiment will search for evidence of physics beyond our current understanding with unprecedented levels of precision, by comparing extremely small deviations in the outcomes of scattering experiments with the predictions of theory.
- Continuation of the international Ton-scale Neutrinoless Double Beta Decay MIE to determine whether the neutrino is its own antiparticle. CD-0, Approve Mission Need, was approved in FY 2019. Funding in FY 2021 supports high priority activities and the management team.

**FY 2021 Research Initiatives**

Nuclear Physics supports the following FY 2021 Research Initiatives.

| | (dollars in thousands) | | | |
|---|---|---|---|---|
| | **FY 2019 Enacted** | **FY 2020 Enacted** | **FY 2021 Request** | **FY 2021 Request vs FY 2020 Enacted** |
| **New Research Initiatives** | | | | |
| Strategic Accelerator Technology Initiative | — | — | 1,000 | +1,000 |
| **Total, New Research Initiatives** | **—** | **—** | **1,000** | **+1,000** |
| | | | | |
| **Ongoing Research Initiatives** | | | | |
| Artificial Intelligence and Machine Learning | — | — | 4,000 | +4,000 |
| DOE Isotope Initiative | — | 3,241 | 16,500 | +13,259 |
| Quantum Information Science | 8,300 | 10,300 | 13,000 | +2,700 |
| **Total, Ongoing Research Initiatives** | **8,300** | **13,541** | **34,500** | **+20,959** |

**Nuclear Physics**
**Funding**

(dollars in thousands)

| | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|
| **Medium Energy Nuclear Physics** | | | | |
| Research | 43,286 | 41,154 | 36,000 | -5,154 |
| Operations | 117,390 | 122,110 | 118,000 | -4,110 |
| Other Research | 3,553 | 3,600 | 2,800 | -800 |
| SBIR/STTR | 19,961 | 20,725 | 19,438 | -1,287 |
| **Total, Medium Energy Nuclear Physics** | **184,190** | **187,589** | **176,238** | **-11,351** |
| | | | | |
| **Heavy Ion Nuclear Physics** | | | | |
| Research | 37,354 | 37,661 | 31,518 | -6,143 |
| Operations | 193,125 | 196,651 | 194,928 | -1,723 |
| Other Project Costs | — | 10,000 | 1,500 | -8,500 |
| **Total, Heavy Ion Nuclear Physics** | **230,479** | **244,312** | **227,946** | **-16,366** |
| | | | | |
| **Low Energy Nuclear Physics** | | | | |
| Research | 70,530 | 70,998 | 60,336 | -10,662 |
| Operations | 30,215 | 55,739 | 50,241 | -5,498 |
| **Total, Low Energy Nuclear Physics** | **100,745** | **126,737** | **110,577** | **-16,160** |
| | | | | |
| **Nuclear Theory** | | | | |
| Theory Research | 46,469 | 43,062 | 46,540 | +3,478 |
| Nuclear Data | 8,858 | 8,800 | 7,726 | -1,074 |
| **Total, Nuclear Theory** | **55,327** | **51,862** | **54,266** | **+2,404** |

(dollars in thousands)

| | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|
| **Isotope Development and Production for Research and Applications** | | | | |
| Research | 9,808 | 11,500 | 22,000 | +10,500 |
| Operations | 33,9451 | 35,900 | 44,000 | +8,100 |
| Other Project Costs | 500 | 2,100 | — | -2,100 |
| **Total, Isotope Development and Production for Research and Applications[a]** | **44,259** | **49,500** | **66,000** | **+16,500** |
| **Subtotal, Nuclear Physics** | **615,000** | **660,000** | **635,027** | **-24,973** |
| | | | | |
| **Construction** | | | | |
| 20-SC-51, U.S. Stable Isotope Production and Research Center | — | 12,000 | 12,000 | — |
| 20-SC-52, Electron Ion Collider | — | 1,000 | 1,000 | — |
| 14-SC-50, Facility for Rare Isotope Beams | 75,000 | 40,000 | 5,300 | -34,700 |
| **Total, Construction** | **75,000** | **53,000** | **18,300** | **-34,700** |
| **Total, Nuclear Physics** | **690,000** | **713,000** | **653,327** | **-59,673** |

SBIR/STTR funding:

- FY 2019 Enacted: SBIR $17,588,000 and STTR $2,373,000
- FY 2020 Enacted: SBIR $18,257,000 and STTR $2,468,000
- FY 2021 Request: SBIR $17,220,000 and STTR $2,218,000

[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.

## Nuclear Physics
## Explanation of Major Changes

| | (dollars in thousands) FY 2021 Request vs FY 2020 Enacted |
|---|---|
| **Medium Energy Nuclear Physics**<br>The Request provides support for the CEBAF accelerator complex, including mission readiness of the four experimental halls, mission readiness of the accelerator, all power and consumables of the site, computing capabilities for data collection and analysis, cryogenics plant, scientific researchers on site and at other laboratories and universities, on site accelerator scientists and technicians, and operation of the recently upgraded CEBAF accelerator to support 3,010 operating hours (68 percent optimal), to exploit the capabilities afforded by the 12 GeV CEBAF Upgrade to address the highest priority scientific opportunities. Funding supports high priority research in heavy ion nuclear physics at universities and national laboratories. The Request provides support for experimental activities that will utilize the newly upgraded experimental halls to implement the 12 GeV CEBAF physics program. The Request continues high priority investments in capital equipment and accelerator improvement projects for CEBAF to maintain viability of the facility, and continues targeted investments in maintenance activities and cryomodule refurbishment at CEBAF to improve the performance and reliability of the machine. Key 12 GeV researchers from national laboratories and universities will implement, commission, and operate high priority new experiments at CEBAF. Scientists will play a leading role in the development of scientific instrumentation and accelerator components for the EIC. The Request provides support to initiate investment in the Strategic Accelerator Technology initiative. | **-11,351** |
| **Heavy Ion Nuclear Physics**<br>The Request provides funding for the RHIC accelerator complex, including mission readiness and development of the experimental halls and instrumentation, mission readiness of the suite of accelerators, all power and consumables of the site, cryogenics plant, computing capabilities for data taking and analysis, scientific researchers on site and at other laboratories and universities, on-site accelerator scientists and technicians, operation of RHIC for a 2,580 hour run (at 100 percent of the capped FY 2021 maximum operations), high priority core competencies, and experimental activities to prepare scientific instrumentation and infrastructure for the scientific program. The Request continues high priority investments in capital equipment and accelerator improvement to maintain viability of the facility. Funding from RHIC operations is provided for the base-lined sPHENIX MIE, which will study high rate jets of particles at RHIC. Funding supports the highest priorities in the NP program, including heavy ion nuclear physics at universities and national laboratories. The Request provides support to initiate the Strategic Accelerator Technology initiative. The Request continues OPC for the EIC, which will enable scientists to play a leading role in R&D and the development of scientific instrumentation and accelerator components for the EIC. | **-16,366** |

| | (dollars in thousands) |
|---|---|
| | **FY 2021 Request vs FY 2020 Enacted** |
| **Low Energy Nuclear Physics**<br>The Request provides support for operations of two low energy user facilities: the ATLAS facility, which operates for 2,980 hours (about 44 percent optimal), and FRIB operations and research. Funding will support the highest priorities in the NP Program including investments in capital equipment and accelerator improvement; these investments will maintain viability of the ATLAS facility and add multi-user capability to address the oversubscription of the facility. The Request sustains operations of the 88-Inch Cyclotron at the Lawrence Berkeley National Lab (LBNL) for a limited in-house nuclear science program and an electronics irradiation capability for DOD and NASA. Funding for core research groups supports the highest priorities in the NP program, including research nuclear structure and astrophysics at universities and national laboratories. Funding supports the ongoing GRETA MIE; implementation of this detector at FRIB 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. Funding is continued for the compelling High Rigidity Spectrometer to exploit the fast beam capabilities at FRIB. Funding continues cost-effective operations of the three experimental University Centers of Excellence: the Texas A&M Cyclotron Facility, the HIGS at the Triangle Universities Nuclear Laboratory, and the CENPA at the University of Washington.<br><br>Targeted support continues for neutrinoless double beta decay research to determine whether the neutrino is its own antiparticle; funding is continued for a world-leading ton-scale experiment MIE to reach unprecedented sensitivities. Funding in Fundamental Symmetries also supports efforts such as the Fundamental Neutron Physics Beamline at the SNS and the continued development of its flagship experiment, the nEDM experiment, to study neutron properties and matter/anti-matter asymmetries in the universe. Funding is continued for the MOLLER MIE, which will measure the parity-violating asymmetry in polarized electron-electron scattering at CEBAF. | **-16,160** |
| **Nuclear Theory**<br>Funding for Nuclear Theory is targeted to high priority activities, including theory research efforts at laboratories and universities, the U.S. Nuclear Data Program, specialized Lattice Quantum Chromodynamics (LQCD) computing hardware at TJNAF, and participation in the Science Discovery through Advanced Computing (SciDAC) program. The Request increases investments in QIS and quantum computing (QC), including R&D on quantum sensors to enable precision NP measurements, development of quantum sensors based on atomic-nuclear interactions, and development of quantum computing algorithms applied to quantum mechanical systems and NP topical problems. The Request initiates support for NP-related activities in AI/ML of relevance to nuclear science research, accelerator facility operations and automated machine operations. | **+2,404** |

| | (dollars in thousands) FY 2021 Request vs FY 2020 Enacted |
|---|---|
| **Isotope Development and Production for Research and Applications** Operations funding increases to support mission readiness at the expanding suite of isotope production and processing sites to meet U.S. demand for isotopes in short supply. Increased funding supports the production and processing capability for Actinium-225 and other promising cancer therapeutic isotopes for clinical trials and applications. The Request increases support for the FRIB Isotope Harvesting project at MSU that will add isotope harvesting capabilities to FRIB. The Request provides additional funding to increase isotope availability and production capabilities, including Helium-3 for cryogenics, Lithium (Li)-7 for reactor operations, infrastructure investments to increase processing capabilities of radioisotopes, and the development of new enrichment capabilities for stable and radio-isotopes. ESIPP operates to produce research quantities of enriched stable isotopes; efforts to develop production capabilities for isotopes of interest to next generation quantum information systems continues. The Request increases university and laboratory research in new isotope production techniques, particularly the development of novel isotopes for cancer therapy. Research in support of the DOE Isotope Initiative will enhance core competencies in the development and operation of a broad array of isotope enrichment technologies, critical for research and applications. The Request supports university operations for a network of university accelerators and reactors for cost-effective, regional production of short-lived isotopes for research and medical applications; this includes the University of Washington cyclotron and University of Missouri Research Reactor. | **+16,500** |
| **Construction** Construction funding decreases according to the baselined profile for the Facility for Rare Isotope Beams. Engineering effort and long-lead procurements continue on the new U.S. SIPRC to expand the Nation's capabilities for enriched stable isotopes. The Request includes funding for the EIC to continue Project Engineering and Design. | **-34,700** |
| **Total, Nuclear Physics** | **-59,673** |

**Basic and Applied R&D Coordination**

The NP mission supports the pursuit of unique opportunities for R&D integration and coordination with other DOE Program Offices, Federal agencies, and non-Federal entities. For example, researchers from the High Energy Physics (HEP), NP, and Advanced Scientific Computing Research (ASCR) programs coordinate and leverage forefront computing resources and/or technical expertise through the SciDAC projects and Lattice QCD research to determine the properties of as-yet unobserved exotic particles predicted by the theory of QCD, advance progress towards a model of nuclear structure with predictive capability, and dramatically improve modeling of neutrino interactions during core collapse supernovae. The U.S. Nuclear Data Program provides evaluated cross-section and decay data relevant to a broad suite of Federal missions and topics such as reactor design (e.g., of interest to the NE and Fusion Energy Sciences (FES) programs), materials under extreme conditions (of interest to the BES and FES programs), and nuclear forensics (NNSA and the Federal Bureau of Investigations (FBI)). NP leads an Interagency working group including NNSA, Department of Homeland Security (DHS), NE, the DOE IP and other Federal Agencies to coordinate targeted experimental efforts on opportunistic measurements to address serious gaps and uncertainties in existing nuclear data archives. NP research develops technological advances relevant to the development of advanced fuel cycles for next generation nuclear reactors (NE); advanced cost-effective accelerator technology and particle detection techniques for medical diagnostics and treatment (National Institutes of Health (NIH)); and research in developing neutron, gamma, and particle beam sources with applications in cargo screening (NNSA, DHS, and the FBI).

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

**Program Accomplishments**

*First beam from the world's highest energy continuous-wave hadron linear accelerator*

In March 2019, FRIB became the world's highest energy continuous-wave (non-pulsed beam)hadron linear accelerator following the successful demonstration of an accelerated beam of Argon ions up to 20.3 million electron-volts per nucleon (MeV/u) with 100 percent transmission and no detectable beam losses. The use of superconducting technology enables FRIB operation in continuous-wave mode in contrast to normal conducting accelerating structures that operate in pulsed-beam mode. FRIB has 100 superconducting radiofrequency cavities capable of a total accelerating voltage of 166 megavolts (MV) for any ion species. Existing heavy-ion superconducting linear accelerators are only capable of providing 100 MV total voltage for acceleration of hadron beams in continuous-wave mode. FRIB construction will be completed in 2022, at which point the number of isotopes available for nuclear structure and nuclear astrophysics research will more than double, including neutron –rich isotopes of great interest for understanding the synthesis of heavy elements (e.g. gold, platinum, etc.) in the cosmos.

*New evidence of a 'super-allowed' alpha-decay*

For the first time, researchers at the ATLAS facility located at ANL observed alpha (helium nucleus) emission in a relatively heavy 'self-conjugate' nucleus. Self-conjugate nuclei have the same number of protons and neutrons. They are particularly interesting since their characteristics can yield important insights for understanding nuclear structure and advancing theoretical models. Theoretical predictions suggest that self-conjugate nuclei might pre-form alpha particles inside them prior to their radioactive decay. The rate of alpha emission observed would then be faster than normal, appearing to evidence a so-called 'super-allowed' decay. New results searching for super-allowed decay rates on a number of nuclei that decay via alpha emission suggest, for example, that $^{108}$Xenon (Xe) and $^{104}$Tellurium (Te) may be thought of as a $^{100}$Tin (Sn) core nucleus coupled to one or two alpha particles, which are kept inside the nucleus by electromagnetic effects. This picture is a dramatic departure from previous models advancing understanding of how pre-formed clusters can exist in the structure of heavy nuclei.

*Groundbreaking Advances in Accelerator Technology*
Since its initial commissioning, RHIC has consistently exceeded performance expectations and provided scientific discoveries and technological advances unattainable at any other facility in the world. Research at RHIC often requires high rates of collisions between heavy nuclei fully stripped of their electron cloud, known as heavy ions. Achieving a high luminosity (rate of collisions) can be challenging due to the tendency of the heavy ion bunches in the beams to "blow up" or expand through intra-beam scattering. A "first ever" achievement recently accomplished at RHIC was the successful demonstration of bunched-beam electron cooling. The project, known as LEReC for Low-Energy RHIC electron Cooling, successfully demonstrated that "bunched" beams of electrons could be successfully matched using radio frequency (RF) technology to bunched beams of ions in the RHIC collider, allowing the electrons to dissipate unwanted motion of the ions, "cooling" the ion bunches in order to prevent their physical expansion with a corresponding loss in luminosity. The successful demonstration of bunched-beam electron cooling is a crucial advance necessary to enable the high-quality hadron beams required by future accelerators, including the planned EIC.

*Fifty-year-old enigma solved*
Beta decay, the process by which a nucleus converts one of its neutrons into a proton, accompanied by the emission of an electron, is largely responsible for synthesizing the heaviest elements in the cosmos during cataclysmic events like neutron star mergers. The details of this process are predictable in nuclear theory, so deviations from this behavior can provide an essential tool in searches for new physics beyond our present understanding. For over 50 years however, use of a phenomenological factor has been necessary to bring theoretical beta-decay calculations into agreement with experimental observations. Recently, state-of-the-art computations of beta decay in light and medium mass nuclei, as well as in the heavy nucleus $^{100}$Sn were carried out by nuclear theorists at Oak Ridge National Laboratory (ORNL) and their international collaborators. These calculations, enabled in part by leadership class computing capabilities, included the effects of strong correlations in the nucleus and the coupling felt by two-nucleon pairs due to the weak force of nature, as well as the coupling of the weak force to two nucleons. The resulting calculations showed excellent agreement between theory and experiment, with no need for a phenomenological factor. This groundbreaking advance will be particularly important in future searches for neutrino-less double beta decay to determine whether the neutrino is its own anti-particle.

*Jets at the planned Electron-Ion Collider*
As evidenced at RHIC, high energy jets, appearing as collimated sprays of particles, are powerful tools for exploring the properties of the hot, dense matter created in head-on collisions of nuclei traveling nearly the speed of light. Theoretical nuclear physicists at Lawrence Berkeley National Laboratory recently demonstrated that jets can also be used to study the properties of "cold" nuclear matter under less extreme conditions. Specifically, sensitive "signatures" were developed to guide future experimental research by developing challenging jet reconstruction algorithms for use at the planned EIC, a next-generation, high-energy, high-luminosity particle accelerator with polarized beams for exploring the structure of nucleons and nuclei in unprecedented detail. The proposed measurements, electron-jet correlation studies, will play a central role in uncovering how the "macroscopic" properties of the proton (e.g. mass, spin) are dynamically generated by interactions of the quarks and gluons it contains.

*Availability of a heavy element named for the father of nuclear physics enables scientific advance*
For the first time in over sixteen years, Fermium was produced in the U.S. Fermium, named after Enrico Fermi who built the first nuclear reactor, is a heavy element in the periodic table. It is extraordinarily challenging to make in significant quantities, and can only be made in the U.S. in the High Flux Isotope Reactor (HFIR) at ORNL. In FY 2019, the DOE IP produced Fermium for the first time since 2003, enabling compelling heavy element chemistry research supported by BES. Fermium is of keen interest in heavy element chemistry research because it has a sufficiently massive nucleus that causes its electrons to behave in ways that depart from well-tested atomic theory. The research attributes this anomalous behavior to the possibility that for such heavy nuclei, the inner atomic electrons must travel so close to the speed of light that relativistic effects become significant. Fermium is now the heaviest element ever studied in the effort to further develop this aspect of atomic theory which promises groundbreaking new insights.

*Proton Radius Puzzle*

The charge radius of the proton, one of the most important building blocks of nature, is an urgent, unanswered puzzle of modern physics. By precisely measuring the energy levels of electrons orbiting a proton, its charge radius can be measured to an accuracy of about one percent. However, a new measurement in which a muon orbits the proton instead of an electron found the proton charge radius to be about four percent smaller. The discrepancy has led to speculation that the different between the two measurements might be due to physics beyond our present understanding. Recently, a precision experiment designed to measure the proton charge radius (the Proton Radius [PRaD] experiment) by a completely different technique was completed at TJNAF. PRaD scatters electrons off of protons contained in hydrogen gas, and improves upon previous electron-proton scattering experiments by catching electrons that scatter away at very small forward angles. This helps to accurately determine the protons' size by probing the outermost edges of its charge distribution. New results from PRaD bolster the case that the proton charge radius is smaller than previously thought, consistent with the measurements made using muons.

*Routine production achieved for actinium (Ac)-225 to support clinical trials of targeted alpha therapy*

A tri-lab effort with scientists from LANL, BNL and ORNL are routinely producing 100 milliCuries (mCi) batches of Ac-225 in a reliable and reproducible way. This milestone enabled the DOE IP to enter the market for Ac-225 and support a suite of clinical trials and medical research focused on targeted alpha therapy for metastasized cancers. In the past, targeted cancer therapy research using the promising alpha emitter Ac-225 had been limited by its availability. Leveraging the capabilities of LANL, BNL and ORNL, a new production route for Ac-225 was developed, utilizing the proton beams available at LANL and BNL and the processing capabilities at ORNL. The DOE IP is now scaling up production capability to be able to meet the needs of the growing number of clinical trials and patient treatment.

**Nuclear Physics**
**Medium Energy Nuclear Physics**

### Description

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

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

Various experimental approaches are used to determine the distribution of up, down, and strange quarks, their antiquarks, and gluons within protons and neutrons, as well as clarifying the role of gluons in confining the quarks and antiquarks within hadrons. Experiments that scatter electrons off of protons, neutrons and nuclei are used to clarify the effects of the quark and gluon spins within nucleons, and the effect of the nuclear medium on the quarks and gluons. The subprogram also supports experimental searches for higher-mass “excited states” and exotic hadrons predicted by QCD, as well as studies of their various production mechanisms and decay properties.

The Medium Energy Nuclear Physics subprogram supports research at and operation of the subprogram’s primary research facility, CEBAF at TJNAF, as well as the spin physics research that is carried out using RHIC at BNL. The subprogram provides support for spin physics research at RHIC, which is the only collider in the world that can provide polarized proton beams.

CEBAF provides high quality beams of polarized electrons that allow scientists to extract information on the quark and gluon structure of protons and neutrons from measurements of how the electrons scatter when they collide with nuclei. CEBAF also uses highly polarized electrons to make very challenging 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 of particle physics. These capabilities are unique in the world. The increase in beam energy provided by the 12 GeV CEBAF Upgrade continues to open up exciting new scientific opportunities and secures continued U.S. world leadership in this area of physics. The upgrade construction project was successfully completed on cost and schedule in 2017, and the highly anticipated science program was launched in FY 2018. Some of the science goals of the 12 GeV experimental program include the search for exotic new quark anti-quark particles to advance our understanding of the strong force, evidence of new physics from sensitive searches for violations of nature’s fundamental symmetries, and a microscopic understanding in the 12 GeV energy regime of the internal structure of the proton, including origin of its spin, and how this structure is modified when the proton is inside a nucleus. Next generation instrumentation to fully exploit the capabilities of the 12 GeV CEBAF are implemented in FY 2021. Research at RHIC using colliding beams of spin-polarized protons, a capability unique to RHIC, is providing information on the spin of the proton in a kinematic range complementary to that at CEBAF to extend present knowledge beyond the kinematic boundaries accessible at CEBAF alone. Research support for CEBAF and RHIC includes laboratory and university scientific and technical staff needed to conduct high priority data analysis to extract scientific results. Complementary special focus experiments that require different capabilities can be conducted at the High Intensity Gamma-Ray Source (HIGS) at the Triangle Universities Nuclear Laboratory (TUNL) – an NP University Center of Excellence, FNAL, European laboratories, and elsewhere. The Research and Engineering Center of the Massachusetts Institute of Technology has specialized infrastructure used to develop and fabricate advanced instrumentation and accelerator equipment for the nuclear physics community.

A high scientific priority for this community is understanding how the fundamental properties of the proton such as its mass and spin are dynamically generated by the extraordinarily strong color fields resulting from dense systems of gluons in nucleons and nuclei. The answer to this question is key to addressing an outstanding grand challenge problem of modern physics: how QCD, the theory of the strong force, which explains all strongly interacting matter in terms of points-like quarks interacting via the exchange of gluons, acts in detail to generate the “macroscopic” properties of protons and neutrons. The planned facility to address this science is the EIC, to be located at BNL; the DOE approved CD-0, Approve

Mission Need, in December 2019. Scientists and accelerator physicists from the Medium Energy sub-program are strongly engaged and play significant leadership roles in the development of the scientific agenda and implementation of the EIC.

Transformative accelerator R&D efforts are pursued within the Strategic Accelerator Technology Initiative, including next generation electron ion source developments and advanced approaches in SRF technology. Accelerator scientist also pursue accelerator science aimed at improving the operations of existing facilities and developing next-generation facilities for nuclear physics.

The SBIR/STTR category provides funding in accordance with the Small Business Innovation Development Act and related legislation, resulting in commercialization opportunities in medicine, homeland security, defense, and industry, as well as products and services that benefit NP. The “Other” category includes funding to meet other obligations, such as the annual Lawrence Awards and Fermi Awards.

Research

The subprogram supports targeted, high priority research at universities, TJNAF, BNL, ANL, the Los Alamos National Laboratory (LANL), and LBNL and carries out high priority experiments at CEBAF, RHIC, and elsewhere. Scientists conduct targeted research to advance knowledge and to identify and develop the science opportunities and goals for next generation instrumentation and facilities, primarily for CEBAF and the EIC. Scientists participate in the development and implementation of targeted advanced instrumentation, including state-of-the-art detectors for experiments that may also have application in areas such as medical imaging instrumentation and homeland security. TJNAF staff focus on the 12 GeV experimental program, including implementation of select experiments, acquisition of data, and data analysis at select CEBAF experimental halls (Halls A, B, C, and D). Staff also participate in the RHIC spin program, and play critical roles in instrumentation development for the EIC. Researchers participate in the conceptual design of the EIC and development of scientific and experimental plans for the proposed machine. The subprogram also supports a visiting scientist program at TJNAF and bridge positions with regional universities as a cost-effective approach to augmenting scientific expertise at the laboratory and boosting research experience opportunities.

ANL scientists play a leadership role in new experiments in the 12 GeV scientific program, and are engaged in commissioning experiments, instrumentation development, and data taking. ANL scientists are engaged in planning for the construction of the EIC and its scientific instrumentation. Scientists continue precise measurements of the electric dipole moments of laser-trapped atoms as part of an intensive world-wide effort to set limits on QCD parameters and contribute to the search for possible explanations of the excess of matter over antimatter in the universe. Research groups at BNL and LBNL play leading roles in RHIC data analysis critical for determining the spin structure of the proton. Researchers at TJNAF are developing high current, polarized electron sources for next generation NP facilities.

Accelerator R&D research proposals for 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. FY 2021 is the first year of funding for the Strategic Accelerator Technology Initiative, which builds on the unique core competencies of NP accelerator scientists to develop transformative technology for the Nation, including next-generation accelerator ion sources, innovative and cost effective cryogenic systems, high gradient SRF cavities, and advancements in hadron beam cooling.

Operations

The subprogram provides Accelerator Operations funding for a team of accelerator physicists at TJNAF that operate CEBAF, as well as for power costs of operations and maintenance of the 12 GeV CEBAF. The Request supports high priority accelerator improvements aimed at addressing CEBAF reliability, and high priority capital equipment for research and facility instrumentation. Activities to increase the reliability and energy gradient of the machine remain a priority. Targeted efforts in developing advances in SRF technology relevant to improving operations of the existing machine continue. The core competency in SRF technology plays a crucial role in many DOE projects and facilities outside of nuclear physics (such as the BES Linac Coherent Light Source (LCLS II) project), and has broad applications in medicine and homeland security. For example, SRF R&D at TJNAF has led to improved land-mine detection techniques and carbon nanotube and nano-structure manufacturing techniques for constructing super-lightweight composites such as aircraft fuselages. TJNAF also has a core competency in cryogenics and has developed award-winning techniques that have led to more cost-effective operations at

TJNAF and several other SC facilities; their cryogenics expertise is being applied to the FRIB project and LCLS-II. TJNAF accelerator physicists help train the next generation of accelerator physicists, enabled in part by a close partnership with nearby universities and other institutions with accelerator physics expertise. Accelerator scientists play critical roles in the design development of the EIC. The subprogram provides Experimental Support for scientific and technical staff, as well as for critical materials and supplies needed for the implementation, integration, assembly, and operation of the large and complex CEBAF experiments. Simultaneous continuous wave (cw) polarized beam delivery to four experimental halls is one of the world-wide unique features of the CEBAF accelerator.

## Activities and Explanation of Changes

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| **Medium Energy Nuclear Physics** | **$187,589** | **176,238** | **-$11,351** |
| Research | $41,154 | $36,000 | -$5,154 |
| Funding supports key scientists participating in the highest priority experiments at the four experimental halls with 12 GeV CEBAF. This includes support for critical scientific workforce resident at TJNAF and outside universities and national laboratories that plan the scientific program; develop, implement and maintain scientific instrumentation; participate in the experimental runs to acquire data; analyze data and publish experimental results; and train students in nuclear science. Funding also continues targeted analysis of RHIC polarized proton beam data to learn more about the origin of the proton's spin and focused support for high priority accelerator R&D, as well as funding for the development of scientific instrumentation and plans for the EIC. | | The Request will support scientists, resident at TJNAF, RHIC, and outside universities and national laboratories, for participation in high priority experiments to acquire data; develop, implement, and maintain scientific instrumentation; analyze data and publish experimental results; and train students in nuclear science. The Request will continue targeted analysis of RHIC polarized proton beam data to learn more about the origin of the proton's spin. The Request will support the development of concepts for detectors to be used at the EIC and further develop the scientific program. The Request will also enable researchers to pursue accelerator science pertinent to improving current operations of NP facilities including applications of artificial intelligence, and it will provide initial support for the Strategic Accelerator Technology Initiative. | Funding will support core scientific workforce at universities and national laboratories conducting research related to CEBAF, RHIC, EIC and other facilities. The Request funding will initiate the Strategic Accelerator Technology Initiative. |

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| Operations | $122,110 | $118,000 | -$4,110 |
| Funding for operations of the newly upgraded CEBAF facility supports the continuation of high priority experiments in the 12 GeV science program. Funding supports 2,560 operational hours for research, tuning, and beam studies. The number of hours is limited by installation of cryoplant infrastructure. Funding also provides support for CEBAF operations, including mission readiness of the accelerator, all power and consumables of the site, cryogenics plant, high priority facility and instrumentation capital equipment, high priority accelerator improvement projects, and the key computing capabilities for data taking and analysis. Support is provided to maintain critical core competencies and essential accelerator scientists, engineers, and technicians, and RHIC operations staff. The End Station Refrigerator GPP project is fully funded. Funding supports accelerator R&D. | | The Request for operations of the newly upgraded CEBAF facility will support the continuation of the high priority experiments in the 12 GeV science program. Funding will provide 3,010 operational hours for research, tuning, and beam studies. The Request supports CEBAF operations, including mission readiness of the accelerator, all power and consumables of the site, cryogenics plant, activities to reduce Helium consumption, high priority facility and instrumentation capital equipment, high priority accelerator improvement and GPP projects, and the key computing capabilities for data taking and analysis. The Request also will support maintenance of critical core competencies and accelerator scientists, engineers, and technicians, and operations staff. The Request will support targeted facility capital equipment and accelerator improvements to modernize SRF equipment. Lab GPP investments will advance the most urgent components of the Campus Strategy for infrastructure. The Request will also support the participation of accelerator scientists in accelerator R&D activities, including those for the EIC. | Funding will support increased CEBAF run time by 450 hours to approximately 68 percent of optimal operations. Within the overall funding level, GPP funding will decrease as the End Station Refrigerator project was fully funded in FY 2020. |
| Other Research | $3,600 | $2,800 | -$800 |
| Funding provides for DOE and SC requirements. | | The Request will meet DOE and SC requirements. | Funding will meet DOE and Office of Science central IT and working capital requirements. |
| SBIR/STTR | $20,725 | $19,438 | -$1,287 |
| In FY 2020, SBIR/STTR funding is 3.65 percent of non-capital funding. | | In FY 2021, SBIR/STTR funding will be at 3.65 percent of non-capital funding. | The SBIR/STTR funding will be consistent with the NP total budget. |

## Nuclear Physics
## Heavy Ion Nuclear Physics

### Description

The Heavy Ion Nuclear Physics subprogram focuses on studies of nuclear matter at extremely high densities and temperatures, directed primarily at answering overarching questions in Nuclear Physics, including:

- What are the phases of strongly interacting matter, and what roles do they play in the cosmos?
- What governs the transition of quarks and gluons into pions and nucleons?
- What determines the key features of QCD and their relation to the nature of gravity and space-time?

At the Relativistic Heavy Ion Collider (RHIC) facility, scientists continue to pioneer the study of condensed quark-gluon matter at the extreme temperatures characteristic of the infant universe. The goal is to explore and understand unique manifestations of QCD in this many-body environment and their influence on the universe's evolution. In the aftermath of collisions at RHIC and at the Large Hadron Collider (LHC) at CERN, researchers have seen signs of the same quark-gluon plasma that is believed to have existed shortly after the Big Bang. With careful measurements, scientists are accumulating data that offer insights into the processes early in the creation of the universe, and how protons, neutrons, and other bits of normal matter developed from that plasma. Important avenues of investigation are directed at learning more about the physical characteristics of the quark-gluon plasma including exploring the energy loss mechanism for quarks and gluons traversing the plasma, determining the speed of sound in the plasma, establishing the threshold conditions (minimum nucleus mass and energy) under which the plasma can be formed, and discovering whether a critical point exists where there is a phase transition between normal nuclear matter and the quark-gluon plasma.

The RHIC facility places heavy ion research at the frontier of discovery in nuclear physics. RHIC is uniquely flexible, providing a full range of colliding nuclei at variable energies spanning the transition to the quark gluon plasma discovered at RHIC. The facility continues to set new records in performance for both integrated Au-Au luminosity at full energy and a number of other beam settings. This flexibility and performance enable a groundbreaking science program to answer outstanding questions about this exotic and fundamental form of matter and whether a critical point exists in the phase diagram of nuclear matter. Scientists participate in instrumentation upgrades, such as enhancements to the capabilities of the Solenoid Tracker at RHIC (STAR) detector, and an upgrade of the PHENIX detector to sPHENIX with funds previously used to operate the PHENIX detector. Accelerator physicists conduct accelerator R&D at RHIC in critical areas that include various types of cooling of high-energy hadron beams, high intensity polarized electron sources, and high-energy, high-current energy recovery linear accelerators. The RHIC facility is typically used by about 1,000 DOE, NSF, and foreign agency-supported researchers annually.

A compelling, persistent, high scientific priority for the U.S. nuclear science community has been understanding how the fundamental properties of the proton such as its mass and spin are dynamically generated by the extraordinarily strong color fields resulting from dense systems of gluons in nucleons and nuclei. The answer to this question is key to addressing an outstanding grand challenge problem of modern physics: how Quantum Chromodynamics, the theory of the strong force, which explains all strongly interacting matter in terms of points-like quarks interacting via the exchange of gluons, acts in detail to generate the "macroscopic" properties of protons and neutrons. In 2018, a National Academies study gave a strong endorsement to a U.S.-based EIC, and recognized its critical role in maintaining U.S. leadership in nuclear science and accelerator R&D[a]. In December 2019, DOE approved CD-0, Approve Mission Need, for the EIC with a Rough Order of Magnitude TPC range of $1.6 billion to $4.2 billion. In January 2020, BNL was selected as the location for the EIC resulting in a revised cost range of $1.6 billion to $2.6 billion. Scientists and accelerator physicists from the Medium Energy sub-program are strongly engaged and will play significant leadership roles in the development of the scientific agenda and implementation of the EIC.

The SC Strategic Accelerator Technology initiative leverages accelerator science core competencies within the NP program and supports transformative technology needed for the next generation of SC facilities. Core competencies exist at NP

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

facilities in the areas of beam and collider physics, hadron beam cooling, high field superconducting magnets, superconducting radio frequency (SRF) technologies, ion source technologies, and AI/ML applications in operation of user facilities. This support is essential for maintaining strategic accelerator technology core competencies at SC-supported laboratories. Accelerator scientists also pursue accelerator science aimed at improving the operations of existing facilities and developing next-generation facilities for nuclear physics.

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 infancy of the 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 comparisons of results from LHC to those from RHIC have led to important new insights. U.S. researchers have been making important scientific contributions to the emerging results from all three LHC experiments. In ALICE and CMS, U.S. researchers have been participating in developing and upgrading instrumentation for future heavy ion campaigns at the LHC.

<u>Research</u>
This activity supports targeted, high priority research at universities and at BNL, LBNL, LANL, and ORNLORNL to participate in essential efforts at RHIC and the LHC. U.S. commitments to the LHC “common funds”, which are fees based on the level of U.S. scientist participation in the LHC program and the use of LHC computing capabilities, are deferred to FY 2022.

Supported university and national laboratory research groups employ personnel and graduate students for taking data within the RHIC heavy ion program; analyzing data; publishing results; conducting R&D of next-generation detectors; developing and implementing scientific equipment; and planning for future experiments. BNL, LBNL, and ORNL provide computing infrastructure for petabyte-scale data analysis and state-of-the-art facilities for detector and instrument development. Researchers participate in the conceptual design of the EIC and its scientific instrumentation, and development of experimental plans for the proposed facility.

Research proposals for 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. FY 2021 will be the first year of funding for the Strategic Accelerator Technology Initiative, which will exploit the unique core competencies of NP accelerator scientists to develop transformative technology for the nation, including next-generation accelerator ion sources, innovative and cost-effective cryogenic systems, high gradient SRF cavities, and advancements in hadron beam cooling.

<u>Operations</u>
The Heavy Ion activity supports the operations and power costs of the RHIC accelerator complex at BNL, which 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 key experimental support to the facility, including the development, implementation, and commissioning of scientific equipment associated with the RHIC program. The FY 2021 Request supports high priority capital equipment and accelerator improvement projects at RHIC to promote enhanced and robust operations. In FY 2021, the only detector operating at RHIC will be STAR; PHENIX operations funding is redirected to continue the sPHENIX MIE. sPHENIX will enable scientists to study how the near-perfect Quark Gluon Plasma liquid, which has the lowest shear viscosity ever observed, arises from the strongly interacting quarks and gluons from which it is formed. The Low Energy RHIC electron Cooling (LEReC) Accelerator Improvement Project was commissioned in FY 2019 and has demonstrated cooling of low energy heavy ion beams with bunched electron beam; this achievement is projected to increase the RHIC luminosity by up to another factor of ten at the lowest beam energies.

RHIC operations have led to advances in accelerator physics which have, in turn improved RHIC performance and NP capabilities. These core competencies provide collateral benefits to applications in industry, medicine, homeland security, and other scientific areas outside of NP. RHIC accelerator physicists are providing leadership and expertise to reduce technical risk of relevance to a possible next-generation collider, including beam cooling techniques and energy recovery linacs. Accelerator physicists also play an important role in the training of next generation accelerator physicists, through support of graduate students and post-doctoral associates.

RHIC operations allow for parallel and cost-effective operations of the Brookhaven Linac Isotope Producer Facility (BLIP), supported by the DOE Isotope Program for the production of research and commercial isotopes critically needed by the Nation, and of the NASA Space Radiation Laboratory Program for the study of space radiation effects applicable to human space flight as well as electronics. Support for the mission readiness of BLIP is included in the Isotope subprogram, while collected revenues from customers support the production costs of the isotopes.

Other Project Costs

Scientists and accelerator physicists from both the Medium Energy and Heavy Ion subprograms are actively engaged in the development of the conceptual design of the EIC and its scientific instrumentation for the proposed facility. Activities advance the conduct of an alternative analysis and preparations for CD-1 approval. Consideration to integration of laboratory core competencies and participation from across the national laboratory complex and universities continues. Accelerator and detector R&D focus on reduction of remaining technical risks and value engineering.

## Activities and Explanation of Changes

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| **Heavy Ion Nuclear Physics** | **$244,312** | **$227,946** | **-$16,366** |
| Research | $37,661 | $31,518 | -$6,143 |
| Researchers participate in high priority analysis and collection of data from RHIC to explore new phenomena in quark-gluon plasma formation. Funding provides targeted support for scientific workforce resident at RHIC and outside universities and national laboratories to develop, fabricate, implement and maintain scientific instrumentation; participate in select experimental runs to acquire data; analyze data and publish experimental results; develop scientific plans and instrumentation for the proposed EIC; and train students in nuclear science. Funding supports scientists to implement the sPHENIX MIE for the study of high rate particle jets. U.S. scientists participate in the highest priority heavy ion efforts at the international ALICE, CMS, and ATLAS LHC experiments. In addition, funding supports high priority accelerator R&D relevant to NP programmatic needs and EIC Conceptual Design. | | The Request will support scientists resident at RHIC and outside universities and national laboratories to develop, fabricate, implement and maintain scientific instrumentation; participate in select experimental runs to acquire data; analyze data and publish experimental results; develop scientific plans and instrumentation for the proposed EIC; and train students in nuclear science. The Request will also enable scientists to continue to fabricate the sPHENIX MIE for the study of high rate particle jets. The Request will also support modest and cost effective upgrades at STAR in preparation for a polarized proton run in 2022. U.S. scientists will participate in the highest priority heavy ion efforts at the international ALICE, CMS, and ATLAS LHC experiments, and the request will support upgrades at these facilities. The Request will support targeted accelerator R&D relevant to NP programmatic needs. The FY 2021 Request also will support the new SC Strategic Accelerator Technology Initiative. | Funding will support the core scientific workforce at universities and national laboratories to conduct research at RHIC, the LHC, and for EIC detector development. U.S. contributions to the LHC "common funds," fees to support individual U.S. scientist participation in the LHC program and the use of LHC computing capabilities, are deferred until FY 2022. The first year of funding for the Strategic Accelerator Technology Initiative will be supported within the NP Medium Energy and Heavy Ion subprograms. |

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| Operations | $196,651 | $194,928 | -$1,723 |
| RHIC operates for 3,260 hours (88 percent of optimum) and focuses on the beam energy scan, including the newly implemented Low Energy RHIC Electron Cooling to increase luminosity of low energy beams. Funding supports the RHIC accelerator complex, including mission readiness and development of the experimental halls and instrumentation, mission readiness of the suite of accelerators, all power and consumables of the site, cryogenics plant, high priority facility and instrumentation capital equipment, high priority accelerator improvement projects, and the key computing capabilities for data taking and analysis. Support is provided to maintain critical core competencies and essential accelerator scientists, engineers, and technicians, and RHIC operations staff. The sPHENIX MIE, which will enable the study of high rate particle jets, receives operations funding in accordance with the planned profile. Accelerator scientists participate in high priority accelerator R&D. | | The Request will support RHIC operations for 2,580 hours (100 percent optimal). Operating hours of 2,580 are lower than the typical hours RHIC can operate, however, the operating hours are capped in FY 2021 due to planned installation requirements. ). The Request also will support the RHIC accelerator complex, including mission readiness and development of the experimental halls and instrumentation, mission readiness of the suite of accelerators, all power and consumables of the site, cryogenics plant, activities to reduce helium consumption, high priority facility and instrumentation capital equipment, high priority accelerator improvement projects, and computing capabilities for data taking and analysis. Support will maintain critical core competencies and accelerator scientists, engineers, and technicians, for RHIC operations and EIC design. Limited operations funding will be redirected to the sPHENIX MIE, which will study high rate particle jets. Accelerator scientists will participate in high priority accelerator R&D. | Funding supports maximum operations of RHIC, which require reduced operating hours (2,580 hours) to accommodate installation requirements at the facility. Funding continues for the sPHENIX MIE. |
| Other Project Costs | $10,000 | $1,500 | -$8,500 |
| Funding provides the first year of Other Project Costs (OPC) for the EIC, aimed at research to reduce technical risk and the development of a conceptual design. While requested in the Theory subprogram in FY 2020, with a site selection of BNL announced in January 2020, the funding is now included in the Heavy Ion Program. | | The Request will provide for OPC for the EIC, aimed at research to reduce technical risk and the development of a conceptual design. | Funding will continue for OPC funding for EIC. |

## Nuclear Physics
## Low Energy Nuclear Physics

### Description

The Low Energy Nuclear Physics subprogram includes two scientific subprograms that focus on using nuclear interactions and decays to answer overarching questions related to 1) Nuclear Structure and Nuclear Astrophysics, and 2) Fundamental Symmetries.

### Nuclear Structure and Nuclear Astrophysics

Questions associated with Nuclear Structure 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 are the origins of the elements in the cosmos?
- What are the nuclear reactions that drive stars and stellar explosions?

The Nuclear Structure and Nuclear Astrophysics 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.

The ATLAS scientific user facility at ANL is the DOE-supported facility providing research opportunities in Nuclear Structure and Nuclear Astrophysics, serving approximately 350 domestic and international scientists per year. ATLAS is the world's premiere facility for stable beams and provides high-quality beams of all the stable elements up to uranium, as well as selected beams of short-lived (radioactive) nuclei to study nuclear properties under extreme conditions and reactions of interest to nuclear astrophysics, using the Californium Rare Ion Breeder Upgrade (CARIBU) ion source. Technologically cutting-edge and unique instrumentation are a hallmark of the facility, and ATLAS continues to be significantly oversubscribed by the user community. ATLAS is also an essential training ground for scientists and students. The facility nurtures an expert core competency in accelerator science with superconducting radio frequency cavities for heavy ions that are relevant to next generation high-performance proton and heavy ion linacs. This competency is important to the SC mission and international stable and radioactive ion beam facilities. ATLAS stewards a target development laboratory, the National Center for Accelerator Target Science, a national asset for the low energy community, including FRIB.

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 nuclear science community has identified necessary to leverage the capabilities of FRIB. GRETA's unprecedented combination of full coverage with high efficiency, and excellent energy and position resolution, will extend the reach of FRIB's ability to study the nuclear landscape, provide new opportunities to discover and characterize key nuclei for electric dipole moment searches, and open new areas of study in nuclear astrophysics. The High Rigidity Spectrometer (HRS) will specifically exploit FRIB's fast beam capabilities and enabling the most sensitive experiments across the entire chart of nuclei with the most neutron-rich nuclei available.

Scientists participate in the international effort to discover and characterize new "super heavy" elements in the periodic table. U.S. researchers played a prominent role in the recent discovery of Elements 115, 117, and 118, and Element 117 was named Tennessine to acknowledge the leadership role of the U.S. in these efforts. Research is ongoing to characterize these new elements and also to discover Elements 119 and 120. All of these past and future experiments were/are made viable by the provision of rare isotopes produced at HFIR through the DOE Isotope Program. NP also supports operations of the LBNL 88-Inch Cyclotron to provide beams for a small in-house nuclear science program focused on studying the properties of newly discovered elements on the periodic table, as well as conducting independent searches for new elements. DOD and NASA exploit materials irradiation capabilities at the 88 Inch to develop radiation-resistant electronics for their missions.

There are three university Centers of Excellence within the Low Energy subprogram, each with specific goals and unique physics programs: the Cyclotron Institute at Texas A&M University (TAMU), the accelerator facility at the TUNL at Duke University, and unique expertise and capabilities for instrumentation development at the Center for Experimental Nuclear Physics and Astrophysics (CENPA) at the University of Washington.

**Fundamental Symmetries**

Questions related to Fundamental Symmetries of nature addressed in low energy nuclear physics experiments include:

- What is the nature of 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 decay (NLDBD) detector is capable of achieving the sensitivity necessary to determine if the neutrino is its own anti-particle?
- Why is there now more matter than antimatter in the universe? Is there evidence from the electric-dipole moments of atomic nuclei and the neutron that indicate our current understanding of the fundamental laws governing nuclear physics is incomplete?
- Will precise measurements in electron scattering and the decay of nuclei indicate forces present at the dawn of the universe that disappeared from view as the universe evolved?

The Fundamental Symmetries portfolio addresses these questions through precision studies using neutron beams and decays of nuclei, including beta decay, double-beta decay, and NLDBD, and electron beams. U.S. scientists are world leaders in the global research effort aimed at neutrino science and owing to the importance of nuclear beta decay in understanding neutrino properties, NP is the steward of neutrino mass measurements and NLDBD in SC. Often in partnership with NSF, NP has invested neutrino experiments both domestically and overseas, playing critical roles in international experiments that depend on U.S. leadership for their ultimate success (Cryogenic Underground Observatory for Rare Events (CUORE), KATRIN), and R&D of candidate technologies for next–generation experiments, including germanium (LEGEND), xenon (nEXO) and molybdenum (CUPID). In partnership with NSF, NP participates in the international LEGEND-200 experiment. The NSAC 2015 LRP recommended "the timely development and deployment of a U.S.-led ton-scale neutrinoless double beta decay experiment." NLDBD can only occur if neutrinos are their own anti-particles and such events would have profound, game changing consequences for the present understanding of the physical universe. The Ton-Scale NLDBD MIE is expected to provide unprecedented resolution for the detection of the rare process; the MIE received CD-0, Approval of Mission Need, in November 2018.

Very precise measurements in parity violating electron scattering, the decay of nuclei, and the properties of neutrons provide sensitivity to new forces and address questions about the matter/anti-matter imbalance rivaling, and even exceeding, the reach of high energy colliders. The MOLLER MIE will measure the parity-violating asymmetry in electron-electron scattering at CEBAF which is uniquely sensitive to the possible existence of new as yet unforeseen particles. Evidence for electric dipole moments of the neutron and atoms violate time reversal invariance and would shed light on the matter/anti-matter imbalance in the universe. Beams of cold and ultracold neutrons with the dedicated Fundamental Neutron Physics Beamline (FNPB) at the SNS are used to study fundamental properties of neutrons, including the flagship experiment to measure the electric dipole moment of the neutron.

Nuclear Structure and Nuclear Astrophysics Research

This activity supports high priority research groups at ANL, LBNL, LLNL, and ORNL and at universities. Scientists develop, fabricate, and use specialized instrumentation at ATLAS, and participate in the acquisition and analysis of data. Scientists participate in the design and fabrication of instrumentation for FRIB and development of upcoming scientific program. Funds transition key scientists that used to be supported by NSF at the National Superconducting Cyclotron Laboratory (NSCL) to this DOE portfolio to support the FRIB scientific mission. The Request continues funding for the GRETA MIE and maintains the HRS project. Scientists participate in research to characterize and discover new super-heavy elements at international facilities and the 88 Inch cyclotron. The Request will provide support to the university Centers of Excellence at TUNL and TAMU for the conduct of nuclear structure and nuclear astrophysics experiments at these niche facilities.

Fundamental Symmetries Research

The activity supports high priority research at BNL, LANL, LBNL, LLNL, ORNL, PNNL, and SLAC, and at universities. R&D for a challenging experiment to measure the electric dipole moment of the neutron, which could shed light on the asymmetry of matter versus antimatter in the universe, and other experiments at the SNS FNPB continue. First-generation NLDBD experiments continue to acquire data, such as the CUORE experiment at Gran Sasso Laboratory in Italy. Conceptual design efforts continue for an international ton-scale NLDBD MIE, along with targeted R&D. Scientists at TJNAF continue to implement the MOLLER MIE. Scientists participate in the operations of the KATRIN experiment at the Karlsruhe Institute of Technology in Karlsruhe, Germany to provide a measurement of the neutrino mass. University Centers of Excellence at TUNL, CENPA, and TAMU with unique capabilities are exploited to advance research in Fundamental Symmetries.

Nuclear Structure and Nuclear Astrophysics Operations

The activity supports facility and operations costs associated with ATLAS, FRIB, and the 88-Inch Cyclotron. ATLAS provides highly reliable and cost-effective stable and selected radioactive beams and specialized instrumentation. Funding provides support for the operations and power costs of the ATLAS, and targeted support for high priority accelerator and scientific instrumentation capital equipment, accelerator improvement projects, and experimental support. ATLAS efficiency and complexity has been increasing with the addition of the Electron Beam Ion Source (EBIS), the cutting edge CARIBU radioactive beam system for accelerated radioactive ion beams, the in-flight radioactive ion separator to increase the intensity of radioactive beams, and a gas-filled analyzer.

The ATLAS facility nurtures a core competency in accelerator science with superconducting radio frequency cavities for heavy ions that are relevant to the next generation of high-performance proton and heavy ion linacs. This competency is important to the Office of Science mission and international stable and radioactive ion beam facilities. Critical efforts continue to address facility oversubscription and increase available beam time, with development of the cost-effective multi-user upgrade Accelerator Improvement Project which will significantly increase the beam hours available for experiments to the scientific community.

The Request includes funding to support FRIB operations in advance of the first year of operations in FY 2022. The funds retain the most critical operations staff as accelerator components are completed on the project and direct their efforts towards the transition to operations, including commissioning, system tests, and developing operational performance of systems.

The Request also sustains operations of the 88-Inch Cyclotron for a focused in-house nuclear physics program which includes characterization and searches for new elements and nuclear data measurements.

## Activities and Explanation of Changes

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| **Low Energy Nuclear Physics** | **$126,737** | **$110,577** | **-$16,160** |
| Research | $70,998 | $60,336 | -$10,662 |
| Funding supports focused university and laboratory nuclear structure and nuclear astrophysics efforts at ATLAS, the world's premiere stable beam facility, and development of the FRIB scientific program. As NSCL staff transition to FRIB, funding is provided to transition scientific personnel from NSF to DOE support. Research continues at the unique university-based Centers of Excellence at TUNL, CENPA and TAMU. Scientists participate in first generation NLDBD experiments. The ton-scale NLDBD and MOLLER MIEs are initiated. Scientists participate in the international KATRIN. Funding continues for the GRETA MIE. The HRS MIE for FRIB is initiated. | | The Request will support high priority university and laboratory nuclear structure and nuclear astrophysics efforts at ATLAS and development of the FRIB scientific program. of the Request includes research support for FRIB scientific personnel. The Request will continue funding for the GRETA and HRS MIEs. Scientists will participate in the characterization of recently discovered elements and search for new ones. Research will continue at the university-based Centers of Excellence at TUNL, CENPA, and TAMU.<br><br>High priority research in NLDBD will continue with CUORE, LEGEND-200, and nEXO. The Request will continue the ton-scale NLDBD MIE and the MOLLER MIE. The Request will continue support for U.S. participation in the operations of the international KATRIN experiment. | Support focuses on high priority efforts and essential workforce at universities and national laboratories. Funding for the ton-scale NLDBD MIE is increased slightly. Funding for the GRETA and Moller MIEs are decreased. |

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| Operations | $55,739 | $50,241 | -$5,498 |
| Funding supports operation of ATLAS to address the high demand for ATLAS beam time, which continues to far exceed availability. ATLAS funding at this cost-effective facility will support 5,950 hours of beam time, operations staff, maintenance, and accelerator improvement projects and capital equipment for the facility and scientific instrumentation, including an upgrade to CARIBU. Funding also sustains operations of the LBNL 88-Inch Cyclotron. Funding provides FRIB with support for activities and transition staff from the construction effort to FRIB operations. | | The Request will support operations of ATLAS at 2,980 hours (44 percent of optimal), and will provide funding for staff, maintenance, and high priority accelerator improvement projects and capital equipment for the facility and scientific instrumentation, including the development of a multi-user capability. Funding will sustain operations of the 88-Inch Cyclotron for high priority experiments studying newly discovered elements. The Request will support high priority activities necessary to prepare for FRIB operations in FY 2022. | Funding supports high priorities in the program, offset by reduced operations support for FRIB, ATLAS, and the LBNL 88-Inch Cyclotron. |

**Description**

The Nuclear Theory subprogram provides the theoretical support needed to interpret the wide range of data obtained from the experimental nuclear science subprograms and to advance new ideas and hypotheses that identify potential areas for future experimental investigations. 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 by the community to describe nuclear many-body phenomena; these approaches will likely also see important applications in condensed matter physics and in other areas of the physical sciences. Another major research area is nuclear astrophysics, which includes efforts to understand the origins of the elements and the consequences that neutrino masses have for nuclear astrophysics.

This subprogram supports the Institute for Nuclear Theory (INT) at the University of Washington. It also supports topical collaborations within the university and national laboratory communities to address only the highest priority topics in nuclear theory that merit a concentrated theoretical effort.

The U.S. Nuclear Data Program (USNDP) aims to provide current, accurate, and authoritative data to workers in basic 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 four and a half million retrievals of nuclear data annually. The USNDP also addresses important gaps in nuclear data through targeted experiments and the development and use of theoretical models. The program involves the combined efforts of approximately 50 nuclear scientists at 10 national laboratories and universities, and is managed by the National Nuclear Data Center (NNDC) at BNL. The USNDP provides evaluated cross-section and decay data relevant to a broad suite of federal missions and topics. NP leads an interagency working group including NNSA, NE, the DOE IP, and other federal agencies to coordinate targeted experimental efforts.

Nuclear physicists participate in activities related to QIS and quantum computing (QC), in coordination with other SC research programs. NP-specific efforts include R&D on quantum sensors to enable precision NP measurements, development of quantum sensors based on atomic-nuclear interactions, and development of quantum computing algorithms applied to quantum mechanical systems and NP topical problems. In support of the National Quantum Initiative, SC QIS Center(s) that will be established in FY 2020 will constitute an interdisciplinary partnership among SC Program Offices, including NP. Support for the SC QIS centers continues in FY 2021.

Scientists will develop cutting-edge techniques based on AI/ML of relevance to nuclear science research, accelerator facility operations and automated machine operations in the DOE IP. NP has been supporting applications of artificial neural networks in the analysis of nuclear physics data for decades. Additionally, NP is supporting technical development at the intersections between real-time ML and control and the optimization of accelerator systems operations and detector design using AI models. Future "intelligent" experiments will seek to incorporate next generation AI hardware and electronics into detector systems. NP also supports researchers engaged in developing learning techniques focused on improving efficiencies of accelerator operations.

The Nuclear Theory subprogram supports and leverages LQCD calculations that are critical for understanding and interpreting many of the experimental results from RHIC, LHC, and CEBAF. NP supports LQCD computing needs for dedicated computational resources with investments at TJNAF.

The Nuclear Theory subprogram also supports SciDAC, a collaborative program with ASCR that partners scientists and computer experts in research teams to address major scientific challenges that require supercomputer facilities performing at current technological limits. The NP SciDAC program operates on a five-year cycle, and supports computationally intensive research projects jointly with other SC and DOE offices in areas of mutual interest.

Theory Research

This activity supports targeted, high priority research at seven national laboratories (ANL, BNL, LANL, LBNL, LLNL, ORNL, and TJNAF). This research advances our fundamental understanding of nuclear physics, interpreting the results of experiments carried out under the auspices of the experimental nuclear physics program, and identifies and explores compelling new areas of research. The Request supports a new cohort of topical collaborations within available funds to bring together theorists to address specific high-priority theoretical challenges. The activity supports high priority efforts on FRIB theory, which is critical to theory research associated with the planned FRIB scientific program in order to optimize the interpretation of the experimental results.

The Request supports increases for research related to QIS and QC to provide technological and computational advances relevant to NP and other fields. Following exploratory QIS/QC workshops at the Institute for Nuclear Theory and at ANL, as well as a QC "test-bed" simulation to demonstrate proof-of-principle use of quantum computing for scientific applications, the NSAC published a report[a] in October 2019 to articulate further priority areas in QIS/QC where unique opportunities exist for nuclear physics contributions. For example, the report noted that the intersection of Quantum Field Theory and QC was an exciting opportunity for important advances achieved through nuclear physics research.

SciDAC-4 awards selected in FY 2017 continue as planned in FY 2021, with progress monitored via peer review. In addition to addressing specific problems relevant for nuclear physics research, SciDAC-4 projects continue to serve as a water-shed for training scientists who can address national needs.

Funding for a new AI/ML initiative is requested within the Nuclear Theory subprogram in FY 2021, which will support efforts throughout NP. The AI/ML Initiative will provide targeted investments to develop cutting-edge techniques based on AI of relevance to nuclear science research, accelerator facility operations, and automated machine operations.

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

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[a] "*Nuclear Physics and Quantum Information Science*" Nuclear Science Advisory Committee, October 2015 (https://science.osti.gov/~/media/np/nsac/pdf/2015LRP/2015_LRPNS_091815.pdf).

## Activities and Explanation of Changes

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| **Nuclear Theory** | **$51,862** | **$54,266** | **+$2,404** |
| Theory Research | $43,062 | $46,540 | +$3,478 |
| Funding supports high priority QIS efforts. LQCD computing hardware investments are supported at TJNAF. Funding supports high priority theoretical research at universities and national laboratories for the interpretation of experimental results obtained at NP facilities, and the exploration of new ideas and hypotheses that identify potential areas for future experimental investigations. Theorists focus on applying QCD to a wide range of problems from nucleon structure and hadron spectroscopy, through the force between nucleons, to the structure of light nuclei. Advanced dynamic calculations to describe relativistic nuclear collisions and nuclear structure and reactions continue to focus on activities related to the research program at the upgraded 12 GeV CEBAF facility, the planned research program at FRIB, and ongoing and planned RHIC experiments. Funding supports the fourth year of SciDAC-4 grants and the final year of theory topical collaborations initiated in FY 2017. | | The Request will support high priority QIS efforts. LQCD computing investments continue at TJNAF. Funding will support high priority theoretical research at universities and national laboratories for the interpretation of experimental results obtained at NP facilities, and the exploration of new ideas and hypotheses that identify potential areas for future experimental investigations. Theorists will focus on applying QCD to a wide range of problems from nucleon structure and hadron spectroscopy, through the force between nucleons, to the structure of light nuclei. Advanced dynamic calculations to describe relativistic nuclear collisions and nuclear structure and reactions will continue to focus on activities related to the research program at the upgraded 12 GeV CEBAF facility, the planned research program at FRIB, and ongoing and planned RHIC experiments. The Request will support the fifth and final year of SciDAC-4 grants and the final year of theory topical collaborations initiated in FY 2017. Funding will target investments in an initiative to develop cutting-edge AI techniques of relevance to nuclear science research, accelerator facility operations, and automated machine operations. | The increase in funding will support QIS research, reflecting the growing importance of this field in nuclear physics, and a new initiative in AI/ML. |

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| Nuclear Data | $8,800 | $7,726 | -$1,074 |
| Funding supports the high priority USNDP efforts to collect, evaluate, and disseminate nuclear physics data for basic nuclear research and for applied nuclear technologies and their development. Funding also supports some critical experimental measurements to address gaps in existing nuclear data. | | The Request will provide support for high priority USNDP efforts to collect, evaluate, and disseminate nuclear physics data for basic nuclear research and for applied nuclear technologies and their development. The Request will also provide funding for critical experimental measurements to address gaps in existing nuclear data. | Funding continues for the high priority experimental nuclear data efforts. |

**Nuclear Physics**
**Isotope Development and Production for Research and Applications[a]**

## Description

The Isotope Development and Production for Research and Applications subprogram (DOE Isotope Program, or DOE IP) 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 and mitigate U.S. dependence on foreign supplies of isotopes. 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 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 for DOE IP is executed through the Isotope Production and Distribution Program revolving fund. The isotope revolving fund maintains its financial viability by utilizing the appropriations for this subprogram along with revenues from the sale of isotopes and services. These resources are used to maintain the staff, facilities, and capabilities at user-ready levels and to support peer-reviewed R&D activities related to the production of isotopes. Isotopes sold to commercial customers are priced to recover the full cost of production, or the market price (whichever is higher). Research isotopes are sold at a reduced price to ensure that the high priority research requiring them does not become cost prohibitive. DOE IP makes investments in new capabilities 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, to improve the efficiency of industrial processes, and to provide precise measurement and investigative tools for materials, biomedical, archeological, and other research. Some examples of produced isotopes are:

- actinium-225, actinium-227, tungsten-188, lutetium-177, strontium-89, strontium-90, and cobalt-60 for cancer therapy;
- americium-241 and californium-252 for oil and gas exploration and production well logging;
- bismuth-213, lead-212, astatine-211, copper-67, thorium-227, and radium-223 for cancer and infectious disease therapy and research; cadmium-109 for X-ray fluorescence imaging and environmental research;
- berkelium-249, americium-243, plutonium-242, californium-251, einsteinium-255, and curium-248 for use as targets for discovery of new super heavy elements;
- fermium-257 for heavy element chemistry research;
- selenium-75 for industrial radiography;
- nickel-63 for explosives detection, and lithium-6 and helium-3 for neutron detectors for homeland security applications; and
- arsenic-73, iron-52, and zinc-65 as tracers in metabolic studies.

Research to support the DOE Isotope Initiative builds upon existing core competencies in the DOE IP to grow expertise and enhance capabilities that promote U.S. independence in isotope supply and leadership in advanced isotope production technology, which does not necessitate immediate sale of product to be viable, enabling longer term and high-risk, high pay-off endeavors. Activities include the establishment of “not for sale” reserves of critical isotopes to mitigate unanticipated disruptions in foreign supply; development of transformative isotope production core competencies; exploration of isotope production techniques used globally; and pursuit of innovative, next-generation technology for

[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 Public Law (P.L.) 101–101 and as modified by P.L. 103–316.

development of long-term product availability. This activity involves partnerships with NNSA, the Office of Nuclear Energy (NE), and other federal agencies.

Stable and radioactive isotopes are vital to the missions of many Federal agencies including the National Institutes of Health (NIH), National Institute of Standards and Technology (NIST), Department of Agriculture, Department of Homeland Security (DHS), NNSA, and other SC programs. The DOE IP continues to work in close collaboration with all federal organizations to develop strategic plans for isotope production and to forecast isotope needs and leverage resources. The DOE IP conducts biennial workshops, attended by representatives of all Federal agencies that require stable and radioactive isotopes, to provide a comprehensive assessment of national needs for isotope products and services, to inform priorities for investments in research for developing new isotope production and processing techniques, to communicate advances in isotope production research and availability, and to communicate concerns about potential constrained supplies of important isotopes to the Federal complex. The DOE IP 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) National Science and Technology Committee Subcommittee on Critical and Strategic Mineral Supply Chains, and the Interagency Group on Helium-3 (He-3), which it leads and that reports to the White House National Security Staff. The DOE IP participates in the Certified Reference Material Working Group which ensures material availability for nuclear forensics applications that support national security missions and also the Nuclear Regulatory Commission Task Force on Radiation Source Protection and Security. As a service, the DOE IP collects demand and usage information on helium-4 from the federal complex and provides it to the Bureau of Land Management (BLM) so that BLM can optimize their plans for the helium-4 federal reserve.

The DOE IP supports innovative research to develop new or improved production and separation techniques for high priority isotopes in short supply.  Priorities in isotope production research are informed by guidance from NSAC as described in the 2015 Long Range Plan for the DOE IP published in July 2015 under the title "Meeting Isotope Needs and Capturing Opportunities for the Future[a]." Emphasis is placed on providing training opportunities to students and post-docs to help assure a vibrant workforce essential to the technologies associated with isotope production. The DOE IP also invests in the Nation's future nuclear chemistry and biomedical researchers through support for the Nuclear Chemistry Summer School (NCSS) program. The NCSS, jointly supported with SC's BES program, consists of an intensive six-week program of formal accredited lectures on the fundamentals of nuclear science, radiochemistry, and their applications in related fields, as well as laboratory practicums focusing on state-of-the-art instrumentation and technology used routinely in basic and applied nuclear science.

The DOE IP is the steward of the Isotope Production Facility (IPF) at LANL, the Brookhaven Linac Isotope Producer (BLIP) facility at BNL, the Enriched Stable Isotope Prototype Plant (ESIPP) at ORNL, and hot cell facilities for processing and handling irradiated materials and purified products at ORNL, BNL, and LANL. Funding provides mission readiness for isotope production at all of these facilities and the Low Energy Accelerator Facility (LEAF) at ANL. Isotope production is also supported at other sites, such as the High Flux Isotope Reactor (HFIR) at ORNL for the production of californium-252, actinium-227 and many other reactor-produced radioactive isotopes, the Idaho National Laboratory Advanced Test Reactor (ATR) for the production of cobalt-60, PNNL for processing and packaging strontium-90, the Y-12 National Security Complex for processing and packaging lithium-6 and lithium-7, the LANL Plutonium Facility for extracting americium-241 from NNSA plutonium processes, and the Savannah River Site for the extraction and distribution of He-3. The DOE IP also supports a network of university facilities for cost-effective production of unique isotopes for research and industry.

Because the U.S. inventory is limited or has even been depleted in the cases of some specific isotopes, the U.S. is dependent on foreign sources for supplies of certain stable isotopes. The DOE IP has developed and implemented modern stable isotope enrichment devices to provide the Nation with enrichment capabilities that were absent since the DOE calutrons ceased operation in 1998. The ESIPP operates at ORNL to produce research quantities of enriched stable isotopes using gas centrifuge and electromagnetic ion separation technology. The Stable Isotope Production Facility (SIPF) MIE adds additional gas centrifuge capability and the new Stable Isotope Production and Research Center (SIPRC) enables the establishment of multiple full scale production lines in each technology. These efforts mitigate U.S. dependence on foreign

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

supply. The DOE IP participates in the QIS initiative within SC, and develops stable isotope production capabilities for isotopes of interest to next generation quantum computers.

While the DOE IP is not responsible for the production of molybdenum-99 (Mo-99), 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, DOE IP also oversees proceedings of the NSAC in response to a charge to annually assess progress by NNSA toward ensuring a domestic supply of Mo-99. Additionally, DOE IP participates in the international High-Level Group on the Security of Supply of Medical Isotopes lead by the Organisation for Economic Co-operation and Development.

The mission of the DOE IP is facilitated by the National Isotope Development Center (NIDC), located at ORNL, which interfaces with the user community and manages business operations involved in the production, marketing, sale, and distribution of isotopes.

Research

The research activity has two primary components: (1) support of R&D via competitive funding opportunity announcements open to both universities and national laboratories, and (2) the provision of core R&D funding to national laboratories and universities with expert competencies in isotope production and processing to nurture that technical expertise and accomplish high priority R&D. In FY 2021, core R&D is increased to strengthen core competencies at LANL, BNL, ORNL, PNNL, the University of Washington, and most recently at ANL and Michigan State University. The Request will increase support for ANL, where the newest addition to the portfolio of accelerators resides – the LEAF accelerator. Years of research support from the DOE IP have enabled isotope production using photo-nuclear reactions at this high power electron linac, culminating in the recent announcement that the isotope copper-67 (a dual purpose diagnostic/therapeutic for cancer treatment) is now routinely available for clinical trials. Likewise, core R&D support is ramped up at Facility for Rare Isotope Beams (FRIB), where the laboratory is establishing capabilities to harvest isotopes. Efforts to create novel approaches to enable the provision of isotopes for targeted alpha therapy for cancer treatments and theragnostic isotopes (combined diagnostic and therapeutic applications) are enhanced at all sites. The DOE IP has become the world leader in the provision of alpha—emitting isotopes for cancer therapy.

Competitive R&D efforts are increased at universities and laboratories to support a myriad of activities focused on making novel and critical isotopes to the Nation for a suite of applications and research, and to develop pathways to promote U.S. independence in isotope supply. A high priority of the DOE IP remains the dedicated research effort to develop large scale production capabilities of actinium-225 (Ac-225), a high priority isotope that has shown stunning success in the treatment of diffuse cancers and infections; in the past, available quantities have limited clinical trials and applications. The DOE IP now routinely produces accelerator-produced Ac-225 and is ramping up research to develop efficient full-scale production and processing capabilities to enable sufficient supply of the isotope for cancer treatment. Research efforts have demonstrated that the accelerator produced Ac-225 functions equivalently to the material derived from the decay of thorium-229 which used to be the only viable source of small quantities of Ac-225. In coordination with NIH, samples of the isotope produced by the accelerator production approach were evaluated by several different researchers involved in medical applications research to confirm these results. The Request will increase funding for research to explore approaches for production of other isotopes for targeted alpha therapy and promising theragnostic isotopes.

Competitive research increases to continue ongoing and new efforts, including research to alleviate the current U.S. dependence on foreign sources of deuterium, which was last produced in the U.S. in 1981. Deuterium is used in the development, production, and sale of compounds used in chemistry, biomedical and diagnostic research, environmental analysis and physics. There are two pathways being investigated: (1) new and efficient production and (2) recovery of deuterium from heavy water. Research also addresses topics such as Li-7 enrichment for molton salt reactors, new sources of He-3 for cryogenics, critical nuclear data measurements, radioisotope enrichment technology, next generation targetry, and Np-236 production feasibility for nuclear forensics.

The DOE IP is developing renewed enrichment capability with both electromagnetic separators and gas centrifuges and is actively enriching isotopes. Research increases to enhance stable isotope enrichment capabilities as well as to enrich new isotopes. Every stable isotope enriched requires an independent research campaign. Current efforts focus on ytterbium-176 as feedstock for prostate cancer treatment, xenon-129 for polarized lung imaging, Mo-100 as feedstock for Mo-99 production, and isotopes of interest for quantum computing. In addition, as this technology tends to be dual-use; nurturing a core competency in this technology is vital to the Nation. R&D associated with purification and processing of the existing isotope inventory continues. Increased research also enables exploration of other enrichment technologies.

Operations

The Request will support personnel and infrastructure essential to ensure mission readiness for the production and processing of isotopes at a growing portfolio of production sites; the isotope production costs are paid by the customer. Operating and capital investments enable substantial and compelling enhancements to productivity or new production or processing capability, including recovery of valuable isotopes from legacy reactor targets (Mark 18A); development of enrichment capabilities for heavier stable isotopes; upgrades and operations of hot cell facilities at BNL, ORNL, LANL and universities to increase the quantity and reliability of radioisotope processing capabilities in order to support the growing demand for radioisotopes like Ac-225 and Lu-177; and infrastructure to support the fabrication and assembly of enrichment technology. In addition, funding will support implementation of Food and Drug Administration (FDA) regulatory requirements for production of isotopes used in FDA-approved pharmaceuticals. Efforts supported the development of a Drug Master File for the accelerator-produced material, submitted to the FDA in FY 2020, and efforts now look towards the development of other Drug Master Files. Mission readiness for reactor-produced actinium-227, the world's first source of new material, is enhanced. Actinium-227 decays to radium-223, which is used in new radiopharmaceutical drugs to treat prostate cancer. The provision of actinium-227 by the DOE IP ensures that prostate cancer patients can have a reliable supply of palliative care drugs.

The DOE IP is increasing funding for production and processing at universities with unique capabilities, such as the multi-particle clinical cyclotron at the University of Washington where full-scale production of astatine-211 was developed to support research into the use of the isotope in cancer therapy; and the University of Missouri Research Reactor which the DOE IP uses for the production of lutetium-177 for cancer therapy research, and selenium-75 for industrial gamma radiography. The establishment of a coordinated network of university-based isotope production was a recommendation in the 2015 NSAC-Isotope Long Range Plan. The network is designed to leverage the unique and often underutilized facilities available at academic institutions which are generally more suited to low-energy production reactions and can support nationwide availability of short-lived radioisotopes. Actions to include additional university sites in the network continue in FY 2021. The Request will increase funding to continue the addition of isotope harvesting at the FRIB.

DOE IP increases operations of ESIPP at ORNL to produce research quantities of enriched stable isotopes through the use of electromagnetic separation and centrifuge technology. The first campaign at ESIPP produced ruthenium-96 in FY 2018 to provide the otherwise unavailable world-wide target material to the RHIC for its planned physics program. ESIPP is now focused on production of Yb-176, currently only produced in Russia, needed for the production of Lu-177, which is used to treat prostate cancer. The DOE IP continues support for the development of production approaches for enriched stable isotopes of interest for future QIS-driven technologies.

The Request will provide funding for the DOE Isotope Initiative. Funding will be invested to explore and grow competence in stable isotope enrichment technologies beyond the current electromagnetic ion separation and gas centrifuge technologies to consider efficiencies in isotope production.

The SIPF MIE is adding additional gas centrifuge capability to the existing ESIPP; the last year of funding for SIPF was in FY 2020. No additional funding is required in FY 2021 for the SIPF MIE. Staff will participate in fabrication activities aiming towards a completion date of FY 2024. Developing modern enrichment technology is high-risk and challenging, and a phased approach in implementing technology is being pursued. Additional capabilities in both electromagnetic ion separation and gas centrifuge capability beyond SIPF and ESIPP are needed to meet the quickly rising demands of the Nation for enriched stable isotopes and fully mitigate U.S. dependence on foreign supply, and operate multiple production lines simultaneously. The Request will continue funding for the U.S. Stable Isotope Production and Research Center (U.S. SIPRC) project to meet those needs. Scientists and engineers are supported in FY 2020 to advance the Conceptual Design of U.S. SIPRC and prepare for CD-1. The Request will support staff to participate in design and long lead procurement activities for U.S. SIRPC.

**Activities and Explanation of Changes**

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes<br>FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| **Isotope Development and Production for Research and Applications** | **$49,500** | **$66,000** | **+$16,500** |
| Research | $11,500 | $22,000 | +$10,500 |
| Funding supports high priority competitive R&D activities at universities and national laboratories leading to new isotope production technologies. Support for core research groups at national laboratories and universities enhance isotope production capabilities specifically relevant to the physical resources and expertise available at the institution. Funding supports the development of two new core R&D groups, one at MSU to support the new isotope harvesting capability being established at FRIB, and the other at ANL to support the new isotope production effort at the LEAF electron facility at ANL. Research activities aimed at the development of production approaches for isotopes of interest to next-generation QIS systems continues. Research to develop enrichment capability for new isotopes of importance increases. | | The Request will support high impact R&D activities at universities and national laboratories leading to advanced and novel isotope production and processing technologies, to increase the availability of isotopes in short supply. Funding will increase for the new R&D groups at MSU for FRIB isotope harvesting, and at ANL to support the new isotope production effort at the LEAF. A priority of the research program will be to continue the development of full scale processing and technology for the production of alpha-emitters for cancer therapy, such as Ac-225. The Request will increase competitive R&D efforts at universities and laboratories to support a myriad of activities focused on making novel and critical isotopes to the Nation for a suite of applications and research, and to develop pathways to promote U.S. independence in isotope supply. The Request will also increase funding to expand theUniversity Isotope Network to perform the R&D necessary to enable routine production. Research activities aimed at the development of production approaches for isotopes of interest to next-generation QIS systems will continue. Research to develop enrichment capability for new isotopes of importance will increase. | The increase will support the strengthening of core research groups at national laboratories and universities to nurture unique core competencies and accomplish high priority R&D that addresses shortages of isotopes important to the nation. The increase also will establish research groups at the new production sites at ANL and MSU, and provides additional funding for research for enriched stable and radioisotope technology, such as therapeutic alpha-emitting isotopes like Ac-225. The increase also will provide additional funds for competitive R&D to consider new opportunities for improving or developing new and unique capabilities for isotope production and processing, enabling U.S. leadership in research and applications, such as discovery of new elements, forefront cancer treatments. Also, the increase provides additional funding for enriched stable isotope production R&D to enable new production campaigns of rare isotopes. |

(dollars in thousands)

| FY 2020 Enacted | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|
| Operations $38,000 | $44,000 | +$6,000 |
| Funding supports mission readiness of the isotope production facilities and nurtures critical core competencies in isotope production and development, ensuring that isotope orders for cancer therapy and other commitments are reliably met. The NIDC activities are increased to effectively interface with the growing stakeholder community and isotope portfolio. Funding expands operations of the University Isotope Production Network and ESIPP operations. Increased funding supports the development of production approaches for isotopes of interest for next generation QIS-driven technologies. Final funding is provided for the SIPF MIE, according to the planned profile. Investments support electromagnetic separation technology optimized to heavy elements, enriched radioisotope separation technology, modest upgrades at BLIP and the IPF for new capabilities, enhanced processing capabilities at universities and national laboratories, infrastructure for assembly and fabrication of stable enrichment components, and the initiation of isotope harvesting capabilities at FRIB. Other Project Costs for SIPRC are supported to advance the Conceptual Design and prepare for CD-1. | The Request will support mission readiness of the isotope production facilities and nurtures critical core competencies in isotope production and development, ensuring that isotope orders for cancer therapy and other commitments are reliably met. Core competencies in isotope production and development will grow to ensure that isotope orders for cancer therapy and other commitments are reliably met. Support will maintain NIDC activities to interface with the growing stakeholder community and rapidly expanding isotope portfolio. Production approaches for isotopes of interest for next generation QIS-driven technologies will be maintained. Funding will continue support of electromagnetic separation technology optimized to heavy elements, enriched radioisotope separation technology, modest upgrades at BLIP and the IPF for new capabilities, enhanced processing capabilities at universities and national laboratories, infrastructure for assembly and fabrication of stable enrichment components, and ramp up of funding for isotope harvesting capabilities at FRIB. The Request will support the DOE Isotope Initiative with a focus on creating core competencies in developing and operating a broad array of isotope enrichment technologies, critical for research and applications. | The funding increase will support the DOE Isotope Initiative, which in FY 2021, explores and grow competence in stable isotope enrichment technologies beyond the current electromagnetic ion separation and gas centrifuge technologies to consider efficiencies in isotope production. The increase also will support the implementation of isotope harvesting at FRIB. |

### Description

This subprogram supports all line-item construction for the entire NP program. All Total Estimated Costs (TEC) are funded in this subprogram, including engineering, design, and construction. Other Project Costs (OPC) are funded in the relevant subprograms.

Consistent with the 2015 NSAC Long-Range Plan's highest priority, the FY 2021 Request includes funding to capitalize on NP's prior scientific facilities investments. Funding provides for design and construction of scientific research facilities needed to meet overall objectives of the Nuclear Physics program. NP currently has two ongoing projects, which receive construction line item funding in FY 2021. In addition, the DOE IP, managed by NP, also continues a line item construction project in FY 2021.

The FRIB at MSU will continue construction activities in FY 2021, with a funding request aligned to the current baseline. FY 2021 is the final budget request for FRIB. The project is proceeding on track within the established project baseline. FRIB will provide intense beams of rare isotopes for world-leading research opportunities in nuclear structure, nuclear astrophysics, and fundamental symmetry studies that will advance knowledge of the origin of the elements and the evolution of the cosmos. It offers a facility for exploring the limits of nuclear existence and identifying new phenomena, with the possibility that a broadly applicable theory of the structure of nuclei will emerge. FRIB will provide an essential scientific tool for over 1,400 scientists each year from across academic, industrial, and government institutions. The project is funded through a cooperative agreement with MSU. The project has a baseline DOE Total Project Cost (TPC) of $635,500,000.

The FY 2021 Request continues the construction effort for the Electron-Ion Collider (EIC). Since the 2002 LRP for Nuclear Science was developed and released, a compelling, persistent, high scientific priority for the U.S. nuclear science community has been understanding how the fundamental properties of the proton, such as its mass and spin, are dynamically generated by the extraordinarily strong color fields resulting from dense systems of gluons in nucleons and nuclei. The answer to this question is key to addressing an outstanding grand challenge problem of modern physics: how QCD, the theory of the strong force, which explains all strongly interacting matter in terms of points like quarks interacting via the exchange of gluons, acts in detail to generate the "macroscopic" properties of protons and neutrons. The 2015 LRP for Nuclear Science concluded, "…a high energy, polarized electron ion collider is the highest priority for new facility construction..." A National Academies study, charged to independently assess the impact, uniqueness, and merit of the science that would be enabled by U.S. construction of an electron ion collider, gave a strong endorsement to a U.S.-based EIC, and recognized its critical role in maintaining U.S. leadership in nuclear science and accelerator R&D. Scientists and accelerator physicists from both the Medium Energy and Heavy Ion subprograms are actively engaged in the development of the scientific agenda, design of the facility and development of scientific instrumentation related to a proposed EIC. Critical Decision-0 (CD-0), Approve Mission Need, was received on December 19, 2019. The Department selected and announced Brookhaven National Laboratory (BNL) as the site for the EIC on January 9, 2020. The Rough Order of Magnitude Total Project Cost range for the EIC project at CD-0 approval was $1.6 billion to $4.2 billion, with an updated post-site selection cost range of $1.6 billion to $2.6 billion.

The FY 2021 Request will continue design efforts for the U.S. Stable Isotope Production and Research Center (U.S. SIPRC) and support long lead procurements. The demand for enriched stable isotopes continues to grow substantially. Demand drivers include enriched stables isotopes for medical, national security and fundamental research projects. DOE produced a legacy inventory of enriched stable isotopes using the former Y-12 plant Calutrons from the 1940s to 1990s, until they were decommissioned. DOE's supply of certain key enriched stable isotopes has been depleted, making the U.S. increasingly dependent on foreign imports for enriched stable isotopes. With support from the DOE IP, ORNL is advancing production capabilities for these stable isotopes, primarily electromagnetic isotope separation (EMIS) and gas centrifuge (GC) technologies. Electromagnetic isotope separators can separate isotopes for many elements to very high purity and at lower production rates while gas centrifuge production cascades can produce much larger quantities of isotopes but is limited to those isotopes that have compatible feedstock chemicals. The prototype capabilities of the Enriched Stable Isotope Prototype Plant (ESIPP), developed through DOE IP-supported research, demonstrated the feasibility of new EMIS and GC technology. The ongoing Stable Isotope Production Facility (SIPF) MIE modestly increases GC production capability. U.S.

SIPRC further expands GC production capability and significantly increases EMIS production capability to meet the Nation's growing demand for stable isotopes. SIPRC will mitigate the Nation's dependence on foreign countries for stable isotope supply. CD-0, Approve Mission Need, was received on January 4, 2019. The current Total Project Cost (TPC) point estimate is $229,000,000 with an updated preliminary TPC range of $175,000,000 to $298,000,000 in preparation for CD-1 consideration.

**Activities and Explanation of Changes**

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|
| **Construction** | **$53,000** | | **$18,300** | **-$34,700** |
| 20-SC-51, U.S. Stable Isotope Production and Research Center (ORNL) | $12,000 | | $12,000 | $— |
| Funding supports engineering design of the U.S. SIPRC and long lead procurements for known designs of technologies developed for prior efforts. | | The Request will support the continuation of engineering design of the U.S. SIPRC and long lead procurements, such as site preparations and materials for known designs of technologies developed under previous projects. | | Funding will support engineering design of the U.S. SIPRC project. |
| 20-SC-52, Electron Ion Collider (EIC) | $1,000 | | $1,000 | $— |
| Funding provides the first year of TEC funding for the EIC. The funds will be used for engineering and design to reduce technical risk after completion of the conceptual design. | | The Request will continue TEC funding for the EIC. The funds will be used for engineering and design to reduce technical risk after completion of the conceptual design. | | Funding will support ongoing engineering and design efforts. |
| 14-SC-50, Facility for Rare Isotope Beams (FRIB) | $40,000 | | $5,300 | -$34,700 |
| Funding continues to support the fabrication, assembly, and testing of cryomodules, as well as their installation within the FRIB linear accelerator located in the tunnel area. As portions of the linear accelerator nears completion, commissioning efforts will also continue in order to validate accelerator's performance according to project requirements. In addition, fabrication, assembly, installation and testing of the experimental technical systems will continue; project completion is planned in FY 2022. | | The Request will complete cryomodule installation, experimental systems installation, and testing. The funds will also continue commissioning efforts associated with technical components as they are completed. This is the final year of funding. Project completion is planned in FY 2022. | | Funding will support the final efforts necessary to complete the FRIB according to its performance baseline cost, schedule, and scope in FY 2022. |

**Nuclear Physics**
**Capital Summary**

(dollars in thousands)

| | Total | Prior Years | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|---|---|
| **Capital Operating Expenses** | | | | | | |
| Capital Equipment | N/A | N/A | 38,025 | 35,392 | 26,660 | -8,732 |
| Minor Construction Activities | | | | | | |
| General Plant Projects (GPP) | N/A | N/A | 2,060 | 9,616 | 2,143 | -7,473 |
| Accelerator Improvement Projects (AIP) | N/A | N/A | 5,077 | 7,268 | 8,783 | +1,515 |
| **Total, Capital Operating Expenses** | **N/A** | **N/A** | **45,162** | **52,276** | **37,586** | **-14,690** |

**Capital Equipment**

(dollars in thousands)

| | Total | Prior Years | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|---|---|
| **Capital Equipment** | | | | | | |
| Major Items of Equipment | | | | | | |
| *Heavy Ion Nuclear Physics* | | | | | | |
| Super-PHENIX (sPHENIX) MIE[a] | 27,000 | N/A | 5,310 | 9,520 | 3,000 | -6,520 |
| *Low Energy Nuclear Physics* | | | | | | |
| Gamma-Ray Energy Tracking Array (GRETA) MIE | 52,000-65,000[b] | 5,700 | 6,600 | 6,600 | 2,500 | -4,100 |
| High Rigidity Spectrometer (HRS)[c] | 80,000-90,000 | N/A | — | 1,000 | 1,000 | — |
| Ton-Scale Neutrinoless Double Beta Decay MIE | 215,000-250,000 | N/A | — | 1,000 | 1,440 | +440 |
| MOLLER MIE | 25,000-28,000 | N/A | — | 2,000 | 300 | -1,700 |

[a] sPHENIX MIE will be funded through existing operations funding which would typically be used to operate the previous version of the detector, PHENIX; no new funds are required. This MIE has been baselined. The impact of the Request will be assessed upon a FY 2021 Appropriation.
[b] Total Project Cost range at CD-3a Approval.
[c] HRS will be funded through a cooperative agreement with MSU and is not a capital asset. The HRS has CD-0 approval.

| | (dollars in thousands) | | | | | |
|---|---|---|---|---|---|---|
| | **Total** | **Prior Years** | **FY 2019 Enacted** | **FY 2020 Enacted** | **FY 2021 Request** | **FY 2021 Request vs FY 2020 Enacted** |
| *Isotope Development and Production for Research and Development* | | | | | | |
| Stable Isotope Production Facility (SIPF) MIE | 25,500-28,000 | 12,500 | 11,500 | 1,500 | — | -1,500 |
| Total, MIEs | N/A | 18,200 | 23,650 | 21,620 | 8,240 | -13,380 |
| Total, Non-MIE Capital Equipment | N/A | N/A | 14,375 | 13,772 | 18,420 | +4,648 |
| **Total Capital Equipment** | **N/A** | **N/A** | **38,025** | **35,392** | **26,660** | **-8,732** |

**Minor Construction Activities**

| | (dollars in thousands) | | | | | |
|---|---|---|---|---|---|---|
| | **Total** | **Prior Years** | **FY 2019 Enacted** | **FY 2020 Enacted** | **FY 2021 Request** | **FY 2021 Request vs FY 2020 Enacted** |
| **General Plant Projects (GPP)** | | | | | | |
| Greater than or equal to $5M and less than $20M | | | | | | |
| End Station Refrigerator at TJNAF | 9,500 | — | — | 9,500 | — | -9,500 |
| Total GPPs (greater than or equal to $5M and less than $20M) | 9,500 | — | — | 9,500 | — | -9,500 |
| Total GPPs less than $5M[a] | N/A | N/A | 2,060 | 116 | 2,143 | +2,027 |
| **Total, General Plant Projects (GPP)** | **N/A** | **N/A** | **2,060** | **9, 616** | **2,143** | **-7,473** |
| | | | | | | |
| **Accelerator Improvement Projects (AIP)** | | | | | | |
| Greater than or equal to $5M and less than $20M | | | | | | |
| RHIC Low Energy Electron Cooling | 8,321 | 8,321 | — | — | — | — |
| FRIB Isotope Harvesting[b] | 9,000-11,000 | N/A | — | 2,000 | 3,500 | +1,500 |
| Total, AIPs (greater than or equal to $5M and less than $20M) | N/A | N/A | — | 2,000 | 3,500 | +1,500 |
| Total, AIPs less than $5M | N/A | 3,652 | 5,077 | 5,268 | 5,283 | +15 |
| **Total, Accelerator Improvement Projects (AIP)** | **N/A** | **11,973** | **5,077** | **7,268** | **8,783** | **+1,515** |
| **Total, Minor Construction Activities** | **N/A** | **N/A** | **7,137** | **16,884** | **10,926** | **-5,958** |

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

## Nuclear Physics
## Major Items of Equipment Description(s)

Heavy Ion Nuclear Physics MIE:

*Super Pioneering High Energy Nuclear Interaction Experiment (sPHENIX)*

sPHENIX directly supports the NP mission by using precision, high rate jet measurements to further characterize the quark-gluon plasma (QGP) discovered at RHIC in order to understand the anomalous energy loss observed in the QGP. sPHENIX will enable scientists to study how the near perfect QGP liquid with the lowest shear viscosity ever observed arises from the strongly interacting quarks and gluons from which it is formed. CD-0 was approved September 13, 2016 and Project Decision (PD)-2/3, which approves the performance baseline and start of construction, was approved in September 19, 2019 with a TPC $27,000,000. This MIE is funded within the existing funds for RHIC operations. Operating funds that are typically used to maintain and operate the PHENIX detector will be used to upgrade the detector. No funding beyond that provided for existing RHIC operations is required. sPHENIX adds electron and hadron calorimeters to the existing silicon tracking capabilities and makes use of a recycled solenoid magnet for a cost effective upgrade. The FY 2021 Request for sPHENIX of $3,000,000 is the third year of TEC funding.

Low Energy Nuclear Physics: Nuclear Structure and Nuclear Astrophysics MIEs:

*Gamma-Ray Energy Tracking Array (GRETA)*

GRETA directly supports the NP mission by addressing the goal to understand the structure of nuclear matter, the processes of nuclear astrophysics, and the nature of the cosmos. A successful implementation of this detector will represent a major advance in gamma-ray tracking detector technology that will impact nuclear science, as well as detection techniques in homeland security and medicine. GRETA will provide unprecedented gains in detection sensitivity, addressing several high priority scientific topics, including how weak binding and extreme proton-to-neutron asymmetries affect nuclear properties and how the properties of nuclei evolve with changes in excitation energy and angular momentum. GRETA will provide transformational improvements in efficiency, peak-to-total ratio, and higher position resolution than the current generation of detector arrays. In particular, the capability of reconstructing the position of the interaction with millimeter resolution will fully exploit the physics opportunities of FRIB. Without GRETA, FRIB will rely on existing instrumentation. In that event, beam-times necessary for the proposed experiments will be expanded significantly, and some proposed experiments will not be feasible at all. CD-0 for GRETA was approved September 15, 2015 and CD-1 was obtained October 4, 2017. CD-3a, which approves long lead procurements, was obtained August 16, 2018 with an estimated TPC of $52,000,000 - $65,000,000. The FY 2021 Request for GRETA of $2,500,000 is the fifth year of TEC funding.

*High Rigidity Spectrometer (HRS)*

The HRS at FRIB will increase the scientific potential of state-of-the-art and community-priority devices, such as GRETA, and other ancillary detectors. FRIB will be the world's premier rare-isotope beam facility producing a majority (approximately 80 percent) of the isotopes predicted to exist. Eleven of the 17 NSAC Rare Isotope Beam Taskforce benchmarks, which were introduced to characterize the scientific research of a rare-isotope facility, require the use of fast beams at FRIB. The scientific impact of the FRIB fast beam science program will be substantially enhanced (by luminosity gain factors of between two and one hundred for neutron-rich isotopes, with the largest gains for the most neutron-rich species) by construction of the HRS. The HRS will allow experiments with beams of rare isotopes at the maximum production rates for fragmentation or in-flight fission. This enhancement in experimental sensitivity provides access to critical isotopes not available otherwise. The 2015 NSAC LRP recognized that the "HRS…will be essential to realize the scientific reach of FRIB." The HRS will be funded through a cooperative agreement with MSU and is not a capital asset. CD-0 was approved November 2018 with a TPC range of $80,000,000 - $90,000,000. CD-1 approval is planned in 4Q 2020. The FY 2021 Request for the HRS of $1,000,000 is the second year of funding.

Low Energy Nuclear Physics: Fundamental Symmetries MIEs:

*Ton-Scale Neutrino-less Double Beta Decay (NLDBD) Experiment*

The Ton-Scale NLDBD Experiment, implemented by instrumenting a large volume of a specially selected isotope to detect neutrino-less nuclear beta decays (where within a single nucleus, two neutrons decay into two protons and two electrons with no neutrinos emitted), directly supports NP's mission to explore all forms of nuclear matter. NLDBD can only occur if neutrinos are their own anti-particles and the observation of "lepton number violation" in such neutrino-less beta decay events would have profound consequences for present understanding of the physical universe. For example, one exciting prospect is that the observation of NLDBD would elucidate the mechanism, completely unknown at present, by which the mass of the neutrino is generated. The observation of lepton number violation would also have major implication for the present day matter/anti-matter asymmetry which has perplexed modern physics for decades. In the current experimental outlook, through FY 2018 a number of demonstrator efforts using smaller volumes of isotopes and various technologies (bolometry in tellurium dioxide (TeO2) crystals, light collection in LXe, charge collection in enriched germanium-76) have been in progress for several years, and all are in the process of delivering new state-of-the-art lifetime limits for neutrino-less double beta decay which are of order a few times 1025 years. The goal of a next generation ton-scale experiment is to reach a lifetime limit of 1028 years. For reference, the "lifetime limit" discussed is the time one might have to wait to observe neutrino-less double beta decay if observing a single nucleus only. Fortunately, in the ton of isotope planned for the ton-scale neutrino-less double beta decay experiment there are many trillions of nuclei. Thus, such decays, if they exist, should be observable on a much more reasonable timescale (five to ten years) similar to other large modern physics experiments. CD-0 was approved in November 2018 with a TPC range of $215,000,000 - $250,000,000. The FY 2021 Request of $1,440,000 is the second year of TEC funding.

*Measurement of a Lepton-Lepton Electroweak Reaction (MOLLER)*
The MOLLER experiment directly supports the NP mission by measuring the parity-violating asymmetry in polarized electron-electron (Møller) scattering. This extremely small asymmetry is predicted to be on the order of 35 parts per billion (ppb), which requires unprecedented experimental techniques employed for this experiment. CD-0 was approved December 2016 with an estimated Total Project Cost of $25,000,000 to $35,000,000. The proposed MOLLER experiment is an ultra-precise measurement of the weak mixing angle using Møller scattering which will improve on existing measurements by a factor of five, yielding the most precise measurement of the weak mixing angle at low or high energy anticipated over the next decade. This new result would be sensitive to the interference of the electromagnetic amplitude with new neutral current amplitudes as weak as approximately $10^{-3}$ $G_F$ (Fermi Factor) from as yet undiscovered dynamics beyond the Standard Model. The resulting discovery reach is unmatched by any proposed experiment measuring a flavor- and CP-conserving process over the next decade, and yields a unique window to new physics at MeV and multi-TeV scales, complementary to direct searches at high energy colliders such as the Large Hadron Collider (LHC). The MOLLER MIE, which was initiated in the Medium Energy subprogram prior to the establishment of a targeted portfolio in Fundamental Symmetries, transitions to the Low Energy subprogram in the FY 2021 Request. The FY 2021 Request for MOLLER of $300,000 is the second year of TEC funding.

Isotope Development and Production for Research and Applications MIE:
*Stable Isotope Production Facility (SIPF)*
SIPF will enhance production capability of stable enriched isotopes to the kilogram throughput to help mitigate the dependence of the U.S. on foreign suppliers and better meet the high demands for enriched stable isotopes for the Nation. This MIE will provide infrastructure and optimized centrifuge capability for isotopes of interest. Fabrication continues until the project's planned completion in FY 2024. There is a high demand for a domestic capability to produce enriched stable isotopes for basic research, medical and industrial applications. For example, foreign NLDBD 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 molybdemnum-99 (Mo-99), a critical medical isotope for cardiac imaging, which is being supported by NNSA, relies on a feedstock of enriched Mo isotopes, which are also not available domestically. Stable isotopic nuclides of heavier elements are used for agricultural, nutritional, industrial, ecological and computing applications could also be produced. CD-1/3a was approved in May 2018 with an estimated TPC range of $25,500,000-$28,000,000. No funding is requested for this MIE in FY 2021, as final funding was requested and provided in FY 2020. Fabrication continues until the project's planned completion in FY 2024. No funding is requested for this MIE in FY 2021, as final funding was requested and provided in FY 2020.

**Nuclear Physics**
**Construction Projects Summary**

(dollars in thousands)

| | Total | Prior Years | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|---|---|
| **14-SC-50, Facility for Rare Isotope Beams** | | | | | | |
| TEC | 635,500[a] | 514,700[b] | 75,000 | 40,000 | 5,300 | -34,700 |
| OPC | — | — | — | — | — | — |
| **TPC** | **635,500** | **514,700** | **75,000** | **40,000** | **5,300** | **-34,700** |
| **20-SC-51, U.S. Stable Isotope Production and Research Center** | | | | | | |
| TEC | 175,000-298,000 | — | — | 12,000 | 12,000 | — |
| OPC | — | — | 500 | 2,100 | — | -2,100 |
| **TPC** | **175,000-298,000** | **—** | **500** | **14,100** | **12,000** | **-2,100** |
| **20-SC-52, Electron Ion Collider[c]** | | | | | | |
| TEC | TBD | — | — | 1,000 | 1,000 | — |
| OPC | — | — | — | 10,000 | 1,500 | -8,500 |
| **TPC** | **TBD** | **—** | **—** | **11,000** | **2,500** | **-8,500** |
| **Total, Construction** | | | | | | |
| **TEC** | **TBD** | **TBD** | **75,000** | **53,000** | **18,300** | **-34,700** |
| **OPC** | **TBD** | **TBD** | **500** | **12,100** | **1,500** | **-10,600** |
| **TPC** | **TBD** | **TBD** | **75,500** | **65,100** | **19,800** | **-45,300** |

[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] The preliminary TPC at CD-0 approval was $1.6 billion to $4.2 billion. On January 9, 2020, DOE selected Brookhaven National Laboratory as the location for the EIC. This selection establishes a new cost range of $1.6 billion to $2.6 billion for the EIC.

## Nuclear Physics
## Funding Summary

| | (dollars in thousands) | | | |
|---|---|---|---|---|
| | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
| Research | 209,705 | 202,575 | 197,880 | -4,695 |
| Facility Operations | 357,521 | 399,380 | 405,169 | +5,789 |
| Projects | | | | |
| Major Items of Equipment | 23,760 | 21,620 | 8,240 | -13,380 |
| Construction | 75,500 | 65,100 | 19,800 | -45,300 |
| Total, Projects | 99,260 | 86,720 | 28,040 | -58,680 |
| Other | 23,514 | 24,325 | 22,238 | -2,087 |
| **Total, Nuclear Physics** | **690,000** | **713,000** | **653,327** | **-59,673** |

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 for TYPE A facilities:**

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

Planned Operating Hours –

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

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

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

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

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

(dollars in thousands)

| | FY 2019 Enacted | FY 2019 Current | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|---|
| **TYPE A FACILITIES** | | | | | |
| **CEBAF (TJNAF)**[a] | **$128,067** | **$131,269** | **$133,907** | **$128,409** | **-$5,498** |
| Number of users | 1,690 | 1,690 | 1,690 | 1,560 | -130 |
| Achieved operating hours | N/A | 4,362 | N/A | N/A | N/A |
| Planned operating hours | 4,080 | 4,080 | 2,560 | 3,010 | +450 |
| Optimal hours | 4,250 | 4,250 | 2,560 | 4,430 | +1,870 |
| Percent optimal hours | 96.0% | 102.6% | 100.0% | 67.9% | -32.1% |
| Unscheduled downtime hours | N/A | — | N/A | N/A | N/A |

[a] During FY 2017, the planned operating hours and optimal hours include 330 hours of operations (commissioning) that are supported from 12 GeV CEBAF Upgrade OPC funding, or pre-ops, that are part of the project TPC. FY 2018 is the first year of operations after project completion; optimal hours increase in FY 2018 and FY 2019 as operational experience is gained.

| | FY 2019 Enacted | FY 2019 Current | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|---|
| | (dollars in thousands) | | | | |
| **RHIC (BNL)** | **$199,705** | **$198,833** | **$203,323** | **$201,044** | **-2,279** |
| Number of users | 990 | 990 | 990 | 990 | — |
| Achieved operating hours | N/A | 3,798 | N/A | N/A | N/A |
| Planned operating hours | 3,290 | 3,290 | 3,260 | 2,580 | -680 |
| Optimal hours | 3,700 | 3,700 | 3,700 | 2,580 | -1,120 |
| Percent optimal hours[a] | 88.9% | 102.6% | 88.1% | 100.0% | +11.9% |
| Unscheduled downtime hours | N/A | — | N/A | N/A | N/A |
| **ATLAS (ANL)** | **$25,947** | **$26,638** | **$25,846** | **$23,077** | **-$2,769** |
| Number of users | 310 | 310 | 340 | 300 | -40 |
| Achieved operating hours | N/A | 6,775 | N/A | N/A | N/A |
| Planned operating hours | 6,400 | 6,400 | 5,950 | 2,980 | -2,970 |
| Optimal hours | 6,800 | 6,800 | 6,400 | 6,800 | +400 |
| Percent optimal hours | 94.1% | 99.6% | 93.0% | 43.8% | -49.1% |
| Unscheduled downtime hours | N/A | — | N/A | N/A | N/A |
| **FRIB (MSU)** | **$3,950** | **$3,950** | **$28,500** | **$25,620** | **-$2,880** |
| Number of users | N/A | N/A | N/A | N/A | N/A |
| Achieved operating hours | N/A | N/A | N/A | N/A | N/A |
| Planned operating hours | N/A | N/A | N/A | N/A | N/A |
| Optimal hours | N/A | N/A | N/A | N/A | N/A |
| Percent optimal hours | N/A | N/A | N/A | N/A | N/A |
| Unscheduled downtime hours | N/A | N/A | N/A | N/A | N/A |

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

(dollars in thousands)

| | FY 2019 Enacted | FY 2019 Current | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|---|
| **Total Facilities** | **$357,669** | **$360,690** | **$391,576** | **$378,150** | **-$13,426** |
| Number of users | 2,990 | 2,990 | 3,020 | 2,850 | -170 |
| Achieved operating hours | N/A | 14,935 | N/A | — | — |
| Planned operating hours | 13,770 | 13,770 | 11,770 | 8,570 | -3,200 |
| Optimal hours | 14,750 | 14,750 | 12,660 | 13,060 | -400 |
| Percent optimal hours[a] | 91.9% | 102.4% | 92.8% | 84.6% | -8.2% |
| Unscheduled downtime hours | N/A | — | N/A | N/A | N/A |

**Nuclear Physics**
**Scientific Employment**

| | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|
| Number of permanent Ph.D.'s (FTEs) | 830 | 839 | 821 | -18 |
| Number of postdoctoral associates (FTEs) | 350 | 326 | 319 | -7 |
| Number of graduate students (FTEs) | 550 | 530 | 481 | -49 |
| Other scientific employment (FTEs)[b] | 1,060 | 1,030 | 964 | -66 |

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

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

**20-SC-51, United States Stable Isotope Production and Research Center (U.S. SIPRC)**
**Oak Ridge National Laboratory, Oak Ridge, Tennessee**
**Project is for Design and Construction**

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


**Summary**
The FY 2021 request for the United States Stable Isotope Production and Research Center (U.S. SIPRC) is $12,000,000 of TEC funding. The current Total Project Cost (TPC) point estimate is $229,000,000 with an updated preliminary TPC range of $175,000,000 to $298,000,000 in preparation for CD-1 consideration.


**Significant Changes**
This project data sheet (PDS) is an update of the FY 2020 PDS; the project is not a new start in FY 2021. The most recent DOE O 413.3B approved Critical Decision (CD) is CD-0, Approve Mission Need, which was approved on January 4, 2019. FY 2021 funding will continue support for project engineering and design activities and planned long lead procurements, such as site preparations and materials for known designs of technologies developed under previous projects. The prior projects referenced include the completed Enriched Stable Isotope Production Prototype (ESIPP) and the ongoing Stable Isotope Production Facility (SIPF) Major Item of Equipment.

A Federal Project Director (FPD) with certification level 3 has been assigned to the U.S. SIPRC.

**Critical Milestone History**

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | D&D Complete | CD-4 |
|---|---|---|---|---|---|---|---|---|
| FY 2020[a] | 1/04/19 | 2Q FY 2020 | 2Q FY 2020 | 2Q FY 2021 | TBD | 2Q FY 2022 | N/A | 4Q FY 2026 |
| FY 2021[b] | 1/04/19 | 4Q FY 2020 | 4Q FY 2020 | 3Q FY 2022 | 2Q FY 2022 | 3Q FY 2022 | N/A | 4Q FY 2027 |

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

| Fiscal Year | Performance Baseline Validation | CD-3A |
|---|---|---|
| FY 2021 | 3Q FY2022 | 4Q FY 2020 |

**CD-3A** – Approve Long-Lead Procurements, (Site preparations, EMIS components)

[a] Dates presented in FY 2020 are pre-CD-1 and are notional.
[b] The project does not have CD-1 or CD-2 approval. The schedules are only estimates and are consistent with the high end of the schedule ranges.

**Project Cost History**

This project is at CD-0 with an updated point estimate of $229,000,000 and Total Project Cost (TPC) range of $175,000,000 to $298,000,000. The point estimate increased as the footprint of the building increased to accommodate the evolving conceptual design of the gas centrifuges. The table below reflects the upper cost of the TPC range as there is not yet a baseline. No construction, excluding for approved long lead procurement, will be performed until the project performance baseline has been validated and CD-3 has been approved.

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC, Except D&D | OPC, D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|---|
| FY 2020 | TBD | TBD | TBD | TBD | TBD | TBD | TBD |
| FY 2021[a] | 14,000 | 274,000 | 288,000 | 10,000 | N/A | 10,000 | 298,000 |

## 2. Project Scope and Justification

**Scope**

The scope of this project includes design and construction of a building and associated instrumentation for enriching isotopes. Electromagnetic isotope separator systems and gas centrifuge cascades will be designed and implemented in this new single facility to promote operational, cost and security effectiveness, with space for future growth. The planned facility will include adequate space for test stands and prototype development and will be a purely technical facility (i.e., minimal office and staff amenities), and located on the ORNL main campus. Gas centrifuges and electromagnetic separators are leveraged by existing designs developed from prior projects and R&D supported by DOE IP. The laboratory is considering the optimal number of each type of technology as part of the alternatives analysis for Critical Decision-1 (CD-1).

**Justification**

U.S. SIPRC is critical to the DOE Isotope Program within SC's Office of Nuclear Physics (NP). The facility will expand the stable isotope production capability to address multiple production capabilities to meet the demand of the nation, while also mitigating our Nation's dependencies on foreign suppliers for critical isotopes. The current capacity within the United States is insufficient to meet the Nation's growing demands, and is spread out geographically at ORNL in smaller buildings, which increases operating complexity, operating costs, and complicates security protection strategies. U.S. SIPRC will provide an adequately sized building and consolidated approach to address our Nation's isotope needs in a more economical and operational efficient manner.

U.S. SIPRC will expand current production capabilities for enriched stable isotopes and provide a new building that will facilitate efficient operations and provide space, not only for all of the current needs, but will also accommodate the projected large-scale expansion of production systems.

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

[a] The project does not have CD-1 or CD-2 approval. The schedules and costs are only estimates and are consistent with the high end of the schedule and cost ranges.

Key Performance Parameters (KPPs)[a]

Preliminary Key Performance Parameters (KPPs) are defined at CD-1 and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| TBD | TBD | TBD |

**3. Funding Schedule**

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Estimated Cost (TEC)[b]** | | | |
| PED | | | |
| FY 2020 | 12,000 | 12,000 | 2,700 |
| FY 2021 | 2,000 | 2,000 | 11,300 |
| Outyears | — | — | — |
| Total, PED | 14,000 | 14,000 | 14,000 |
| Construction | | | |
| FY 2020 | — | — | — |
| FY 2021 | 10,000 | 10,000 | 8,000 |
| Outyears | N/A | N/A | 266,000 |
| Total, Construction | N/A | N/A | 274,000 |
| Total Estimated Cost (TEC) | | | |
| FY 2020 | 12,000 | 12,000 | 2,700 |
| FY 2021 | 12,000[c] | 12,000 | 19,300 |
| Outyears | 264,000 | 264,000 | 266,000 |
| **Total, TEC** | **288,000** | **288,000** | **288,000** |
| **Other Project Cost (OPC)** | | | |
| OPC except D&D | | | |
| FY 2019 | 500 | 500 | 171 |
| FY 2020 | 2,100 | 2,100 | 2,429 |
| FY 2021 | — | — | — |
| Outyears | 7,400 | 7,400 | 7,400 |
| **Total, OPC** | **10,000** | **10,000** | **10,000** |

[a] The project does not have CD-1 approval. Preliminary KPPs are defined at CD-1. CD-1 is planned for 2020.

[b] The project does not have CD-1 or CD-2 approval. The schedules and costs are only estimates and are consistent with the high end of the schedule and cost ranges.

[c] Includes an estimated $10,000,000 for long lead procurements associated with site preparations and EMIS components.

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Project Cost (TPC)** | | | |
| FY 2019 | 500 | 500 | 171 |
| FY 2020 | 14,100 | 14,100 | 5,129 |
| FY 2021 | 12,000 | 12,000 | 19,300 |
| Outyears | 271,400 | 271,400 | 273,400 |
| **Total, TPC[a]** | **298,000** | **298,000** | **298,000** |

**4. Details of Project Cost Estimate**

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| Design | 12,000 | 11,700[b] | N/A |
| Contingency | 2,000 | 2,000 | N/A |
| Total, Design | 14,000 | 13,700 | N/A |
| Construction | | | |
| Construction | 210,000 | TBD | N/A |
| Contingency | 64,000 | TBD | N/A |
| Total, Construction | 274,000 | TBD | N/A |
| **Total, TEC** | **288,000** | **13,700** | **N/A** |
| *Contingency, TEC* | *66,000* | *2,000* | *N/A* |
| **Other Project Cost (OPC)** | | | |
| OPC except D&D | | | |
| R&D | — | TBD | N/A |
| Conceptual Design | 2,600 | 500 | N/A |
| Start-up | 5,000 | TBD | N/A |
| Contingency | 2,400 | TBD | N/A |
| **Total, OPC** | **10,000** | **TBD** | **N/A** |
| *Contingency, OPC* | *2,400* | *TBD* | *N/A* |
| **Total Project Cost[a]** | **298,000** | **TBD** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***68,400*** | ***TBD*** | ***N/A*** |

[a] The project does not have CD-1 or CD-2 approval. The schedules and costs are only estimates and are consistent with the high end of the schedule and cost ranges.
[b] The "Previous Total Estimate" of $5,000 for Design in the FY 2020 submitted PDS represented only the value requested in that year, not the total estimate.

### 5. Schedule of Appropriations Requests[a]

(dollars in thousands)

| Request Year | Type | Prior Years | FY 2019 | FY 2020 | FY 2021 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| FY 2020 | TEC | — | — | 5,000 | — | — | TBD |
| | OPC | — | 500 | — | — | — | TBD |
| | TPC | — | 500 | — | — | — | TBD |
| FY 2021 | TEC | — | — | 12,000 | 12,000 | 264,000 | 288,000 |
| | OPC | — | 500 | 2,100 | — | 7,400 | 10,000 |
| | TPC | — | 500 | 14,100 | 12,000 | 271,400 | 298,000[a] |

### 6. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy[a] | 4Q FY 2027 |
| Expected Useful Life | — |
| Expected Future Start of D&D of this capital asset | — |

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | Previous Total Estimate | Current Total Estimate | Previous Total Estimate | Current Total Estimate |
| Operations | N/A | — | N/A | — |
| Utilities | N/A | — | N/A | — |
| Maintenance and Repair | N/A | — | N/A | — |
| Total, Operations and Maintenance | N/A | — | N/A | — |

### 7. D&D Information

| | Square Feet |
|---|---|
| Area of new construction | 43,000 |
| Area of existing facility(ies) being replaced | N/A |
| Area of any additional D&D space to meet the “one-for-one” requirement | N/A |

The new area being constructed in this project is not replacing existing facilities. Any existing space that is freed up from consolidating activities into SIPRC will likely be repurposed.

[a] This project does not yet have CD-1 approval. CD-1 approval is scheduled for FY 2020. Section 6 will be filled out in the next budget cycle, after CD-1 approval.

**8. Acquisition Approach**

The acquisition approach will be approved with CD-1 approval, anticipated to be in FY 2020. ORNL will manage all acquisitions with appropriate DOE oversight. DOE and ORNL will monitor cost, schedule, and technical performance using an earned-value process consistent with DOE O 413.3B, *Program and Project Management for the Acquisition of Capital Assets*. ORNL will construct the building and production machines, including the acquisition of specialty equipment.

**20-SC-52, Electron-Ion Collider (EIC)**
**Brookhaven National Laboratory**
**Project is for Design**

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

**Summary**

The FY 2021 Request for the Electron-Ion Collider is $2,500,000 in Total Project Cost (TPC) funding. DOE O 413.3B Critical Decision (CD)-0, Approve Mission Need, was received on December 19, 2019. The preliminary TPC at CD-0 approval was $1.6 billion to $4.2 billion. On January 9, 2020, DOE selected Brookhaven National Laboratory as the location for the EIC. This selection establishes a new cost range of $1.6 billion to $2.6 billion for the EIC.

**Significant Changes**

The EIC was initiated in the FY 2020 Enacted Appropriation. This initial construction project data sheet for FY 2021 funding does not represent a new start for the budget year.

Of the $2,500,000 TPC funding requested in FY 2021, $1,500,000 will continue to support the conceptual design and research and development efforts funded under Other Project Costs. The remaining $1,000,000 of Total Estimated Costs will support engineering and design efforts.

A Federal Project Director (FPD) will be assigned by CD-1.

**Critical Milestone History**

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | D&D Complete | CD-4 |
|---|---|---|---|---|---|---|---|---|
| FY 2021[a] | 12/19/19 | 4Q FY 2021 | 4Q FY 2021 | 4Q FY 2023 | 4Q FY 2024 | 4Q FY 2024 | N/A | 4Q FY 2032 |

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

| Fiscal Year | Performance Baseline Validation | CD-3A | CD-3B |
|---|---|---|---|
| FY 2021 | 4Q 2023 | TBD | N/A |

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

[a] The project is pre-CD-2; therefore, funding and schedule estimates are preliminary.

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC, Except D&D | OPC, D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|---|
| FY 2020 | TBD | TBD | TBD | TBD | TBD | TBD | TBD |
| FY 2021[a] | 340,000 | 2,010,000 | 2,350,000 | 250,000 | N/A | 250,000 | 2,600,000 |

The preliminary TPC at CD-0 approval was $1.6 billion to $4.2 billion. On January 9, 2020, DOE selected Brookhaven National Laboratory as the location for the EIC. This selection establishes a new cost range of $1.6 billion to $2.6 billion for the EIC. The project does not have CD-1 or CD-2 approval. The schedules and costs are only estimates and are consistent with the high end of the schedule and cost ranges.

**2. Project Scope and Justification**

**Scope**

The scope of this project includes the key EIC machine parameters required to address the scientific agenda listed in the 2015 Nuclear Science Advisory Committee (NSAC) Long Range Plans (LRP). These parameters include a high degree of beam polarization (approximately 70 percent) for electrons and light ions, availability of ion beams from deuterons to the heaviest stable nuclei, variable center of mass energies about 20–100 GeV, upgradable to about 140 GeV (e-p), high collision luminosity about $10^{33\text{-}34}$ $cm^{-2}s^{-1}$, and possibly more than one interaction region. The scope will also include the ancillary facilities, such as power and cryoplants, necessary to support the operations of the EIC.

**Justification**

The last three NSAC LRP reports have supported the EIC with recommendations ranging from investing in accelerator research and development (R&D) in the 2002 NSAC LRP, to reducing technical risks in the 2007 NSAC LRP, to the actual construction of a U.S.-based EIC in the 2015 NSAC LRP. Specifically, the 2015 NSAC LRP for Nuclear Science recommended a high-energy, high-luminosity polarized EIC as the highest priority for new facility construction following the completion of FRIB. Consistent with that vision, in 2016 NP commissioned a National Academies of Sciences (NAS) study by an independent panel of external experts to assess the uniqueness and scientific merit of such a facility. The report, released in July 2018, strongly supports the scientific case for building a U.S.-based EIC, documenting that an EIC will advance the understanding of the origins of nucleon mass, the origin of the spin properties of nucleons, and the behavior of gluons.

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)[b]

Preliminary Key Performance Parameters (IPPs) are defined at CD-1 and may change as the project continues towards CD-2. At CD-2 approval, the KPPs are baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| TBD | TBD | TBD |

[a] The project does not have CD-1 or CD-2 approval. The schedules and costs are only estimates and are consistent with the high end of the schedule and cost ranges.

[b] The project does not have CD-1 approval. Preliminary KPPs are defined at CD-1. CD-1 is planned for 2021.

### 3. Financial Schedule[a]

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| FY 2020 | 1,000 | 1,000 | — |
| FY 2021 | 1,000 | 1,000 | 1,750 |
| Outyears | 338,000 | 338,000 | 338,250 |
| Total, Design[b] | 340,000 | 340,000 | 340,000 |
| Construction | | | |
| FY 2020 | — | — | — |
| FY 2021 | — | — | — |
| Outyears | 2,010,000 | 2,010,000 | 2,010,000 |
| Total, Construction[b] | 2,010,000 | 2,010,000 | 2,010,000 |
| Total Estimated Costs (TEC) | | | |
| FY 2020 | 1,000 | 1,000 | — |
| FY 2021 | 1,000 | 1,000 | 1,750 |
| Outyears | 2,348,000 | 2,348,000 | 2,348,250 |
| **Total, TEC[b]** | **2,350,000** | **2,350,000** | **2,350,000** |
| **Other Project Costs (OPC)** | | | |
| FY 2020 | 10,000 | 10,000 | 9,500 |
| FY 2021 | 1,500 | 1,500 | 2,000 |
| Outyears | 238,500 | 238,500 | 238,500 |
| **Total, OPC[b]** | **250,000** | **250,000** | **250,000** |
| **Total Project Costs (TPC)** | | | |
| FY 2020 | 11,000 | 11,000 | 9,500 |
| FY 2021 | 2,500 | 2,500 | 3,750 |
| Outyears | 2,586,500 | 2,586,500 | 2,586,750 |
| **Total, TPC[b]** | **2,600,000** | **2,600,000** | **2,600,000** |

[a] This project is at the CD-0 stage. Dollars presented are through current budget request only. An estimated financial schedule will be provided in the FY 2022 President's Request.

[b] The project does not have CD-1 or CD-2 approval. The schedules are costs are only estimates and are consistent with the high end of the schedule and cost ranges.

## 4. Details of Project Cost Estimate[a]

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| Design | 250,000 | N/A | N/A |
| Contingency | 90,000 | N/A | N/A |
| Total, Design | 340,000 | N/A | N/A |
| Construction | | | |
| Construction | 1,490,000 | N/A | N/A |
| Contingency | 520,000 | N/A | N/A |
| Total, Construction | 2,010,000 | N/A | N/A |
| **Total, TEC** | **2,350,000** | **N/A** | **N/A** |
| *Contingency, TEC* | 610,000 | N/A | N/A |
| **Other Project Cost (OPC)** | | | |
| OPC except D&D | | | |
| R&D | 30.000 | N/A | — |
| Conceptual Design | 40,000 | N/A | N/A |
| Other OPC Costs | 115,000 | N/A | N/A |
| Contingency | 65,000 | N/A | N/A |
| **Total, OPC** | **250,000** | **N/A** | **N/A** |
| *Contingency, OPC* | 65,000 | N/A | — |
| **Total Project Cost[a]** | **2,600,000** | **TBD** | **TBD** |
| ***Total, Contingency (TEC+OPC)*** | **675,000** | **TBD** | **TBD** |

## 5. Schedule of Appropriations Requests[b]

(dollars in thousands)

| Request Year | Type | Prior Years | FY 2019 | FY 2020 | FY 2021 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| FY 2021 | TEC | — | — | 1,000 | 1,000 | — | — |
| | OPC | — | — | 10,000 | 1,500 | — | — |
| | TPC | — | — | 11,000 | 2,500 | — | — |

[a] This project does not have CD-1 or CD-2 approval. The schedules and costs are only estimates and are consistent with the high end of the schedule and cost ranges.
[b] This project is at the CD-0 stage. Dollars presented are through current budget request only. Estimated values for the schedule of appropriation requests will be provided in the FY 2022 President's Request.

## 6. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 4Q FY 2032 |
| Expected Useful Life | TBD |
| Expected Future Start of D&D of this capital asset | TBD |

Related Funding Requirements
(dollars in thousands)

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

## 7. D&D Information

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

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

## 8. Acquisition Approach

The acquisition approach will be approved with CD-1, anticipated to be in FY 2020. Brookhaven National Laboratory has been selected as the site. It will manage all acquisitions with appropriate Department of Energy oversight, and monitor cost, schedule, and technical performance with DOE using an earned-value process consistent with DOE O 413.3B, *Program and Project Management for the Acquisition of Capital Assets*.

**14-SC-50, Facility for Rare Isotope Beams (FRIB)**
**Michigan State University (MSU), East Lansing, MI**
**Project is for a Cooperative Agreement**

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

**Summary**

The FY 2021 Request for the Facility for Rare Isotope Beams (FRIB) project is $5,300,000. The Total Project Cost (TPC) at CD-3B approval is $635,500,000, with a scheduled CD-4 by 3Q FY 2022. Michigan State University (MSU) is providing an additional cost share of $94,500,000, bringing the total project cost to $730,000,000.

**Significant Changes**

This PDS is an update of the FY 2020 PDS and does not include a new start for FY 2021. The most recent Critical Decision (CD) for the FRIB project is CD-3B, Approve Start of Technical Construction of the Accelerator and Experimental Systems, which was approved on August 26, 2014.

Start of civil construction officially began in March 2014, and technical construction began in August 2014. Since the start of the civil and technical construction, multiple independent project assessments, the most recent being in May 2019, have determined the project is proceeding on track and within the established project baseline. There are no changes in the project's scope since the establishment of the project's baseline. The Request will complete installation and testing of cryomodules and experimental systems, as well as commissioning efforts associated with technical components as they are completed.

FRIB is funded through a cooperative agreement financial assistance award with MSU per 2 CFR 200, and the project is required by this agreement to follow the principles of the DOE Order 413.3B. Funding tables contained in sections 3 and 4 of this PDS differ slightly from a traditional PDS for a federal capital asset construction project for how the baseline is presented in that they include the MSU cost share. The table in section 5, Schedule of Appropriations Requests, displays only DOE funding.

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

**Critical Milestone History**

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3A | CD-3B | D&D Complete | CD-4 |
|---|---|---|---|---|---|---|---|---|---|
| FY 2011 | 2/09/04 | | 4Q FY 2010 | TBD | TBD | TBD | TBD | N/A | FY 2017-2019 |
| FY 2012 | 2/09/04 | | 9/01/10 | 4Q FY 2012 | TBD | TBD | TBD | N/A | FY 2018-2020 |
| FY 2013 | 2/09/04 | | 9/01/10 | TBD | TBD | TBD | TBD | N/A | TBD |
| FY 2014 | 2/09/04 | | 9/01/10 | 3Q FY 2013 | TBD | 3Q FY 2013 | TBD | N/A | TBD |
| FY 2015 | 2/09/04 | | 9/01/10 | 8/01/13 | 4Q FY 2014 | 8/01/13 | 4Q FY 2014 | N/A | 3Q FY 2022 |

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3A | CD-3B | D&D Complete | CD-4 |
|---|---|---|---|---|---|---|---|---|---|
| FY 2016 | 2/09/04 | 9/01/10 | 9/01/10 | 8/01/13 | 8/26/14[a] | 8/01/13 | 8/26/14 | N/A | 3Q FY 2022 |
| FY 2017 | 2/09/04 | 9/01/10 | 9/01/10 | 8/01/13 | 8/26/14[a] | 8/01/13 | 8/26/14 | N/A | 3Q FY 2022 |
| FY 2018 | 2/09/04 | 9/01/10 | 9/01/10 | 8/01/13 | 8/26/14 | 8/01/13 | 8/26/14 | N/A | 3Q FY 2022 |
| FY 2019 | 2/09/04 | 9/01/10 | 9/01/10 | 8/01/13 | 8/26/14 | 8/01/13 | 8/26/14 | N/A | 3Q FY 2022 |
| FY 2020 | 2/09/04 | 9/01/10 | 9/01/10 | 8/01/13 | 8/26/14 | 8/01/13 | 8/26/14 | N/A | 3Q FY 2022 |
| FY 2021 | 2/09/04 | 9/01/10 | 9/01/10 | 8/01/13 | 8/26/14 | 8/01/13 | 8/26/14 | 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 Alternative Selection and Cost Range
**CD-2** – Approve Performance Baseline
**Final Design Complete** – Estimated/Actual date the project design will be/was complete (d)
**CD-3** – Approve Start of Construction
**CD-3A** – Approve Long-Lead Procurements, Original Scope
**CD-3B** – Approve Long-Lead Procurements, Revised Scope
**D&D Complete** – Completion of D&D work
**CD-4** – Approve Start of Operations or Project Closeout

**Project Cost History** [b]

(dollars in thousands)

| Fiscal Year | Design/ Construction | R&D/ Conceptual Design/NEPA | Pre-Operations | Total TPC | Less MSU Cost Share | DOE TPC |
|---|---|---|---|---|---|---|
| FY 2015 | 655,700 | 24,600 | 49,700 | 730,000 | -94,500 | 635,500 |
| FY 2016 | 655,700 | 24,600 | 49,700 | 730,000 | -94,500 | 635,500 |
| FY 2017 | 655,700 | 24,600 | 49,700 | 730,000 | -94,500 | 635,500 |
| FY 2018 | 655,700 | 24,600 | 49,700 | 730,000 | -94,500 | 635,500 |
| FY 2019 | 655,700 | 24,600 | 49,700 | 730,000 | -94,500 | 635,500 |
| FY 2020 | 655,700 | 24,600 | 49,700 | 730,000 | -94,500 | 635,500 |
| FY 2021 | 655,700 | 24,600 | 49,700 | 730,000 | -94,500 | 635,500 |

## 2. Project Scope and Justification

### Scope

FRIB scope includes the design, construction, fabrication, assembly, testing, and commissioning of the civil and technical scope that will enable high intensity primary beams of stable isotopes to be accelerated up to a minimum energy of 200 MeV per nucleon by a superconducting linear accelerator (linac) capable of delivering 400 kW of beam power at full energy. The scope also includes the capability for secondary beams of rare isotopes to be produced "in-flight" and separated from

[a] This date represents when the design was substantially complete to allow the start of technical construction (CD-3B). A limited amount of design effort continued through 4Q FY 2017.

[b] 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.

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.

**Justification**

The science that 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 these rare isotopes. High intensity primary beams of stable isotopes are produced in Electron Cyclotron Resonator ion sources and accelerated up to a minimum energy of 200 MeV per nucleon by a superconducting linear accelerator capable of delivering 400 kW of beam power at full energy. Secondary beams of rare isotopes are produced "in-flight" and separated from unwanted fragments by magnetic analysis. These rare isotope beams are delivered to experimental areas or stopped in a suite of ion-stopping stations where they can be extracted and used for experiments at low energy, or reaccelerated for astrophysical experiments or for nuclear structure experiments. The project includes the necessary infrastructure and support facilities for operations and the 1,000-person user community.

As contractually required under the financial assistance award agreement, FRIB is being constructed in accordance with the project management principles in DOE Order 413.3B, Program and Project Management for the Acquisition of Capital Assets, and all appropriate project management requirements have been met.

Key Performance Parameters (KPPs)

The Key Performance Parameters (KPPs) are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

| 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 |

| System | Parameter | Performance Criteria |
|---|---|---|
| Conventional Facilities | Linac tunnel | Beneficial occupancy of subterranean tunnel structure of approximately 500 feet path length (minimum) to house FRIB driver linear accelerator |
| | Cryogenic helium liquefier plant—building and equipment | Beneficial occupancy of the cryogenic helium liquefier plant building and installation of the helium liquefier plant complete |
| | Target area | Beneficial occupancy of target area and one beam line installed and ready for commissioning |

### 3. Financial Schedule[a]

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs[b] |
|---|---|---|---|
| **DOE Total Project Cost (TPC)** | | | |
| FY 2009 | 7,000 | 7,000 | 4,164 |
| FY 2010 | 12,000 | 12,000 | 13,283 |
| FY 2011 | 10,000 | 10,000 | 11,553 |
| FY 2012 | 22,000 | 22,000 | 18,919 |
| FY 2013 | 22,000 | 22,000 | 20,677 |
| FY 2014[c] | 55,000 | 55,000 | 48,369 |
| FY 2015 | 90,000 | 90,000 | 79,266 |
| FY 2016 | 100,000 | 100,000 | 121,769 |
| FY 2017 | 100,000 | 100,000 | 100,000 |
| FY 2018 | 97,200 | 97,200 | 84,124 |
| FY 2019 | 75,000 | 75,000 | 38,344 |
| FY 2020 | 40,000 | 40,000 | 42,000 |
| FY 2021 | 5,300 | 5,300 | 31,000 |
| Outyears | — | — | 22,032 |
| **Total, DOE TPC** | **635,500** | **635,500** | **635,500** |

[a] The funding profile represents DOE's requested portion, which is less than the current baselined TPC which includes MSU's cost share.
[b] Costs through FY 2018 reflect actual costs; costs for FY 2019 and the outyears are estimates.
[c] The first project data sheet submitted for FRIB was in the FY 2015 Congressional Budget Request. It was established as a control point in the FY 2014 appropriation. Funding for the project in FY 2013 and prior years was provided within the Low Energy subprogram.

### 4. Details of Project Cost Estimate[a]

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **DOE Total Estimated Cost (TEC)** | | | |
| Design & Construction | | | |
| Management and Support | 39,599 | 37,288 | 35,400 |
| Conventional Facilities | 208,100 | 208,100 | 165,300 |
| Accelerator Systems | 301,551 | 295,216 | 241,400 |
| Experimental Systems | 81,686 | 75,520 | 55,000 |
| Contingency (DOE Held) | 24,814 | 39,626 | 158,650 |
| Total, Design & Construction | 655,750 | 655,750 | 655,750 |
| **Other Project Cost (OPC)** | | | |
| Conceptual Design/Tech R&D/NEPA | 24,641 | 24,641 | 24,600 |
| Pre-ops/ Commissioning/Spares | 34,187 | 34,659 | 35,500 |
| Contingency (DOE Held) | 15,422 | 14,950 | 14,150 |
| Total, OPC | 74,250 | 74,250 | 74,250 |
| **Total, TPC** | **730,000** | **730,000** | **730,000** |
| *MSU Cost Share* | *94,500* | *94,500* | *94,500* |
| **Total Project Cost (DOE Share)** | **635,500** | **635,500** | **635,500** |
| ***Total, Contingency (DOE Held)*** | ***40,236*** | ***54,576*** | ***172,800*** |

### 5. Schedule of Appropriations Requests[b]

(dollars in thousands)

| Request Year | Type | Prior Years | FY 2019 | FY 2020 | FY 2021 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| FY 2011 | TEC | — | — | — | — | — | — |
| | OPC | — | — | — | — | — | — |
| | TPC | 29,000 | — | — | — | — | 29,000 |
| FY 2012 | TEC | — | — | — | — | — | — |
| | OPC | — | — | — | — | — | — |
| | TPC | 59,000 | — | — | — | — | 59,000 |

[a] This section shows a breakdown of the total project cost of $730,000,000 as of 6/30/2019, 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. TEC/OPC type efforts are managed at the DOE and MSU funding levels ($730,000,000) and not available for the DOE funding portion only.

(dollars in thousands)

| Request Year | Type | Prior Years | FY 2019 | FY 2020 | FY 2021 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| FY 2013 | TEC | — | — | — | — | — | — |
| | OPC | — | — | — | — | — | — |
| | TPC | 73,000 | — | — | — | — | 73,000 |
| FY 2014 | TEC | — | — | — | — | — | — |
| | OPC | — | — | — | — | — | — |
| | TPC | 128,000 | — | — | — | — | 128,000 |
| FY 2015 | TEC | — | — | — | — | — | — |
| | OPC | — | — | — | — | — | — |
| | TPC | 515,200 | 75,000 | 40,000 | 5,300 | — | 635,500 |
| FY 2016 | TEC | — | — | — | — | — | — |
| | OPC | — | — | — | — | — | — |
| | TPC | 515,200 | 75,000 | 40,000 | 5,300 | — | 635,500 |
| FY 2017 | TEC | — | — | — | — | — | — |
| | OPC | — | — | — | — | — | — |
| | TPC | 515,200 | 75,000 | 40,000 | 5,300 | — | 635,500 |
| FY 2018 | TEC | — | — | — | — | — | — |
| | OPC | — | — | — | — | — | — |
| | TPC | 498,000 | 75,000 | 57,200 | 5,300 | — | 635,500 |
| FY 2019 | TEC | — | — | — | — | — | — |
| | OPC | — | — | — | — | — | — |
| | TPC | 498,000 | 75,000 | 57,200 | 5,300 | — | 635,500 |
| FY 2020 | TEC | — | — | — | — | — | — |
| | OPC | — | — | — | — | — | — |
| | TPC | 515,200 | 75,000 | 40,000 | 5,300 | — | 635,500 |
| FY 2021 | TEC | — | — | — | — | — | — |
| | OPC | — | — | — | — | — | — |
| | TPC | 515,200 | 75,000 | 40,000 | 5,300 | — | 635,500 |

### 6. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 3Q FY 2022 |
| Expected Useful Life | 20 years |
| Expected Future Start of D&D of this capital asset | N/A[a] |

Related Funding Requirements
(dollars in thousands)

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

[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.

## 7. D&D Information

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

## 8. Acquisition Approach

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

## Isotope Production and Distribution Program Fund

### Overview

The Department of Energy's Isotope Program (DOE IP) produces and sells radioactive and stable isotopes, byproducts, surplus materials, and related isotope services worldwide. It operates under a revolving fund, the Isotope Production and Distribution Program Fund, established by the 1990 Energy and Water Development Appropriations Act (Public Law 101-101), as amended by the 1995 Energy and Water Development Appropriations Act (Public Law 103-316). Funding for the Isotope Production and Distribution Program Fund is provided by the combination of annual appropriations from the Isotope Development and Production for Research and Applications subprogram within the Nuclear Physics (NP) program in the Science appropriation account, and collections from isotope sales; both are needed to maintain the Isotope Program's viability. This revolving fund allows continuous and smooth operations of isotope production, sales, and distribution independent of the federal budget cycle and fluctuating sales revenue. An independent cost review of the fund's revenues and expenses is conducted annually by an external contractor.

Annual appropriations in NP funds a payment into the revolving fund to maintain mission-readiness of facilities, including the support of core scientists and engineers needed to carry out the Isotope Program and the maintenance of isotope facilities to assure reliable production. In addition, appropriated funds provide support for research and development (R&D) activities associated with development of new production and processing techniques for isotopes, production of research isotopes, and training of new personnel in isotope production. Each site's production expenses, including processing and distributing isotopes, are offset by revenue generated from sales. About 80 percent of the resources in the revolving fund are used for operations, maintenance, isotope production, and R&D for new isotope production techniques, with approximately 20 percent available for process improvements, unanticipated changes in volume, and purchases of small capital equipment, such as assay equipment and shipping containers needed to ensure on-time deliveries.

The Department supplies isotopes and related services to the Nation under the authority of the Atomic Energy Act of 1954, which specifies the role of the U.S. Government in isotope distribution. Substantial national and international scientific, medical, and research infrastructure relies upon the use of isotopes and is strongly dependent on the Department's products and services. Isotopes are used for hundreds of applications that benefit society every day, such as diagnostic medical imaging, cancer therapy, smoke detectors, neutron detectors for homeland security applications, explosives detection, oil exploration, and tracers for environmental research. For example, radioisotopes are used in the diagnosis or treatment of about one-third of all patients admitted to hospitals.[a] More than 20 million Americans benefit each year from nuclear medicine procedures used to diagnose and treat a wide variety of diseases.[b] Such nuclear medicine procedures are among the safest and most effective diagnostic tests available and enhance patient care by avoiding exploratory surgery and other invasive procedures. DOE IP continuously assesses isotope needs to inform program direction including biennial Federal workshops to evaluate stakeholder requirements in order to optimize the utilization of resources and assure the greatest availability of isotopes.

Radioisotopes are primarily produced and processed at three facilities stewarded by DOE IP: the Brookhaven Linac Isotope Producer (BLIP) and associated processing labs at Brookhaven National Laboratory (BNL), the Isotope Production Facility (IPF) and associated processing labs at Los Alamos National Laboratory (LANL), and the processing labs at Oak Ridge National Laboratory (ORNL). Enriched stable isotopes are produced at the Enriched Stable Isotope Prototype Plant (ESIPP) also at ORNL. In addition, production and distribution activities are supported at the Advanced Test Reactor (ATR) at Idaho National Laboratory (INL), the High Flux Isotope Reactor (HFIR) at ORNL, the Y-12 National Security Complex near ORNL, the Low Energy Accelerator Facility (LEAF) at Argonne National Laboratory (ANL), and processing facilities at the Pacific Northwest National Laboratory (PNNL) and the Savannah River Site. IPF, BLIP, and LEAF provide accelerator production capabilities, while HFIR and ATR provide reactor production capability. HFIR has the highest neutron flux available for isotope production in the United States. ESIPP represents the re-establishment of general enriched stable isotope production capabilities in the U.S. and started operations in 2016. DOE IP is further broadening capability by including university-supported accelerator and reactor facilities used for research, education, and isotope production that can

[a] https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/med-use-radioactive-materials.html
[b] http://www.snmmi.org/ClinicalPractice/content.aspx?ItemNumber=4825

provide cost-effective and unique production capabilities, as the University of Washington and the Missouri University Research Reactor are now part of the DOE IP University Production Network. Many other universities have expressed interest in participating in the network.

In FY 2019, a total of $102,421,821 was deposited into the revolving fund. This consisted of the FY 2019 appropriation of $44,259,000 paid into the revolving fund from the Nuclear Physics program, plus collections of $58,162,821 to recover costs related to isotope production and isotope services. Collections in FY 2019 included, for example, sales of actinium-225, actinium-227, strontium-82, strontium-89, germanium-68, californium-252, helium-3, cobalt-60, nickel-63, selenium-75, and barium-133.

Actinium-225 (Ac-225) is used in pharmaceuticals under development to more effectively treat cancer and other diseases. Actinium-227 provides radium-223 for Xofigo®, which was the first alpha particle-emitting radioisotopic drug approved by the Federal Drug Administration; Xofigo® extends patient survival as well as alleviates the excruciating pain associated with cancer that has metastasized to bone. Strontium-82 has gained world-wide acceptance for use in heart imaging and strontium-89 alleviates the pain associated with bone metastases. Germanium-68 supports development of gallium-68 diagnostic imaging pharmaceuticals and the FDA-approved drug NETSPOT™ for detection of neuroendocrine tumors. Californium-252 has a variety of industrial applications, including oil and gas well-logging, and fission start-up in nuclear reactors; helium-3 is used in neutron detectors for national security and cryogenics; cobalt-60 is used in gamma-ray cancer surgery; nickel-63 enhances national security through its use in detectors for explosives and illicit material; selenium-75 is used as a radiography source; and barium-133 is a gamma-ray source used for calibration standards, including as a standard for iodine-131 for calibration of medical equipment.

In FY 2020, the DOE IP expects to sell about 160 different radioactive and stable isotopes to a broad range of research and commercial customers, including major pharmaceutical companies, industrial stakeholders, and researchers at hospitals, national laboratories, other Federal agencies, universities, and private companies. Among the isotopes produced, eleven are high-volume isotopes often with commercial applications and the remaining are low-volume, mostly research isotopes, which are more expensive to produce. 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 that the high priority research requiring them does not become cost prohibitive.

**Program Accomplishments**

*Eliminating U.S. Dependence on Foreign Supply.*

Strontium-90 is used as a generator of yttrium-90 which is used in medical applications such as the treatment of liver cancer. Until 2019, the U.S. had been dependent on Russia, the only world-wide supplier. The DOE IP is supporting an effort at PNNL to separate approximately 3,000 curies from legacy material. The first material was distributed to customers in 2019 and the DOE IP is now capable of fully meeting U.S. annual demand.

*Inventory of Scarce Isotope Created.*

The Enriched Stable Isotope Prototype Plant (ESIPP) at Oak Ridge National Laboratory completed its first production campaign for the rare isotope ruthenium-96 in FY 2019, generating the only ruthenium-96 available on the globe. Part of this inventory was used to enable a crucial nuclear physics experiment at Brookhaven's Relativistic Heavy Ion Collider to study matter that has not existed since the early Universe. The production was accomplished via electromagnetic separation technology. Efforts have now transitioned to ytterbium-176, another highly scarce isotope currently in demand to produce lutetium-177 for the treatment of prostate cancer.

*Commercialization of Strontium-82 (Sr-82) Production.*

The DOE IP worked with industry to establish the first domestic commercial producer of Sr-82, an isotope widely used for cardiac imaging. DOE IP introduced Sr-82 to the market decades ago, and has steadily increased production and the customer base to create an economically viable isotope, ready for commercialization. DOE IP provided technical assistance to private companies interested in developing Sr-82 production capabilities, and one was successful in entering the market in the U.S. DOE IP provided assistance in keeping them stable until their product was qualified to be used for FDA-approved cardiac imaging procedures. They are now the first domestic commercial producer of Sr-82, mitigating U.S. reliance on

Russian and Canadian producers. The DOE IP remains as a backup supplier, poised to cover any supply shortages, should they occur.

**Highlights of the FY 2021 Request**

For FY 2021, the Department foresees growth in isotope demand, with particular interest in alpha-emitters for cancer therapy and stable isotopes to exploit the newly established domestic production capabilities. The DOE IP portfolio continues to grow rapidly as isotope availability increases. The FY 2021 Request of $66,000,000 is an increase of $16,500,000, or 33.3 percent above the FY 2020 Enacted level. Revolving fund resources will be used to:

- maintain isotope production infrastructure and core competencies
- perform research and development on new isotope production and enrichment technology
- produce isotopes in short supply, add isotope harvesting to the Facility for Rare Isotope Beams (FRIB)
- enhance processing and production capabilities to increase isotope availability
- reduce U.S. dependence on foreign supply of isotopes, increase helium-3 extraction capabilities
- develop and operate radioisotope enrichment capabilities
- explore and enhance stable isotope enrichment capabilities
- increase production of Ac-225 and other high-in-demand alpha emitters for cancer therapy
- introduce new isotopes to the market for research and applications
- develop isotope production capabilities for quantum information science

The FY 2021 Request includes $3,500,000 to continue the FRIB Isotope Harvesting accelerator improvement effort. FRIB is a next generation scientific user facility being constructed at Michigan State University for nuclear structure and astrophysics measurements. This project will add isotope harvesting capabilities to the FRIB, which will provide access to a wide range of isotopes, including unusual isotopes for exploratory studies.

The FY 2021 Request for the Nuclear Physics program includes $12,000,000 to continue the U.S. Stable Isotope Production and Research Center at ORNL, which will significantly enhance stable isotope production capacity for the Nation. This Line Item Construction Project has a Total Project Cost (TPC) range of $200,000,000 - $260,000,000. This new facility will build upon the expertise in centrifuge and electromagnetic isotope separation technology nurtured by the Stable Isotope Production Facility (SIPF) major item of equipment.

## Workforce Development for Teachers and Scientists

### Overview

The Workforce Development for Teachers and Scientists (WDTS) program mission is to help ensure that DOE has a sustained pipeline for the science, technology, engineering, and mathematics (STEM) workforce. Accomplishing this mission depends on continued support for undergraduate internships, graduate thesis research opportunities, and visiting faculty research appointments; administration of the Albert Einstein Distinguished Educator Fellowship for K–12 STEM teachers for the federal government; and annual, nationwide, middle and high school science competitions culminating in the National Science Bowl® finals in Washington, D.C. These activities support the development of the next generation of scientists and engineers to address the DOE mission, administer programs, and conduct research.

WDTS activities rely significantly on DOE's 17 national laboratories and scientific facilities, which employ more than 30,000 individuals with STEM backgrounds. The DOE laboratory system provides access to leading scientists; world-class scientific user facilities and instrumentation; and large-scale, multidisciplinary research programs unavailable in universities or industry. WDTS leverages these assets to develop and train post-secondary students and educators in support of the DOE mission. WDTS experience-based STEM learning opportunity programs enable highly qualified applicants to conduct research at DOE laboratories and facilities in support of the DOE workforce development mission.

### Highlights of the FY 2021 Request

The FY 2021 Request for $20,500,000 prioritizes funding for programs that place highly qualified applicants in authentic STEM learning, training, and research experiences at DOE laboratories. The Request increases support for outreach activities to the scientific community targeting Office of Science (SC) mission-driven disciplinary workforce needs. It also prioritizes support for the DOE National Science Bowl®, a signature STEM competition testing middle and high school students' knowledge in science and mathematics. By encouraging students to pursue STEM careers, these programs address the DOE's STEM mission critical workforce pipeline needs required to advance national security and promote American competitiveness.

### Description

#### <u>Activities at the DOE Laboratories</u>

WDTS supports activities such as the Science Undergraduate Laboratory Internships (SULI) program, the Community College Internships (CCI) program, the Office of Science Graduate Student Research (SCGSR) program, and the Visiting Faculty Program (VFP). One of the primary goals of these programs is to prepare students to enter STEM careers that are especially relevant to the DOE mission. By providing research experiences at DOE laboratories under the direction of scientific and technical laboratory staff who serve as research advisors and mentors, these activities provide opportunities for participants to engage in research requiring specialized instrumentation, large-scale, multidisciplinary efforts, and/or scientific user facilities. WDTS activities are aligned with the STEM workforce training recommendations of the Federal Advisory Committees of SC's six research program offices, the strategic objectives of the National Science and Technology Council's Committee on STEM Education (CoSTEM) Federal STEM Education 5-Year Strategic Plan, and the Administration's goals for educating and training an American workforce for the 21st century economy.

SULI places students from two- and four-year undergraduate institutions as paid interns in science and engineering research activities at DOE laboratories, working with laboratory staff scientists and engineers on projects related to ongoing research programs. Appointments are for 10 weeks during the summer term and 16 weeks during the fall and spring terms.

CCI places community college students as paid interns in technological activities at DOE laboratories, working under the supervision of a laboratory technician or researcher. Appointments are for 10 weeks during the summer, fall, and spring terms.

SCGSR's goal is to prepare graduate students for STEM careers critically important to the SC mission by providing graduate thesis research opportunities at DOE laboratories. The SCGSR program provides supplemental awards for graduate students to pursue part of their graduate thesis research at a DOE laboratory or facility in areas that address scientific challenges central to the SC mission. U.S. graduate students pursuing Ph.D. degrees in physics, chemistry, materials sciences, non-medical biology, mathematics, computer or computational sciences, or specific areas of environmental sciences aligned with the SC mission, are eligible for research awards to conduct part of their graduate thesis research at a DOE laboratory or facility in collaboration with a DOE laboratory scientist. Research award terms range from three months to one year.

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

**Albert Einstein Distinguished Educator Fellowship**

The Albert Einstein Distinguished Educator Fellowship Act of 1994 charges the Department of Energy (DOE) with administering a fellowship program for elementary and secondary school mathematics and science teachers that focuses on bringing teachers' real-world expertise to government to help inform federal STEM education programs. Selected teachers spend 11 months in a Federal agency or a Congressional office. WDTS manages the Albert Einstein Distinguished Educator Fellowship (AEF) Program for the Federal government. Fellows are supported by DOE and other Federal agencies. SC sponsors placement opportunities in WDTS and in Congressional offices. Other Federal agencies sponsor placement opportunities in their own offices. Participating agencies have included the National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA), the Library of Congress, the Department of Defense, the Smithsonian, and the U.S. Geological Survey (USGS). The Fellows provide educational expertise, years of teaching experience, and personal insights to these offices to advance Federal science, mathematics, and technology education programs.

**National Science Bowl®**

The DOE National Science Bowl® is a nationwide academic competition testing students' knowledge in all areas of mathematics and science, including energy. High school and middle school students are quizzed in a fast-paced, question-and-answer format. Approximately 305,000 students have participated in the National Science Bowl® throughout its 29-year history, and it is one of the nation's largest science competitions. The DOE Office of Science manages the National Science Bowl®, and sponsors the National Science Bowl® finals competition. Regional competitions rely upon volunteers and are supported by numerous local organizations, both public and private.

The National Science Bowl® regional winning teams receive expenses-paid trips to Washington, D.C. to compete at the National Finals in late April. Competing teams are composed of four students, one alternate, and a teacher who serves as an advisor and coach. SC sponsors the National Science Bowl® finals, and provides central management of its regional events.

In FY 2019, more than 5,400 middle school students (from 649 schools) and 9,200 high school students (from 1,200 schools) participated in 111 regional competitions, with 48 middle school teams (215 students) and 64 high school teams (310 students) participating in the National Finals in Washington, D.C. All 50 U.S. States, the District of Columbia, and Puerto Rico were represented at regionals. More than 5,000 volunteers also participate in the local and national competitions.

The National Science Bowl® championship finals are held at the Lisner Auditorium, located on the campus of The George Washington University, and features a live web-streaming broadcast of the event.

**Technology Development and On-Line Application**

This activity modernizes on-line systems used to manage application solicitations, review applications, facilitate data collection, perform outreach, and integrate evaluation for WDTS programs. A project to develop, build, and launch new online application and program support systems continues, with evolving new elements that improve accessibility to applicants, advance program oversight and evaluation by WDTS program staff, and allow more efficient management and execution of programs 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 implement new and improved features. WDTS uses embedded toolsets to improve data-management and to enable quantitative analyses for measuring progress and optimizing program management.

**Evaluation Studies**

The Evaluation Studies activity supports work to assess whether WDTS programs meet established goals. This is accomplished through the use of triennial reviews of its program performers, and of WDTS itself. These reviews are either subject matter program peer reviews, or Federal Advisory Committee commissioned Committee of Visitors reviews, respectively. Additional supported activities that measure and assess program performance involve the collection and analysis of data and other materials, including pre- and post-participation questionnaires, participant deliverables, notable outcomes (publications, presentations, patents, etc.), and longitudinal participant tracking. As directed by the 2018 Co-STEM 5-Year Plan on STEM Education[a], WDTS is also tracking and reporting how its programs, and activities at DOE labs and SC scientific user facilities, fulfill the objectives of that plan.

The Evaluation Studies activity is aligned with the Government Performance and Results Act (GPRA) Modernization Act of 2010, which emphasizes the need for federal programs (including STEM education programs) to demonstrate their effectiveness through rigorous evidence-based evaluation. WDTS works cooperatively with SC programs, other DOE programs, and other federal agencies through CoSTEM to share best practices for STEM program evaluation to ensure the implementation of evaluation processes appropriate to the nature and scale of the program effort.

**Outreach**

WDTS engages in outreach activities, some in cooperation with other DOE program offices and select federal agencies, to widely publicize its opportunities. The WDTS website is the most widely used tool for prospective program participants to obtain information about WDTS and provides a gateway to accessing the online applications for the WDTS programs. To help diversify the applicant pool, outreach is also conducted via presentations to targeted stakeholder groups, and via the web using virtual webinar meetings that highlight the programs, their opportunities, and the WDTS internship experience. Additional online tools have been implemented to directly publicize opportunities for students via their academic institutional career offices, which is a rapidly expanding outreach modality amongst student populations seeking internship opportunities.

WDTS also annually solicits proposals from DOE host laboratories and facilities to develop and execute outreach activities aimed at recruiting a more diverse spectrum of applicants to WDTS laboratory-based programs, and encouraging the pipeline of WDTS program participants to pursue careers supporting the SC and DOE mission at DOE National Laboratories. Emphasis of laboratory outreach activities is on reaching potential applicants who are underrepresented in STEM fields, including targeted outreach to minority serving institutions. Eligible laboratories and facilities are those that host participants in the SULI, CCI, VFP, and/or SCGSR programs. Based upon reported outcomes of annually completed activities, a portfolio of model practices is evolving to help ensure that WDTS activities are fully open and accessible to all members of the population.

The Laboratory Equipment Donation Program (LEDP) is operated under Outreach and provides excess laboratory equipment to STEM faculty at accredited post-secondary educational institutions. Through the General Services Administration 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] https://www.whitehouse.gov/wp-content/uploads/2018/12/STEM-Education-Strategic-Plan-2018.pdf

## Workforce Development for Teachers and Scientists
## Funding

(dollars in thousands)

| | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|
| **Activities at the DOE Laboratories** | | | | |
| Science Undergraduate Laboratory Internships | 10,300 | 13,600 | 9,100 | -4,500 |
| Community College Internships | 1,000 | 1,700 | 1,100 | -600 |
| Office of Science Graduate Student Research Program | 3,500 | 4,500 | 2,600 | -1,900 |
| Visiting Faculty Program | 1,700 | 2,000 | 1,700 | -300 |
| **Total, Activities at the DOE Laboratories** | **16,500** | **21,800** | **14,500** | **-7,300** |
| **Albert Einstein Distinguished Educator Fellowship** | **1,200** | **1,200** | **800** | **-400** |
| **National Science Bowl®** | **2,900** | **2,900** | **2,900** | **—** |
| **Technology Development and On-Line Application** | **750** | **700** | **500** | **-200** |
| **Evaluation Studies** | **600** | **600** | **300** | **-300** |
| **Outreach** | **550** | **800** | **1,500** | **+700** |
| **Total, Workforce Development for Teachers and Scientists** | **22,500** | **28,000** | **20,500** | **-7,500** |

**Program Accomplishments**

***Science Undergraduate Laboratory Internships (SULI)*** — FY 2019 funding supported approximately 940 placements, of which more than 65 were from Minority Serving Institutions (MSIs), and approximately 41 percent were women. 97 percent of the participants reported receiving a high quality internship experience, with 98 percent reporting impacts to their educational and career goals, and would recommend SULI to their peers. As in prior years, participants continue to make notable contributions to research projects as evidenced by co-authorship in peer reviewed journals, patents, and/or presentations at scientific meetings. A new SULI eligibility category called "Recent Graduates" was implemented in the Summer 2019 Term application period, which replaced "Graduating Seniors" and extends the period of eligibility for graduates of 4-year institutions and community colleges to two years (formerly one year) between the date of graduation and the start of the SULI term. This change provides additional experience based learning opportunities for students considering a STEM research career and addresses recommendations from the 2016 COV review.

***Community College Internships (CCI)*** — In FY 2019, approximately 25 percent of the participants were from MSIs. 98 percent of the participants reported receiving a high quality internship experience, with 100 percent reporting impacts to their educational and career goals, and would recommend CCI to their peers. In FY 2019 General Atomics (San Diego, CA) also joined the CCI program as a host institution.

***Office of Science Graduate Student Research Program (SCGSR)*** — In FY 2019, SCGSR added new research areas that address STEM disciplines not well represented in academic curricula; that address STEM disciplines in high demand, nationally and/or internationally, resulting in difficulties in recruitment and retention at U.S. universities and at DOE laboratories; that address STEM disciplines for which the DOE laboratories may play a role in providing needed workforce development; and at the graduate student level that can address SC discipline-specific workforce development needs. Additionally, the program developed new convergence research areas (e.g. data science, microelectronics, and accelerator science) to address workforce needs able to fulfill SC's long-range vision on emerging frontiers in science discovery and innovation that increasingly require transdisciplinary approaches. Convergence is a recognized priority in the National Science and Technology Council CoSTEM Federal STEM Education 5-Year Strategic Plan, and it supports the Administration's goals for educating and training an American workforce for the 21$^{st}$ century economy. Since 2014, there have been 489 SCGSR awardees from 135 institutions across the U.S.

***Visiting Faculty Program (VFP)*** — FY 2019 funding supported 55 faculty and 39 student placements, and of these participants, at least 23 were women and 24 were from MSIs. The Savannah River National Laboratory (Aiken, SC) also joined the VFP program as a host institution. All VFP Faculty participants reported a positive impact on their careers, with 98 percent expressing interest in continuing their research collaboration. All would recommend VFP to their peers. All VFP-Student participants reported receiving a high quality internship experience, with 98 percent reporting impacts to their educational and career goals, and would recommend VFP to their peers.

***Albert Einstein Distinguished Educator Fellowship (AEF)*** — In FY 2019, one of the six WDTS sponsored AEF participants held a WDTS office appointment. In addition to engaging in WDTS programmatic activities, as nationally recognized STEM educators, the WDTS placed Fellow collaborated onsite with Brookhaven National Laboratory, the National Renewable Energy Laboratory, Fermi National Accelerator Laboratory, Argonne National Laboratory, and Los Alamos National Laboratory, applying their expertise to portions of the laboratories' STEM education outreach activities. In efforts to expand federal agency participation, the incoming 2019-2020 cohort includes a placement at the Department of Defense's Naval Surface Warfare Center, and WDTS established partnerships with other agencies who have expressed interest in hosting a Fellow for the FY 2019 application cycle (2020-2021 cohort), including USGS and the Smithsonian's National Air and Space Museum.

***The National Science Bowl®*** — The National Finals of the 29$^{th}$ DOE National Science Bowl® took place in the Washington, DC, area from April 25 - 29, 2019. The Administrator of the National Nuclear Security Administration delivered congratulatory remarks to the 64 high schools and 48 middle schools at the finals, and conferred awards to the winning teams.

The National Science Bowl®'s Science Day is a cornerstone event, opening the finals competition with a tradition of attracting prominent speakers, including outstanding researchers from DOE laboratories, who are able to connect DOE laboratory workplace experience and careers to these students' STEM areas of study. Having Science Day speakers from across the DOE laboratory complex is particularly relevant from a workforce mission perspective, as this is often the first time that these students become aware of DOE mission research, and the national laboratory complex. The 2019 National Science Bowl® Science Day for high-school finalists had as its theme DOE National Scientific User Facilities, comprising the most advanced tools of modern science, helping researchers propel the U.S. to the forefront of science, technology development, and deployment through innovation.

The Cyber-Challenge middle school activity continued in FY 2019. This Cyber-Challenge activity leverages NNSA's *Cybersecurity Workforce Pipeline Consortium* investments, and is based upon activities developed at Lawrence Livermore National Laboratory. The National Science Bowl® event provides an opportunity to develop and test these cybersecurity outreach and training activities at large concurrent participant scales. Based upon this success, as well as on additional activities sponsored under WDTS Outreach, Cyber Challenge events is being piloted at 4 different FY 2020 Middle School Regional Competitions hosted by DOE laboratories. This expansion will provide additional access to computational thinking activities prioritized in the CoSTEM Federal STEM Education 5-Year Strategic Plan, in alignment with the Administration's goals for educating and training an American workforce for the 21$^{st}$ century economy. It also expands DOE's portfolio of cyber challenge activities currently focused on more advanced STEM students.

***Technology Development and On-Line Application*** — In FY 2019, under WDTS direction, the technical development performed by the Oak Ridge Institute for Science and Education (ORISE) for a National Science Bowl® alumni website commenced, with development for the National Science Bowl® Travel Portal completed and pending final testing and acceptance for launch in FY 2020. Additionally, the technical requirements and information architecture for a virtual National Science Bowl® training site on SC's website have been defined, with development commencing for a planned launch in FY 2020. Technical requirements for enhancements and features supporting WDTS online systems also include a national virtualized National Science Bowl® scoring system, a national virtualized Cyber Challenge capability developed in coordination with Lawrence Livermore National Laboratory, and integration of toolsets to establish a virtual workspace environment/portal for WDTS program collaboration with its program performers enabling labs to leverage, share, and use participant professional development content and capabilities. Additional development focused on embedded commercial outreach toolsets such as Handshake, and a STEM activity reporting tool with inputs that include event type, sponsorship, targeted audience(s), amplification, and connection to the 2018 CoSTEM 5-Year Plan on STEM Education. This reporting tool provides a single point-of-contact portal enabling facile data collection, management, and archiving in a manner that minimizes burdens of specialized unscheduled data calls to the DOE labs.

***Evaluation*** — In FY 2019, WDTS completed a triennial program external peer review of SULI, CCI, and VFP. As in past program peer reviews, labs received individual guidance and feedback on their programs, with findings also used to advance operational baselines through complex-wide discussion and feedback. The peer review criteria, established by WDTS, evaluated whether host institutions are managing and executing SULI, CCI, and VFP through WDTS established Model Practices so that: 1) participants receive best-in-class faculty or intern experiences and, as a result of the program, have increased their preparedness for a STEM career; 2) the activities support DOE's goal "to develop the next generation of scientists and engineers to support Department missions, administer its programs, and conduct the research that will realize the nation's science and innovation agenda"; and 3) the programmatic baseline as defined by the WDTS Core Requirements is being met. The review criteria and inputs also included elements of the 2018 CoSTEM 5-Year Plan on STEM Education, so that the review's outcomes can help guide SC/WDTS when implementing that plan.

***Outreach*** — DOE host laboratories and facilities executed projects aimed at recruiting a more diverse applicant pool to WDTS laboratory-based programs, targeting recruitment of individuals traditionally underrepresented in STEM and addressing needs to increase the applicant pool diversity for one or more of the WDTS programs currently implemented at DOE host laboratories and facilities. As one outcome, a "Mini-Semester" experience that brings prospective applicants from underrepresented communities to DOE labs in a week-long immersion experience is proving successful and being adopted by increasing numbers of host labs. A complex-wide virtual career was also held where labs were able to access and recruit potential applicants using an online "recruitment booth" presence.

WDTS completed the LEDP online system migration from the Office of Scientific and Technical Information (OSTI) to the Oak Ridge Institute for Science and Education (ORISE) that integrates LEDP's equipment catalog, applications, reviews, and processing into WDTS online systems. By using established online resources, and their capabilities, this migration improves the client experience when accessing and applying for equipment, and also improves management and execution of equipment transfer processes. Updates to eligibility and use requirements better align LEDP to SC and DOE workforce mission priorities, as well as improves accountability for the excess donated equipment.

## Workforce Development for Teachers and Scientists

**Activities and Explanation of Changes**

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| **Workforce Development for Teachers and Scientists** | **$28,000** | **$20,500** | **-$7,500** |
| Activities at the DOE Laboratories | $21,800 | $14,500 | -$7,300 |
| *Science Undergraduate Laboratory Internships* | *$13,600* | *$9,100* | *-$4,500* |
| Funding for SULI supports approximately 1,170 students. Student stipends, which have been flat for eight years, modestly increase to keep up with market value. | | The Request for SULI will support approximately 785 students. | Funding will support 385 fewer students. |
| *Community College Internships* | *$1,700* | *$1,100* | *-$600* |
| Funding for CCI supports approximately 150 students. Student stipends, which have been flat for eight years, modestly increase to keep up with market value. | | The Request for CCI will support approximately 100 students. | Funding will support 50 fewer students. |
| *Graduate Student Research Program* | *$4,500* | *$2,600* | *-$1,900* |
| Funding for the SCGSR program supports approximately 185 graduate students. Targeted priority research areas will be informed by SC's workforce training needs studies. | | The Request for the SCGSR program will support approximately 115 graduate students. Targeted priority research areas will be informed by SC's workforce training needs studies. | Funding will support 70 fewer students. |
| *Visiting Faculty Program* | *$2,000* | *$1,700* | *-$300* |
| Funding for the VFP supports approximately 70 faculty and 45 students. Faculty and student stipends, which have been flat for eight years, modestly increase to keep up with market value. | | The Request for the VFP will support approximately 62 faculty and 36 students. | Funding will support 8 fewer faculty and 9 fewer students. |

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| Albert Einstein Distinguished Educator Fellowship | $1,200 | $800 | -$400 |
| Funding supports 6 Fellows. | | The Request will support 4 Fellows. | Funding will support 2 fewer Fellows. |
| National Science Bowl® | $2,900 | $2,900 | $— |
| Funding continues support to sponsor the finals competition and provide central management of 116 regional events, involving 14,300 students from all fifty states, the District of Columbia, Puerto Rico, and the U.S. Virgin Islands. | | The Request will provide support to sponsor the finals competition and provide central management of 116 regional events, involving 14,300 students from all fifty states, the District of Columbia, Puerto Rico, and the U.S. Virgin Islands. | No change. |
| Technology Development and On-line Application Systems | $700 | $500 | -$200 |
| Funding continues development and operation of the on-line systems, including continued enhancements for operations of the NSB. | | The Request will continue development and operation of the on-line systems. | Funding will maintain operation of the on-line systems; the rate of development will be slowed. |
| Evaluation | $600 | $300 | -$300 |
| Funding continues support for evaluation activities, including data archiving, curation, and analyses. WDTS continues a systematic review of data-derived evidence from its current and past program participants, to be further augmented by the design and implementation of a longitudinal study of its cohorts of prior SULI participants, looking back more than 20 years. | | The Request will continue support for evaluation activities, including data archiving, curation, and analyses. | No new longitudinal evaluation activities will be initiated. |

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| Outreach | $800 | $1,500 | +$700 |
| Funding supports outreach activities to the scientific community targeting Office of Science mission-driven disciplinary workforce needs in the next 5 to 10 years, including additional outreach activity proposal solicitations from DOE host labs and facilities. Support continues for the LEDP program. | | The Request will support outreach activities to the scientific community targeting Office of Science mission-driven disciplinary workforce needs in the next 5 to 10 years, including additional outreach activity proposal solicitations from DOE host labs and facilities. Support continues for the LEDP program. | WDTS will increase support of activities such as those that promote inclusion and diversity; reflect one or more goals/objectives/pathways of the 2018 CoSTEM Five Year Plan on STEM Education; and/or prioritize recruitment of STEM students to DOE research and development workforce mission-relevant fields of study, and particularly to fields related to Office of Science research programs. Laboratories and facilities eligible for funding are those that hosted FY 2019 WDTS participants in SULI, CCI, VFP, and SCGSR. |

**Workforce Development for Teachers and Scientists**
**Funding Summary**

(dollars in thousands)

| | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|
| Other | 22,500 | 28,000 | 20,500 | -7,500 |
| **Total, Workforce Development for Teachers and Scientists** | **22,500** | **28,000** | **20,500** | **-7,500** |

## Science Laboratories Infrastructure

### Overview

The Science Laboratories Infrastructure (SLI) program mission is to support scientific and technological innovation at the Office of Science (SC) laboratories by funding and sustaining general purpose infrastructure and fostering safe, efficient, reliable, and environmentally responsible operations. The main priorities of the SLI program are improving SC's existing physical assets (including major utility systems) and funding new cutting-edge facilities that enable emerging science opportunities. The SLI program also funds Payments in Lieu of Taxes (PILT) to local communities around the Argonne, Brookhaven, and Oak Ridge National Laboratories as well as Nuclear Operations at Oak Ridge National Laboratory (ORNL) and landlord responsibilities across the Oak Ridge Reservation.

SC manages an infrastructure portfolio worth nearly $22.0 billion, which is composed of 13 sites with nearly 23 million gross square feet (gsf) in 1,570 government owned buildings. SC assets at their 10 national laboratories include major research and user facilities, laboratory and office buildings, support facilities, and a vast network of utilities that form the backbone of each site. While SC has provided significant stewardship of research facilities, the renovation and replacement of general purpose infrastructure, including buildings and support infrastructure, continues to lag behind. Of the buildings, 47 percent are rated substandard or inadequate to meet mission needs. In addition, 64 percent of support infrastructure, including utility systems, is rated as substandard or inadequate, resulting in unplanned outages, costly repairs, and inefficiencies. Collectively, these deficiencies impede mission accomplishment and scientific progress. In collaboration with SC programs and the laboratories, the SLI program works to address identified deficiencies.

SC laboratories conduct rigorous and consistent analyses of the condition, utilization, and functionality of the facilities and infrastructure which are most critical to mission accomplishment. SC and the laboratories use these assessments to develop comprehensive Campus Strategies in the annual laboratory planning process. Each laboratory's Campus Strategy identifies activities and infrastructure investments (e.g., Line-Item (LI) Construction and General Plant Projects (GPPs)) required to support the core capabilities and achieve the scientific vision of the laboratory. SC leadership uses these Campus Strategies to determine the facilities and infrastructure needs and priorities, which, combined with complex-wide infrastructure analyses, form the basis of SLI Budget requests.

To sustain and enhance its general purpose infrastructure, SC invested nearly $500,000,000 in maintenance, repair, and upgrades in FY 2019. These investments came from a variety of funding sources including Federal appropriations for line-item and general plant projects and overhead funding of Institutional GPP (IGPP) projects and maintenance and repair. The SLI investments in line-item construction and science-supporting infrastructure are key elements of this overall investment strategy.

### Highlights of the FY 2021 Request

The SLI program Request for $174,110,000 continues to focus on improving infrastructure across the SC national laboratory complex. The FY 2021 Request includes funding for three new construction starts: the Princeton Plasma Innovation Center at Princeton Plasma Physics Laboratory (PPPL), the Critical Infrastructure Recovery & Renewal project at PPPL, and the Ames Infrastructure Modernization project at Ames Laboratory.

The Request also supports fifteen ongoing construction projects: the Critical Utilities Rehabilitation Project at Brookhaven National Laboratory (BNL), the Seismic and Safety Modernization project at Lawrence Berkeley National Laboratory (LBNL), the Continuous Electron Beam Accelerator Facility (CEBAF) Renovation and Expansion project at Thomas Jefferson National Accelerator Facility (TJNAF), the Large Scale Collaboration Center at SLAC National Accelerator Laboratory (SLAC), the Argonne Utilities Upgrade project at Argonne National Laboratory (ANL), the Linear Assets Modernization Project at LBNL, the Critical Utilities Infrastructure Revitalization project at SLAC, the Utilities Infrastructure Project at Fermi National Accelerator Laboratory (FNAL), the Science User Support Center at BNL, the Translational Research Capability project at Oak Ridge National Laboratory (ORNL), the Biological and Environmental Program Integration Center (BioEPIC) at LBNL, and the Integrated Engineering Research Center at FNAL, and provides final funding for three construction projects: the Craft Resources Support Facility at ORNL, the Tritium System Demolition and Disposal project at PPPL, and the Energy Sciences Capability project at Pacific Northwest National Laboratory (PNNL). These ongoing projects, along with the newly proposed projects, will upgrade and improve aging utility systems and facilities and provide new laboratory space with the necessary performance capabilities to enhance SC's mission.

The FY 2021 Request also includes funding for general purpose infrastructure projects that will address high priority core infrastructure and utility needs across SC laboratories and facilities. The laboratory infrastructure needs and priorities are revaluated annually by SLI.

## Science Laboratories Infrastructure
## Funding

| | (dollars in thousands) | | | |
|---|---|---|---|---|
| | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
| **Infrastructure Support** | **79,690** | **93,000** | **22,710** | **-70,290** |
| | | | | |
| **Construction** | | | | |
| 21-SC-71, Princeton Plasma Innovation Center, PPPL | — | — | 2,000 | +2,000 |
| 21-SC-72, Critical Infrastructure Recovery & Renewal, PPPL | — | — | 2,000 | +2,000 |
| 21-SC-73, Ames Infrastructure Modernization, Ames | — | — | 2,000 | +2,000 |
| 20-SC-71, Critical Utilities Rehabilitation Project, BNL | — | 20,000 | 15,000 | -5,000 |
| 20-SC-72, Seismic and Safety Modernization, LBNL | — | 10,000 | 10,000 | — |
| 20-SC-73, CEBAF Renovation and Expansion, TJNAF | — | 2,000 | 2,000 | — |
| 20-SC-74, Craft Resources Support Facility, ORNL | — | 15,000 | 25,000 | +10,000 |
| 20-SC-75, Large Scale Collaboration Center, SLAC | — | 11,000 | 8,000 | -3,000 |
| 20-SC-76, Tritium System Demolition and Disposal, PPPL | — | 13,000 | 19,400 | +6,400 |
| 20-SC-77, Argonne Utilities Upgrade, ANL | — | 500 | 2,000 | +1,500 |
| 20-SC-78, Linear Assets Modernization Project, LBNL | — | 500 | 2,000 | +1,500 |
| 20-SC-79, Critical Utilities Infrastructure Revitalization, SLAC | — | 500 | 2,000 | +1,500 |
| 20-SC-80, Utilities Infrastructure Project, FNAL | — | 500 | 2,000 | +1,500 |
| 19-SC-71, Science User Support Center, BNL | 7,000 | 20,000 | 7,000 | -13,000 |
| 19-SC-72, Electrical Capacity and Distribution Capability, ANL | 30,000 | 30,000 | — | -30,000 |
| 19-SC-73, Translational Research Capability, ORNL | 25,000 | 25,000 | 10,000 | -15,000 |
| 19-SC-74, BioEPIC, LBNL | 5,000 | 15,000 | 6,000 | -9,000 |
| 18-SC-71, Energy Sciences Capability, PNNL | 24,000 | 23,000 | 23,000 | — |
| 17-SC-71, Integrated Engineering Research Center, FNAL | 20,000 | 22,000 | 12,000 | -10,000 |
| 17-SC-73, Core Facility Revitalization, BNL | 42,200 | — | — | — |
| **Total, Construction** | **153,200** | **208,000** | **151,400** | **-56,600** |
| **Total, Science Laboratories Infrastructure** | **232,890** | **301,000** | **174,110** | **-126,890** |

## Science Laboratories Infrastructure
## Explanation of Major Changes

| | (dollars in thousands) FY 2021 Request vs FY 2020 Enacted |
|---|---|
| **Infrastructure Support**<br>The Request continues funding to support Payment in Lieu of Taxes (PILT), nuclear facilities at ORNL, and landlord responsibilities at the Oak Ridge Reservation. Overall funding decreases due to the request for final funding in FY 2020 for the de-inventory, removal, and transfer of nuclear material at Building 350, formerly the site of New Brunswick National Laboratory (NBL) on the ANL campus. Funding for critical core infrastructure across the SC complex also decreases in FY 2021. | **-70,290** |
| **Construction**<br>Funding supports fifteen ongoing line-item projects at FNAL, PNNL, LBNL, ANL, ORNL, BNL, SLAC, PPPL, and TJNAF. The increase also supports the initiation of three new line-item projects at Ames and PPPL. | **-56,600** |
| **Total, Science Laboratories Infrastructure** | **-126,890** |

**Program Accomplishments**

Since FY 2006, the SLI program has invested over $1.5 billion in general purpose infrastructure across the SC-stewarded laboratory complex. These investments have provided state-of-the-art science user support facilities, renovated and repurposed aged facilities, upgraded inadequate core infrastructure and systems, and removed excess.

*Line-Item Construction Projects.*

Since FY 2006, the SLI program has successfully completed 15 line-item projects while garnering eleven DOE Secretary's Achievement Awards. These investments occurred following an FY 2006 SC decision to initiate a major effort to modernize infrastructure across the SC-stewarded laboratory complex. With these investments, the SLI program constructed more than 1,120,000 gsf of new space and modernized more than 450,000 gsf of existing space. As a result, an estimated 2,500 laboratory users and researchers now occupy newly constructed and/or modernized buildings that better support scientific and technological innovation in a collaborative environment.

*Core General Plant Project upgrades across SC Laboratories.*

Since FY 2016, SLI has funded over $150,000,000 in laboratory core infrastructure improvements including over $97,000,000 in electrical and utility improvements and over $44,000,000 in facility improvements. Examples of recent SLI investments in core infrastructure include renovating post-World War II era laboratory and support space and contamination mitigation at BNL, upgrading an outdated legacy fabrication facility at ORNL, and renovating mission critical buildings at Ames Laboratory. At LBNL, SLI funded the replacement of inadequate critical portions of the supply water and storm water drainage systems that serve all SC programs. At ANL, SLI funded upgrades to the laboratory's water and sewer system. At the Oak Ridge Institute for Science and Education (ORISE), SLI funded electrical and infrastructure improvements. Lastly, at SLAC, SLI funded the replacement of the low conductivity water cooling system and cooling towers serving the Stanford Synchrotron Radiation Light Source and the Linac Coherent Light Source.

*Building 350 Legacy Project at Argonne National Laboratory (ANL).*

As of the end of FY 2019, this SLI-funded project removed 16,944 of the approximately 20,000 nuclear material items from the former New Brunswick Laboratory building. The project also cleaned up approximately 20,481 square feet of the building's 28,598 total square feet that is within this project's scope for cleanout, a part of which is currently being used for programmatic work. The project continues to remove the remaining nuclear materials and clean-up space so the building can eventually be renovated and repurposed as a radiological facility by ANL, with project completion scheduled for FY 2022.

*Infrastructure and Operational Improvements project at PPPL.*

This project addressed inadequate facilities at PPPL that were impeding progress towards achieving research goals as well as hindering the attraction and retention of talented staff. It included renovation of 70,000 gsf of space in existing buildings to provide space for offices and equipment, and demolition of trailers used for office space and storage of equipment. This project was completed in FY 2019 and has provided the laboratory with upgraded infrastructure to support its mission of advancing the fields of fusion energy and plasma physics research necessary to realize fusion as an energy source.

*Photon Science Laboratory Building at SLAC.*

This project provided modern day laboratory space to accommodate a range of simulation, theory, and modeling for synthetic and characterization capabilities, while also supporting research collaborations with outside scientists engaged with SLAC's LCLS and SSRL user facilities. This was accomplished through a partnership with Stanford University, SLAC, and DOE. Stanford University provided a three-story building shell and the DOE provided 65,000 gsf of wet labs, dry labs, vibration-sensitive labs, cleanrooms, offices, and meetings rooms in support of the project's Mission Need Statement. The project was completed in FY 2019.

*Material Design Laboratory at ANL.*

This project provided a 124,000 gsf high performance laboratory building, with a variety of laboratories (including radiological labs), offices, meeting rooms, interaction areas and support functions for energy-related research and development. The building was programmed to meet the minimum needs of the Materials for Energy programs consistent with SC's vision for these programs at ANL: Frontiers of materials, molecular synthesis, and fabrication of devices; Interfacial engineering for energy applications; Materials under extreme conditions; and In situ characterization and modeling.

## Science Laboratories Infrastructure
## Infrastructure Support

**Description**
This subprogram funds infrastructure support investments that focus on laboratory core infrastructure and operations. Continuing Investments in core infrastructure (e.g., utility systems, site-wide services, and general purpose facilities) ensure that facilities and utilities are upgraded or replaced when they approach end-of-life, have improved reliability, efficiency, and performance, and that excess space is removed so that it no longer requires operation and maintenance funding and frees up valuable space for re-utilization. Without this type of investment, SC laboratories would not be able to keep up with needed upgrades and repairs. The funded activities include core infrastructure upgrades at various laboratories, general infrastructure support, and support for the nuclear facilities at ORNL.

This subprogram also funds Payment In Lieu of Taxes (PILT) to local communities around ANL, BNL, and ORNL, as well as stewardship-type needs (e.g., roads and grounds maintenance) across the Oak Ridge Reservation.

<u>Facilities and Infrastructure</u>
This activity funds infrastructure support investments that focus on laboratory core infrastructure and operations. SC laboratories conduct rigorous condition assessments of their core infrastructure, which determine the need for investments in these basic systems that form the backbone of their campuses. Each year, the SLI program continues this focus and collaborates with the SC research programs to review proposed investments and maintains an active list of critical core infrastructure needs. Priorities are evaluated continuously and the highest priority projects are selected for funding upon entry into the corresponding execution year.

<u>Nuclear Operations</u>
To support critical DOE nuclear operations, this Request includes base funding to operate ORNL's nuclear facilities (i.e., Buildings 7920, 7930, 3525, and 3025E). These facilities support a variety of users including the National Nuclear Security Agency (NNSA), SC, the Office of Nuclear Energy (NE), and other agencies. This funding supports maintenance and repair of hot cells and supporting systems while ensuring compliance with safety standards and procedures.

<u>Oak Ridge Landlord</u>
This funding supports landlord responsibilities, including infrastructure for the 24,000 acre Oak Ridge Reservation and DOE facilities in the city of Oak Ridge, Tennessee. Activities include maintenance of roads, grounds, and other infrastructure; and support and improvement of environmental protection, safety, and health.

<u>Payments in Lieu of Taxes</u>
Funding within this activity supports SC stewardship responsibilities for PILT. The Department is authorized to provide discretionary payments to state and local government authorities for real property that is not subject to taxation because it is owned by the United States Federal Government and operated by the Department. Under this authorization, PILT is provided to communities around ANL, BNL, and ORNL 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**

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| **Infrastructure Support** | **$93,000** | **$22,710** | **-$70,290** |
| Facilities and Infrastructure | $56,850 | $6,200 | -$50,650 |
| Funding continues to support de-inventory and removal of nuclear material at the former New Brunswick Laboratory (NBL) Building at ANL, and the highest priority core infrastructure needs. In addition, this funding supports the acquisition of real property at PNNL. | | The Request will continue to support the highest priority core infrastructure needs across the SC complex. | Funding decreases to reflect the request for final funding in FY 2020 for both the NBL de-inventory project and the completion of acquisition of real property at PNNL. Funding is also reduced for critical core infrastructure needs. |
| Nuclear Operations | $26,000 | $6,000 | -$20,000 |
| Funding continues to support critical nuclear operations and provides funding to manage ORNL's nuclear facilities. | | The Request will continue to support critical nuclear operations and will provide funding to manage ORNL's nuclear facilities. | Funding supports the most critical nuclear operations and facilities at ORNL. |
| Oak Ridge Landlord | $5,610 | $5,860 | +$250 |
| Funding supports landlord responsibilities across the Oak Ridge Reservation. Activities include maintenance of roads, grounds, and other infrastructure; and support and improvement of environmental protection, safety, and health. | | The Request will continue support of landlord responsibilities across the Oak Ridge Reservation. Activities include maintenance of roads, grounds, and other infrastructure; and support and improvement of environmental protection, safety, and health. | Funding increases to address necessary road maintenance and repairs. |
| Payment in Lieu of Taxes | $4,540 | $4,650 | +$110 |
| Funding supports PILT payments to communities around ANL, BNL, and ORNL. | | The Request will provide funding for PILT payments to communities around ANL, BNL, and ORNL. | Funding increases to support anticipated PILT requirements in FY 2021. |

**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 2021 Request includes funding for:

Three new line-item construction projects:

- Princeton Plasma Innovation Center at PPPL;
- Critical Infrastructure Recovery & Renewal at PPPL; and
- Ames Infrastructure Modernization at Ames.

Fifteen ongoing line-item construction projects:

- Critical Utilities Rehabilitation Project at BNL;
- Seismic and Safety Modernization at LBNL;
- CEBAF Renovation and Expansion at TJNAF;
- Craft Resources Support Facility at ORNL;
- Large Scale Collaboration Center at SLAC;
- Tritium System Demolition and Disposal at PPPL;
- Argonne Utilities Upgrade at ANL;
- Linear Assets Modernization Project at LBNL;
- Critical Utilities Infrastructure Revitalization at SLAC;
- Utilities Infrastructure Project at FNAL;
- Science User Support Center at BNL;
- Translational Research Capability at ORNL;
- Biological and Environmental Program Integration Center (BioEPIC) at LBNL;
- Energy Sciences Capability project at PNNL; and,
- Integrated Engineering Research Center at FNAL.

<u>Princeton Plasma Innovation Center, PPPL</u>

The Princeton Plasma Innovation Center (PPIC) will provide a multi-purpose facility to PPPL, with laboratory and office space to support the Office of Science mission and fulfill the research needs of the Fusion Energy Sciences (FES), Advanced Scientific Computing Research (ASCR), and Basic Energy Sciences (BES) programs.

The most recent DOE Order 413.3B Critical Decision (CD) is CD-0, Approve Mission Need, approved on September 9, 2019. The preliminary estimate for CD-1, Approve Alternative Selection and Cost Range, is anticipated in the fourth quarter of FY 2020. This project is pre-CD-2; therefore, schedule estimates are preliminary and subject to change. The current preliminary Total Estimated Cost (TEC) range for this project is $65,500,000 to $109,000,000 and the preliminary Total Project Cost (TPC) range of $68,000,000 to $111,500,000. These cost ranges encompass the most feasible preliminary alternatives at this time.

<u>Critical Infrastructure Recovery & Renewal, PPPL</u>

The Critical Infrastructure Recovery & Renewal (CIRR) project at PPPL will revitalize critical infrastructure that supports the PPPL campus. Upgrades that may be completed as part of the CCIR project include: the electrical distribution system; standby power; chilled water generation and distribution; distribution networks for steam, compressed air, sanitary waste, and condenser, storm, canal, and potable water; HVAC systems; and communication systems.

The most recent DOE Order 413.3B Critical Decision (CD) is CD-0, Approve Mission Need, approved on September 16, 2019. The preliminary estimate for CD-1, Approve Alternative Selection and Cost Range, is anticipated in the second quarter of FY 2020. This project is pre-CD-2; therefore, schedule estimates are preliminary and subject to change. The current preliminary Total Estimated Cost (TEC) range for this project is $48,900,000 to $80,400,000. The preliminary Total Project

Cost (TPC) range for this project is $50,400,000 to $81,900,000. These cost ranges encompass the most feasible preliminary alternatives at this time.

Ames Infrastructure Modernization, Ames

The Ames Infrastructure Modernization (AIM) project will support the SC mission by providing a safer and more operationally efficient campus for the employees, visitors, and guests at Ames, as well as reduce deferred maintenance costs. This project is designed to support DOE mission-critical programs and initiatives, increase the reliability of utility infrastructure, minimize facility costs through effective and efficient operations, and modernize laboratories in Ames Laboratory's research buildings, thereby enhancing Ames Laboratory's ability to continue to deliver on SC's mission across multiple program offices.

Specifically, this project will provide updated infrastructure building systems in existing research and operations buildings at Ames Laboratory, such as plumbing systems; building envelopes; electrical systems-emergency, backup power, and uninterruptible power supplies; and telecommunication systems. In addition, some of the laboratory spaces will be modernized to support the SC mission and associated equipment.

The most recent DOE Order 413.3B Critical Decision (CD) is CD-0, Approve Mission Need*,* approved on September 16, 2019. The preliminary estimate for CD-1, Approve Alternative Selection and Cost Range, is anticipated in the third quarter of FY 2021. This project is pre-CD-2; therefore, schedule estimates are preliminary and subject to change. The current preliminary Total Estimated Cost (TEC) range for this project is $21,000,000 to $88,000,000. The preliminary Total Project Cost (TPC) range for this project is $23,000,000 to $90,000,000. These cost ranges encompass the most feasible preliminary alternatives at this time.

Critical Utilities Rehabilitation Project, BNL

The Critical Utilities Rehabilitation Project at BNL will revitalize and upgrade highest risk major utility systems to meet the needs of supporting SC facilities and Nuclear Physics (NP), Basic Energy Sciences (BES), High Energy Physics (HEP), Biological and Environmental Research (BER), and Advanced Scientific Computing Research (ASCR) program missions.

Specifically, this project will replace piping in areas prone to water main breaks and provide other water system improvements to improve system operations and reliability. Select sections of the sanitary utility systems with failing pumps, controllers, and/or manholes will be replaced. This project will also provide several required modifications to the central chilled water system in order to support growth of process loads and ensure reliability. Deteriorated and leaking steam systems along Cornell Avenue will be replaced to ensure safe, reliable, and efficient steam service to mission-critical facilities on the north side of the campus. In addition, older feeder cables and inadequate breakers will be replaced along Cornell Avenue, increasing capacity, reliability and personnel safety.

The most recent DOE Order 413.3B Critical Decision (CD) is CD-0, Approve Mission Need, approved on July 20, 2018. The preliminary estimate for CD-1, Approve Alternative Selection and Cost Range, is anticipated in the second quarter of FY 2020. This project is pre-CD-2; therefore, schedule estimates are preliminary and subject to change. The preliminary TEC range for this project is $70,000,000 to $92,000,000. The preliminary TPC range for this project is $70,800,000 to $92,800,000. These cost ranges encompass the most feasible preliminary alternatives at this time.

Seismic and Safety Modernization, LBNL

The Seismic and Safety Modernization project will address seismic safety issues and emergency response capabilities, specifically related to facilities with large congregation areas as well as improve facilities that are necessary for emergency response personnel and to maintain continuity of operations. The facilities that are the primary focus of this project are the Cafeteria, Health Services, and Fire House sleeping quarters.

The most recent DOE Order 413.3B Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range, approved on September 4, 2019. The preliminary estimate for CD-2, Approve Performance Baseline, is anticipated in the third quarter of FY 2021. This project is pre-CD-2; therefore, schedule estimates are preliminary and subject to change. This project has a preliminary TEC range of $65,600,000 to $95,400,000 and the preliminary TPC range of $67,800,000 to $97,600,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The preliminary TEC point estimate for this project is $95,400,000 and the preliminary TPC point estimate for this project is $97,600,000.

<u>CEBAF Center Renovation and Expansion, TJNAF</u>

The CEBAF Renovation and Expansion project will renovate existing space and provide new research, administrative, and support service space enabling TJNAF to better support SC missions. The CEBAF center at TJNAF is currently overcrowded and has inadequate utility systems that are experiencing frequent failures. This project will renovate 123,000 to 250,000 gross square feet (gsf) of existing space in the CEBAF center and the Applied Research Center (ARC), upgrade high risk utility systems, and provide 82,000 to 150,000 gsf of additional space for visitors, users, research, education, and support.

The most recent DOE Order 413.3B Critical Decision (CD) is CD-0, Approve Mission Need, approved on July 20, 2018. The preliminary estimate for CD-1, Approve Alternative Selection and Cost Range, is anticipated in the first quarter of FY 2020. This project is pre-CD-2; therefore, schedule estimates are preliminary and subject to change. This project has a preliminary TEC range of $47,000,000 to $96,000,000 and a preliminary TPC range of $48,900,000 to $99,300,000. These cost ranges encompass the most feasible preliminary alternatives at this time.

<u>Craft Resources Support Facility, ORNL</u>

The Craft Resources Support Facility project will relocate and consolidate craft resource services that are currently housed in multiple, inadequate facilities spread across the campus in the 7000 area. ORNL supports the mission work of all six of SC's research program offices and three scientific user facilities. The complex infrastructure required to support the SC mission and associated one-of-a-kind large scale facilities places a substantial demand on craft resource support functions, which is comprised of 28 different trades ranging from automotive mechanics to instrument technicians. Craft resource support services are currently housed in multiple facilities spread across the 7000 campus area which are outdated and poorly configured resulting in inefficient operations, congested vehicle and pedestrian traffic patterns, and increased safety risks. These conditions are creating inefficient, and unreliable operations, which are directly impacting many high-priority SC programs at ORNL.

The most recent DOE Order 413.3B Critical Decision (CD) is CD-0, Approve Mission Need, approved on July 20, 2018. The preliminary estimate for CD-1, Approve Alternative Selection and Cost Range, is anticipated in the second quarter of FY 2020. This project is pre-CD-2; therefore, schedule estimates are preliminary and subject to change. This project has a preliminary TEC range of $34,000,000 to $48,000,000 and a preliminary TPC range of $35,000,000 to $49,000,000. These cost ranges encompass the most feasible preliminary alternatives at this time.

<u>Large Scale Collaboration Center, SLAC</u>

The Large Scale Collaboration Center project will construct a multi-office building of approximately 38,000 to 45,000 gsf to consolidate and provide space for 100-150 occupants in a common building, provide synergies among all major SC-sponsored programs at SLAC, and provide a centralized office and collaboration space for cross-functional teams with the necessary performance capabilities to grow the science research programs. With the growth in SC mission activities at SLAC – from the Linac Coherent Light Source (LCLS), LCLS-II, LCLS-II-HE projects to Facility for Advanced Accelerator Experimental Tests (FACET)-II and the Matter in Extreme Conditions project – the lab currently lacks office spaces for scientists and staff as current spaces are fully occupied or oversubscribed, and therefore do not support the needs for joint collaborations for exploring challenges and developing solutions using large-scale data sets. Adjacent office spaces that enable researchers to benefit from collaboration with subject matter experts in computational science, machine learning, artificial intelligence, exascale computing, data management, data acquisition, simulation, imaging, visualization, and modeling are also not currently available.

The most recent DOE Order 413.3B Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range, approved on November 18, 2019. The preliminary estimate for CD-2, Approve Performance Baseline, is anticipated in the first quarter of FY 2022. This project is pre-CD-2; therefore, schedule estimates are preliminary and subject to change. This project has a preliminary TEC range of $56,000,000 to $90,400,000 and a preliminary TPC range of $59,400,000 to $92,400,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The preliminary TEC point estimate for this project is $64,000,000 and the preliminary TPC point estimate for this project is $66,000,000.

Tritium System Demolition and Disposal, PPPL
The Tritium System Demolition and Disposal (TSDD) project at PPPL will remove tritium-contaminated items, components, equipment, sub-systems, etc., through demolition and disposal off-site. Execution of the TSDD project will result in reducing the risk of tritium release, reducing the risk of worker exposure to tritium, and reducing operating dollars expended on a legacy system.

The most recent DOE Order 413.3B Critical Decision (CD) is CD-0, Approve Mission Need, approved on September 16, 2019. The preliminary estimate for CD-1, Approve Alternative Selection and Cost Range, is anticipated in the fourth quarter of FY 2020. This project is pre-CD-2; therefore, schedule estimates are preliminary and subject to change. The current preliminary Total Estimated Cost (TEC) range for this project is $19,500,000 to $32,400,000. The preliminary Total Project Cost (TPC) range for this project is $20,500,000 to $33,400,000. These cost ranges encompass the most feasible preliminary alternatives at this time.

Argonne Utilities Upgrade, ANL
The Argonne Utilities Upgrade project at ANL is proposed to revitalize and selectively upgrade ANL's existing major utility systems including steam, water, sanitary sewer, chilled water, and electrical systems.

The most recent DOE Order 413.3B Critical Decision (CD) is CD-0, Approve Mission Need, approved on May 17, 2019. The preliminary estimate for CD-1, Approve Alternative Selection and Cost Range, is anticipated in the fourth quarter of FY 2020. This project is pre-CD-2; therefore, schedule estimates are preliminary and subject to change. The preliminary Total Estimated Cost (TEC) range for this project is $72,000,000 to $215,000,000. The preliminary Total Project Cost (TPC) range for this project is $73,000,000 to $216,000,000. These cost ranges encompass the most feasible preliminary alternatives at this time.

Linear Assets Modernization Project, LBNL
The Linear Assets Modernization Project at LBNL is proposed to upgrade high priority utility systems to increase the reliability, capability, and safety of LBNL's infrastructure to meet the DOE's mission. The project will upgrade utility systems including, but not limited to, domestic water, natural gas, storm drain, sanitary sewer, electrical, and communication.

The most recent DOE Order 413.3B Critical Decision (CD) is CD-0, Approve Mission Need, approved on May 17, 2019. The preliminary estimate for CD-1, Approve Alternative Selection and Cost Range, is anticipated in the fourth quarter of FY 2020. This project is pre-CD-2, therefore schedule estimates are preliminary and subject to change. The preliminary Total Estimated Cost (TEC) range for this project is $142,000,000 to $236,000,000. The preliminary Total Project Cost (TPC) range for this project is $146,000,000 to $240,000,000. These cost ranges encompass the most feasible preliminary alternatives at this time.

Critical Utilities Infrastructure Revitalization, SLAC
The primary objective of CUIR is to close infrastructure gaps to support multi-program science missions as technologies, instruments, experimental parameters, sensitivities, and complexity associated with evolving science demand increases required reliability, resiliency, and service levels in electrical, mechanical, and civil systems site wide. The CUIR project will address the critical campus-wide utility and infrastructure issues by replacing, repairing, and modernizing the highest risk water/fire protection, sanitary sewer, storm drain, electrical, and cooling water system deficiencies. Subject matter experts responsible for stewardship of the systems have identified these needs through condition assessments, inspections, and recommendations.

The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-0, Approve Mission Need, approved May 17, 2019. The preliminary estimate for CD-1, Approve Alternative Selection and Cost Range, is anticipated in the fourth quarter of FY 2020. This project is pre-CD-2; therefore, schedule estimates are preliminary and subject to change. The preliminary Total Estimated Cost (TEC) range for this project is $80,000,000 to $186,000,000. The preliminary Total Project Cost (TPC) range for this project is $83,000,000 to $189,000,000. These cost ranges encompass the most feasible preliminary alternatives at this time.

Utilities Infrastructure Project, FNAL

The Utilities Infrastructure Project at FNAL will identify, recapitalize, and upgrade the highest risk major utility systems across the FNAL campus. Specifically, this project will evaluate the current condition of the industrial cooling water system, potable water distribution system, sanitary sewer and storm collection systems, natural gas distribution system, electrical distribution system, and the Central Utility Building. Selected portions of the systems will be recapitalized or replaced to assure safe, reliable, and efficient service to mission critical facilities. In addition, upgrades to obsolete, end-of-life components will increase capacity, reliability, and personnel safety for critical utilities.

The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-0, Approve Mission Need, approved on May 17, 2019. The preliminary estimate for CD-1, Approve Alternative Selection and Cost Range, is anticipated in the first quarter of FY 2021. This project is pre-CD-2; therefore, schedule estimates are preliminary and subject to change. The current preliminary Total Estimated Cost (TEC) range for this project is $146,000,000 to $310,000,000 and the preliminary Total Project Cost (TPC) range of $150,000,000 to $314,000,000. These cost ranges encompass the most feasible preliminary alternatives at this time.

Science User Support Center, BNL

Construction of the Science User Support Center will provide convenient and efficient facilities for processing and supporting the users of BNL's premier research facilities by replacing the current dispersed and inefficient facilities. It will also provide conference facilities to support the collaborative science and research agenda for the user community and BNL scientists. BNL user facilities and capabilities supported by DOE and partnering agencies attract over 40,000 visiting scientists, guests, users, and contractors annually to conduct research in a broad range of basic and applied sciences. However, the ability to efficiently process and support the needs of this growing community of researchers is limited by the age, deteriorated condition, and dispersed nature of BNL's current facilities.

The most recent DOE Order 413.3B Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range, approved on December 18, 2018. The preliminary estimate for CD-2, Approve Performance Baseline, is anticipated in the fourth quarter of FY 2020. This project is pre-CD-2; therefore, schedule estimates are preliminary and subject to change. This project has a preliminary TEC range of $70,800,000 to $94,800,000. The preliminary total TPC range for this project is $72,000,000 to $96,000,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The preliminary TEC point estimate for this project is $85,000,000 and the preliminary TPC point estimate for this project is $86,200,000.

Translational Research Capability, ORNL

The Translational Research Capability project is proposed to provide a new building with laboratory space to support mission-critical research sponsored by ASCR, BES, FES and HEP. Currently, ORNL has a shortage of modern, flexible, and adaptable space, wet and dry laboratories, and high bay space needed to support research directed by these SC programs. Aging infrastructure and utilities have caused severe temperature, humidity and power quality problems, particularly in the advanced materials development and research. Finally, dispersed research space across the ORNL campus remains a challenge in supporting the increasingly interdisciplinary and collaborative research required to advance SC program mission areas.

The most recent DOE Order 413.3B Critical Decision (CD) is CD-3A, Approve Long-Lead Procurements and Start of Early Construction Activities, approved on February 5, 2019. The preliminary estimate for CD-2, Approve Performance Baseline, is anticipated in the third quarter of FY 2020. This project is pre-CD-2, therefore schedule estimates are preliminary and subject to change. This project has a preliminary TEC range of $80,300,000 to $93,500,000 and a preliminary TPC range of $81,800,000 to $95,000,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The preliminary TEC point estimate for this project is $93,500,000 and the preliminary TPC point estimate for this project is $95,000,000.

Biological and Environmental Program Integration Center (BioEPIC), LBNL

The BioEPIC project will construct a new, state-of-the-art facility with laboratory space to support high performance research by the BER, ASCR and BES programs. LBNL has grown from a pioneering particle and nuclear physics laboratory into a multidisciplinary research facility with broad capabilities in physical, chemical, computational, biological, and environmental systems research in support of the DOE mission. Much of the biological sciences program at LBNL is located off-site and away from the main laboratory and other parts are dispersed across several locations on the LBNL campus. This arrangement has posed a challenge to research and operational capabilities limiting scientific progress and the kind of collaborative science that is required for understanding, predicting, and harnessing the Earth's microbiome for energy and environmental benefits.

The most recent DOE Order 413.3B Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range, approved on May 9, 2019. The preliminary estimate for CD-2, Approve Performance Baseline, is anticipated in the fourth quarter of FY 2021. This project is pre-CD-2; therefore, schedule estimates are preliminary and subject to change. This project has a preliminary TEC range of $110,000,000 to $190,000,000 and a preliminary TPC range of $112,200,000 to $192,200,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The preliminary TEC point estimate for this project is $140,000,000 and the preliminary TPC point estimate for this project is $142,200,000.

Energy Sciences Capability, PNNL

The Energy Sciences Capability project will enhance PNNL's core fundamental science programs by addressing many infrastructure capability gaps, including insufficient hood space for catalysis synthesis and collaboration, lack of proper environmental controls for state-of-the-art in situ characterization, limited space to integrate experimental capabilities for visualization supporting research in data analytics, modeling, and simulation, and performance modeling (for the Center for Advanced Technology Evaluation/ASCR related capability), and limited collaboration space for users and strategic partners.

The most recent DOE Order 413.3B Critical Decision (CD) is CD-2/3, Approve Project Performance Baseline and Approve Start of Construction, approved on December 7, 2018. The preliminary estimate for CD-4, Approve Start of Operations or Project Completion, is anticipated in the fourth quarter of FY 2023. The Total Estimated Cost (TEC) for this project is $90,000,000. The Total Project Cost (TPC) for this project is $93,000,000.

Integrated Engineering Research Center, FNAL

The Integrated Engineering Research Center project will construct a scientific user support facility to accommodate increased collaboration and interactions among staff at FNAL, who will in turn be working with scientific collaborators and international partners in the design, construction, and operation of physics experiments. Currently, FNAL staff and their associated manufacturing, assembly, engineering, and technical facilities are scattered among three parts of the campus. As a result, they are unable to efficiently collaborate on ongoing and planned projects in support of the mission of the laboratory. The Integrated Engineering Research Center will provide FNAL with a collaborative, multi-divisional and interdisciplinary research center, will reduce the overall footprint of outdated facilities and collocate engineering and associated research staff near the central campus, and will improve operational efficiency and collaboration because groups working on key projects would be in close proximity.

The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-3A, Approve Long Lead Procurement, which was approved on July 16, 2019. The preliminary estimate for CD-2/3, Approve Project Baseline and Approve Start of Construction Activities, is anticipated in the fourth quarter of FY 2020. This project is pre-CD-2, therefore schedule estimates are preliminary and subject to change. This project has a preliminary TEC range of $73,000,000 to $98,000,000. The TPC range for this project is $74,000,000 to $99,000,000. The preliminary TEC point estimate for this project is $85,000,000 and the preliminary TPC point estimate for this project is $86,000,000.

**Activities and Explanation of Changes**

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|
| **Construction** | **$208,000** | | **$151,400** | **-$56,600** |
| 21-SC-71, Princeton Plasma Innovation Center, PPPL | $— | | $2,000 | +$2,000 |
| No funding was appropriated. | | The Request will initiate Project Engineering and Design (PED) activities. | | The increase will support the initiation of PED activities for this new project. |
| 21-SC-72, Critical Infrastructure Recovery & Renewal, PPPL | $— | | $2,000 | +$2,000 |
| No funding was appropriated. | | The Request will initiate PED activities. | | The increase will support the initiation of PED activities for this new project. |
| 21-SC-73, Ames Infrastructure Modernization | $— | | $2,000 | +$2,000 |
| No funding was appropriated. | | The Request will initiate PED activities. | | The increase will support the initiation of PED activities for this new project. |
| 20-SC-71, Critical Utilities Rehabilitation Project, BNL | $20,000 | | $15,000 | -$5,000 |
| Funding supports the initiation of PED and construction activities. | | The Request will support construction activities. | | Funding will support ongoing construction activities for this project. |
| 20-SC-72, Seismic and Safety Modernization, LBNL | $10,000 | | $10,000 | $— |
| Funding fully supports PED activities for this project. | | The Request will initiate construction activities. | | Funding initiates construction activities for this project. |

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| 20-SC-73, CEBAF Renovation and Expansion, TJNAF | $2,000 | $2,000 | $— |
| Funding initiates PED activities for this project. | | The Request will support ongoing PED activities. | Funding continues ongoing PED activities for this project. |
| 20-SC-74, Craft Resources Support Facility, ORNL | $15,000 | $25,000 | +$10,000 |
| Funding initiates PED and construction activities for this project. | | The Request will support ongoing construction activities. | Requested funding will provide final funding for this project. |
| 20-SC-75, Large Scale Collaboration Center, SLAC | $11,000 | $8,000 | -$3,000 |
| Funding initiates PED and construction activities for this project. | | The Request will support ongoing construction activities. | Funding supports ongoing construction for this project. |
| 20-SC-76, Tritium System Demolition and Disposal, PPPL | $13,000 | $19,400 | +$6,400 |
| Funding initiates PED and construction activities. | | The Request will support ongoing construction activities. | Increase provides final funding for this project and supports ongoing construction. |
| 20-SC-77, Argonne Utilities Upgrade, ANL | $500 | $2,000 | +$1,500 |
| Funding initiates PED activities. | | The Request will support ongoing PED activities. | The increase will provide funding to support ongoing PED activities for this project. |
| 20-SC-78, Linear Assets Modernizaton, LBNL | $500 | $2,000 | +$1,500 |
| Funding initiates PED activities. | | The Request will support ongoing PED activities. | The increase will provide funding to support ongoing PED activities for this project. |
| 20-SC-79, Critical Utilities Infrastructure Revitalization, SLAC | $500 | $2,000 | +$1,500 |
| Funding initiates PED activities. | | The Request will support ongoing PED activities. | The increase will provide funding to support ongoing PED activities for this project. |

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|
| 20-SC-80, Utilities Infrastructure Project, FNAL | $500 | | $2,000 | +$1,500 |
| Funding initiates PED activities. | | The Request will support ongoing PED activities. | | The increase will support ongoing PED activities for this project. |
| 19-SC-71, Science User Support Center, BNL | $20,000 | | $7,000 | -$13,000 |
| Funding supports the completion of PED activities and start of construction activities. | | The Request will support construction activities. | | Funding supports ongoing construction activities for this project. |
| 19-SC-72, Electrical Capacity and Distribution Capability, ANL | $30,000 | | $— | -$30,000 |
| Funding supports the completion of construction activities. | | No funding is requested. | | Final funding was provided in FY 2020 for this project. |
| 19-SC-73, Translational Research Capability, ORNL | $25,000 | | $10,000 | -$15,000 |
| Funding supports construction activities. | | The Request will support construction activities. | | Funding will support ongoing construction activities for this project. |
| 19-SC-74, BioEPIC, LBNL | $15,000 | | $6,000 | -$9,000 |
| Funding supports the completion of PED activities and start of construction activities. | | The Request will support construction activities | | Funding supports ongoing construction activities for this project. |
| 18-SC-71, Energy Sciences Capability, PNNL | $23,000 | | $23,000 | $— |
| Funding supports construction activities. | | The Request will support the completion of construction activities. | | Requested funding will provide final funding for this project. |
| 17-SC-71, Integrated Engineering Research Center, FNAL | $22,000 | | $12,000 | -$10,000 |
| Funding supports construction activities. | | The Request will support construction activities. | | Funding supports ongoing construction activities for this project. |

## Science Laboratories Infrastructure
## Capital Summary

(dollars in thousands)

| | Total | Prior Years | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|---|---|
| **Capital Operating Expenses** | | | | | | |
| Minor Construction Activities | | | | | | |
| General Plant Projects (GPP) | N/A | N/A | 13,188 | 38,578 | 6,000 | -32,578 |
| Institutional General Plant Projects (IGPP) | N/A | N/A | 86,408 | 87,835 | 85,450 | -2,385 |
| **Total, Capital Operating Expenses** | **N/A** | **N/A** | **99,596** | **126,413** | **91,450** | **-34,963** |

### Minor Construction Activities

(dollars in thousands)

| | Total | Prior Years | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|---|---|
| **General Plant Projects (GPP)** | | | | | | |
| Greater than or equal to $5M and less than $20M | | | | | | |
| Cooling Water Tower System at SLAC | N/A | N/A | 9,400 | — | — | — |
| Accelerated PFAS Source Area Groundwater Characterization and Remediation at BNL | N/A | N/A | — | 10,900 | — | -10,900 |
| Grizzly Substation Yard Expansion at LBNL | N/A | N/A | — | 15,000 | — | -15,000 |
| Village Sanitary Improvements/Lift Station at FNAL | N/A | N/A | — | 6,000 | — | -6,000 |
| Cryogenics Test Facility (CTF) Upgrade at TJNAF | N/A | N/A | — | 5,200 | — | -5,200 |
| Total GPPs (greater than or equal to $5M and less than $20M) | N/A | N/A | 9,400 | 37,100 | — | -37,100 |
| Total GPPs less than $5M | N/A | N/A | 3,788 | 1,478 | 6,000 | +4,522 |
| **Total, General Plant Projects (GPP)[a]** | **N/A** | **N/A** | **13,188** | **38,578** | **6,000** | **-32,578** |

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

(dollars in thousands)

| | Total | Prior Years | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|---|---|
| **Institutional General Plant Projects (IGPP)** | | | | | | |
| Greater than or equal to $5M and less than $20M | | | | | | |
| Bayview Site Utility Replacement Project at LBNL | N/A | N/A | 8,500 | — | — | — |
| Sitewide Electrical Safety and Maintenance Upgrades Phase 1 at LBNL | N/A | N/A | 17,800 | — | — | — |
| Sitewide Mechanical Plant Maintenance Upgrades Phase 1 at LBNL | N/A | N/A | 17,150 | — | — | — |
| 7000 Area Storage at ORNL | N/A | N/A | 6,330 | — | — | — |
| 7000 Area Utility Modernization at ORNL | N/A | N/A | 7,600 | — | — | — |
| 4500N General Use Office Space at ORNL | N/A | N/A | 5,850 | — | — | — |
| 2000/3000 Area Utility Modernization at ORNL | N/A | N/A | 9,200 | — | — | — |
| Building 6010 Generic Research & Office Swing-space Buildout at ORNL | N/A | N/A | 9,000 | — | — | — |
| B77 Enclosure Installation at LBNL | N/A | N/A | — | 5,150 | — | -5,150 |
| B77 Engineering Facility Capabilities Modernization at LBNL | N/A | N/A | — | 6,000 | — | -6,000 |
| B73 Seismic Upgrade and Modernization at LBNL | N/A | N/A | — | 12,615 | — | -12,615 |
| Transit Hub and Utility Improvements at LBNL | N/A | N/A | — | 14,865 | — | -14,865 |
| Secondary Sewage Treatment Upgrade at ORNL | N/A | N/A | — | 19,000 | — | -19,000 |
| Centennial Bridge Replacement at LBNL | N/A | N/A | — | — | 13,000 | +13,000 |
| Grizzly Substation Upgrade at LBNL | N/A | N/A | — | — | 18,500 | +18,500 |
| General Purpose Data Center Expansion at LBNL | N/A | N/A | — | — | 16,000 | +16,000 |
| Total IGPPs (greater than or equal to $5M and less than $20M) | N/A | N/A | 81,430 | 57,630 | 47,500 | -10,130 |
| Total IGPPs less than $5M | N/A | N/A | 4,978 | 30,205 | 37,950 | +7,745 |
| **Total, Institutional General Plant Projects (IGPP)[a]** | **N/A** | **N/A** | **86,408** | **87,835** | **85,450** | **-2,385** |
| | | | | | | |
| **Total, Direct Funded Minor Construction** | **N/A** | **N/A** | **13,188** | **38,578** | **6,000** | **-32,578** |
| **Total, Indirect Funded Minor Construction** | **N/A** | **N/A** | **86,408** | **87,835** | **85,450** | **-2,385** |
| **Total, Minor Construction Activities** | **N/A** | **N/A** | **99,596** | **126,413** | **91,450** | **-34,963** |

[a] Institutional General Plant Projects (IGPPs) are indirect funded minor construction activities that are general institutional in nature and address general purpose, site-wide needs.

## Science Laboratories Infrastructure
## Construction Projects Summary

(dollars in thousands)

| | Total | Prior Years | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|---|---|
| **21-SC-71, Princeton Plasma Innovation Center, PPPL** | | | | | | |
| TEC | 109,000[a] | — | — | — | 2,000 | +2,000 |
| OPC[b] | 2,500 | — | 300 | 2,000 | — | -2,000 |
| **TPC** | **111,500**[a] | **—** | **300** | **2,000** | **2,000** | **—** |
| **21-SC-72, Critical Infrastructure Recovery & Renewal, PPPL** | | | | | | |
| TEC | 80,400[a] | — | — | — | 2,000 | +2,000 |
| OPC[b] | 1,500 | — | 100 | 1,200 | — | -1,200 |
| **TPC** | **81,900**[a] | **—** | **100** | **1,200** | **2,000** | **+800** |
| **21-SC-73 Ames Infrastructure Modernization** | | | | | | |
| TEC | 30,000[a] | — | — | — | 2,000 | +2,000 |
| OPC[b] | 1,000 | — | — | 250 | 250 | — |
| **TPC** | **31,000**[a] | **—** | **—** | **250** | **2,250** | **+2,000** |
| **20-SC-71, Critical Utilities Rehabilitation Project, BNL** | | | | | | |
| TEC | 92,000[a] | — | — | 20,000 | 15,000 | -5,000 |
| OPC[b] | 800 | — | 800 | — | — | — |
| **TPC** | **92,800**[a] | **—** | **800** | **20,000** | **15,000** | **-5,000** |
| **20-SC-72, Seismic and Safety Modernization, LBNL** | | | | | | |
| TEC | 95,400[a] | — | — | 10,000 | 10,000 | — |
| OPC[b] | 2,200 | — | 1,500 | 100 | — | -100 |
| **TPC** | **97,600**[a] | **—** | **1,500** | **10,100** | **10,000** | **-100** |

[a] This project has not received CD-2 approval; therefore, preliminary estimates are shown for TEC and TPC.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

| | Total | Prior Years | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|---|---|
| | (dollars in thousands) | | | | | |
| **20-SC-73, CEBAF Renovation and Expansion, TJNAF** | | | | | | |
| TEC | 87,000[a] | — | — | 2,000 | 2,000 | — |
| OPC[b] | 2,300 | — | 1,000 | 700 | — | -700 |
| **TPC** | **89,300**[a] | **—** | **1,000** | **2,700** | **2,000** | **-700** |
| **20-SC-74, Craft Resources Support Facility, ORNL** | | | | | | |
| TEC | 40,000[a] | — | — | 15,000 | 25,000 | +10,000 |
| OPC[b] | 1,000 | — | 800 | — | — | — |
| **TPC** | **41,000**[a] | **—** | **800** | **15,000** | **25,000** | **+10,000** |
| **20-SC-75, Large Scale Collaboration Center, SLAC** | | | | | | |
| TEC | 64,000[a] | — | — | 11,000 | 8,000 | -3,000 |
| OPC[b] | 2,000 | — | 500 | 200 | 1,300 | +1,100 |
| **TPC** | **66,000**[a] | **—** | **500** | **11,200** | **9,300** | **-1,900** |
| **20-SC-76, Tritium System Demolition and Disposal, PPPL** | | | | | | |
| TEC | 32,400[a] | — | — | 13,000 | 19,400 | +6,400 |
| OPC[b] | 1,000 | — | 100 | 800 | 100 | -700 |
| **TPC** | **33,400**[a] | **—** | **100** | **13,800** | **19,500** | **+5,700** |
| **20-SC-77, Argonne Utilities Upgrade, ANL** | | | | | | |
| TEC | 215,000[a] | — | — | 500 | 2,000 | +1,500 |
| OPC[b] | 1,000 | — | 100 | 600 | 300 | -300 |
| **TPC** | **216,000**[a] | **—** | **100** | **1,100** | **2,300** | **+1,200** |

[a] This project has not received CD-2 approval; therefore, preliminary estimates are shown for TEC and TPC.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

| | (dollars in thousands) | | | | | |
|---|---|---|---|---|---|---|
| | **Total** | **Prior Years** | **FY 2019 Enacted** | **FY 2020 Enacted** | **FY 2021 Request** | **FY 2021 Request vs FY 2020 Enacted** |
| **20-SC-78, Linear Assets Modernization Project, LBNL** | | | | | | |
| TEC | 236,000[a] | — | — | 500 | 2,000 | +1,500 |
| OPC[b] | 4,000 | — | 300 | 1,700 | — | -1,700 |
| **TPC** | **240,000[a]** | **—** | **300** | **2,200** | **2,000** | **-200** |
| **20-SC-79, Critical Utilities Infrastructure Revitalization, SLAC** | | | | | | |
| TEC | 186,000[a] | — | — | 500 | 2,000 | +1,500 |
| OPC[b] | 3,000 | — | — | 1,000 | 1,000 | — |
| **TPC** | **189,000[a]** | **—** | **—** | **1,500** | **3,000** | **+1,500** |
| **20-SC-80, Utilities Infrastructure Project, FNAL** | | | | | | |
| TEC | 310,000[a] | — | — | 500 | 2,000 | +1,500 |
| OPC[b] | 4,000 | — | 100 | 1,900 | — | -1,900 |
| **TPC** | **314,000[a]** | **—** | **100** | **2,400** | **2,000** | **-400** |
| **19-SC-71, Science User Support Center, BNL** | | | | | | |
| TEC | 85,000[a] | — | 7,000 | 20,000 | 7,000 | -13,000 |
| OPC[b] | 1,200 | 1,000 | 200 | — | — | — |
| **TPC** | **86,200[a]** | **1,000** | **7,200** | **20,000** | **7,000** | **-13,000** |
| **19-SC-72, Electrical Capacity and Distribution Capability, ANL** | | | | | | |
| TEC | 60,000[a] | — | 30,000 | 30,000 | — | -30,000 |
| OPC[b] | 1,000 | — | — | — | — | — |
| **TPC** | **61,000[a]** | **—** | **30,000** | **30,000** | **—** | **-30,000** |

[a] This project has not received CD-2 approval; therefore, preliminary estimates are shown for TEC and TPC.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

(dollars in thousands)

| | Total | Prior Years | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|---|---|
| **19-SC-73, Translational Research Capability, ORNL** | | | | | | |
| TEC | 93,500[a] | — | 25,000 | 25,000 | 10,000 | -15,000 |
| OPC[b] | 1,500 | 1,190 | 210 | — | — | — |
| **TPC** | **95,000[a]** | **1,190** | **25,210** | **25,000** | **10,000** | **-15,000** |
| **19-SC-74, BioEPIC, LBNL** | | | | | | |
| TEC | 140,000[a] | — | 5,000 | 15,000 | 6,000 | -9,000 |
| OPC[b] | 2,200 | — | 1,500 | — | — | — |
| **TPC** | **142,200[a]** | **—** | **6,500** | **15,000** | **6,000** | **-9,000** |
| **18-SC-71, Energy Sciences Capability, PNNL** | | | | | | |
| TEC | 90,000 | 20,000 | 24,000 | 23,000 | 23,000 | — |
| OPC[b] | 3,000 | 1,236 | — | — | — | — |
| **TPC** | **93,000** | **21,236** | **24,000** | **23,000** | **23,000** | **—** |
| **17-SC-71, Integrated Engineering Research Center, FNAL** | | | | | | |
| TEC | 85,000[a] | 22,500 | 20,000 | 22,000 | 12,000 | -10,000 |
| OPC[b] | 1,000 | 930 | — | — | — | — |
| **TPC** | **86,000[a]** | **23,430** | **20,000** | **22,000** | **12,000** | **-10,000** |
| **17-SC-73, Core Facility Revitalization, BNL** | | | | | | |
| TEC | 74,000 | 31,800 | 42,200 | — | — | — |
| OPC[b] | 850 | 850 | — | — | — | — |
| **TPC** | **74,850** | **32,650** | **42,200** | **—** | **—** | **—** |
| **Total, Construction** | | | | | | |
| **TEC** | **N/A** | **N/A** | **153,200** | **208,000** | **151,400** | **-56,600** |
| **OPC[b]** | **N/A** | **N/A** | **7,410** | **10,450** | **2,950** | **-7,500** |
| **TPC** | **N/A** | **N/A** | **160,610** | **218,450** | **154,350** | **-64,100** |

[a] This project has not received CD-2 approval; therefore, preliminary estimates are shown for TEC and TPC.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

**Science Laboratories Infrastructure**
**Funding Summary**

(dollars in thousands)

| | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|
| Projects | 153,200 | 208,000 | 151,400 | -56,600 |
| Other | 79,690 | 93,000 | 22,710 | -70,290 |
| **Total, Science Laboratories Infrastructure** | **232,890** | **301,000** | **174,110** | **-126,890** |

**21-SC-71, Princeton Plasma Innovation Center**
**Princeton Plasma Physics Laboratory (PPPL)**
**Project is for Design and Construction**

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

**Summary**

The FY 2021 Request for the Princeton Plasma Innovation Center (PPIC) project is $2,000,000. This project has a preliminary Total Estimated Cost (TEC) range of $65,500,000 to $109,000,000 and a preliminary Total Project Cost (TPC) range of $68,000,000 to $111,500,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The preliminary TPC estimate for this project is $111,500,000.

This project will provide a multi-purpose facility with modern, flexible, efficient, and agile research laboratories and office space to conduct plasma research activities in support of multiple SC programs.

**Significant Changes**

This project is a new start in FY 2021. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-0, Approve Mission Need, which was approved September 9, 2019. FY 2021 funds will initiate Project Engineering and Design (PED) activities.

A Federal Project Director with the appropriate certification level will be assigned to this project prior to CD-1 approval.

**Critical Milestone History**

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | D&D Complete | CD-4 |
|---|---|---|---|---|---|---|---|---|
| FY 2021 | 9/09/19 | N/A | 4Q FY 2020[a] | 2Q FY 2022[a] | N/A | 2Q FY 2023[a] | N/A | 4Q FY 2029[a] |

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

| Fiscal Year | Performance Baseline Validation | CD-3A |
|---|---|---|
| FY 2021 | N/A | 2Q FY 2022[a] |

**CD-3A** – Approve Long-Lead Procurements and Start of Early Construction Activities

[a]This project is pre-CD-2 approval: therefore, schedule estimates are preliminary.

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC[a], Except D&D | OPC, D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|---|
| FY 2021 | 9,000 | 100,000[b] | 109,000 | 2,500 | N/A | 2,500 | 111,500[b] |

**2. Project Scope and Justification**

**Scope**
The Princeton Plasma Innovation Center (PPIC) is envisioned as a 67,000 to 84,000 gross square feet (gsf) multi-story office and laboratory building at Princeton Plasma Physics Laboratory (PPPL) to serve as a single new multi-use facility that will house space for offices, medium bay research labs for diagnostics and fabrication, remote participation and collaboration, and research support.

**Justification**
In order to advance the plasma science and fusion frontier in support of the DOE mission, PPPL requires new or enhanced facilities and infrastructure to foster innovation to make fusion energy a practical reality and further U.S. economic competitiveness. The primary SC program relevant to the PPIC project is Fusion Energy Sciences (FES), and the primary Core Capability is Plasma and Fusion Energy Sciences. The missions of SC's Advanced Scientific Computing Research and Basic Energy Sciences programs are also relevant to the mission need for the PPIC with second order effect to Large Scale User Facilities/Advanced Instrumentation and Systems Engineering and Integration.

PPPL is a United States DOE national laboratory operated by Princeton University, and plays a key role in assisting FES achieve its strategic goals. The PPPL vision is "enabling a world powered by safe, clean, and plentiful fusion energy while leading discoveries in plasma science and technology." To support this vision, PPPL carries out experiments and computer simulations of the behavior of plasma, which is hot electrically-charged gas. Plasmas with sufficient temperature generate fusion reactions. Therefore, PPPL's aim is to be a leading center for future fusion concepts. The understanding of plasma and its related technologies also has a broad impact on many other scientific fields and applications that are central to U.S. economic health and competitiveness. This impact extends to astrophysics and space sciences, plasma-material interactions, plasma processing, particle acceleration, and high energy density plasmas. Many industries, such as the microelectronics industry, utilize plasmas to synthesize and shape the materials in their products. These industries are increasingly seeking collaboration with PPPL to improve their understanding of existing plasma processes and to develop new modeling and measurement techniques potentially leading to new processes and applications. PPPL, in collaboration with Princeton University, is strengthening its efforts to develop innovations for the next generation microelectronics to advance economic competitiveness, national security, and future energy applications.

However, the current condition, capabilities, and configuration of PPPL infrastructure do not support current or planned scientific efforts, in particular, the lack of adequate laboratory infrastructure, modern collaboration space, and modern office infrastructure. PPPL would benefit from office and laboratories capabilities that can effectively accomplish the advancement of the FES mission.

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

[a] Other Project Costs (OPC) are funded through laboratory overhead.
[b] This project has not received CD-2 approval, therefore, funding estimates are preliminary.

Key Performance Parameters (KPPs)

The Key Performance Parameters (KPPs) are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| Multi-Story Building | 67,000 gsf | 84,000 gsf |

**3. Financial Schedule**

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| FY 2021 | 2,000 | 2,000 | 2,000 |
| Outyears | 7,000 | 7,000 | 7,000 |
| Total, Design | 9,000 | 9,000 | 9,000 |
| Construction | | | |
| Outyears | 100,000 | 100,000 | 100,000 |
| Total, Construction | 100,000 | 100,000 | 100,000 |
| Total Estimated Cost (TEC) | | | |
| FY 2021 | 2,000 | 2,000 | 2,000 |
| Outyears | 107,000 | 107,000 | 107,000 |
| **Total, TEC[a]** | **109,000** | **109,000** | **109,000** |
| **Other Project Cost (OPC)** | | | |
| FY 2019 | 300 | 300 | 11 |
| FY 2020 | 2,000 | 2,000 | 2,289 |
| Outyears | 200 | 200 | 200 |
| **Total, OPC[b]** | **2,500** | **2,500** | **2,500** |
| **Total Project Cost (TPC)** | | | |
| FY 2019 | 300 | 300 | 11 |
| FY 2020 | 2,000 | 2,000 | 2,289 |
| FY 2021 | 2,000 | 2,000 | 2,000 |
| Outyears | 107,200 | 107,200 | 107,200 |
| **Total, TPC[a]** | **111,500** | **111,500** | **111,500** |

[a] This project has not received CD-2 approval, therefore, funding estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

#### 4. Details of Project Cost Estimate

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| Design | 7,500 | N/A | N/A |
| Contingency | 1,500 | N/A | N/A |
| Total, Design | 9,000 | N/A | N/A |
| Construction | | | |
| Construction | 83,300 | N/A | N/A |
| Contingency | 16,700 | N/A | N/A |
| Total, Construction | 100,000 | N/A | N/A |
| **Total, TEC[a]** | **109,000** | **N/A** | **N/A** |
| *Contingency, TEC* | *18,200* | *N/A* | *N/A* |
| **Other Project Cost (OPC)[b]** | | | |
| OPC except D&D | | | |
| Conceptual Planning | 300 | N/A | N/A |
| Conceptual Design | 2,000 | N/A | N/A |
| Contingency | 200 | N/A | N/A |
| **Total, OPC** | **2,500** | **N/A** | **N/A** |
| *Contingency, OPC* | *200* | *N/A* | *N/A* |
| **Total Project Cost[a]** | **111,500** | **N/A** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***18,400*** | ***N/A*** | ***N/A*** |

#### 5. Schedule of Appropriations Requests

(dollars in thousands)

| Request Year | Type | FY 2019 | FY 2020 | FY 2021 | Outyears | Total |
|---|---|---|---|---|---|---|
| FY 2021 | TEC | — | — | 2,000 | 107,000 | 109,000[a] |
| | OPC[b] | 300 | 2,000 | — | 200 | 2,500 |
| | TPC | 300 | 2,000 | 2,000 | 107,200 | 111,500[a] |

#### 6. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 4Q FY 2029 |
| Expected Useful Life | 50 years |
| Expected Future Start of D&D of this capital asset | 4Q FY 2079 |

[a] This project has not received CD-2 approval, therefore, funding estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs[a] | |
|---|---|---|---|---|
| | Previous Total Estimate | Current Total Estimate | Previous Total Estimate | Current Total Estimate |
| Operations | N/A | TBD | N/A | TBD |
| Utilities | N/A | TBD | N/A | TBD |
| Maintenance and Repair | N/A | TBD | N/A | TBD |
| Total, Operations and Maintenance | N/A | TBD | N/A | TBD |

**7. D&D Information**

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

| | Square Feet |
|---|---|
| New area being constructed by this project at Princeton Plasma Physics Laboratory ..................... | 67,000-84,000 |
| Area of D&D in this project at Princeton Plasma Physics Laboratory .............................................. | 13,400 |
| Area at Princeton Plasma Physics Laboratory to be transferred, sold, and/or D&D outside the project, including area previously "banked" .................................................................................... | None[b] |
| Area of D&D in this project at other sites ......................................................................................... | None |
| Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked" .............................................................................................................. | None |
| Total area eliminated ............................................................................................................... | 13,400 |

**8. Acquisition Approach**

The PPPL Management and Operating (M&O) Contractor, Princeton University, will perform the acquisition for this project, overseen by the Princeton Site Office. The M&O Contractor will be responsible for awarding and managing all subcontracts related to the project. It will evaluate various acquisition and project delivery methods prior to achieving CD-1 and potential benefits of using single or multiple contracts to procure materials, equipment, construction, commissioning and other project scope elements. The M&O Contractor's annual performance and evaluation measurement plan will include project performance metrics on which it will be evaluated.

[a] Life-Cycle costs will be performed as part of CD-1.
[b] With the implementation of OMB's Reduce the Footprint initiative, DOE no longer maintains the space bank. Footprint is managed using the Facility Information Management System, with decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

**21-SC-72, Critical Infrastructure Recovery & Renewal (CIRR)**
**Princeton Plasma Physics Laboratory (PPPL)**
**Project is for Design and Construction**

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

**Summary**

The FY 2021 Request for the Critical Infrastructure Recovery & Renewal (CIRR) project is $2,000,000. The current preliminary Total Estimated Cost (TEC) range for this project is $48,900,000 to $80,400,000. The preliminary Total Project Cost (TPC) range for this project is $50,400,000 to $81,900,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The preliminary TPC estimate for this project is $81,900,000.

PPPL's aging utility infrastructure is non-redundant and increasingly unreliable, which negatively impacts lab operations. Scientific productivity is dependent on a capable, available, flexible, maintainable, and reliable support infrastructure. This project will provide critical infrastructure needed to safely and efficiently operate the laboratory missions. These systems will be modern and energy efficient, reducing the operating cost of the facility.

**Significant Changes**

This project is a new start in FY 2021. The most recent DOE Order 413.3B Critical Decision (CD) is CD-0, Approve Mission Need, which was approved on September 16, 2019. FY 2021 funds will initiate Project Engineering and Design (PED) activities.

A Federal Project Director with the appropriate certification level will be assigned to this project prior to CD-1 approval.

**Critical Milestone History**

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | D&D Complete | CD-4 |
|---|---|---|---|---|---|---|---|---|
| FY 2021 | 9/16/19 | N/A | 2Q FY 2020[a] | 4Q FY 2022[a] | 4Q FY 2023 | 4Q FY 2023[a] | N/A | 4Q FY 2029[a] |

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

| Fiscal Year | Performance Baseline Validation | CD-3A |
|---|---|---|
| FY 2021 | 4Q FY 2022[a] | 1Q FY 2023[a] |

**CD-3A** – Approve Long-Lead Procurements and Start of Early Construction Activities

[a] This project is pre-CD-2 approval: therefore, schedule estimates are preliminary.

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC[a], Except D&D | OPC, D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|---|
| FY 2021 | 8,000 | 72,400[b] | 80,400 | 1,500 | N/A | 1,500 | 81,900[b] |

## 2. Project Scope and Justification

**Scope**

The CIRR project's preliminary scope includes upgrades that may include: the electrical distribution system; standby power; chilled water generation and distribution; distribution networks for steam, compressed air, sanitary waste, and condenser, storm, canal, and potable water; HVAC systems; and communication systems.

**Justification**

Princeton Plasma Physics Laboratory (PPPL) is a significant element of the DOE capability in plasma science and directly supports the DOE mission to make fusion energy a practical reality and further U.S. economic competitiveness. In order to maintain system operability, it is essential to have reliable infrastructure in place. The current systems are outdated, at capacity, unreliable, and inefficient. Portions of the current system are part of the original infrastructure built in 1958. In order to maintain current missions and enable future ones, the infrastructure must be upgraded with modern, efficient, and reliable systems.

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

Key Performance Parameters (KPPs)

The Key Performance Parameters (KPPs) are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| ▪ Rehabilitate and selectively upgrade PPPL's existing major utility systems | ▪ Renovate select electrical generation and distribution systems and components<br>▪ Renovate chilled water facility<br>▪ Renovate select building HVAC equipment<br>▪ Renovate select data and communication systems<br>▪ Renovate select sections steam piping and components<br>▪ Renovate select sections of sanitary/storm water system | ▪ Replace additional electrical distribution system components<br>▪ Replace additional building HVAC equipment<br>▪ Replace additional sections of underground piping |

[a] Other Project Costs (OPC) are funded through laboratory overhead.

[b] This project has not received CD-2 approval; therefore, funding estimates are preliminary.

### 3. Financial Schedule

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| FY 2021 | 2,000 | 2,000 | 2,000 |
| Outyears | 6,000 | 6,000 | 6,000 |
| Total, Design | 8,000 | 8,000 | 8,000 |
| Construction | | | |
| Outyears | 72,400 | 72,400 | 72,400 |
| Total, Construction | 72,400 | 72,400 | 72,400 |
| Total Estimated Cost (TEC) | | | |
| FY 2021 | 2,000 | 2,000 | 2,000 |
| Outyears | 78,400 | 78,400 | 78,400 |
| **Total, TEC[a]** | **80,400** | **80,400** | **80,400** |
| **Other Project Cost (OPC)** | | | |
| FY 2019 | 100 | 100 | 100 |
| FY 2020 | 1,200 | 1,200 | 1,200 |
| Outyears | 200 | 200 | 200 |
| **Total, OPC[b]** | **1,500** | **1,500** | **1,500** |
| **Total Project Cost (TPC)** | | | |
| FY 2019 | 100 | 100 | 100 |
| FY 2020 | 1,200 | 1,200 | 1,200 |
| FY 2021 | 2,000 | 2,000 | 2,000 |
| Outyears | 78,600 | 78,600 | 78,600 |
| **Total, TPC[a]** | **81,900** | **81,900** | **81,900** |

### 4. Details of Project Cost Estimate

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| Design | 6,700 | N/A | N/A |
| Contingency | 1,300 | N/A | N/A |
| Total, Design | 8,000 | N/A | N/A |

[a] This project has not received CD-2 approval; therefore, funding estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| Construction | | | |
| Construction | 60,300 | N/A | N/A |
| Contingency | 12,100 | N/A | N/A |
| Total, Construction | 72,400 | N/A | N/A |
| **Total, TEC[a]** | **80,400** | **N/A** | **N/A** |
| *Contingency, TEC* | *13,400* | *N/A* | *N/A* |
| **Other Project Cost (OPC)[b]** | | | |
| OPC except D&D | | | |
| Conceptual Planning | 100 | N/A | N/A |
| Conceptual Design | 1,200 | N/A | N/A |
| Contingency | 200 | N/A | N/A |
| **Total, OPC** | **1,500** | **N/A** | **N/A** |
| *Contingency, OPC* | *200* | *N/A* | *N/A* |
| **Total Project Cost[a]** | **81,900** | **N/A** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***13,600*** | ***N/A*** | ***N/A*** |

**5. Schedule of Appropriations Requests**

(dollars in thousands)

| Request Year | Type | FY 2019 | FY 2020 | FY 2021 | Outyears | Total |
|---|---|---|---|---|---|---|
| FY 2021 | TEC | — | — | 2,000 | 78,400 | 80,400[a] |
| | OPC[b] | 100 | 1,200 | — | 200 | 1,500 |
| | TPC | 100 | 1,200 | 2,000 | 78,600 | 81,900[a] |

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

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 4Q FY 2025 |
| Expected Useful Life | 50 years |
| Expected Future Start of D&D of this capital asset | N/A |

[a] This project has not received CD-2 approval; therefore, funding estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs[a] | |
|---|---|---|---|---|
| | **Previous Total Estimate** | **Current Total Estimate** | **Previous Total Estimate** | **Current Total Estimate** |
| Operations | N/A | TBD | N/A | TBD |
| Utilities | N/A | N/A | N/A | N/A |
| Maintenance and Repair | N/A | TBD | N/A | TBD |
| Total, Operations and Maintenance | N/A | TBD | N/A | TBD |

**7. D&D Information**

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

| | **Square Feet** |
|---|---|
| New area being constructed by this project at Princeton Plasma Physics Laboratory ..................... | None |
| Area of D&D in this project at Princeton Plasma Physics Laboratory .............................................. | None |
| Area at Princeton Plasma Physics Laboratory to be transferred, sold, and/or D&D outside the project, including area previously "banked" .................................................................................... | None[b] |
| Area of D&D in this project at other sites ......................................................................................... | None |
| Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked" ............................................................................................................................ | None |
| Total area eliminated ............................................................................................................................ | None |

**8. Acquisition Approach**

The PPPL Management and Operating (M&O) Contractor, Princeton University, will perform the acquisition for this project, overseen by the Princeton Site Office. The M&O Contractor will be responsible for awarding and managing all subcontracts related to the project. It will evaluate various acquisition and project delivery methods prior to achieving CD-1 and potential benefits of using a single or multiple contracts to procure materials, equipment, construction, commissioning and other project scope elements. The M&O Contractor's annual performance and evaluation measurement plan will include project performance metrics on which it will be evaluated.

[a] Life-Cycle costs will be performed as part of CD-1.
[b] With the implementation of OMB's Reduce the Footprint initiative, DOE no longer maintains the space bank. Footprint is managed using the Facility Information Management System, with decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

**21-SC-73, Ames Infrastructure Modernization**
**Ames Laboratory**
**Project is for Design and Construction**

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

### Summary

The FY 2021 Request for the Ames Infrastructure Modernization (AIM) project is $2,000,000. This project has a preliminary Total Estimated Cost (TEC) range of $21,000,000 to $88,000,000 and a preliminary Total Project Cost (TPC) range of $23,000,000 to $90,000,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The preliminary TPC estimate for this project is $31,000,000.

AIM's objective is to support the SC mission by providing a safer and more operationally efficient campus for the employees, visitors, and guests at Ames, as well as to reduce deferred maintenance costs. This project is designed to support DOE mission-critical programs and initiatives, increase the reliability of utility infrastructure, minimize facility costs through effective and efficient operations, and modernize laboratories in Ames Laboratory's research buildings, thereby enhancing Ames Laboratory's ability to continue to deliver on SC mission across multiple program offices.

### Significant Changes

This project is a new start in FY 2021. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-0, Approve Mission Need, which was approved September 16, 2019. FY 2021 funds will initiate Project Engineering and Design (PED) activities.

A Federal Project Director with the appropriate certification level will be assigned to this project prior to CD-1 approval.

### Critical Milestone History

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | D&D Complete | CD-4 |
|---|---|---|---|---|---|---|---|---|
| FY 2021 | 9/16/19 | 4Q FY 2020 | 3Q FY 2021[a] | 3Q FY 2022[a] | 1Q FY 2023[a] | 2Q FY 2023[a] | N/A | 4Q FY 2026[a] |

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

| Fiscal Year | Performance Baseline Validation | CD-3A |
|---|---|---|
| FY 2021 | 3Q FY 2022 | 3Q FY 2022[a] |

**CD-3A** – Approve Long-Lead Procurements and Start of Early Construction Activities

[a] This project is pre-CD-2 approval: therefore, schedule estimates are preliminary.

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC[a], Except D&D | OPC, D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|---|
| FY 2021 | 3,000 | 27,000[b] | 30,000 | 1,000 | N/A | 1,000 | 31,000[b] |

**2. Project Scope and Justification**

**Scope**

The AIM project will provide updated infrastructure building systems in existing research and operations buildings at Ames Laboratory, such as: plumbing systems; building envelopes; electrical systems-emergency, backup power, and uninterruptible power supplies; and telecommunication systems. In addition, some existing laboratory spaces will be modernized to support the SC mission and associated equipment.

**Justification**

SC utilizes the capabilities of Ames Laboratory to execute three of SC's 24 core capabilities and the mission of multiple SC program offices, including research by the offices of Basic Energy Sciences, Advanced Scientific Computing Research, Biological and Environment Research, and to a lesser extent, Fusion Energy Sciences. These core capabilities are 1) Condensed Matter Physics and Materials Science, 2) Chemical and Molecular Science, and 3) Applied Materials Science and Engineering. Ames Laboratory is dedicated to creating materials, inspiring minds to solve problems, and addressing global challenges. Ames Laboratory provides SC with the ability for research in the discovery, synthesis, analysis, and use of new materials, novel chemistries, and transformational analytical tools. In pursuing its SC Mission to deliver scientific discoveries, Ames Laboratory invents materials with new physical and chemical functionalities, especially those that harness the potential of rare-earth elements, through creative and innovative synthesis techniques; determines novel physics and chemistry of quantum materials and molecules using instrumentation developed at Ames Laboratory; shares these materials and knowledge with partners and collaborates nationwide and worldwide to advance fundamental knowledge in physics, chemistry, and materials science; and promotes the applications of these materials for economic and national security through in-house activities and external collaborations.

The current condition of the building systems and infrastructure impedes the execution and advancement of the SC mission for the following reasons: 1) aging plumbing systems result in unplanned events such as sanitary sewer or major water leaks that lead to disruption of scientific operations, jeopardizing instrumentation, and presenting a safety and health risk to personnel; 2) deteriorating building envelopes negatively impact the SC mission through increased operational costs, elevated risk to research equipment, and a poor work environment for Ames Laboratory staff; 3) lack of an adequate electrical supply and distribution, including reliability during outages, places sensitive scientific equipment at risk of damage, prevents program expansion, and limits SC continued investment in state-of-the-art equipment and instrumentation; 4) inadequate telecommunication systems impede program expansion and limits SC investment in state-of-the-art equipment and instrumentation; and 5) limited amount of modern research laboratory space impacts SC mission through several outcomes, such as the inability to house state-of-the-art equipment and instrumentation; implement best safety management practices; create collaborative environments; and attract, recruit, and retain the scientific talent.

Therefore, to better accommodate the current and future DOE Office of Science mission, minimize disruptions to critical research activities, reduce risks to operations, and improve the safety and reliability, Ames Laboratory needs improved infrastructure systems and work spaces.

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

[a] Other Project Costs (OPC) are funded through laboratory overhead.
[b] This project has not received CD-2 approval, therefore, funding estimates are preliminary.

Key Performance Parameters (KPPs)

The Key Performance Parameters (KPPs) are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| ▪ Rehabilitate and selectively upgrade Ames' existing major utility systems | ▪ Replace and upgrade plumbing systems in research buildings<br>▪ Upgrade the building envelope on mission critical research buildings<br>▪ Replace two backup generators | ▪ Improve emergency/backup power distribution systems<br>▪ Modernize 23,000 sf of wet and dry labs, and office space in research buildings |

### 3. Financial Schedule

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| FY 2021 | 2,000 | 2,000 | 2,000 |
| Outyears | 1,000 | 1,000 | 1,000 |
| Total, Design | 3,000 | 3,000 | 3,000 |
| Construction | | | |
| Outyears | 27,000 | 27,000 | 27,000 |
| Total, Construction | 27,000 | 27,000 | 27,000 |
| Total Estimated Cost (TEC) | | | |
| FY 2021 | 2,000 | 2,000 | 2,000 |
| Outyears | 28,000 | 28,000 | 28,000 |
| **Total, TEC[a]** | **30,000** | **30,000** | **30,000** |
| **Other Project Cost (OPC)** | | | |
| FY 2020 | 250 | 250 | 25 |
| FY 2021 | 250 | 250 | 475 |
| Outyears | 500 | 500 | 500 |
| **Total, OPC[b]** | **1,000** | **1,000** | **1,000** |
| **Total Project Cost (TPC)** | | | |
| FY 2020 | 250 | 250 | 25 |
| FY 2021 | 2,250 | 2,250 | 2,475 |
| Outyears | 28,500 | 28,500 | 28,500 |
| **Total, TPC[a]** | **31,000** | **31,000** | **31,000** |

[a] This project has not received CD-2 approval, therefore, funding estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

## 4. Details of Project Cost Estimate

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| Design | 2,500 | N/A | N/A |
| Contingency | 500 | N/A | N/A |
| Total, Design | 3,000 | N/A | N/A |
| Construction | | | |
| Construction | 22,500 | N/A | N/A |
| Contingency | 4,500 | N/A | N/A |
| Total, Construction | 27,000 | N/A | N/A |
| **Total, TEC[a]** | **30,000** | **N/A** | **N/A** |
| *Contingency, TEC* | *5,000* | *N/A* | *N/A* |
| **Other Project Cost (OPC)[b]** | | | |
| OPC except D&D | | | |
| Conceptual Planning | 250 | N/A | N/A |
| Conceptual Design | 250 | N/A | N/A |
| Contingency | 500 | N/A | N/A |
| **Total, OPC** | **1,000** | **N/A** | **N/A** |
| *Contingency, OPC* | *500* | *N/A* | *N/A* |
| **Total Project Cost[a]** | **31,000** | **N/A** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***5,500*** | ***N/A*** | ***N/A*** |

## 5. Schedule of Appropriations Requests

(dollars in thousands)

| Request Year | Type | FY 2020 | FY 2021 | Outyears | Total |
|---|---|---|---|---|---|
| FY 2021 | TEC | — | 2,000 | 28,000 | 30,000[a] |
| | OPC[b] | 250 | 250 | 500 | 1,000 |
| | TPC | 250 | 2,250 | 28,500 | 31,000[a] |

## 6. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 4Q FY 2026 |
| Expected Useful Life | 25 years |
| Expected Future Start of D&D of this capital asset | 4Q FY 2051 |

[a] This project has not received CD-2 approval, therefore, funding estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs[a] | |
|---|---|---|---|---|
| | **Previous Total Estimate** | **Current Total Estimate** | **Previous Total Estimate** | **Current Total Estimate** |
| Operations | N/A | TBD | N/A | TBD |
| Utilities | N/A | TBD | N/A | TBD |
| Maintenance and Repair | N/A | TBD | N/A | TBD |
| Total, Operations and Maintenance | N/A | TBD | N/A | TBD |

**7. D&D Information**

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

| | Square Feet |
|---|---|
| New area being constructed by this project at Ames Laboratory ........ | None |
| Area of D&D in this project at Ames Laboratory ........ | None |
| Area at Ames Laboratory to be transferred, sold, and/or D&D outside the project, including area previously "banked" ........ | None[b] |
| Area of D&D in this project at other sites ........ | None |
| Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked" ........ | None |
| Total area eliminated ........ | None |

**8. Acquisition Approach**

The Ames Management and Operating (M&O) contractor, Iowa State University, will perform the acquisition for this project, overseen by the Ames Site Office. It will evaluate various acquisition approaches and consider project delivery methods prior to achieving CD-1. The M&O contractor will be responsible for awarding and administering all subcontracts related to this project. The M&O contractor's annual performance evaluation and measurement plan will include project performance metrics on which it will be evaluated.

[a] Life-Cycle costs will be performed as part of CD-1.
[b] With the implementation of OMB's Reduce the Footprint initiative, DOE no longer maintains the space bank. Footprint is managed using the Facility Information Management System, with decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

**20-SC-71, Critical Utilities Rehabilitation Project**
**Brookhaven National Laboratory (BNL)**
**Project is for Design and Construction**

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

### Summary

The FY 2021 Request for the Critical Utilities Rehabilitation Project (CURP) is $15,000,000. The current preliminary Total Estimated Cost (TEC) range for this project is $70,000,000 to $92,000,000. The preliminary Total Project Cost (TPC) range for this project is $70,800,000 to $92,800,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The preliminary TPC estimate for this project is $92,800,000.

This project will upgrade failing utility infrastructure that is still in use from BNL's origins as World War II Army Camp Upton. Utility systems including steam, water, sanitary sewer, chilled water, and electrical systems will be revitalized and upgraded to meet the needs of supporting SC facilities and the Nuclear Physics (NP), Basic Energy Sciences (BES), High Energy Physics (HEP), Biological and Environmental Research (BER), and Advanced Scientific Computing Research (ASCR) programs.

### Significant Changes

This project was initiated in FY 2020. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-0, Approve Mission Need, which was approved on July 20, 2018. The project performed an analysis of Alternatives, which was approved by the SLI program, and approval of CD-1 is expected in the second quarter of FY 2020. The selected alternative is to repair or replace critical systems and components of the utility systems. FY 2021 funds will support long-lead procurement and early construction activities after the appropriate CD approvals.

A Federal Project Director with the appropriate certification level (Level II: TPC greater than $50,000,000 and equal to or less than $100,000,000) will be assigned to this project.

### Critical Milestone History

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | D&D Complete | CD-4 |
|---|---|---|---|---|---|---|---|---|
| FY 2020 | 7/20/18 | 4Q FY 2019 | 4Q FY 2019[a] | 4Q FY 2020[a] | 4Q FY 2021 | 4Q FY 2021[a] | N/A | 4Q FY 2026[a] |
| FY 2021 | 7/20/18 | 4Q FY 2019 | 2Q FY 2020[a] | 2Q FY 2021[a] | 3Q FY 2021 | 4Q FY 2021[a] | N/A | 4Q FY 2024[a] |

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

| Fiscal Year | Performance Baseline Validation | CD-3A |
|---|---|---|
| FY 2020 | 4Q FY 2020[a] | N/A |
| FY 2021 | 4Q FY 2020[a] | 2Q FY 2020 |

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

[a] This project is pre-CD-2; therefore, funding and schedule estimates are preliminary.

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC[a], Except D&D | OPC, D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|---|
| FY 2020 | 8,500 | 76,500 | 85,000 | 800 | N/A | 800 | 85,800 |
| FY 2021 | 7,100 | 84,900 | 92,000[b] | 800 | N/A | 800 | 92,800[b] |

**2. Project Scope and Justification**

**Scope**

CURP's scope is to revitalize and upgrade highest risk major utility systems across the BNL campus by replacing piping in areas prone to water main breaks and provide other water system improvements to improve system operations and reliability. The project will also replace select sections of the sanitary utility systems with failing pumps, controllers, and/or manholes, and provide several required modifications to the central chilled water system in order to support growth of process loads and assure reliability. CURP will replace deteriorated and leaking steam systems along Cornell Avenue to assure safe, reliable, and efficient steam service to mission critical facilities on the north side of the campus, and older feeder cables and inadequate breakers along Cornell Avenue, which will increase capacity, reliability, and personnel safety.

**Justification**

BNL is a multi-program DOE national laboratory with recognized impact on national science needs. BNL provides scientific leadership in NP, photon sciences, energy science for BES, and data-driven discovery for ASCR, with leading programs in selected areas of HEP, BER, accelerator science and technology, and national security and non-proliferation. BNL utilizes world-class facilities and core expertise to: advance energy and environment-related basic research and apply them to 21st Century problems of critical importance to the Nation; and advance fundamental research in nuclear and particle physics to gain a deeper understanding of matter, energy, space, and time.

Although there has been substantial investment in recent years to modernize and construct new research facilities at BNL, much of BNL's utility infrastructure serving these facilities is over 50 years old and some is over 70 years old, dating to BNL's origin as a U. S. Army base during World Wars I and II. Efficient, maintainable, and reliable utilities are critical to the success and mission capability of BNL's research facilities. Currently, a significant portion of BNL's utility infrastructure is beyond useful life and suffering from failures, decreased reliability, lack of redundancy, and limitations in capacity. As such, there is an urgent need to revitalize and selectively upgrade BNL's existing major utility systems to assure reliable service, meet capacity requirements, and enable readiness of facilities critical to the research mission.

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

[a] Other Project Costs (OPC) are funded through laboratory overhead.
[b] This project has not received CD-2 approval, therefore, funding estimates are preliminary.

Key Performance Parameters (KPPs)
The Key Performance Parameters (KPPs) are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| ▪ Rehabilitate and selectively upgrade BNL's existing major utility systems including steam, water, sanitary sewer, chilled water and electrical systems. | ▪ Renovate the Central Chilled Water Facility<br>▪ Replace 3,000 linear feet (LF) of steam/condensate piping<br>▪ Renovate Building 610 (B610)<br>▪ Renovate Wellhouse #12<br>▪ Replace 300,000 gallon water tank<br>▪ Install new 13.8 kilovolt feeder<br>▪ Renovate substation 603<br>▪ Re-line 200 LF of sewer lines | ▪ Renovate chilled water system<br>▪ Upgrade B610 Building Envelope<br>▪ Replace up to 45 miles of water service lines<br>▪ Renovate 1 million gallon water tank<br>▪ Renovate electrical system<br>▪ Renovate sanitary sewer system. |

**3. Financial Schedule**

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| FY 2020 | 7,100 | 7,100 | 7,100 |
| Total, Design | 7,100 | 7,100 | 7,100 |
| Construction | | | |
| FY 2020 | 12,900 | 12,900 | 2,900 |
| FY 2021 | 15,000 | 15,000 | 15,000 |
| Outyears | 57,000 | 57,000 | 67,000 |
| Total, Construction | 84,900 | 84,900 | 84,900 |
| Total Estimated Cost (TEC) | | | |
| FY 2020 | 20,000 | 20,000 | 10,000 |
| FY 2021 | 15,000 | 15,000 | 15,000 |
| Outyears | 57,000 | 57,000 | 67,000 |
| **Total, TEC[a]** | **92,000** | **92,000** | **92,000** |
| **Other Project Cost (OPC)[b]** | | | |
| FY 2019 | 800 | 800 | 800 |
| **Total, OPC** | **800** | **800** | **800** |

[a] This project has not received CD-2 approval, therefore, funding estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Project Cost (TPC)** | | | |
| FY 2019 | 800 | 800 | 800 |
| FY 2020 | 20,000 | 20,000 | 10,000 |
| FY 2021 | 15,000 | 15,000 | 15,000 |
| Outyears | 57,000 | 57,000 | 67,000 |
| **Total, TPC[a]** | **92,800** | **92,800** | **92,800** |

**4. Details of Project Cost Estimate**

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| Design | 5,680 | 6,800 | N/A |
| Contingency | 1,420 | 1,700 | N/A |
| Total, Design | 7,100 | 8,500 | N/A |
| Construction | | | |
| Construction | 70,320 | 61,200 | N/A |
| Contingency | 14,580 | 15,300 | N/A |
| Total, Construction | 84,900 | 76,500 | N/A |
| **Total, TEC[a]** | **92,000** | **85,000** | **N/A** |
| *Contingency, TEC* | *16,000* | *17,000* | *N/A* |
| **Other Project Cost (OPC)** | | | |
| OPC except D&D | | | |
| Other OPC Costs | 800 | 800 | N/A |
| Contingency | — | — | N/A |
| **Total, OPC[b]** | **800** | **800** | **N/A** |
| *Contingency, OPC* | — | — | *N/A* |
| **Total Project Cost[a]** | **92,800** | **85,800** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***16,000*** | ***17,000*** | ***N/A*** |

[a] This project has not received CD-2 approval, therefore, funding estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

### 5. Schedule of Appropriations Requests

(dollars in thousands)

| Request Year | Type | FY 2019 | FY 2020 | FY 2021 | Outyears | Total |
|---|---|---|---|---|---|---|
| FY 2020 | TEC | — | 12,000 | — | 73,000 | 85,000[a] |
| | OPC[b] | 800 | — | — | — | 800 |
| | TPC | 800 | — | — | 73,000 | 85,800[a] |
| FY 2021 | TEC | — | 20,000 | 15,000 | 57,000 | 92,000[a] |
| | OPC[b] | 800 | — | — | — | 800 |
| | TPC | 800 | 20,000 | 15,000 | 57,000 | 92,800[a] |

### 6. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | N/A |
| Expected Useful Life | Varies by System |
| Expected Future Start of D&D of this capital asset | N/A |

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | Previous Total Estimate | Current Total Estimate | Previous Total Estimate | Current Total Estimate |
| Operations | N/A | N/A | N/A | N/A |
| Utilities | N/A | N/A | N/A | N/A |
| Maintenance and Repair | N/A | N/A | N/A | N/A |
| Total, Operations and Maintenance | N/A | N/A | N/A | N/A |

### 7. D&D Information

This project replaces critical infrastructure components and minimal, if any, support buildings will be constructed. The new area being constructed in this project is not replacing existing facilities.

| | Square Feet |
|---|---|
| New area being constructed by this project at Brookhaven National Laboratory ............................ | None |
| Area of D&D in this project at Brookhaven National Laboratory ................................................... | None |
| Area at Brookhaven National Laboratory to be transferred, sold, and/or D&D outside the project, including area previously "banked" ........................................................................................... | None[c] |
| Area of D&D in this project at other sites ........................................................................... | None |
| Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked" ........................................................................................................ | None |
| Total area eliminated .......................................................................................................... | None |

[a] This project has not received CD-2 approval, therefore, funding estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.
[c] With the implementation of OMB's Reduce the Footprint initiative, DOE no longer maintains the space bank. Footprint is managed using the Facility Information Management System, with decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

**8. Acquisition Approach**

The BNL Management and Operating (M&O) Contractor, Brookhaven Science Associates, will perform the acquisition for this project, overseen by the Brookhaven Site Office. The M&O contractor is responsible for awarding and managing all subcontracts related to this project and will evaluate various acquisition alternatives and project delivery methods prior to achieving CD-1. Potential acquisition and project delivery methods include, but are not limited to, firm-fixed-price contracts for design-bid-build and construction manager/general contractor methods. The M&O contractor will also evaluate potential benefits of using a single or multiple contracts to procure materials, equipment, construction, commissioning and other project scope elements. The M&O contractor's annual performance and evaluation measurement plan will include project performance metrics on which it will be evaluated.

**20-SC-72, Seismic and Safety Modernization**
**Lawrence Berkeley National Laboratory (LBNL)**
**Project is for Design and Construction**

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

### Summary

The FY 2021 Request for the Seismic and Safety Modernization (SSM) project is $10,000,000. The preliminary Total Estimated Cost (TEC) range is $76,320,000 to 95,400,000 and the preliminary the Total Project Cost (TPC) range is $78,520,000 to $97,600,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The preliminary TPC estimate for this project is $97,600,000.

### Significant Changes

This project was initiated in FY 2020. The most recent DOE Order 413.3B Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range, which was approved on September 4, 2019. FY 2021 funds will initiate long-lead procurement and early construction activities after the appropriate CD approvals.

A Federal Project Director with the appropriate certification level (Level II: TPC greater than $50,000,000 and equal to or less than $100,000,000) has been assigned to this project.

### Critical Milestone History

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | D&D Complete | CD-4 |
|---|---|---|---|---|---|---|---|---|
| FY 2020 | 9/06/18 | 4Q FY 2019 | 4Q FY 2019[a] | 4Q FY 2021[a] | 4Q FY 2022 | 4Q FY 2022[a] | N/A | 4Q FY 2027[a] |
| FY 2021 | 9/06/18 | 6/17/19 | 9/04/19 | 3Q FY 2021[a] | 1Q FY 2022 | 2Q FY 2022[a] | N/A | 2Q FY 2027[a] |

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

| Fiscal Year | Performance Baseline Validation | CD-3A | CD-3B |
|---|---|---|---|
| FY 2020 | 4Q FY 2021 | N/A | N/A |
| FY 2021 | 3Q FY 2021 | 3Q FY 2021 | N/A |

**CD-3A** – Approve Long-Lead Procurement and Site Preparation Activities
**CD-3B** – Approve Start of Remaining Construction Activities

[a] This project is pre-CD-2; therefore, schedule estimates are preliminary.

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC[a], Except D&D | OPC, D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|---|
| FY 2020 | 10,000 | 85,400 | 95,400[b] | 2,200 | N/A | 2,200 | 97,600[b] |
| FY 2021 | 10,000 | 85,400 | 95,400[b] | 2,200 | N/A | 2,200 | 97,600[b] |

## 2. Project Scope and Justification

**Scope**

The SSM project will construct a new facility on the existing cafeteria site to house the cafeteria, health services and operational support services (human resources, conferencing and other potential groups) to meet the requirements of Risk Category IV of the California Building Code (CBC). In addition, the second floor of the B48 (Fire House) will be seismically upgraded to meet Risk Category IV of the CBC.

**Justification**

The Lawrence Berkeley National Laboratory executes 22 of the Office of Science's (SC'S) 24 core capabilities and the mission of multiple SC program offices, with specifically strong presences of the Advanced Scientific Computing Research, Biological and Environment Research, Basic Energy Sciences, and High Energy Physics programs. LBNL is located on a 202 acre site in the hills above the University of California, Berkeley campus employs approximately 3,400 full time employees; and is home to five SC national user facilities: the Advanced Light Source, the Energy Sciences Network, the Joint Genome Institute, the Molecular Foundry, and the National Energy Research Scientific Computing Center. In FY 2016, over 11,000 researchers used these facilities, representing roughly one third of the total for all SC user facilities. In pursuing the SC mission, LBNL leverages collaborative science to bring together teams of individuals with different fields of expertise to work together on common solutions to the SC mission. However, these research activities must be executed with a unique caution since LBNL is located less than one mile from the Hayward Fault and less than 25 miles from the San Andreas Fault, which would both pose a life safety risk to employees, visitors, and guests during a significant seismic event.

The U.S. Geological Survey's newest earthquake forecast, the third Uniform California Earthquake Rupture Forecast (UCERF3), states a 98 percent probability of a 6.0 magnitude or higher earthquake in the San Francisco Bay Area before 2043. Recent engineering evaluations from a San Francisco Bay Area structural engineering firm have identified significant and extensive seismic safety hazards in critical LBNL support buildings, including the Cafeteria, Health Services, and Fire House. Structural deficiencies identified in these buildings will likely cause significant structural damage with life safety hazards during a magnitude 6.0+ earthquake on the Hayward Fault or a magnitude 8.3 earthquake on the San Andreas Fault and will impede LBNL's ability to resume operations.

The SSM project will address seismic safety issues and emergency response capabilities, specifically related to facilities with large congregation areas as well as improve facilities and transportation capabilities that are necessary for emergency response personnel and maintaining continuity of operations. The facilities that are the primary focus of this project are the Cafeteria, Health Services, and Fire House sleepquarters. Demolition of the cafeteria is anticipated to allow for construction of a new facility. Additional supporting functions such as utilities or site modifications may be included in the project, if they are deemed necessary.

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

[a] Other Project Costs (OPC) are funded through laboratory overhead.
[b] This project is pre-CD-2; therefore, funding estimates are preliminary.

Key Performance Parameters (KPPs)

The Key Performance Parameters (KPPs) are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| New Facility to include a Cafeteria, Health Services & Operational Support Services | ▪ 35,000 gross square feet (gsf)<br>▪ Meet requirements of Risk Category III of the CBC | ▪ 60,000 gsf<br>▪ Meet requirements of Risk Category III of the CBC |
| Seismic Upgrade of B48 (Fire House) | ▪ Meet requirements of Risk Category IV of CBC | N/A |

**3. Financial Schedule**

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| FY 2020 | 10,000 | 10,000 | 8,000 |
| FY 2021 | — | — | 2,000 |
| Total, Design | 10,000 | 10,000 | 10,000 |
| Construction | | | |
| FY 2021 | 10,000 | 10,000 | 5,000 |
| Outyears | 75,400 | 75,400 | 80,400 |
| Total, Construction | 85,400 | 85,400 | 85,400 |
| Total Estimated Cost (TEC) | | | |
| FY 2020 | 10,000 | 10,000 | 8,000 |
| FY 2021 | 10,000 | 10,000 | 7,000 |
| Outyears | 75,400 | 75,400 | 80,400 |
| **Total, TEC[a]** | **95,400** | **95,400** | **95,400** |
| **Other Project Cost (OPC)** | | | |
| FY 2019 | 1,500 | 1,500 | 1,490 |
| FY 2020 | 100 | 100 | 100 |
| Outyears | 600 | 600 | 610 |
| **Total, OPC[b]** | **2,200** | **2,200** | **2,200** |

[a] This project has not received CD-2 approval, therefore, funding estimates are preliminary.

[b] Other Project Costs (OPC) are funded through laboratory overhead.

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Project Cost (TPC)** | | | |
| FY 2019 | 1,500 | 1,500 | 1,490 |
| FY 2020 | 10,100 | 10,100 | 8,100 |
| FY 2021 | 10,000 | 10,000 | 7,000 |
| Outyears | 76,000 | 76,000 | 81,010 |
| **Total, TPC[a]** | **97,600** | **97,600** | **97,600** |

## 4. Details of Project Cost Estimate

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| Design | 8,300 | 8,500 | N/A |
| Contingency | 1,700 | 1,500 | N/A |
| Total, Design | 10,000 | 10,000 | N/A |
| Construction | | | |
| Construction | 70,400 | 68,400 | N/A |
| Contingency | 15,000 | 17,000 | N/A |
| Total, Construction | 85,400 | 85,400 | N/A |
| **Total, TEC[a]** | **95,400** | **95,400** | **N/A** |
| *Contingency, TEC* | *16,700* | *18,500* | — |
| **Other Project Cost (OPC)** | | | |
| OPC except D&D | | | |
| OPC except D&D | 2,000 | 2,000 | N/A |
| Contingency | 200 | 200 | N/A |
| **Total, OPC[b]** | **2,200** | **2,200** | **N/A** |
| *Contingency, OPC* | *200* | *200* | *N/A* |
| **Total Project Cost[a]** | **97,600** | **97,600** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***16,900*** | ***18,700*** | ***N/A*** |

[a] This project has not received CD-2 approval, therefore, funding estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

### 5. Schedule of Appropriations Requests

(dollars in thousands)

| Request Year | Type | FY 2019 | FY 2020 | FY 2021 | Outyears | Total |
|---|---|---|---|---|---|---|
| FY 2020 | TEC | — | 5,000 | — | 90,400 | 95,400[a] |
| | OPC[b] | 1,500 | — | — | 700 | 2,200 |
| | TPC | 1,500 | 5,000 | — | 91,100 | 97,600[a] |
| FY 2021 | TEC | — | 10,000 | 10,000 | 75,400 | 95,400[a] |
| | OPC[b] | 1,500 | 100 | — | 600 | 2,200 |
| | TPC | 1,500 | 10,100 | 10,000 | 76,000 | 97,600[a] |

### 6. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 4Q FY 2027 |
| Expected Useful Life | 50 years |
| Expected Future Start of D&D of this capital asset | 4Q FY 2077 |

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | Previous Total Estimate | Current Total Estimate | Previous Total Estimate | Current Total Estimate |
| Operations | TBD | N/A | TBD | N/A |
| Utilities | TBD | 53 | TBD | 2,658 |
| Maintenance and Repair | TBD | 318 | TBD | 15,882 |
| Total, Operations and Maintenance | TBD | 371 | TBD | 18,540 |

### 7. D&D Information

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

| | Square Feet |
|---|---|
| New area being constructed by this project at Lawrence Berkeley National Laboratory.......... | 35,000 - 60,000 |
| Area of D&D in this project at Lawrence Berkeley National Laboratory.................................. | None |
| Area at Lawrence Berkeley National Laboratory to be transferred, sold, and/or D&D outside the project, including area previously "banked" ...................................................................... | None[c] |
| Area of D&D in this project at other sites.............................................................................. | None |
| Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked"........................................................................................................... | None |
| Total area eliminated.................................................................................................... | 15,000 - 60,000 |

[a] This project has not received CD-2 approval, therefore, funding estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.
[c] With the implementation of OMB's Reduce the Footprint initiative, DOE no longer maintains the space bank. Footprint is managed using the Facility Information Management System, with decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

## 8. Acquisition Approach

The LBNL Management and Operating (M&O) Contractor, University of California, will perform the acquisition for this project, overseen by the Bay Area Site Office. The M&O contractor evaluated various acquisition approaches and project delivery methods prior to achieving CD-1, and selected a Construction Manager/General Contractor approach as the best method to deliver the project. The M&O contractor is also responsible for awarding and administering all subcontracts related to this project. Its annual performance evaluation and measurement plan will include project performance metrics on which it will be evaluated.

**20-SC-73, CEBAF Renovation and Expansion**
**Thomas Jefferson National Accelerator Facility (TJNAF)**
**Project is for Design and Construction**

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

### Summary

The FY 2021 Request for the CEBAF Renovation and Expansion project is $2,000,000. The preliminary Total Estimated Cost (TEC) range for this project is $47,000,000 to $96,000,000. The preliminary Total Project Cost (TPC) range for this project is $48,900,000 to $99,300,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The preliminary TPC estimate for this project is $89,300,000.

The CEBAF center at TJNAF is currently overcrowded and has inadequate utility systems that are experiencing frequent failures. This project will renovate 123,000 to 250,000 gross square feet (gsf) of existing space in the CEBAF center and the Applied Research Center (ARC), upgrade high risk utility systems, and provide 82,000 to 150,000 gsf of additional space for visitors, users, research, education, and support.

### Significant Changes

This project was initiated in FY 2020. The most recent DOE Order 413.3B Critical Decision (CD) is CD-0, Approve Mission Need, which was approved on July 20, 2018. FY 2021 funds will support the continuation of Project Engineering and Design (PED) activities.

A Federal Project Director with the appropriate certification (Level II: TPC greater than $50,000,000 and equal to or less than $100,000,000) has been assigned to this project.

### Critical Milestone History

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | D&D Complete | CD-4 |
|---|---|---|---|---|---|---|---|---|
| FY 2020 | 7/20/18 | 4Q FY 2019 | 4Q FY 2019 | 4Q FY 2020[a] | 3Q FY 2021 | 4Q FY 2021[a] | N/A | 4Q FY 2026[a] |
| FY 2021 | 7/20/18 | 4Q FY 2019 | 2Q FY 2020 | 4Q FY 2020[a] | 3Q FY 2021 | 4Q FY 2021[a] | N/A | 4Q FY 2026[a] |

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

| Fiscal Year | Performance Baseline Validation | CD-3A | CD-3B |
|---|---|---|---|
| FY 2020 | 4Q FY 2020[a] | N/A | N/A |
| FY 2021 | 4Q FY 2020[a] | 4Q FY 2020[a] | 4Q FY 2021[a] |

**CD-3A** – Approve Long-Lead Procurements and Start of Early Construction Activities
**CD-3B** – Approve Start of Remaining Construction Activities

[a] This project is pre-CD-2; therefore, schedule estimates are preliminary.

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC[a], Except D&D | OPC, D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|---|
| FY 2020 | 4,200 | 61,800 | 66,000[b] | 1,900 | N/A | 1,900 | 67,900[b] |
| FY 2021 | 5,000 | 82,000 | 87,000[b] | 2,300 | N/A | 2,300 | 89,300[b] |

## 2. Project Scope and Justification

**Scope**

The scope of the CEBAF Renovation and Expansion project will include renovating 123,000 to 250,000 gsf of existing space and providing 82,000 to 150,000 gsf of additional office and laboratory space (including acquisition of the ARC) for 120 to 200 research, education, and support staff. The renovation will include reconfiguration to provide more functional, flexible, and efficient spaces that meet current code standards. The CEBAF Renovation and Expansion project will replace the mechanical systems in the existing CEBAF Center, which have exceeded their service life and experienced multiple failures. The renovated building will be energy sustainable and will meet high performance building standards, including energy conservation, green building principles, and sustainable design, and the project will design the building to meet Federal legislative objectives. Upon completion, SC will relocate administrative and support staff from the Service Support Center (SSC) (leased space) into the ARC, and TJNAF will dedicate the CEBAF Center to scientific staff to more efficiently address functional workspace needs for TJNAF staff and users.

**Justification**

With a population of nearly 1,600 users, TJNAF supports one of the largest nuclear physics user communities in the world. The expanded scientific scope associated with the 12 GeV upgrade (e.g., double the energy with simultaneous delivery to four experimental halls) is creating more and larger collaborations, requiring more technical workshops, and resulting in more visitors to the Lab. The Laboratory expects staff and user population to increase 2 percent per year for the next 10 years and will soon exceed available space, which is already near capacity. Further, TJNAF is actively pursuing a number of large inter-entity transfer projects such as the cryomodules and cryogenics plants for LCLS-I, LCLS-II-HE, FRIB, and UUP that it projects will require additional staffing. TJNAF will continue to play a key role in the design and development of emerging SC initiative(s).

Currently TJNAF is lacking technically-equipped and functional space to accommodate advanced scientific research and major missions on the immediate horizon. The existing CEBAF Center is well beyond full capacity. The current occupant density of this building is 110 gsf per occupant which is significantly below the DOE standard of 180 gsf per occupant. In addition, utility systems at the CEBAF center are inadequate, failing, and inefficient for the existing usage, let alone the potential anticipated usage in the near future.

TJNAF also continues to advance a strategic campus plan designed to deliver more attractive, mission-focused, and functional workspaces by consolidating the Lab workforce scattered over several leased buildings in a single center that provides more effective and efficient operations. This includes appropriately consolidating workers currently housed in the ARC and SSC leased spaces. This would allow for costly leases to be discontinued and reduce the cost to sustain existing buildings and infrastructure and more efficiently address functional workspace needs for TJNAF staff and users.

TJNAF must be prepared to accommodate planned staff and user growth which means additional office space must be programmed soon. The Laboratory is pursuing Major Items of Equipment, several large inter-entity transfer projects for other National Labs, and a pivotal technical role in a proposed Electron Ion Collider.

[a] Other Project Costs (OPC) are funded through laboratory overhead.
[b] This project is pre-CD-2; therefore, funding estimates are preliminary.

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

Key Performance Parameters (KPPs)
The Key Performance Parameters (KPPs) are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| CEBAF Center Renovation | 66,000 gsf | 128,000 gsf |
| CEBAF Center Expansion | 22,000 gsf | 82,000 gsf |
| ARC Renovation | 57,000 gsf | 121,000 gsf |

**3. Financial Schedule**

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| FY 2020 | 2,000 | 2,000 | 2,000 |
| FY 2021 | 2,000 | 2,000 | 2,000 |
| Outyears | 1,000 | 1,000 | 1,000 |
| Total, Design | 5,000 | 5,000 | 5,000 |
| Construction | | | |
| Outyears | 82,000 | 82,000 | 82,000 |
| Total, Construction | 82,000 | 82,000 | 82,000 |
| Total Estimated Cost (TEC) | | | |
| FY 2020 | 2,000 | 2,000 | 2,000 |
| FY 2021 | 2,000 | 2,000 | 2,000 |
| Outyears | 83,000 | 83,000 | 83,000 |
| **Total, TEC[a]** | **87,000** | **87,000** | **87,000** |
| **Other Project Cost (OPC)** | | | |
| FY 2019 | 1,000 | 1,000 | 1,000 |
| FY 2020 | 700 | 700 | 700 |
| Outyears | 600 | 600 | 600 |
| **Total, OPC[b]** | **2,300** | **2,300** | **2,300** |

[a] This project has not received CD-2 approval, therefore, funding estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Project Cost (TPC)** | | | |
| FY 2019 | 1,000 | 1,000 | 1,000 |
| FY 2020 | 2,700 | 2,700 | 2,700 |
| FY 2021 | 2,000 | 2,000 | 2,000 |
| Outyears | 83,600 | 83,600 | 83,600 |
| **Total, TPC[a]** | **89,300** | **89,300** | **89,300** |

### 4. Details of Project Cost Estimate

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| Design | 4,200 | 3,400 | N/A |
| Contingency | 800 | 800 | N/A |
| Total, Design | 5,000 | 4,200 | N/A |
| Construction | | | |
| Construction | 68,300 | 49,800 | N/A |
| Contingency | 13,700 | 12,000 | N/A |
| Total, Construction | 82,000 | 61,800 | N/A |
| **Total, TEC[a]** | **87,000** | **66,000** | **N/A** |
| *Contingency, TEC* | *14,500* | *12,800* | *N/A* |
| **Other Project Cost (OPC)** | | | |
| OPC except D&D | | | |
| OPC except D&D | 2,300 | 1,900 | N/A |
| Contingency | — | N/A | N/A |
| **Total, OPC** | **2,300** | **1,900** | **N/A** |
| *Contingency, OPC* | — | *N/A* | *N/A* |
| **Total Project Cost[a]** | **89,300** | **67,900** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***14,500*** | ***12,800*** | ***N/A*** |

[a] This project has not received CD-2 approval, therefore, funding estimates are preliminary

## 5. Schedule of Appropriations Requests

(dollars in thousands)

| Request Year | Type | Prior Years | FY 2019 | FY 2020 | FY 2021 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| FY 2020 | TEC | — | — | 2,000 | — | 64,000 | 66,000[a] |
| | OPC[b] | 20 | 1,465 | — | — | 415 | 1,900 |
| | TPC | 20 | 1,465 | 2,000 | — | 64,415 | 67,900[a] |
| FY 2021 | TEC | — | — | 2,000 | 2,000 | 83,000 | 87,000[a] |
| | OPC[b] | — | 1,000 | 700 | — | 600 | 2,300 |
| | TPC | — | 1,000 | 2,700 | 2,000 | 83,600 | 89,300[a] |

## 6. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 4Q FY 2026 |
| Expected Useful Life | 50 years |
| Expected Future Start of D&D of this capital asset | 4Q FY 2076 |

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | Previous Total Estimate | Current Total Estimate | Previous Total Estimate | Current Total Estimate |
| Operations | 288 | 288 | 14,400 | 14,400 |
| Utilities | 432 | 432 | 21,600 | 21,600 |
| Maintenance and Repair | 1,008 | 1,008 | 50,400 | 50,400 |
| Total, Operations and Maintenance | 1,728 | 1,728 | 86,400 | 86,400 |

## 7. D&D Information

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

| | Square Feet |
|---|---|
| New area being constructed by this project at Thomas Jefferson National Accelerator Facility....... | 82,000 - 150,000 |
| Area of D&D in this project at Thomas Jefferson National Accelerator Facility................................ | None |
| Area at Thomas Jefferson National Accelerator Facility to be transferred, sold, and/or D&D outside the project, including area previously "banked" ................................................................. | None[c] |
| Area of D&D in this project at other sites ........................................................................... | None |
| Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked" ........................................................................................................... | None |
| Total area eliminated ........................................................................................................ | None |

[a] This project has not received CD-2 approval, therefore, funding estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.
[c] With the implementation of OMB's Reduce the Footprint initiative, DOE no longer maintains the space bank. Footprint is managed using the Facility Information Management System, with decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

## 8. Acquisition Approach

The TJNAF Management and Operating (M&O) contractor, Jefferson Science Associates, will perform the acquisition for this project, overseen by the Thomas Jefferson Site Office. The M&O contractor will consider various acquisition approaches and project delivery methods prior to achieving CD-1 and will be responsible for awarding and administering all subcontracts related to this project. Its annual performance evaluation and measurement plan will include project performance metrics on which it will be evaluated.

**20-SC-74, Craft Resources Support Facility**
**Oak Ridge National Laboratory (ORNL)**
**Project is for Design and Construction**

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

### Summary

The FY 2021 Request for the Craft Resources Support Facility (CRSF) is $25,000,000. The preliminary Total Estimated Cost (TEC) range for this project is $34,000,000 to $48,000,000 and the preliminary Total Project Cost (TPC) range for this project is $35,000,000 to $49,000,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The preliminary TPC estimate for this project is $41,000,000.

This project will provide a new facility for ORNL craft services (vehicle maintenance, etc.) to facilitate more efficient and consolidated operations. Additional meeting space and shower facilities will be provided for many ORNL craft groups as efficiencies are achieved. It will also demolish small buildings currently within the footprint of the proposed building.

### Significant Changes

This project was initiated in FY 2020. The most recent DOE Order 413.3B Critical Decision (CD) is CD-0, Approve Mission Need, which was approved on July 20, 2018. The project recently held an independent project review for CD-1, Alternatives Selection and Cost Range, which occurred in August 2019. FY 2021 funds will support construction and associated activities after the appropriate CD approvals.

A Federal Project Director with the appropriate certification level (Level I: TPC greater than $5,000,000 and equal to or less than $50,000,000) was assigned to this project.

In an August 2, 2018 memorandum, Dr. Stephen Binkley set an SC policy "… *to initiate a process that devolves the responsibility for planning, executing, and successfully delivering selected SC projects to a lower level in DOE's line management. The intent is to exempt capital asset projects with a Total Project Cost (TPC) less than $50 million from the requirements of DOE Order 413.3B, and delegate responsibility for their successful delivery from SC Associate Director's to the cognizant SC Laboratory Director*…" In keeping with the intent of this policy, ORNL is seeking to have the responsibility for management of the CRSF project delegated to the laboratory, and will have submitted a formal delegation request, that may also be approved at CD-1. If it is delegated, a notable outcome will be inserted into the annual Performance Evaluation and Measurement Plan for the ORNL M&O contractor that will allow DOE to evaluate the M&O's performance in meeting this project's established milestones.

### Critical Milestone History

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | KD-2[a] | Final Design Complete | KD-3[a] | D&D Complete | KD-4[a] |
|---|---|---|---|---|---|---|---|---|
| FY 2020 | 7/20/18 | 4Q FY 2019 | 4Q FY 2019[b] | 3Q FY 2020[b] | 3Q FY 2019 | 3Q FY 2020[b] | N/A | 4Q FY 2023[b] |
| FY 2021 | 7/20/18 | 4Q FY 2019 | 2Q FY 2020[b] | 2Q FY 2021[b] | 4Q FY 2021 | 1Q FY 2022[b] | N/A | 4Q FY 2025[b] |

**CD-0** – Approve Mission Need for a construction project with a conceptual scope and cost range
**Conceptual Design Complete** – Actual date the conceptual design was completed (if applicable)
**CD-1** – Approve Alternative Selection and Cost Range
**KD-2** – "Key Decision" to indicate responsibility for project management has been delegated to the Laboratory. Approve Performance Baseline
**Final Design Complete** – Estimated/Actual date the project design will be/was complete(d)
**KD-3** – Approve Start of Construction

[a] If Delegation is approved, Critical Decisions (CD) will transition to "Key Decisions (KD)" for the duration of the project.
[b] This project is pre-CD-2; therefore, schedule estimates are preliminary.

**KD-4 –** Approve Start of Operations or Project Closeout
**KD-4B / KD-4** – Completion of D&D work / Approve Start of Operations or Project Closeout

| Fiscal Year | Performance Baseline Validation | CD-2/3[a] | CD-3A[a] | CD-3B[a] | KD-4A | KD-4B |
|---|---|---|---|---|---|---|
| FY 2020 | 3Q FY 2020[b] | 3Q FY 2020[b] | N/A | N/A | N/A | N/A |
| FY 2021 | 2Q FY 2021[b] | N/A | N/A | N/A | 4Q FY 2024[b] | 4Q FY 2025[b] |

**CD-2/3** – Approve Performance Baseline and Start of Construction
**CD-3A** – Approve Long-Lead Procurement and Site Preparation Activities
**CD-3B** – Approve Start of Remaining Construction Activities
**KD-4A** – Completion of CRSF construction
**KD-4B/KD-4** – Completion of potential demolition of vacated buildings / Project Closeout

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC[c], Except D&D | OPC, D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|---|
| FY 2020 | 4,000 | 36,000 | 40,000[b] | 500 | N/A | 500 | 40,500[b] |
| FY 2021 | 3,600 | 36,400 | 40,000[b] | 1,000 | N/A | 1,000 | 41,000[b] |

## 2. Project Scope and Justification

**Scope**

The CRSF project's scope includes constructing an estimated 60,900 gross square feet (gsf) to 79,300 gsf building that will provide modern space with an appropriate design, configuration, and environmental conditions to maintain ORNL infrastructure and support activities in support of multiple SC research programs. Activities to be relocated from obsolete buildings into new facility include skilled craft services like vehicle garage and maintenance, grounds maintenance, painting and signage, hoisting and rigging, etc., as well as storage for high-value equipment and materials. The project also includes demolition of several small buildings (approximately 3,600 gsf) currently within the footprint of the proposed building. Additive scope would include demolition of up to 50,000 gsf of vacated facilities once construction of CRSF facilities is complete and would be based on the accomplishment of the base scope.

**Justification**

SC utilizes over 20 core capabilities supported by ORNL and core mission facilities at ORNL, such as the Spallation Neutron Source (SNS), the High Flux Isotope Reactor (HFIR), and the Oak Ridge Leadership Computing Facility (OLCF). These core capabilities and facilities support the mission of Basic Energy Sciences, Fusion Energy Sciences, Nuclear Physics, Biological & Environmental Research, and Advanced Scientific Computing Research.

The complex infrastructure required to support the SC mission and associated facilities places a substantial demand on craft resource support functions, which is comprised of 28 different trades ranging from automotive mechanics to instrument technicians. Craft resources within ORNL's Facilities and Operations Directorate maintains and/or supports the Laboratory's 5.7 million square feet of space, maintains a fleet of over 400 vehicles, and supplies utilities to this footprint including nearly 50 miles of water distribution piping, 670 million pounds of high-pressure steam distributed over 10 miles of steam lines, three major electrical substations, 60 miles of overhead transmission lines, and 14,000 tons of chilled water production.

[a] If Delegation is approved, Critical Decisions (CD) will transition to "Key Decisions (KD)" for the duration of the project.
[b] This project is pre-CD-2; therefore, funding and schedule estimates are preliminary.
[c] Other Project Costs (OPC) are funded through laboratory overhead.

Continued research at ORNL that supports over 3,200 users utilizing the many user facilities, as well as experimental and developmental research facilities, are dependent on support services provided by craft resources. Due to the distinctive nature and complexity of many of ORNL infrastructure systems, in house craft services are often required to respond to unique circumstances. Similarly, operational inefficiencies in these areas result in a ripple effect that increases risk to SC research productivity and the ORNL science mission. Inefficient operation of craft resource support services directly impacts many high-priority science programs at ORNL.

ORNL mission support personnel provide multiple services supporting the ORNL science mission such as roads, grounds maintenance, vehicle maintenance and repair garage, electricians, inspectors, and others. These support services are currently housed in multiple inadequate facilities spread across the 7000 area, which are outdated and poorly configured, resulting in inefficient operations, congested vehicle and pedestrian traffic patterns, and increased safety risks. These conditions are creating inefficient, unreliable operations that are directly impacting many high-priority SC programs at ORNL. Current facilities also lack conditioned space and covered storage that reduces life for high value equipment and materials as well provide poor working conditions for staff.

This project provides modern space with appropriate design, configuration, and environmental conditions to support activities conducted at user, experimental, and developmental research facilities for multiple SC research programs including SNS, HFIR, and OLCF.

The project is being conducted in accordance with the project management requirements in DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets* through CD-1, after which, project management is expected to be delegated.

Key Performance Parameters (KPPs)
The Key Performance Parameters (KPPs) are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| Craft services support buildings | 60,900 gsf | 79,300 gsf |

**3. Financial Schedule**

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| FY 2020 | 3,600 | 3,600 | 1,600 |
| FY 2021 | — | — | 2,000 |
| Total, Design | 3,600 | 3,600 | 3,600 |
| Construction | | | |
| FY 2020 | 11,400 | 11,400 | — |
| FY 2021 | 25,000 | 25,000 | — |
| Outyears | — | — | 36,400 |
| Total, Construction | 36,400 | 36,400 | 36,400 |

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| Total Estimated Cost (TEC) | | | |
| FY 2020 | 15,000 | 15,000 | 1,600 |
| FY 2021 | 25,000 | 25,000 | 2,000 |
| Outyears | — | — | 36,400 |
| **Total, TEC[a]** | **40,000** | **40,000** | **40,000** |
| **Other Project Cost (OPC)** | | | |
| FY 2019 | 800 | 800 | 800 |
| Outyears | 200 | 200 | 200 |
| **Total, OPC[b]** | **1,000** | **1,000** | **1,000** |
| **Total Project Cost (TPC)** | | | |
| FY 2019 | 800 | 800 | 800 |
| FY 2020 | 15,000 | 15,000 | 1,600 |
| FY 2021 | 25,000 | 25,000 | 2,000 |
| Outyears | 200 | 200 | 36,600 |
| **Total, TPC[a]** | **41,000** | **41,000** | **41,000** |

### 4. Details of Project Cost Estimate

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| Design | 2,790 | 3,500 | N/A |
| Contingency | 780 | 500 | N/A |
| Total, Design | 3,570 | 4,000 | N/A |
| Construction | | | |
| Construction | 28,510 | 30,000 | N/A |
| Contingency | 7,920 | 6,000 | N/A |
| Total, Construction | 36,430 | 36,000 | N/A |
| **Total, TEC[a]** | **40,000** | **40,000** | **N/A** |
| *Contingency, TEC* | *8,700* | *6,500* | *N/A* |

[a] This project has not received CD-2 approval; therefore, funding estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Other Project Cost (OPC)** | | | |
| OPC except D&D | | | |
| Conceptual Design | 800 | 420 | N/A |
| Contingency | 200 | 80 | N/A |
| **Total, OPC[a]** | **1,000** | **500** | **N/A** |
| *Contingency, OPC* | *200* | *80* | *N/A* |
| **Total Project Cost[b]** | **41,000** | **40,500** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***8,900*** | ***6,580*** | ***N/A*** |

**5. Schedule of Appropriations Requests**

(dollars in thousands)

| Request Year | Type | FY 2019 | FY 2020 | FY 2021 | Outyears | Total |
|---|---|---|---|---|---|---|
| FY 2020 | TEC | — | 20,000 | 20,000 | — | 40,000[b] |
| | OPC[a] | 400 | — | 100 | — | 500 |
| | TPC | 400 | 20,000 | 20,100 | — | 40,500[b] |
| FY 2021 | TEC | — | 15,000 | 25,000 | — | 40,000[b] |
| | OPC[a] | 800 | — | — | 200 | 1,000 |
| | TPC | 800 | 15,000 | 25,000 | 200 | 41,000[b] |

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

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 4Q FY 2024 |
| Expected Useful Life | 50 years |
| Expected Future Start of D&D of this capital asset | 4Q FY 2074 |

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | Previous Total Estimate | Current Total Estimate | Previous Total Estimate | Current Total Estimate |
| Operations | 101 | 135 | 4,249 | 6,750 |
| Utilities | 146 | 90 | 6,141 | 4,500 |
| Maintenance and Repair | 194 | 145 | 8,161 | 7,250 |
| Total, Operations and Maintenance | 441 | 370 | 18,551 | 18,500 |

[a] Other Project Costs (OPC) are funded through laboratory overhead.
[b] This project has not received CD-2 approval; therefore, funding estimates are preliminary.

## 7. D&D Information

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

| | Square Feet |
|---|---|
| New area being constructed by this project at Oak Ridge National Laboratory........................ | 60,900 - 79,300 |
| Area of D&D in this project at Oak Ridge National Laboratory................................................. | 3,568 |
| Area at Oak Ridge National Laboratory to be transferred, sold, and/or D&D outside the project, including area previously "banked"............................................................................ | None[a] |
| Area of D&D in this project at other sites................................................................................ | None |
| Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked"........................................................................................................ | None |
| Total area eliminated (in base scope)...................................................................................... | 3,568 |

## 8. Acquisition Approach

The ORNL Management and Operating (M&O) Contractor, UT-Battelle, will perform the acquisition for this project overseen by the ORNL Site Office. The M&O Contractor will be responsible for awarding and managing all subcontracts related to the project. The M&O contractor will evaluate various acquisition and project delivery methods prior to achieving CD-1 and will evaluate potential benefits of using a single contract or multiple contracts to procure materials, equipment, construction, commissioning and other project scope elements. The M&O's annual performance and evaluation measurement plan will include project performance metrics on which it will be evaluated.

[a] With the implementation of OMB's Reduce the Footprint initiative, DOE no longer maintains the space bank. Footprint is managed using the Facility Information Management System, with decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

**20-SC-75, Large Scale Collaboration Center**
**SLAC National Accelerator Laboratory (SLAC)**
**Project is for Design and Construction**

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

**Summary**
The FY 2021 Request for the Large Scale Collaboration Center (LSCC) is $8,000,000. The current preliminary Total Estimated Cost (TEC) range for this project is $56,000,000 to $90,400,000. The current preliminary Total Project Cost (TPC) range for this project is $59,400,000 to $92,400,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The preliminary TPC estimate for this project is $66,000,000.

This project will construct a new facility allowing for collocation of cross-functional teams in a common building, providing synergies between all major SC-sponsored programs.

**Significant Changes**
This project was initiated in FY 2020. The most recent DOE Order 413.3B Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range, which was approved on November 18, 2019. The project performed an analysis of Alternatives, which was approved by the SLI program, and determined the preferred alternative is to construct a new building. FY 2021 funds will support long-lead procurements and early construction activities after the appropriate CD approvals.

A Federal Project Director with the appropriate certification level (Level II: TPC greater than $50,000,000 and equal to or less than $100,000,000) has been assigned to this project.

**Critical Milestone History**

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | D&D Complete | CD-4 |
|---|---|---|---|---|---|---|---|---|
| FY 2020 | 7/20/18 | 4Q FY 2019 | 4Q FY 2019[a] | 4Q FY 2020[a] | 4Q FY 2020 | 4Q FY 2020[a] | N/A | 4Q FY 2026[a] |
| FY 2021 | 7/20/18 | 4Q FY 2019 | 11/18/19 | 1Q FY 2022[a] | 1Q FY 2023[a] | 1Q FY 2023[a] | 3Q FY 2023 | 4Q FY 2027[a] |

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

| Fiscal Year | Performance Baseline Validation | CD-3A | CD-3B |
|---|---|---|---|
| FY 2020 | TBD | N/A | N/A |
| FY 2021 | TBD | 1Q FY 2020[a] | 1Q FY 2023[a] |

**CD-3A** – Approve Long-Lead Procurements and Start of Early Construction
**CD-3B** – Approve Remaining Construction Activities

[a] This project is pre-CD-2; therefore, schedule and funding estimates are preliminary.

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC[a], Except D&D | OPC, D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|---|
| FY 2020 | 6,000 | 54,000[b] | 60,000[b] | 1,000 | N/A | 1,000 | 61,000[b] |
| FY 2021 | 9,000 | 55,000[b] | 64,000[b] | 2,000 | N/A | 2,000 | 66,000[b] |

**2. Project Scope and Justification**

**Scope**

The Large Scale Collaboration Center (LSCC) project will construct a multi-office building of approximately 34,000 to 42,000 gross square feet (gsf) to consolidate and provide space for 100-150 occupants in a common building. The LSCC will provide synergies among all major SC-sponsored programs at SLAC and provide a centralized office and collaboration space for cross-functional teams with the necessary performance capabilities to grow the science research programs.

**Justification**

Advances in scientific exploration require the coordinated development of an extensive range of sophisticated imaging tools and extremely large amounts of data sets and images for current and future user facilities and research programs, including the Linac Coherent Light Source (LCLS), the LCLS-II and LCLS-II-HE, the Stanford Synchrotron Radiation Laboratory (SSRL), Cryo-Electron Microscopy (EM), ATLAS at the Large Hadron Collider (LHC), the Large Synoptic Survey Telescope (LSST), the Deep Underground Neutrino Experiment (DUNE), and the Facility for Advanced Accelerator Experimental Tests (FACET)-II.

Existing buildings provide sufficient laboratory and experimental space. Current office spaces near experimental areas, however, are fully occupied or oversubscribed, and projected staff and user increases exceed availability of adequate space. Office spaces in current buildings are not properly configured and do not address the pressing need to accommodate teams that are developing critical algorithms and data analysis techniques alongside staff scientists or visiting researchers and users.

With growing numbers of scientific staff and users dealing with increased rates of data generation on the order of terabytes per second streaming from detectors, it is essential to reduce data volumes while preserving the science content of the data. This can be accomplished by collaborating with expertise in data science and massive-scale data analytics. The real-time computing for data reduction and, most importantly, for feedback defines the scale of the computing infrastructure required onsite and offsite. This real-time feedback, done during experiment operation and between shifts, is instrumental for the user to optimize the experiment and receive datasets as complete as possible before leaving the facility. Cross-functional teams that understand accelerator and instrument operations also need to collaborate to address the common and expanding need for substantial computation support.

Furthermore, the High Energy Density program is also working closely with SLAC's LCLS directorate and the U.S. scientific community to advance the Matter in Extreme Conditions (MEC) project, which will result in much improved optical and x-ray laser capabilities that will enable novel experiments to push the scientific frontier. Scientists at the MEC project will perform these activities in collaboration with LCLS and academic partners and users ahead of full-scale experiments at LCLS.

SLAC currently lacks office spaces for scientists and staff to jointly explore challenges and develop solutions using large-scale data sets. Adjacent office spaces that enable researchers to benefit from collaboration with subject matter experts in computational science, AI/ML, exascale computing, data management, data acquisition, simulation, imaging, visualization, and modeling are also not currently available.

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[a] Other Project Costs (OPC) are funded through laboratory overhead.
[b] This project is pre-CD-2; therefore, funding estimates are preliminary.

To address these capability gaps, SLAC proposes to construct a new LSCC. Without it, SLAC will be unable to collocate cross-functional teams that understand accelerator and instrument operations, provide synergies between all major SC-sponsored programs at SLAC, engage a broad spectrum of researchers in a common building to explore materials science, chemical science, cosmology, computational support, AI/ML, exascale applications, and quantum information science (QIS); engage in private partnerships; and provide a centralized office and collaboration space with the necessary performance capabilities to grow the photon science research program.

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

Key Performance Parameters (KPPs)

The Key Performance Parameters (KPPs) are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| Multi-Story Office Building | 34,000 gsf | 45,000 gsf |

**3. Financial Schedule**

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| FY 2020 | 9,000 | 9,000 | 7,000 |
| FY 2021 | — | — | 2,000 |
| Total, Design | 9,000 | 9,000 | 9,000 |
| Construction | | | |
| FY 2020 | 2,000 | 2,000 | — |
| FY 2021 | 8,000 | 8,000 | 1,000 |
| Outyears | 45,000 | 45,000 | 54,000 |
| Total, Construction | 55,000 | 55,000 | 55,000 |
| Total Estimated Cost (TEC) | | | |
| FY 2020 | 11,000 | 11,000 | 7,000 |
| FY 2021 | 8,000 | 8,000 | 3,000 |
| Outyears | 45,000 | 45,000 | 54,000 |
| **Total, TEC[a]** | **64,000** | **64,000** | **64,000** |

[a] This project has not received CD-2 approval; therefore, funding estimates are preliminary.

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Other Project Cost (OPC)** | | | |
| FY 2019 | 500 | 500 | 500 |
| FY 2020 | 200 | 200 | 200 |
| FY 2021 | 1,300 | 1,300 | 1,300 |
| **Total, OPC[a]** | **2,000** | **2,000** | **2,000** |
| **Total Project Cost (TPC)** | | | |
| FY 2019 | 500 | 500 | 500 |
| FY 2020 | 11,200 | 11,200 | 7,200 |
| FY 2021 | 9,300 | 9,300 | 4,300 |
| Outyears | 45,000 | 45,000 | 54,000 |
| **Total, TPC[b]** | **66,000** | **66,000** | **66,000** |

**4. Details of Project Cost Estimate**

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| Design | 7,200 | 4,800 | N/A |
| Contingency | 1,800 | 1,200 | N/A |
| Total, Design | 9,000 | 6,000 | N/A |
| Construction | | | |
| Construction | 45,000 | 43,000 | N/A |
| Contingency | 10,000 | 11,000 | N/A |
| Total, Construction | 55,000 | 54,000 | N/A |
| **Total, TEC[b]** | **64,000** | **60,000** | **N/A** |
| *Contingency, TEC* | *11,800* | *12,200* | *N/A* |

[a] Other Project Costs (OPC) are funded through laboratory overhead.
[b] This project has not received CD-2 approval; therefore, funding estimates are preliminary.

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Other Project Cost (OPC)** | | | |
| OPC except D&D | | | |
| OPC Costs | 1,600 | 1,000 | N/A |
| Contingency | 400 | — | N/A |
| **Total, OPC[a]** | **2,000** | **1,000** | **N/A** |
| *Contingency, OPC* | *400* | — | *N/A* |
| **Total Project Cost[b]** | **66,000** | **61,000** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***12,200*** | ***12,200*** | ***N/A*** |

**5. Schedule of Appropriations Requests**

(dollars in thousands)

| Request Year | Type | FY 2019 | FY 2020 | FY 2021 | Outyears | Total |
|---|---|---|---|---|---|---|
| FY 2020 | TEC | — | 3,000 | — | 57,000 | 60,000[b] |
| | OPC[a] | 700 | — | — | 300 | 1,000 |
| | TPC | 700 | 3,000 | — | 57,300 | 61,000[b] |
| FY 2021 | TEC | — | 11,000 | 8,000 | 45,000 | 64,000[b] |
| | OPC[a] | 500 | 200 | 1,300 | — | 2,000 |
| | TPC | 500 | 11,200 | 9,300 | 45,000 | 66,000[b] |

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

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 4Q FY 2026 |
| Expected Useful Life | 50 years |
| Expected Future Start of D&D of this capital asset | 4Q FY 2076 |

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | Previous Total Estimate | Current Total Estimate | Previous Total Estimate | Current Total Estimate |
| Operations | 81 | 81 | 4,050 | 4,050 |
| Utilities | 154 | 154 | 7,700 | 7,700 |
| Maintenance and Repair | 170 | 170 | 8,500 | 8,500 |
| Total, Operations and Maintenance | 405 | 405 | 20,250 | 20,250 |

[a] Other Project Costs (OPC) are funded through laboratory overhead.
[b] This project has not received CD-2 approval; therefore, funding estimates are preliminary.

## 7. D&D Information

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

| | Square Feet |
|---|---|
| New area being constructed by this project at SLAC National Accelerator Laboratory | 34,000-45,000 |
| Area of D&D in this project at SLAC National Accelerator Laboratory | 8,260 |
| Area at SLAC National Accelerator Laboratory to be transferred, sold, and/or D&D outside the project, including area previously "banked" | None[a] |
| Area of D&D in this project at other sites | None |
| Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked" | None |
| Total area eliminated | None |

## 8. Acquisition Approach

The SLAC Management and Operating (M&O) contractor, Stanford University, will perform the acquisition for this project, overseen by the Bay Area Site Office. The M&O contractor is responsible for awarding and managing all subcontracts related to this project. Various acquisition alternatives were considered for this project, such as traditional design-bid-build, design-build, and construction manager/general contractor. After considering these alternatives in relation to the schedule, size, and risk, the design-build approach was selected. The M&O contractor's annual performance evaluation and measurement plan will include project performance metrics on which it will be evaluated

[a] With the implementation of OMB's Reduce the Footprint initiative, DOE no longer maintains the space bank. Footprint is managed using the Facility Information Management System, with decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

**20-SC-76, Tritium System Demolition and Disposal (TSDD)**
**Princeton Plasma Physics Laboratory (PPPL)**
**Project is for Design and Demolition**

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

**Summary**

The FY 2021 Request for the Tritium System Demolition and Disposal (TSDD) project is $19,400,000. The current preliminary Total Estimated Cost (TEC) range for this project is $19,500,000 to $32,400,000. The current preliminary Total Project Cost (TPC) range for this project is $20,500,000 to $33,400,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The preliminary TPC estimate for this project is $33,400,000.

This project will remove tritium contaminated legacy systems at PPPL.

**Significant Changes**

This project was initiated through FY 2020 Enacted Appropriations. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-0, Approve Mission Need, which was approved September 16, 2019. FY 2021 funds will support Project Engineering and Design (PED) and construction activities after the appropriate CD approvals.

A Federal Project Director with the appropriate certification level (Level I: TPC greater than $5,000,000 and equal to or less than $50,000,000) will be assigned to this project prior to CD-1 approval.

**Critical Milestone History**

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | D&D Complete | CD-4 |
|---|---|---|---|---|---|---|---|---|
| FY 2021 | 9/16/19 | 2Q FY 2020[a] | 4Q FY 2020[a] | 4Q FY 2021[a] | 4Q FY 2021 | 4Q FY 2021[a] | N/A | 2Q FY 2025[a] |

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

| Fiscal Year | Performance Baseline Validation |
|---|---|
| FY 2021 | 4Q FY 2021[a] |

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC[b], Except D&D | OPC, D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|---|
| FY 2021 | 4,000 | 28,400[a] | 32,400 | 1,000 | N/A | 1,000 | 33,400[a] |

[a] This project is pre-CD-2 approval: therefore, schedule and funding estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

## 2. Project Scope and Justification

**Scope**

The Tritium System Demolition and Disposal (TSDD) project's scope includes removing tritium contaminated items, components, equipment, and sub-systems, including glove boxes, gas holding tanks, tritium purification system (TPS) process piping, contaminated HVAC ductwork and neutral beam boxes, through demolition and disposal.

**Justification**

The aging tritium systems pose a risk to personnel at PPPL, are expensive to maintain, and take up valuable space that could be put to better use. The TSDD project will reduce the risk of tritium release, the risk of public or worker radiological exposure, and operating dollars expended on a legacy system, as well as free-up laboratory space for other uses. The project would remove and dispose of the legacy tritium that remains on PPPL by:

- Eliminating risk of tritium release on-site and off-site,
- Eliminating worker exposure to tritium,
- Attenuating operational costs by reducing radiological monitoring, compliance and oversight. This includes greatly reducing the need for (tritium) occupational radiological worker safety requirements (for most of the site) at the conclusion of the work,
- Creating available high value research space.

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

Key Performance Parameters (KPPs)

The Key Performance Parameters (KPPs) are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| PPPL Tritium Areas | ▪ Remove and dispose of all of the tritium contaminated process equipment, contaminated ductwork, and waste from PPPL Tritium Areas<br>▪ Eliminate or reduce surface contamination in contaminated areas | N/A |
| TFTR Test Cell (TTC) | ▪ Remove, and dispose of tritium-contaminated Neutral Beam Boxes from the TTC — with the exception of any parts identified for re-use on NSTX-U<br>▪ Remove all Tritium contaminated ductwork<br>▪ Decontaminate or encapsulate floors and walls. | N/A |

### 3. Financial Schedule

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| FY 2020 | 4,000 | 4,000 | 4,000 |
| Total, Design | 4,000 | 4,000 | 4,000 |
| Construction | | | |
| FY 2020 | 9,000 | 9,000 | 2,000 |
| FY 2021 | 19,400 | 19,400 | 10,000 |
| Outyears | — | — | 16,400 |
| Total, Construction | 28,400 | 28,400 | 28,400 |
| Total Estimated Cost (TEC) | | | |
| FY 2020 | 13,000 | 13,000 | 6,000 |
| FY 2021 | 19,400 | 19,400 | 10,000 |
| Outyears | — | — | 16,400 |
| **Total, TEC[a]** | **32,400** | **32,400** | **32,400** |
| **Other Project Cost (OPC)** | | | |
| FY 2019 | 100 | 100 | 100 |
| FY 2020 | 800 | 800 | 800 |
| FY 2021 | 100 | 100 | 100 |
| **Total, OPC[b]** | **1,000** | **1,000** | **1,000** |
| **Total Project Cost (TPC)** | | | |
| FY 2019 | 100 | 100 | 100 |
| FY 2020 | 13,800 | 13,800 | 6,800 |
| FY 2021 | 19,500 | 19,500 | 10,100 |
| Outyears | — | — | 16,400 |
| **Total, TPC[a]** | **33,400** | **33,400** | **33,400** |

[a] This project has not received CD-2 approval, therefore, funding estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

## 4. Details of Project Cost Estimate

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| Design | 3,200 | N/A | N/A |
| Contingency | 800 | N/A | N/A |
| Total, Design | 4,000 | N/A | N/A |
| Construction | | | |
| Construction | 23,400 | N/A | N/A |
| Contingency | 5,000 | N/A | N/A |
| Total, Construction | 28,400 | N/A | N/A |
| **Total, TEC**[a] | **32,400** | **N/A** | **N/A** |
| *Contingency, TEC* | *5,800* | *N/A* | *N/A* |
| **Other Project Cost (OPC)**[b] | | | |
| OPC except D&D | | | |
| Conceptual Planning | 200 | N/A | N/A |
| Conceptual Design | 800 | N/A | N/A |
| Contingency | N/A | N/A | N/A |
| **Total, OPC** | **1,000** | **N/A** | **N/A** |
| *Contingency, OPC* | *N/A* | *N/A* | *N/A* |
| **Total Project Cost**[a] | **33,400** | **N/A** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***5,800*** | ***N/A*** | ***N/A*** |

## 5. Schedule of Appropriations Requests

(dollars in thousands)

| Request Year | Type | FY 2019 | FY 2020 | FY 2021 | Total |
|---|---|---|---|---|---|
| FY 2021 | TEC | — | 13,000 | 19,400 | 32,400[a] |
| | OPC[b] | 100 | 800 | 100 | 1,000 |
| | TPC | 100 | 13,800 | 19,500 | 33,400[a] |

## 6. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | N/A |
| Expected Useful Life | N/A |
| Expected Future Start of D&D of this capital asset | N/A |

[a] This project has not received CD-2 approval, therefore, funding estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | **Previous Total Estimate** | **Current Total Estimate** | **Previous Total Estimate** | **Current Total Estimate** |
| Operations | N/A | N/A | N/A | N/A |
| Utilities | N/A | N/A | N/A | N/A |
| Maintenance and Repair | N/A | N/A | N/A | N/A |
| Total, Operations and Maintenance | N/A | N/A | N/A | N/A |

### 7. D&D Information

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

| | Square Feet |
|---|---|
| New area being constructed by this project at Princeton Plasma Physics Laboratory ..................... | None |
| Area of D&D in this project at Princeton Plasma Physics Laboratory .............................................. | 13,400 |
| Area at Princeton Plasma Physics Laboratory to be transferred, sold, and/or D&D outside the project, including area previously "banked" .................................................................................... | None[a] |
| Area of D&D in this project at other sites ......................................................................................... | None |
| Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked" ............................................................................................................... | None |
| Total area eliminated ............................................................................................................... | None |

### 8. Acquisition Approach

The PPPL Management and Operating (M&O) Contractor, Princeton University, will perform the acquisition for this project, overseen by the Princeton Site Office. The M&O Contractor will be responsible for awarding and managing all subcontracts related to the project. It will evaluate various acquisition and project delivery methods prior to achieving CD-1 and potential benefits of using a single or multiple contracts to procure materials, equipment, construction, commissioning and other project scope elements. The M&O Contractor's annual performance and evaluation measurement plan will include project performance metrics on which it will be evaluated.

[a] With the implementation of OMB's Reduce the Footprint initiative, DOE no longer maintains the space bank. Footprint is managed using the Facility Information Management System, with decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

**20-SC-77, Argonne Utilities Upgrade Project**
**Argonne National Laboratory (ANL)**
**Project is for Design and Construction**

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

**Summary**

The FY 2021 Request for the Argonne Utilities Upgrade (AU2) project is $2,000,000. This project has a preliminary Total Estimated Cost (TEC) range of $72,000,000 to $215,000,000 and a preliminary Total Project Cost (TPC) range of $73,000,000 to $216,000,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The preliminary TPC estimate for this project is $216,000,000.

AU2 is proposed to revitalize and selectively upgrade ANL's existing major utility systems including steam, water, sanitary sewer, chilled water, and electrical systems.

**Significant Changes**

This project was initiated in FY 2020 Enacted Appropriations. The most recent DOE Order 413.3B Critical Decision (CD) is CD-0, Approve Mission Need, which was approved on May 17, 2019. FY 2021 funds will support Project Engineering and Design (PED) activities.

A Federal Project Director with the appropriate certification level will be assigned to this project prior to CD-1 approval.

**Critical Milestone History**

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | D&D Complete | CD-4 |
|---|---|---|---|---|---|---|---|---|
| FY 2021 | 5/17/19 | 4Q FY 2020[a] | 4Q FY 2020[a] | 4Q FY 2021[a] | 4Q FY 2021[a] | 4Q FY 2022[a] | N/A | 4Q FY 2026[a] |

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

| Fiscal Year | Performance Baseline Validation | CD-3A | CD-3B |
|---|---|---|---|
| FY 2021 | 4Q FY 2021[a] | 1Q FY 2021[a] | N/A |

**CD-3A** – Approve Long-Lead Procurements and Start of Early Construction
**CD-3B** – Approve Remaining Construction Activities

[a] This project is pre-CD-2; therefore, schedule estimates are preliminary.

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC[a], Except D&D | OPC, D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|---|
| FY 2021 | 21,000 | 194,000 | 215,000[b] | 1,000 | N/A | 1,000 | 216,000[b] |

## 2. Project Scope and Justification

**Scope**

The AU2 project is in the pre-conceptual stage of development, and the preliminary scope includes upgrading failing 1940's-era utilities across the ANL campus. These utilities include steam, water, sanitary sewer, chilled water, and electrical systems.

**Justification**

An efficient, maintainable, and reliable infrastructure is critical to the success and mission capability of ANL's research facilities. As such, there is an urgent mission need to revitalize and selectively upgrade ANL's existing major utility systems including steam, water, sanitary sewer, chilled water and electrical systems.

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

Key Performance Parameters (KPPs)

The Key Performance Parameters (KPPs) are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| ▪ Cooling, Water, Steam, Condensate and Sewer Systems | ▪ Repair, replace or construct new distribution piping for 10,000 linear feet of sewer, potable/non-potable water, steam and condensate piping and support structures (e.g. steam vaults, pipe supports, valves, culverts, etc.)<br>▪ Replace boiler house control system<br>▪ Construct new >6,300 ton chilled water plant<br>▪ Replace or retrofit 4,000 tons of existing chilled water capacity including support infrastructure (e.g. cooling towers, pumps, heat exchangers, etc.) | ▪ Repair, replace or construct new distribution piping for >10,000 linear feet of sewer, potable/non-potable water, steam and condensate piping and support structures (e.g. steam vaults, pipe supports, valves, culverts, etc.)<br>▪ Install secondary potable water connection to site<br>▪ Replace or retrofit >4,000 tons of existing chilled water capacity including support infrastructure (e.g. cooling towers, pumps, heat exchangers, etc.) |

[a] Other Project Costs (OPC) are funded through laboratory overhead.
[b] This project is pre-CD-2; therefore, funding estimates are preliminary.

## 3. Financial Schedule

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| FY 2020 | 500 | 500 | 500 |
| FY 2021 | 2,000 | 2,000 | 1,000 |
| Outyears | 35,000 | 35,000 | 36,000 |
| Total, Design | 37,500 | 37,500 | 37,500 |
| Construction | | | |
| Outyears | 177,500 | 177,500 | 177,500 |
| Total, Construction | 177,500 | 177,500 | 177,500 |
| Total Estimated Cost (TEC) | | | |
| FY 2020 | 500 | 500 | 500 |
| FY 2021 | 2,000 | 2,000 | 1,000 |
| Outyears | 212,500 | 212,500 | 213,500 |
| **Total, TEC[a]** | **215,000** | **215,000** | **215,000** |
| **Other Project Cost (OPC)** | | | |
| FY 2019 | 100 | 100 | 100 |
| FY 2020 | 600 | 600 | 600 |
| FY 2021 | 300 | 300 | 300 |
| **Total, OPC[b]** | **1,000** | **1,000** | **1,000** |
| **Total Project Cost (TPC)** | | | |
| FY 2019 | 100 | 100 | 100 |
| FY 2020 | 1,100 | 1,100 | 1,100 |
| FY 2021 | 2,300 | 2,300 | 1,300 |
| Outyears | 212,500 | 212,500 | 213,500 |
| **Total, TPC[a]** | **216,000** | **216,000** | **216,000** |

[a] This project is pre-CD-2; therefore, funding estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

## 4. Details of Project Cost Estimate

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| Design | 30,000 | N/A | N/A |
| Contingency | 7,500 | N/A | N/A |
| Total, Design | 37,500 | N/A | N/A |
| Construction | | | |
| Construction | 142,000 | N/A | N/A |
| Contingency | 35,500 | N/A | N/A |
| Total, Construction | 177,500 | — | — |
| **Total, TEC[a]** | **215,000** | **N/A** | **N/A** |
| *Contingency, TEC* | *43,000* | — | — |
| **Other Project Cost (OPC)** | | | |
| OPC except D&D | | | |
| OPC Costs | 1,000 | N/A | N/A |
| Contingency | — | N/A | N/A |
| **Total, OPC[b]** | **1,000** | **N/A** | **N/A** |
| *Contingency, OPC* | — | *N/A* | *N/A* |
| **Total Project Cost[a]** | **216,000** | **N/A** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***43,000*** | ***N/A*** | ***N/A*** |

## 5. Schedule of Appropriations Requests

(dollars in thousands)

| Request Year | Type | FY 2019 | FY 2020 | FY 2021 | Outyears | Total |
|---|---|---|---|---|---|---|
| FY 2021 | TEC | — | 500 | 2,000 | 212,500 | 215,000[a] |
| | OPC[b] | 100 | 600 | 300 | — | 1,000 |
| | TPC | 100 | 1,100 | 2,300 | 212,500 | 216,000[a] |

## 6. Related Operations and Maintenance Funding Requirements

N/A

[a] This project is pre-CD-2; therefore, funding estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

**7. D&D Information**

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

| | Square Feet |
|---|---|
| New area being constructed by this project at Argonne National Laboratory ................................. | None |
| Area of D&D in this project at Argonne National Laboratory.......................................................... | None |
| Area at Argonne National Laboratory to be transferred, sold, and/or D&D outside the project, including area previously "banked" .................................................................................................. | None[a] |
| Area of D&D in this project at other sites ........................................................................ | None |
| Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked" ............................................................................................................... | None |
| Total area eliminated ............................................................................................................ | None |

**8. Acquisition Approach**

The ANL Management and Operating (M&O) Contractor, UChicago Argonne, LLC, will perform the acquisition for this project, overseen by the Argonne Site Office. The M&O contractor is responsible for awarding and managing all subcontracts related to this project. The M&O contractor will evaluate various acquisition alternatives and project delivery methods prior to achieving CD-1. Potential acquisition and project delivery methods include, but are not limited to, firm-fixed-price contracts for design-bid-build and design-build. The M&O contractor will also evaluate potential benefits of using a single or multiple contracts to procure materials, equipment, construction, commissioning, and other project scope elements. Its annual performance and evaluation measurement plan will include project performance metrics for ANL, on which it will be evaluated.

[a] With the implementation of OMB's Reduce the Footprint initiative, DOE no longer maintains the space bank. Footprint is managed using the Facility Information Management System, with decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

**20-SC-78, Linear Assets Modernization Project (LAMP)**
**Lawrence Berkeley National Laboratory (LBNL)**
**Project is for Design and Construction**

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

### Summary

The FY 2021 Request for the Linear Assets Modernization Project (LAMP) at LBNL is $2,000,000. The preliminary Total Estimated Cost (TEC) range for this project is $142,000,000 to $236,000,000. The Total Project Cost (TPC) range for this project is $146,000,000 to $240,000,000. The cost range encompasses the most feasible preliminary alternative at this time. The preliminary TPC estimate for this project is $240,000,000.

LAMP is proposed to upgrade high priority utility systems to increase the reliability, capability, and safety of LBNL's infrastructure to meet DOE's mission. The project will upgrade utility systems, including, but not limited to, domestic water, natural gas, storm drain, sanitary sewer, electrical, and communication.

### Significant Changes

This project was initiated the in FY 2020 Enacted Appropriations. The most recent DOE Order 413.3B Critical Decision (CD) is CD-0, Approve Mission Need, which was approved on May 17, 2019. FY 2021 funds will support Project Engineering and Design (PED) activities.

A Federal Project Director with the appropriate certification level will be assigned to this project prior to CD-1 approval.

### Critical Milestone History

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | D&D Complete | CD-4 |
|---|---|---|---|---|---|---|---|---|
| FY 2021 | 5/17/19 | 4Q FY 2020[a] | 4Q FY 2020 | 4Q FY 2021[a] | 3Q FY 2022[a] | 4Q FY 2022[a] | N/A | 4Q FY 2032[a] |

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

| Fiscal Year | Performance Baseline Validation | CD-3A |
|---|---|---|
| FY 2021 | 4Q FY 2021 | 1Q FY 2021[a] |

**CD-3A** – Approve Long-Lead Procurements and Start of Early Construction

[a] This project is pre-CD-2; therefore, funding and schedule estimates are preliminary.

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC[a], Except D&D | OPC, D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|---|
| FY 2021 | 48,000[a] | 188,000[a] | 236,000[a] | 4,000 | N/A | 4,000 | 240,000[a] |

**2. Project Scope and Justification**

**Scope**

The Linear Assets Modernization project will implement a multi-system-based, common geographical approach (“corridors” across the lab with a number of different systems included in corridor) to repair, improve, and modernize linear systems which could include domestic water, natural gas, storm drain, sanitary sewer, electrical, and communication. The project will identify locations where utility corridors would provide operational and construction efficiencies while reducing deferred maintenance. The project may also address improvements to roadways or other traffic circulation elements, particularly where utility reconfigurations may necessitate or otherwise provide opportunities for enhancement.

**Justification**

Established in 1931, LBNL is the oldest DOE national laboratory. SC utilizes the capabilities of LBNL to execute 23 of the 24 core capabilities and the mission of multiple SC program offices, including a strong presence of Advanced Scientific Computing Research, Biological and Environmental Research, Basic Energy Sciences, and High Energy Physics. The mission need of this project is to support the SC mission and multiple scientific programs by increasing the reliability, capability, and safety of LBNL’s underground utility infrastructure while significantly reducing deferred maintenance. Utility infrastructure represents 48 percent of the current $249,000,000 deferred maintenance backlog and represents a significant capability gap in the LBNL’s ability to provide reliable and safe services to meet DOE’s mission needs. Direct investment is necessary to enable transformational infrastructure improvements to accelerate deferred maintenance reduction, restore operational reliability, and enhance support for scientific advancements. Moreover, existing infrastructure is insufficient to support the future vision of planned facility modernization and growth. Without a modern utility infrastructure backbone, future growth of the science mission at LBNL may not be able to be fully accommodated.

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

Key Performance Parameters (KPPs)

The Key Performance Parameters (KPPs) are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

[a] Other Project Costs (OPC) are funded through laboratory overhead.

| Performance Measure | Threshold | Objective |
|---|---|---|
| ▪ Rehabilitate and selectively upgrade LBNL's existing major underground utility systems | ▪ Renovate and modernize select underground linear corridors containing distribution systems and components for:<br>o Electrical<br>o Natural Gas<br>o Domestic water supply/Sanitary /storm water; and/or<br>o Data and communication<br>▪ Establish critical loops for redundancy | ▪ Renovate additional underground corridors |

### 3. Financial Schedule

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| FY 2020 | 500 | 500 | 500 |
| FY 2021 | 2,000 | 2,000 | 1,000 |
| Outyears | 45,500 | 45,500 | 46,500 |
| Total, Design | 48,000 | 48,000 | 48,000 |
| Construction | | | |
| Outyears | 188,000 | 188,000 | 188,000 |
| Total, Construction | 188,000 | 188,000 | 188,000 |
| Total Estimated Cost (TEC) | | | |
| FY 2020 | 500 | 500 | 500 |
| FY 2021 | 2,000 | 2,000 | 1,000 |
| Outyears | 233,500 | 233,500 | 234,500 |
| **Total, TEC[a]** | **236,000** | **236,000** | **236,000** |
| **Other Project Cost (OPC)[b]** | | | |
| FY 2019 | 300 | 300 | 300 |
| FY 2020 | 1,700 | 1,7000 | 1,700 |
| Outyears | 2,000 | 2,000 | 2,000 |
| **Total, OPC** | **4,000** | **4,000** | **4,000** |

[a] This project has not received CD-2 approval, therefore, funding estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Project Cost (TPC)[a]** | | | |
| FY 2019 | 300 | 300 | 300 |
| FY 2020 | 2,200 | 2,200 | 2,200 |
| FY 2021 | 2,000 | 2,000 | 1,000 |
| Outyears | 235,500 | 235,500 | 236,500 |
| **Total, TPC[a]** | **240,000** | **240,000** | **240,000** |

**4. Details of Project Cost Estimate**

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| Design | 38,000 | N/A | N/A |
| Contingency | 10,000 | N/A | N/A |
| Total, Design | 48,000 | N/A | N/A |
| Construction | | | |
| Construction | 150,000 | N/A | N/A |
| Contingency | 38,000 | N/A | N/A |
| Total, Construction | 188,000 | N/A | N/A |
| **Total, TEC[a]** | **236,000** | **N/A** | **N/A** |
| *Contingency, TEC* | *48,000* | *N/A* | *N/A* |
| **Other Project Cost (OPC)[b]** | | | |
| OPC except D&D | | | |
| Conceptual Design | 1,700 | N/A | N/A |
| Start-up | 1,600 | N/A | N/A |
| Contingency | 700 | N/A | N/A |
| **Total, OPC** | **4,000** | **N/A** | **N/A** |
| *Contingency, OPC* | *700* | *N/A* | *N/A* |
| **Total Project Cost[a]** | **240,000** | **N/A** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***47,700*** | ***N/A*** | ***N/A*** |

[a] This project has not received CD-2 approval, therefore, funding estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

## 5. Schedule of Appropriations Requests

(dollars in thousands)

| Request Year | Type | FY 2019 | FY 2020 | FY 2021 | Outyears | Total |
|---|---|---|---|---|---|---|
| FY 2021 | TEC | — | 500 | 2,000 | 233,500 | 236,000[a] |
| | OPC[b] | 300 | 1,700 | — | 2,000 | 4,000 |
| | TPC | 300 | 2,200 | 2,000 | 235,500 | 240,000[a] |

## 6. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | TBD |
| Expected Useful Life | 50 years |
| Expected Future Start of D&D of this capital asset | N/A |

Related Funding Requirements
(dollars in thousands)[c]

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | Previous Total Estimate | Current Total Estimate | Previous Total Estimate | Current Total Estimate |
| Operations | TBD | TBD | TBD | TBD |
| Utilities | TBD | TBD | TBD | TBD |
| Maintenance and Repair | TBD | TBD | TBD | TBD |
| Total, Operations and Maintenance | TBD | TBD | TBD | TBD |

## 7. D&D Information

This project replaces critical infrastructure components; no new construction area is anticipated to be constructed in this project and it will not replace existing facilities.

| | Square Feet |
|---|---|
| New area being constructed by this project at Lawrence Berkeley National Laboratory | None |
| Area of D&D in this project at Lawrence Berkeley National Laboratory | None |
| Area at Lawrence Berkeley National Laboratory to be transferred, sold, and/or D&D outside the project, including area previously "banked" | None[d] |
| Area of D&D in this project at other sites | None |
| Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked" | None |
| Total area eliminated | None |

[a] This project has not received CD-2 approval, therefore, funding estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.
[c] This project has not received CD-1 approval; related operations and maintenance funding requirements are yet to be determined.
[d] With the implementation of OMB's Reduce the Footprint initiative, DOE no longer maintains the space bank. Footprint is managed using the Facility Information Management System, with the decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

**8. Acquisition Approach**

The LBNL Management and Operating (M&O) Contractor, University of California, will perform the acquisition for this project, overseen by the Bay Area Site Office. The M&O contractor is responsible for awarding and managing all subcontracts related to this project. It will evaluate various acquisition approaches and project delivery methods prior to achieving CD-1 and potential benefits of using a single or multiple contracts to procure materials, equipment, construction, commissioning, and other project scope elements. The M&O contractor's annual performance and evaluation measurement plan will include Project performance metrics for LBNL on which it will be evaluated.

**20-SC-79, Critical Utilities Infrastructure Revitalization (CUIR)**
**SLAC National Accelerator Laboratory (SLAC)**
**Project is for Design and Construction**

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

### Summary

The FY 2021 Request for the Critical Utilities Infrastructure Revitalization (CUIR) project is $2,000,000. The preliminary Total Estimated Cost (TEC) range for this project is $80,000,000 to $186,000,000. The preliminary Total Project Cost (TPC) range for this project is $83,000,000 to $189,000,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The preliminary TPC estimate for this project is $189,000,000.

The primary objective of this project is to close utilities infrastructure gaps to support multi-program science missions at SLAC. Evolving technologies, instruments, experimental parameters, sensitivities, and complexity require increased reliability, resiliency, and service levels in electrical, mechanical, and civil systems site wide. The CUIR project will address the critical campus-wide utility and infrastructure issues by replacing, repairing, and modernizing the highest risk water/fire protection, sanitary sewer, storm drain, electrical, and cooling water system deficiencies. These needs have been identified through condition assessments, inspections, and recommendations from subject matter experts responsible for stewardship of the systems.

### Significant Changes

This project was initiated in FY 2020 Enacted Appropriations. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-0, Approve Mission Need, which was approved May 17, 2019. FY 2021 funds will support Project Engineering and Design (PED) activities.

A Federal Project Director with the appropriate certification level will be assigned to this project prior to CD-1 approval.

### Critical Milestone History

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | D&D Complete | CD-4 |
|---|---|---|---|---|---|---|---|---|
| FY 2021 | 5/17/19 | 4Q FY 2020[a] | 4Q FY 2020[a] | 4Q FY 2021[a] | 3Q FY 2022[a] | 4Q FY 2022[a] | N/A | 4Q FY 2032[a] |

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

| Fiscal Year | Performance Baseline Validation | CD-3A |
|---|---|---|
| FY 2021 | 4Q FY 2021[a] | 1Q FY 2021[a] |

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

[a] This project has not received CD-2 approval; therefore, schedule estimates are preliminary.

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC[a], Except D&D | OPC, D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|---|
| FY 2021 | 20,000 | 166,000[b] | 186,000 | 3,000 | N/A | 3,000 | 189,000[b] |

## 2. Project Scope and Justification

**Scope**
CUIR's preliminary scope is to provide underground domestic water/fire protection, sanitary sewer, and storm drain systems site-wide. Additionally, it will provide updated major electrical gear, instrumentation, and cooling water systems for the two-mile long klystron gallery and accelerator housing constructed in 1962.

**Justification**
SLAC is currently implementing a Campus Strategy based on its goals, which are designed to support the DOE Science Mission, increase reliability, and minimize costs through safe, effective, and efficient operations. The objective of the CUIR project is to reduce risks and close the capability gaps identified in SLAC's infrastructure assessments and surveys as they relate to storm water, sanitary sewer, domestic water/fire protection, electrical, and cooling water systems.

Disruptions caused by utility piping breaks, power fluctuations, faults, and cooling water interruptions, have frequently impacted science research site wide. Electrical systems, pumps, and motors fail, valves on piping systems freeze, and there are inoperable or unsafe electrical components that require broad outages to respond and repair, which impact more science research and the greater SLAC population. Work-arounds and administrative controls placed on existing equipment and systems, which are under-rated, not operating as intended, or not designed/operational for today's science needs, create tremendous inefficiencies and safety concerns, and sub-optimize operations.

The proposed project will retire $18,000,000 in deferred maintenance. The timely delivery of this project is essential for current and future success of SLAC's science programs. Alternatives will be evaluated prior to CD-1 during acquisition strategy development.

The CUIR project will also reduce operational risks in critical infrastructure and utility support systems for all science programs, decrease utilization of unique, old and outdated equipment; and increase operational reliability, flexibility, and sustainability throughout our site infrastructure. If these existing reliability gaps are not fulfilled, the operational efficiency, reliability, productivity, and competitive viability in science programs and other related science research breakthroughs will continue to be impeded.

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

[a] Other Project Costs (OPC) are funded through laboratory overhead.
[b] This project has not received CD-2 approval; therefore, funding estimates are preliminary.

Key Performance Parameters (KPPs)

The Key Performance Parameters (KPPs) are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| ▪ Deliver identified underground utility capabilities | ▪ Repair/Replace 1,500 linear feet (LF) sanitary sewer piping and one lift station.<br>▪ Repair/Replace 9,000 LF of domestic water/ fire protection piping.<br>▪ Repair/Replace 1,500 LF of storm water drain piping and one lift station. | ▪ Repair/Replace 5,000 LF of sanitary sewer piping and two lift stations.<br>▪ Repair/Replace 28,000 LF of domestic water/ fire protection piping.<br>▪ Repair/Replace 6,000 LF of storm water drain piping and three lift stations. |
| ▪ Deliver identified cooling capabilities | ▪ Provides one new 5 megawatt (MW) cooling towers at Linac<br>▪ Increase the existing underground cooling tower header pipe capacity to 18 inches. | ▪ Provides two new 5 MW cooling towers at Linac.<br>▪ Increase the existing underground cooling tower header pipe capacity to 20 inches.<br>▪ Install new non-radioactive Low Conductivity Water systems for cooling at sectors 4-10<br>▪ Provide new controls and instrumentation for the LCW system at sectors 4-10 |
| ▪ Deliver identified electrical power capabilities | ▪ Replace one Motor Control Center on Linac<br>▪ Replace five electrical switchgear in substations in Linac<br>▪ Install two new 12 kilovolt (kV) electrical feeder and switching equipment for Linac<br>▪ Provide partial SCADA (supervisory control and data acquisition) for of the SLAC power system in master substation and Linac | ▪ Replace twelve Motor Control Centers on Linac<br>▪ Replace sixteen electrical switchgear in substations in Linac<br>▪ Replace six 12kV electrical feeders across site<br>▪ Provide complete SCADA of the SLAC power system in master substation and Linac |

### 3. Financial Schedule

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| FY 2020 | 500 | 500 | 500 |
| FY 2021 | 2,000 | 2,000 | 1,000 |
| Outyears | 35,000 | 35,000 | 36,000 |
| Total, Design | 37,500 | 37,5000 | 37,500 |
| Construction | | | |
| Outyears | 148,500 | 148,500 | 148,500 |
| Total, Construction | 148,500 | 148,500 | 148,500 |
| Total Estimated Cost (TEC) | | | |
| FY 2020 | 500 | 500 | 500 |
| FY 2021 | 2,000 | 2,000 | 1,000 |
| Outyears | 183,500 | 183,500 | 184,500 |
| **Total, TEC[a]** | **186,000** | **186,000** | **186,000** |
| **Other Project Cost (OPC)** | | | |
| FY 2020 | 1,000 | 1,000 | 1,000 |
| FY 2021 | 1,000 | 1,000 | 1,000 |
| Outyears | 1,000 | 1,000 | 1,000 |
| **Total, OPC[b]** | **3,000** | **3,000** | **3,000** |
| **Total Project Cost (TPC)** | | | |
| FY 2020 | 1,500 | 1,500 | 1,500 |
| FY 2021 | 3,000 | 3,000 | 2,000 |
| Outyears | 184,500 | 184,500 | 185,500 |
| **Total, TPC[a]** | **189,000** | **189,000** | **189,000** |

[a] This project has not received CD-2 approval, therefore, funding estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

## 4. Details of Project Cost Estimate

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| Design | 16,000 | N/A | N/A |
| Contingency | 4,000 | N/A | N/A |
| Total, Design | 20,000 | N/A | N/A |
| Construction | | | |
| Construction | 132,000 | N/A | N/A |
| Contingency | 34,000 | N/A | N/A |
| Total, Construction | 166,000 | N/A | N/A |
| **Total, TEC[a]** | **186,000** | **N/A** | **N/A** |
| *Contingency, TEC* | *38,000* | *N/A* | *N/A* |
| **Other Project Cost (OPC)[b]** | | | |
| OPC except D&D | | | |
| OPC except D&D | 3,000 | N/A | N/A |
| Contingency | — | N/A | N/A |
| **Total, OPC** | **3,000** | **N/A** | **N/A** |
| *Contingency, OPC* | — | *N/A* | *N/A* |
| **Total Project Cost[a]** | **189,000** | **N/A** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***38,000*** | ***N/A*** | ***N/A*** |

## 5. Schedule of Appropriations Requests

(dollars in thousands)

| Request Year | Type | FY 2020 | FY 2021 | Outyears | Total |
|---|---|---|---|---|---|
| FY 2021 | TEC | 500 | 2,000 | 183,500 | 186,000[a] |
| | OPC[b] | 1,000 | 1,000 | 1,000 | 3,000 |
| | TPC | 1,500 | 3,000 | 184,500 | 189,000[a] |

## 6. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 4Q FY 2026 |
| Expected Useful Life | 50 years |
| Expected Future Start of D&D of this capital asset | 4Q FY 2076 |

[a] This project has not received CD-2 approval, therefore, funding estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | Previous Total Estimate | Current Total Estimate | Previous Total Estimate | Current Total Estimate |
| Operations | N/A | 7,805 | N/A | 885,000 |
| Utilities | N/A | 14,940 | N/A | 158,930 |
| Maintenance and Repair | N/A | 5,700 | N/A | 702,000 |
| Total, Operations and Maintenance | N/A | 28,445 | N/A | 1,745,930 |

**7. D&D Information**

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

| | Square Feet |
|---|---|
| New area being constructed by this project at SLAC National Accelerator Facility .......................... | None |
| Area of D&D in this project at SLAC National Accelerator Facility .................................................. | None |
| Area at SLAC National Accelerator Facility to be transferred, sold, and/or D&D outside the project, including area previously "banked" ...................................................................................... | None[a] |
| Area of D&D in this project at other sites ........................................................................................ | None |
| Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked" ........................................................................................................................ | None |
| Total area eliminated .......................................................................................................................... | None |

**8. Acquisition Approach**

The SLAC Management and Operating (M&O) contractor, Stanford University, will perform the acquisition for this project, overseen by the Bay Area Site Office. The M&O contractor is responsible for awarding and managing all subcontracts related to this project. The M&O contractor will evaluate various acquisition alternatives and project delivery methods prior to achieving CD-1. Potential acquisition and project delivery methods include, but are not limited to, firm-fixed-price contracts for design-bid-build, construction management, and design-build subcontracts. The M&O contractor will also evaluate potential benefits of using a single or multiple contracts to procure materials, equipment, construction, commissioning and other project scope elements. Its annual performance and evaluation measurement plan will include project performance metrics for SLAC on which it will be evaluated.

[a] With the implementation of OMB's Reduce the Footprint initiative, DOE no longer maintains the space bank. Footprint is managed using the Facility Information Management System, with decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

**20-SC-80, Utilities Infrastructure Project**
**Fermi National Accelerator Laboratory (FNAL)**
**Project is for Design and Construction**

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

### Summary

The FY 2021 Request for the Utilities Infrastructure Project (UIP) is $2,000,000. This project has a preliminary Total Estimated Cost (TEC) range of $146,000,000 to $310,000,000 and a preliminary Total Project Cost (TPC) range of $150,000,000 to $314,000,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The preliminary TPC estimate for this project is $314,000,000.

This project will modernize aging, obsolete, and severely deteriorated utilities infrastructure at Fermi National Accelerator Laboratory (FNAL).

### Significant Changes

This project was initiated in FY 2020 Enacted Appropriations. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-0, Approve Mission Need, which was approved on May 17, 2019. FY 2021 funds will support Project Engineering and Design (PED) activities.

A Federal Project Director with the appropriate certification level will be assigned to this project prior to CD-1 approval.

### Critical Milestone History

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | D&D Complete | CD-4 |
|---|---|---|---|---|---|---|---|---|
| FY 2021 | 5/17/19 | 4Q FY 2020 | 4Q FY 2020[a] | 4Q FY 2021[a] | 3Q FY 2022[a] | 4Q FY 2022[a] | N/A | 4Q FY 2034[a] |

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

| Fiscal Year | Performance Baseline Validation | CD-3A |
|---|---|---|
| FY 2021 | 4Q FY 2021[a] | 4Q FY 2020[a] |

**CD-3A** – Approve Long-Lead Procurements and Start of Early Construction Activities

[a] This project is pre-CD-2; therefore, schedule estimates are preliminary.

### Project Cost History

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC[a], Except D&D | OPC, D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|---|
| FY 2021 | 73,000 | 237,000[b] | 310,000 | 4,000 | N/A | 4,000 | 314,000[b] |

## 2. Project Scope and Justification

### Scope

The UIP's preliminary scope includes upgrading the highest risk major utility systems across the FNAL campus. Specifically, this project will first evaluate the current condition of the industrial cooling water system, potable water distribution system, sanitary sewer and storm collection systems, natural gas distribution system, electrical distribution system, and the Central Utility Building. Selected portions of the systems will then be replaced to assure safe, reliable, and efficient service to mission critical facilities. In addition, the project will perform upgrades to obsolete, end-of-life components, which will increase capacity, reliability, and personnel safety for critical utilities.

### Justification

DOE's Office of Science (SC) advances new experiments, international partnerships, and research programs to transform the understanding of nature and to advance U.S. energy, economic and national security interests. This mission requires the modernization of aging, obsolete, and severely deteriorated utilities infrastructure at FNAL. SC has identified a need to recapitalize FNAL's Central Utilities Building and distributed site utility infrastructure to ensure the stewardship of SC's investments and to provide modern, world-class facilities for scientific experiments and research.

Although there has been substantial investment in recent years to modernize and construct new research facilities at FNAL, much of FNAL's utility infrastructure serving these facilities is over 50 years old. Efficient, maintainable, and reliable utilities are critical to the success and mission capability of FNAL's research facilities. Currently, a significant portion of FNAL's utility infrastructure is beyond useful life and suffering from failures, decreased reliability, lack of redundancy, and limitations in capacity. As such, there is an urgent need to revitalize and selectively upgrade FNAL's existing major utility systems to ensure reliable service, meet capacity requirements, and enable readiness of facilities critical to the research mission.

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

[a] Other Project Costs (OPC) are funded through laboratory overhead.
[b] This project has not received CD-2 approval, therefore, funding estimates are preliminary.

Key Performance Parameters (KPPs)

The Key Performance Parameters (KPPs) are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| ▪ Rehabilitate and selectively upgrade FNAL's existing major utility systems | ▪ Revitalize 20% of the Industrial Cooling Water (ICW) system extending from backbone<br>▪ Replace 70% of the Domestic Water System (DWS) identified as inadequate or sub-standard<br>▪ Replace 50% of the Sanitary Sewer & Storm Collection systems identified as inadequate or sub-standard<br>▪ Replace 2 miles of underground Natural Gas lines<br>▪ Provide necessary repairs to the Central Utility Building (CUB) to ensure viability for current and near future (PIP-II, IERC, LBNF-Dune) projects | ▪ Revitalize 60% of the Industrial Cooling Water (ICW) system extending from backbone<br>▪ Replace 100% of the Domestic Water System (DWS) identified as inadequate or sub-standard<br>▪ Replace 100% of the Sanitary Sewer & Storm Collection systems identified as inadequate or sub-standard<br>▪ Replace 22 miles of underground Natural Gas lines<br>▪ Provide Safety / Reliability upgrades to Kautz Road Substation<br>▪ Replace Central Utility Building |

**3. Financial Schedule**

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| FY 2020 | 500 | 500 | 500 |
| FY 2021 | 2,000 | 2,000 | 1,000 |
| Outyears | 70,500 | 70,500 | 71,500 |
| Total, Design | 73,000 | 73,000 | 73,000 |
| Construction | | | |
| Outyears | 237,000 | 237,000 | 237,000 |
| Total, Construction | 237,000 | 237,000 | 237,000 |
| Total Estimated Cost (TEC) | | | |
| FY 2020 | 500 | 500 | 500 |
| FY 2021 | 2,000 | 2,000 | 1,000 |
| Outyears | 307,500 | 307,500 | 308,500 |
| **Total, TEC[a]** | **310,000** | **310,000** | **310,000** |

[a] This project has not received CD-2 approval, therefore, funding estimates are preliminary.

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Other Project Cost (OPC)** | | | |
| FY 2019 | 100 | 100 | 26 |
| FY 2020 | 1,900 | 1,900 | 1,974 |
| Outyears | 2,000 | 2,000 | 2,000 |
| **Total, OPC[a]** | **4,000** | **4,000** | **4,000** |
| **Total Project Cost (TPC)** | | | |
| FY 2019 | 100 | 100 | 26 |
| FY 2020 | 2,400 | 2,400 | 2,474 |
| FY 2021 | 2,000 | 2,000 | 1,000 |
| Outyears | 309,500 | 309,500 | 310,500 |
| **Total, TPC[b]** | **314,000** | **314,000** | **314,000** |

**4. Details of Project Cost Estimate**

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| Design | 60,800 | N/A | N/A |
| Contingency | 12,200 | N/A | N/A |
| Total, Design | 73,000 | N/A | N/A |
| Construction | | | |
| Construction | 197,500 | N/A | N/A |
| Contingency | 39,500 | N/A | N/A |
| Total, Construction | 237,000 | N/A | N/A |
| **Total, TEC[b]** | **310,000** | **N/A** | **N/A** |
| *Contingency, TEC* | *51,700* | *N/A* | *N/A* |

[a] Other Project Costs (OPC) are funded through laboratory overhead.
[b] This project has not received CD-2 approval, therefore, funding estimates are preliminary.

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Other Project Cost (OPC)** | | | |
| OPC except D&D | | | |
| OPC except D&D | 3,300 | N/A | N/A |
| Contingency | 700 | N/A | N/A |
| **Total, OPC[a]** | **4,000** | **N/A** | **N/A** |
| *Contingency, OPC* | *700* | *N/A* | *N/A* |
| **Total Project Cost[b]** | **314,000** | **N/A** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***52,400*** | ***N/A*** | ***N/A*** |

**5. Schedule of Appropriations Requests**

(dollars in thousands)

| Request Year | Type | FY 2019 | FY 2020 | FY 2021 | Outyears | Total |
|---|---|---|---|---|---|---|
| FY 2021 | TEC | — | 500 | 2,000 | 307,500 | 310,000[b] |
| | OPC[a] | 100 | 1,900 | — | 2,000 | 4,000 |
| | TPC | 100 | 2,400 | 2,000 | 309,500 | 314,000[b] |

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

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | TBD[c] |
| Expected Useful Life | 50 years |
| Expected Future Start of D&D of this capital asset | TBD[c] |

Related Funding Requirements[c]
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | **Previous Total Estimate** | **Current Total Estimate** | **Previous Total Estimate** | **Current Total Estimate** |
| Operations | TBD | TBD | N/A | TBD |
| Utilities | TBD | TBD | TBD | TBD |
| Maintenance and Repair | TBD | TBD | TBD | TBD |
| Total, Operations and Maintenance | TBD | TBD | TBD | TBD |

[a] Other Project Costs (OPC) are funded through laboratory overhead.
[b] This project has not received CD-2 approval, therefore, funding estimates are preliminary.
[c] This project has not received CD-1 approval; the related operations and maintenance funding requirements are yet to be determined.

## 7. D&D Information

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

| | Square Feet |
|---|---|
| New area being constructed by this project at Fermi National Accelerator Laboratory.................... | TBD |
| Area of D&D in this project at Fermi National Accelerator Laboratory............................................ | TBD |
| Area at Fermi National Accelerator Laboratory to be transferred, sold, and/or D&D outside the project, including area previously "banked" .......................................................................... | None[a] |
| Area of D&D in this project at other sites ........................................................................... | None |
| Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked" ............................................................................................................ | None |
| Total area eliminated ............................................................................................................ | TBD |

## 8. Acquisition Approach

The FNAL Management and Operating (M&O) contractor, Fermi Research Alliance LLC, will perform the acquisition for this project. The M&O contractor is responsible for awarding and managing all subcontracts related to this project and will evaluate various acquisition alternatives and project delivery methods prior to achieving CD-1. The M&O will also evaluate potential benefits of using a single or multiple contracts to procure materials, equipment, construction, commissioning, and other project scope elements. Its annual performance and evaluation measurement plan will include project performance metrics for FNAL on which will be evaluated.

[a] With the implementation of OMB's Reduce the Footprint initiative, DOE no longer maintains the space bank. Footprint is managed using the Facility Information Management System, with decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

**19-SC-71, Science User Support Center**
**Brookhaven National Laboratory (BNL)**
**Project is for Design and Construction**

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

### Summary

The FY 2021 Request for the Science User Support Center (SUSC) is $7,000,000. This project has a preliminary Total Estimated Cost (TEC) range of $70,800,000 to $94,800,000 and a preliminary Total Project Cost (TPC) range of $72,000,000 to $96,000,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The preliminary TPC estimate for this project is $86,200,000.

This project will provide a facility to serve the research community and improve scientific and operational productivity by consolidating visitor and support services.

### Significant Changes

This project was initiated in FY 2019. The most recent DOE Order 413.3B Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range, which was approved on December 18, 2018. FY 2021 funds will support construction and associated activities.

A Federal Project Director with the appropriate certification level (Level II: TPC greater than $50,000,000 and equal to or less than $100,000,000) has been assigned to this project.

### Critical Milestone History

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | D&D Complete | CD-4 |
|---|---|---|---|---|---|---|---|---|
| FY 2019 | 12/12/16 | 4Q FY 2018 | 2Q FY 2019[a] | 4Q FY 2020[a] | 3Q FY 2021 | 4Q FY 2021[a] | N/A | 4Q FY 2025[a] |
| FY 2020 | 12/12/16 | 9/07/18 | 12/18/18 | 4Q FY 2020[a] | 3Q FY 2021 | 4Q FY 2021[a] | N/A | 4Q FY 2025[a] |
| FY 2021 | 12/12/16 | 9/07/18 | 12/18/18 | 4Q FY 2020[a] | 3Q FY 2021 | 3Q FY 2021[a] | N/A | 4Q FY 2026[a] |

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

| Fiscal Year | Performance Baseline Validation | CD-3A |
|---|---|---|
| FY 2019 | 4Q FY 2020 | N/A |
| FY 2020 | 4Q FY 2020 | 4Q FY 2019 |
| FY 2021 | 4Q FY 2020[a] | 4Q FY 2020[a] |

**CD-3A** – Approve Long Lead Procurements and Site Preparation

[a] This project is pre-CD-2; therefore, schedule estimates are preliminary.

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC[a], Except D&D | OPC, D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|---|
| FY 2019 | 9,400 | 75,600[b] | 85,000[b] | 1,000 | N/A | 1,000 | 86,000[b] |
| FY 2020 | 9,400 | 75,600[b] | 85,000[b] | 1,200 | N/A | 1,200 | 86,200[b] |
| FY 2021 | 9,400 | 75,600[b] | 85,000[b] | 1,200 | N/A | 1,200 | 86,200[b] |

## 2. Project Scope and Justification

**Scope**

The scope of the SUSC project is to construct a multi-story office building of approximately 70,000 to 120,000 gross square feet (gsf) to consolidate and provide space for visitor processing, offices for approximately 200-350 occupants, space for conferences, extension of utilities to the building, and related roadway modifications and parking lot development. Demolition of excess facilities to meet offsetting space requirements will be done off-project, unless specific facilities are required to be included on-project. Additional supporting functions such as utilities or site modifications may be included in the project, if they are deemed necessary.

**Justification**

Brookhaven National Laboratory (BNL) has nine user facilities that attract over 40,000 visiting scientists, guests, users, and contractors annually to conduct research in a broad range of basic and applied sciences; however, the ability to efficiently process and support the needs of this growing community of researchers is limited by the age, condition, and dispersed nature of BNL's current facilities. The laboratory's scientific impact can be improved by a facility that centralizes its administrative support functions and provides easier visitor access to conferencing and collaboration space to support the Office of Science (SC) research mission. BNL also has many World War II era facilities dispersed around the site that house research support organizations in deteriorated facilities that are no longer sustainable and contribute to operational inefficiencies. Construction of the SUSC is conceived to provide convenient and efficient facilities for processing and supporting the users of BNL's premier research facilities, which would enable for the demolition of the current substandard, dispersed, and inefficient facilities. It will also provide conference facilities to support the collaborative science and research mission for the user community and BNL scientists.

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

Key Performance Parameters (KPPs)

The Key Performance Parameters (KPPs) are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| Multi-story Building | 70,000 gsf | 120,000 gsf |

[a] Other Project Costs (OPC) are funded through laboratory overhead.
[b] This project has not received CD-2 approval, therefore, funding estimates are preliminary.

### 3. Financial Schedule

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs[a] |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| FY 2019 | 7,000 | 7,000 | 398 |
| FY 2020 | 2,400 | 2,400 | 9,002 |
| Total, Design | 9,400 | 9,400 | 9,400 |
| Construction | | | |
| FY 2020 | 17,600 | 17,600 | 4,000 |
| FY 2021 | 7,000 | 7,000 | 16,000 |
| Outyears | 51,000 | 51,000 | 55,600 |
| Total, Construction | 75,600 | 75,600 | 75,600 |
| Total Estimated Cost (TEC) | | | |
| FY 2019 | 7,000 | 7,000 | 398 |
| FY 2020 | 20,000 | 20,000 | 13,002 |
| FY 2021 | 7,000 | 7,000 | 16,000 |
| Outyears | 51,000 | 51,000 | 55,600 |
| **Total, TEC[b]** | **85,000** | **85,000** | **85,000** |
| **Other Project Cost (OPC)** | | | |
| FY 2017 | 700 | 700 | 700 |
| FY 2018 | 300 | 300 | 286 |
| FY 2019 | 200 | 200 | 214 |
| **Total, OPC[c]** | **1,200** | **1,200** | **1,200** |
| **Total Project Cost (TPC)** | | | |
| FY 2017 | 700 | 700 | 700 |
| FY 2018 | 300 | 300 | 286 |
| FY 2019 | 7,200 | 7,200 | 612 |
| FY 2020 | 20,000 | 20,000 | 13,002 |
| FY 2021 | 7,000 | 7,000 | 16,000 |
| Outyears | 51,000 | 51,000 | 55,600 |
| **Total, TPC[b]** | **86,200** | **86,200** | **86,200** |

[a] Costs through 2019 reflect actual Costs; costs for FY 2020 and the outyears are estimates.
[b] This project has not received CD-2 approval, therefore, funding estimates are preliminary.
[c] Other Project Costs (OPC) are funded through laboratory overhead.

## 4. Details of Project Cost Estimate

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| Design | 7,800 | 7,800 | N/A |
| Contingency | 1,600 | 1,600 | N/A |
| Total, Design | 9,400 | 9,400 | N/A |
| Construction | | | |
| Construction | 63,000 | 63,000 | N/A |
| Contingency | 12,600 | 12,600 | N/A |
| Total, Construction | 75,600 | 75,600 | N/A |
| **Total, TEC[a]** | **85,000** | **85,000** | **N/A** |
| *Contingency, TEC* | *14,200* | *14,200* | *N/A* |
| **Other Project Cost (OPC)** | | | |
| OPC except D&D | | | |
| Conceptual Planning | 500 | 500 | N/A |
| Conceptual Design | 500 | 500 | N/A |
| Contingency | 200 | 200 | N/A |
| **Total, OPC[b]** | **1,200** | **1,200** | **N/A** |
| *Contingency, OPC* | *200* | *200* | *N/A* |
| **Total Project Cost[a]** | **86,200** | **86,200** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***14,400*** | ***14,400*** | ***N/A*** |

## 5. Schedule of Appropriations Requests

(dollars in thousands)

| Request Year | Type | Prior Years | FY 2019 | FY 2020 | FY 2021 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| FY 2019 | TEC | — | 2,000 | 7,400 | — | 75,600 | 85,000[a] |
| | OPC[b] | 1,000 | — | — | — | — | 1,000 |
| | TPC | 1,000 | — | 7,400 | — | 75,600 | 86,000[a] |
| FY 2020 | TEC | — | 7,000 | 6,400 | — | 71,600 | 85,000[a] |
| | OPC[b] | 1,000 | 200 | — | — | — | 1,200 |
| | TPC | 1,000 | 7,200 | 6,400 | — | 71,600 | 86,200[a] |
| FY 2021 | TEC | — | 7,000 | 20,000 | 7,000 | 51,000 | 85,000[a] |
| | OPC[b] | 1,000 | 200 | — | — | — | 1,200 |
| | TPC | 1,000 | 7,200 | 20,000 | 7,000 | 51,000 | 86,200[a] |

[a] This project has not received CD-2 approval, therefore, funding estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

## 6. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 4Q FY 2026 |
| Expected Useful Life | 60 years |
| Expected Future Start of D&D of this capital asset | 4Q FY 2086 |

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | Previous Total Estimate | Current Total Estimate | Previous Total Estimate | Current Total Estimate |
| Operations | 166 | 166 | 8,307 | 8,307 |
| Utilities | 78 | 78 | 3,879 | 3,879 |
| Maintenance and Repair | 384 | 384 | 19,200 | 19,200 |
| Total, Operations and Maintenance | 628 | 628 | 31,386 | 31,386 |

## 7. D&D Information

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

| | Square Feet |
|---|---|
| New area being constructed by this project at Brookhaven National Laboratory .......................... | 70,000 - 120,000 |
| Area of D&D in this project at Brookhaven National Laboratory .................................................. | None |
| Area at Brookhaven National Laboratory to be transferred, sold, and/or D&D outside the project, including area previously "banked" .................................................................................. | None[a] |
| Area of D&D in this project at other sites ..................................................................................... | None |
| Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked" ................................................................................................................... | None |
| Total area eliminated ........................................................................................................... | 70,000 - 120,000 |

## 8. Acquisition Approach

The BNL Management and Operating (M&O) Contractor, Brookhaven Science Associates, will perform the acquisition for this project, overseen by the Brookhaven Site Office and will be responsible for awarding and managing all subcontracts related to the project. The M&O contractor evaluated various acquisition and project delivery methods prior to achieving CD-1 and selected a Construction Manager/General Contractor approach as the best method to deliver the project. The M&O Contractor will evaluate potential benefits of using single or multiple contracts for site preparation activities. The M&O Contractor's annual performance and evaluation measurement plan includes Project performance metrics on which it will be evaluated.

[a] With the implementation of OMB's Reduce the Footprint initiative, DOE no longer maintains the space bank. Footprint is managed using the Facility Information Management System, with decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

**19-SC-73, Translational Research Capability**
**Oak Ridge National Laboratory (ORNL)**
**Project is for Design and Construction**

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

### Summary

The FY 2021 Request for the Translational Research Capability (TRC) project is $10,000,000. The preliminary Total Estimated Cost (TEC) range for this project is of $80,300,000 to $93,500,000. The preliminary Total Project Cost (TPC) range for this project is $81,800,000 to $95,000,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The preliminary TPC estimate for this project is $95,000,000.

This project will provide laboratory, high bay, office, and collaboration space to support advancement in high-performance computing and materials science in support of multidisciplinary research.

### Significant Changes

This project was initiated in FY 2019. The most recent DOE Order 413.3B Critical Decision (CD) is CD-3A, Approve Long-Lead Procurements and Start of Early Construction Activities, which was approved on February 05, 2019. FY 2021 funds will support construction and associated activities.

A Federal Project Director with the appropriate certification (Level II: TPC greater than $50,000,000 and equal to or less than $100,000,000) has been assigned to this project.

### Critical Milestone History

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | D&D Complete | CD-4 |
|---|---|---|---|---|---|---|---|---|
| FY 2020 | 10/26/17 | 7/20/18 | 11/02/18[a] | 1Q FY 2020[a] | 4Q FY 2019 | 1Q FY 2020[a] | N/A | 4Q FY 2025[a] |
| FY 2021 | 10/26/17 | 7/20/18 | 11/02/18[a] | 3Q FY 2020[a] | 4Q FY 2019 | 3Q FY 2020[a] | N/A | 4Q FY 2025[a] |

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

| Fiscal Year | Performance Baseline Validation | CD-3A | CD-2/3 | CD-3B |
|---|---|---|---|---|
| FY 2020 | N/A | 2Q FY 2019 | 1Q FY 2020[a] | N/A |
| FY 2021 | N/A | 2/05/19 | 3Q FY 2020[a] | N/A |

**CD-2/3** – Approve Performance Baseline and Start of Construction Activities
**CD-3A** – Approve Long-Lead Procurements, Original Scope
**CD-3B** – Approve Long-Lead Procurements, Revised Scope

[a] This project is pre-CD-2; therefore, schedule estimates are preliminary.

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC[a], Except D&D | OPC, D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|---|
| FY 2020 | 9,700 | 83,800 | 93,500[b] | 1,500 | N/A | 1,500 | 95,000[b] |
| FY 2021 | 7,400 | 86,100 | 93,500[b] | 1,500 | N/A | 1,500 | 95,000[b] |

**2. Project Scope and Justification**

**Scope**

The scope of the TRC project is to provide 79,700 to 115,000 gross square feet (gsf) of laboratory, high bay, office, and collaboration space to support advancement in high-performance computing and materials science in support of multidisciplinary research. Additional supporting functions such as utilities or site modifications may be included in the project, if they are deemed necessary.

**Justification**

The Office of Science (SC) has 24 core capabilities distributed across ten of the world-class national laboratories with the following four core capabilities that are relevant to this project in support of the SC mission at Oak Ridge National Laboratory (ORNL): advanced computer science, visualization, and data; materials science and engineering; decision science and analysis; and plasma and fusion energy science. Several SC Advisory Committee reports support the continuing need for these core capabilities encouraging development and integration of several multidisciplinary efforts, such as developing computational tools and the increasing necessity for interdisciplinary collaboration. This project will provide modern, flexible, and adaptable space that is that will enable ORNL to respond to the pressing demand to support advancement in computing and materials science in support of multidisciplinary research.

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

Key Performance Parameters (KPPs)

The Key Performance Parameters (KPPs) are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| Multifunction Laboratory and Office Building | 79,700 gsf | 115,000 gsf |

[a] Other Project Costs (OPC) are funded through laboratory overhead.
[b] This project has not received CD-2 approval, therefore, funding estimates are preliminary.

## 3. Financial Schedule

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| FY 2019 | 7,400 | 7,400 | 460 |
| FY 2020 | — | — | 4,000 |
| FY 2021 | — | — | 2,940 |
| Total, Design | 7,400 | 7,400 | 7,400 |
| Construction | | | |
| FY 2019 | 17,600 | 17,600 | 1,900 |
| FY 2020 | 25,000 | 25,000 | 3,100 |
| FY 2021 | 10,000 | 10,000 | 30,000 |
| Outyears | 33,500 | 33,500 | 51,100 |
| Total, Construction | 86,100 | 86,100 | 86,100 |
| Total Estimated Cost (TEC) | | | |
| FY 2019 | 25,000 | 25,000 | 2,360 |
| FY 2020 | 25,000 | 25,000 | 7,100 |
| FY 2021 | 10,000 | 10,000 | 32,940 |
| Outyears | 33,500 | 33,500 | 51,100 |
| **Total, TEC[a]** | **93,500** | **93,500** | **93,500** |
| **Other Project Cost (OPC)[b]** | | | |
| OPC except D&D | | | |
| FY 2017 | 190 | 190 | 190 |
| FY 2018 | 1,000 | 1,000 | 1,000 |
| FY 2019 | 210 | 210 | 89 |
| Outyears | 100 | 100 | 221 |
| **Total, OPC** | **1,500** | **1,500** | **1,500** |
| **Total Project Cost (TPC)** | | | |
| FY 2017 | 190 | 190 | 190 |
| FY 2018 | 1,000 | 1,000 | 1,000 |
| FY 2019 | 25,210 | 25,210 | 2,449 |
| FY 2020 | 25,000 | 25,000 | 7,100 |
| FY 2021 | 10,000 | 10,000 | 32,940 |
| Outyears | 33,600 | 33,600 | 51,321 |
| **Total, TPC[a]** | **95,000** | **95,000** | **95,000** |

[a] This project has not received CD-2 approval, therefore, funding estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

## 4. Details of Project Cost Estimate

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)[a]** | | | |
| Design | | | |
| Design | 6,400 | 8,200 | N/A |
| Contingency | 1,000 | 1,500 | N/A |
| Total, Design | 7,400 | 9,700 | N/A |
| Construction | | | |
| Construction | 70,100 | 70,500 | N/A |
| Contingency | 16,000 | 13,300 | N/A |
| Total, Construction | 86,100 | 83,800 | N/A |
| **Total, TEC** | **93,500** | **93,500** | **N/A** |
| *Contingency, TEC* | *17,000* | *14,800* | *N/A* |
| **Other Project Cost (OPC)[b]** | | | |
| OPC except D&D | | | |
| Conceptual Planning | 500 | 500 | N/A |
| Conceptual Design | 800 | 800 | N/A |
| Contingency | 200 | 200 | N/A |
| **Total, OPC** | **1,500** | **1,500** | **N/A** |
| *Contingency, OPC* | *200* | *200* | *N/A* |
| **Total Project Cost[a]** | **95,000** | **95,000** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***17,200*** | ***15,000*** | ***N/A*** |

## 5. Schedule of Appropriations Requests

(dollars in thousands)

| Request Year | Type | Prior Years | FY 2019 | FY 2020 | FY 2021 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| FY 2020 | TEC | — | 25,000 | 15,000 | — | 53,500 | 93,500[a] |
| | OPC[b] | 1,190 | — | — | — | 310 | 1,500 |
| | TPC | 1,190 | 25,000 | 15,000 | — | 53,810 | 95,000[a] |
| FY 2021 | TEC | — | 25,000 | 25,000 | 10,000 | 33,500 | 93,500[a] |
| | OPC[b] | 1,190 | 210 | — | — | 100 | 1,500 |
| | TPC | 1,190 | 25,210 | 25,000 | 10,000 | 33,600 | 95,000[a] |

[a] This project has not received CD-2 approval, therefore, funding estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

## 6. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 4Q FY 2025 |
| Expected Useful Life | 50 years |
| Expected Future Start of D&D of this capital asset | 4Q FY 2075 |

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | Previous Total Estimate | Current Total Estimate | Previous Total Estimate | Current Total Estimate |
| Operations | — | 742 | — | 26,823 |
| Utilities | — | 258 | — | 9,030 |
| Maintenance and Repair | — | 720 | — | 25,201 |
| Total, Operations and Maintenance | — | 1,720 | — | 61,054 |

## 7. D&D Information

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

| | Square Feet |
|---|---|
| New area being constructed by this project at Oak Ridge National Laboratory | 79,700-115,000 |
| Area of D&D in this project at Oak Ridge National Laboratory | None |
| Area at Oak Ridge National Laboratory to be transferred, sold, and/or D&D outside the project, including area previously "banked" | None[a] |
| Area of D&D in this project at other sites | None |
| Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked" | None |
| Total area eliminated | 79,700-115,000 |

## 8. Acquisition Approach

The ORNL Management and Operating (M&O) Contractor, UT-Battelle, will perform the acquisition for this project overseen by the ORNL Site Office and will be responsible for awarding and managing all subcontracts related to the project. The M&O contractor evaluated various acquisition and project delivery methods prior to achieving CD-1, and selected a design/build best value technical qualification approach as the best method to deliver the project. The ORNL M&O Contractor will evaluate potential benefits of using a single or multiple contracts to procure materials, equipment, construction, commissioning and other project scope elements. The M&O Contractor's annual performance and evaluation measurement plan includes project performance metrics on which it will be evaluated.

[a] With the implementation of OMB's Reduce the Footprint initiative, DOE no longer maintains the space bank. Footprint is managed using the Facility Information Management System, with decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

**19-SC-74, Biological and Environmental Program Integration Center (BioEPIC)**
**Lawrence Berkeley National Laboratory (LBNL)**
**Project is for Design and Construction**

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

**Summary**

The FY 2021 Request for the Biological and Environmental Program Integration Center (BioEPIC) project is $6,000,000. The preliminary Total Estimated Cost (TEC) range for this project is $110,000,000 to $190,000,000. The preliminary Total Project Cost (TPC) range for this project is $112,200,000 to $192,200,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The preliminary TPC estimate for the project is $142,200,000.

This project will construct a new building with high performance laboratory space in close proximity to key LBNL facilities and programs. Research operations currently located in commercially leased space and dispersed across the campus will be collocated into this building allowing for better facilitation of Biological and Environmental Research (BER), Advanced Scientific Computing Research (ASCR), and Basic Energy Sciences (BES) program research activities.

**Significant Changes**

This project was initiated in FY 2019. The most recent DOE Order 413.3B Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range, which was approved on May 9, 2019. FY 2021 funds will support construction and associated activities after the appropriate CD approvals.

A Federal Project Director with the appropriate certification level (Level III: TPC greater than $100,000,000 and equal to or less than $400,000,000) has been assigned to this project.

**Critical Milestone History**

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | D&D Complete | CD-4 |
|---|---|---|---|---|---|---|---|---|
| FY 2020 | 3/13/18 | 2Q FY 2019 | 3Q FY 2019 | 4Q FY 2020[a] | 2Q FY 2022[a] | 4Q FY 2021[a] | N/A | 4Q FY 2027[a] |
| FY 2021 | 3/13/18 | 5/09/19 | 5/09/19 | 4Q FY 2021[a] | 2Q FY 2021[a] | 4Q FY 2021[a] | N/A | 4Q FY 2027[a] |

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

| Fiscal Year | Performance Baseline Validation |
|---|---|
| FY 2020 | 4Q FY 2020[a] |
| FY 2021 | 4Q FY 2021[a] |

[a] This project is pre-CD-2; therefore, schedule estimates are preliminary.

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC[a], Except D&D | OPC, D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|---|
| FY 2020 | 13,000[b] | 127,000[b] | 140,000[b] | 2,200 | N/A | 2,200 | 142,200[b] |
| FY 2021 | 13,000[b] | 127,000[b] | 140,000[b] | 2,200 | N/A | 2,200 | 142,200[b] |

## 2. Project Scope and Justification

**Scope**

The scope of the BioEPIC project is to construct a new, state-of-the-art facility between 55,000 and 90,000 gross square feet (gsf) with laboratory space to support high performance research by BER, ASCR, and BES programs. This facility will be constructed in close proximity to key LBNL facilities and programs. Research operations currently located in commercially leased space and dispersed across the campus will be collocated to the BioEPIC building. Collocation of researchers in this unique experimental facility, near other important Office of Science (SC) assets, will increase synergy and efficiency, which will better facilitate collaborative research in support of the SC mission.

**Justification**

The mission need of this project is to increase the synergy and efficiency of biosciences and other SC research at LBNL. LBNL has grown from a pioneering particle and nuclear physics laboratory into a multidisciplinary research facility with broad capabilities in physical, chemical, computational, biological, and environmental systems research in support of the DOE mission. Much of the biological sciences program at LBNL is located off-site, away from the main laboratory, while others are dispersed across several locations on the LBNL campus. This arrangement has produced research and operational capability gaps that limit scientific progress and is a significant roadblock to the kind of collaborative science that is required for understanding, predicting, and harnessing the Earth's microbiome for energy and environmental benefits. This project will close the present capability gap by providing a state-of-the-art facility that will collocate biosciences research and other programs.

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

Key Performance Parameters (KPPs)

The Key Performance Parameters (KPPs) are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| Biosciences and other research space | 55,000 gsf | 90,000 gsf |

[a] Other Project Costs (OPC) are funded through laboratory overhead.
[b] This project has not received CD-2 approval; therefore, funding estimates are preliminary.

## 3. Financial Schedule

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| FY 2019 | 5,000 | 5,000 | 5,000 |
| FY 2020 | 8,000 | 8,000 | 8,000 |
| Total, Design | 13,000 | 13,000 | 13,000 |
| Construction | | | |
| FY 2020 | 7,000 | 7,000 | — |
| FY 2021 | 6,000 | 6,000 | 8,000 |
| Outyears | 114,000 | 114,000 | 119,000 |
| Total, Construction | 127,000 | 127,000 | 127,000 |
| Total Estimated Cost (TEC) | | | |
| FY 2019 | 5,000 | 5,000 | 5,000 |
| FY 2020 | 15,000 | 15,000 | 8,000 |
| FY 2021 | 6,000 | 6,000 | 8,000 |
| Outyears | 114,000 | 114,000 | 119,000 |
| **Total, TEC**[a] | **140,000** | **140,000** | **140,000** |
| **Other Project Cost (OPC)**[b] | | | |
| FY 2019 | 1,500 | 1,500 | 1,500 |
| Outyears | 700 | 700 | 700 |
| **Total, OPC** | **2,200** | **2,200** | **2,200** |
| **Total Project Cost (TPC)**[a] | | | |
| FY 2019 | 6,500 | 6,500 | 6,500 |
| FY 2020 | 15,000 | 15,000 | 8,000 |
| FY 2021 | 6,000 | 6,000 | 8,000 |
| Outyears | 114,700 | 114,700 | 119,700 |
| **Total, TPC**[a] | **142,200** | **142,200** | **142,200** |

[a] This project has not received CD-2 approval; therefore, funding estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

## 4. Details of Project Cost Estimate

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| Design | 10,600 | 12,800 | N/A |
| Contingency | 2,400 | 3,200 | N/A |
| Total, Design | 13,000 | 16,000 | N/A |
| Construction | | | |
| Construction | 105,000 | 103,000 | N/A |
| Contingency | 22,000 | 21,000 | N/A |
| Total, Construction | 127,000 | 124,000 | N/A |
| **Total, TEC**[a] | **140,000** | **140,000** | **N/A** |
| *Contingency, TEC* | *24,400* | *24,200* | *N/A* |
| **Other Project Cost (OPC)**[b] | | | |
| OPC except D&D | | | |
| Conceptual Design | 1,500 | 1,300 | N/A |
| Start-up | 600 | 600 | N/A |
| Contingency | 100 | 300 | N/A |
| **Total, OPC** | **2,200** | **2,200** | **N/A** |
| *Contingency, OPC* | *100* | *300* | *N/A* |
| **Total Project Cost**[a] | **142,200** | **142,200** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***24,500*** | ***24,500*** | ***N/A*** |

## 5. Schedule of Appropriations Requests

(dollars in thousands)

| Request Year | Type | FY 2019 | FY 2020 | FY 2021 | Outyears | Total |
|---|---|---|---|---|---|---|
| FY 2020 | TEC | 5,000 | 6,000 | — | 129,000 | 140,000[a] |
| | OPC[b] | 1,500 | — | — | 700 | 2,200 |
| | TPC | 6,500 | 6,000 | — | 129,700 | 142,200[a] |
| FY 2021 | TEC | 5,000 | 15,000 | 6,000 | 114,000 | 140,000[a] |
| | OPC[b] | 1,500 | — | — | 700 | 2,200 |
| | TPC | 6,500 | 15,000 | 6,000 | 114,700 | 142,200[a] |

[a] This project has not received CD-2 approval; therefore, funding estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

### 6. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 4Q FY 2027 |
| Expected Useful Life | 50 years |
| Expected Future Start of D&D of this capital asset | 1Q FY 2077 |

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | Previous Total Estimate | Current Total Estimate | Previous Total Estimate | Current Total Estimate |
| Operations | 150 | 150 | 5,700 | 5,700 |
| Utilities | 270 | 270 | 11,900 | 11,900 |
| Maintenance and Repair | 530 | 530 | 20,600 | 20,600 |
| Total, Operations and Maintenance | 950 | 950 | 38,200 | 38,200 |

### 7. D&D Information

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

| | Square Feet |
|---|---|
| New area being constructed by this project at Lawrence Berkeley National Laboratory | 55,000 -90,000 |
| Area of D&D in this project at Lawrence Berkeley National Laboratory | None |
| Area at Lawrence Berkeley National Laboratory to be transferred, sold, and/or D&D outside the project, including area previously "banked" | None[a] |
| Area of D&D in this project at other sites | None |
| Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked" | None |
| Total area eliminated | None |

### 8. Acquisition Approach

The LBNL Management and Operating (M&O) Contractor, University of California, will perform the acquisition for this project, overseen by the Bay Area Site Office. The M&O contractor evaluated various acquisition approaches and project delivery methods prior to achieving CD-1 and selected a tailored Design-Bid-Build approach with a Construction Manager as General Contractor as the overall best project delivery method with the lowest risk to DOE. The M&O contractor is also responsible for awarding and administering all subcontracts related to this project. The M&O contractor's annual performance evaluation and measurement plan includes project performance metrics on which it will be evaluated.

[a] With the implementation of OMB's Reduce the Footprint initiative, DOE no longer maintains the space bank. Footprint is managed using the Facility Information Management System, with decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

**18-SC-71, Energy Sciences Capability**
**Pacific Northwest National Laboratory (PNNL)**
**Project is for Design and Construction**

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

**Summary**
The FY 2021 Request for the Energy Sciences Capability project is $23,000,000. The Total Estimated Cost (TEC) for this project is $90,000,000 and the Total Project Cost (TPC) for this project is $93,000,000.

This project will provide a facility for the consolidation of multidisciplinary efforts related to the advancement of catalysis science which are currently located in multiple facilities, on and off the PNNL Richland campus.

**Significant Changes**
This project was initiated in FY 2018. The most recent DOE Order 413.3B Critical Decision (CD) is CD-2/3, Approve Performance Baseline and Approve Start of Construction, which was approved on December 7, 2018. FY 2021 funds will support construction and associated activities.

A Federal Project Director with the appropriate certification level (Level II: TPC greater than $50,000,000 and equal to or less than $100,000,000) has been assigned to this project.

**Critical Milestone History**

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | D&D Complete | CD-4 |
|---|---|---|---|---|---|---|---|---|
| FY 2018 | 12/12/16 | N/A | 4Q FY 2018 | 4Q FY 2019 | N/A | 4Q FY 2020 | N/A | 4Q FY 2025 |
| FY 2019 | 12/12/16 | 3Q FY 2018 | 2Q FY 2018 | 4Q FY 2019 | 4Q FY 2019 | 4Q FY 2019 | N/A | 4Q FY 2025 |
| FY 2020 | 12/12/16 | 3Q FY 2018 | 2/13/18 | 12/07/18 | 12/07/18 | 120/7/18 | N/A | 12/31/23 |
| FY 2021 | 12/12/16 | 2/13/18 | 2/13/18 | 12/07/18 | 12/07/18 | 12/07/18 | N/A | 4Q FY 2023 |

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

| Fiscal Year | Performance Baseline Validation |
|---|---|
| FY 2018 | 4Q FY 2019 |
| FY 2019 | 4Q FY 2019 |
| FY 2020 | 12/07/18 |
| FY 2021 | 12/07/18 |

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC[a], Except D&D | OPC, D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|---|
| FY 2018 | 9,000 | 81,000 | 90,000 | 3,000 | N/A | 3,000 | 93,000 |
| FY 2019 | 9,000 | 81,000 | 90,000 | 3,000 | N/A | 3,000 | 93,000 |
| FY 2020 | 9,000 | 81,000 | 90,000 | 3,000 | N/A | 3,000 | 93,000 |
| FY 2021 | 9,000 | 81,000 | 90,000 | 3,000 | N/A | 3,000 | 93,000 |

### 2. Project Scope and Justification

**Scope**

The scope of the proposed ESC project is to design, construct and turnover facilities and infrastructure that nominally provides 110,000 to 145,000 gross square feet of wet chemistry, instrumentation, and computational space in 40 to 52 laboratory modules along with offices for 150 to 200 research and support staff.

**Justification**

PNNL operates facilities for research in chemistry, materials sciences, subsurface science, biology, physics, medicine, and applied science, as well as for the study of a diverse range of advanced technologies. PNNL's science mission, which supports DOE's mission, is to understand, predict, and control complex adaptive systems for earth, energy, and security missions. PNNL's recognized Core Capabilities are essential to advance and accelerate SC research sponsored by BES, BER, and ASCR. All of these research areas benefit from multidisciplinary approaches that accelerate scientific advances.

The objective behind the ESC project is to increase the impact of chemical conversion research and development at PNNL and expand the reach of user programs. Ultimately, PNNL requires greater multidisciplinary collaboration, controlled environments, and increasing computational needs beyond current capabilities to accomplish this end state. Currently, key PNNL staff members and instrumentation driving multidisciplinary efforts are located in multiple facilities, separated miles apart, on and off of the PNNL Richland campus. With less than 0.25percent vacant lab space and less than 1.5 percent vacant office space currently available and scattered across the campus, PNNL needs a new facility to allow for collaboration. This consolidation will free up space that also allows for increased optimization and greater colocation of Environmental Molecular Sciences Laboratories and Atmospheric Radiation Measurement user missions.

The geographic separation of scientific capabilities at PNNL creates a capability gap by impacting collaborative work and limits interdisciplinary research required to realize the critical advances offered through integration (i.e., "convergence"). As stated in the report "The Convergence of the Life Sciences, Physical Sciences, and Engineering"[b] from the Massachusetts Institute of Technology, convergence "involves the coming together of different fields of study—particularly engineering, physical sciences, and life sciences—through collaboration among research groups and the integration of approaches" and "is a new paradigm that can yield critical advances in a broad array of sectors, from health care to energy, food, climate, and water." It also entails "a broad rethinking of how all scientific research can be conducted, so that we capitalize on a range of knowledge bases."

The ESC project will provide for the needed space of the proper configuration and types to afford acceleration of convergent science—a need that can be achieved only through material means. It also will enable a cascade of moves to enable location of synergistic capabilities in optimal spaces without losing those capabilities for extended time periods and negatively impacting research. The ESC project also further advances the PNNL campus strategy to modernize and increase federal ownership of the Laboratory and seeks to directly impact PNNL's core capabilities by creating space that enables research in support of BES, BER, and ASCR programs.

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[a] Other Project Costs (OPC) are funded through laboratory overhead.
[b] https://www.aplu.org/projects-and-initiatives/research-science-and-technology/hibar/resources/MITwhitepaper.pdf

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

Key Performance Parameters (KPPs)
The Threshold KPPs, represent the minimum acceptable performance that the project must achieve. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion. The Objective KPPs represent the desired project performance.

| Performance Measure | Threshold | Objective |
|---|---|---|
| Multi-story Laboratory Building | 110,000 gross square feet (gsf) | 145,000 gsf |

### 3. Financial Schedule

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs[a] |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| FY 2018 | 9,000 | 9,000 | 489 |
| FY 2019 | — | — | 8,511 |
| Total, Design | 9,000 | 9,000 | 9,000 |
| Construction | | | |
| FY 2018 | 11,000 | 11,000 | — |
| FY 2019 | 24,000 | 24,000 | 20,000 |
| FY 2020 | 23,000 | 23,000 | 20,000 |
| FY 2021 | 23,000 | 23,000 | 20,000 |
| Outyears | — | — | 21,000 |
| Total, Construction | 81,000 | 81,000 | 81,000 |
| Total Estimated Cost (TEC) | | | |
| FY 2018 | 20,000 | 20,000 | 489 |
| FY 2019 | 24,000 | 24,000 | 28,511 |
| FY 2020 | 23,000 | 23,000 | 20,000 |
| FY 2021 | 23,000 | 23,000 | 20,000 |
| Outyears | — | — | 21,000 |
| **Total, TEC** | **90,000** | **90,000** | **90,000** |
| **Other Project Cost (OPC)** | | | |
| FY 2017 | 839 | 839 | 839 |
| FY 2018 | 397 | 397 | 397 |
| Outyears | 1,764 | 1,764 | 1,764 |
| **Total, OPC[b]** | **3,000** | **3,000** | **3,000** |

[a] Costs through 2019 reflect actual Costs; costs for FY 2020 and the outyears are estimates.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs[a] |
|---|---|---|---|
| **Total Project Cost (TPC)** | | | |
| FY 2017 | 839 | 839 | 839 |
| FY 2018 | 20,397 | 20,397 | 886 |
| FY 2019 | 24,000 | 24,000 | 28,511 |
| FY 2020 | 23,000 | 23,000 | 20,000 |
| FY 2021 | 23,000 | 23,000 | 20,000 |
| Outyears | 1,764 | 1,764 | 22,764 |
| **Total, TPC** | **93,000** | **93,000** | **93,000** |

### 4. Details of Project Cost Estimate

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| Design | 7,500 | 7,500 | 7,500 |
| Contingency | 1,500 | 1,500 | 1,500 |
| Total, Design | 9,000 | 9,000 | 9,000 |
| Construction | | | |
| Construction | 70,000 | 70,000 | 70,000 |
| Contingency | 11,000 | 11,000 | 11,000 |
| Total, Construction | 81,000 | 81,000 | 81,000 |
| **Total, TEC** | **90,000** | **90,000** | **90,000** |
| *Contingency, TEC* | *12,500* | *12,500* | *12,500* |
| **Other Project Cost (OPC)** | | | |
| OPC except D&D | | | |
| OPC except D&D | 1,650 | 1,650 | 1,650 |
| Conceptual Planning | 100 | 100 | 100 |
| Conceptual Design | 1,000 | 1,000 | 1,000 |
| Contingency | 250 | 250 | 250 |
| **Total, OPC[b]** | **3,000** | **3,000** | **3,000** |
| *Contingency, OPC* | *250* | *250* | *250* |
| **Total Project Cost** | **93,000** | **93,000** | **93,000** |
| ***Total, Contingency (TEC+OPC)*** | ***12,750*** | ***12,750*** | ***12,750*** |

[a] Costs through 2019 reflect actual Costs; costs for FY 2020 and the outyears are estimates.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

### 5. Schedule of Appropriations Requests

(dollars in thousands)

| Request Year | Type | Prior Years | FY 2019 | FY 2020 | FY 2021 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| FY 2018 | TEC | 20,000 | TBD | TBD | TBD | TBD | 90,000 |
| | OPC[a] | — | — | — | — | — | 3,000 |
| | TPC | 20,000 | TBD | TBD | TBD | TBD | 93,000 |
| FY 2019 | TEC | 1,000 | 4,000 | 8,194 | 22,209 | 54,597 | 90,000 |
| | OPC[a] | 2,600 | — | — | — | 400 | 3,000 |
| | TPC | 3,600 | 4,000 | 8,194 | 22,209 | 54,997 | 93,000 |
| FY 2020 | TEC | 20,000 | 24,000 | 9,000 | 20,000 | 17,000 | 90,000 |
| | OPC[a] | 1,639 | — | — | — | 1,361 | 3,000 |
| | TPC | 21,639 | 24,000 | 9,000 | 20,000 | 18,361 | 93,000 |
| FY 2021 | TEC | 20,000 | 24,000 | 23,000 | 23,000 | — | 90,000 |
| | OPC[a] | 1,236 | — | — | — | 1,764 | 3,000 |
| | TPC | 21,236 | 24,000 | 23,000 | 23,000 | 1,764 | 93,000 |

### 6. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 1Q FY 2024 |
| Expected Useful Life | 50 years |
| Expected Future Start of D&D of this capital asset | 1Q FY 2074 |

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | Previous Total Estimate | Current Total Estimate | Previous Total Estimate | Current Total Estimate |
| Operations | 480 | 480 | 23,989 | 23,989 |
| Utilities | 547 | 547 | 27,370 | 27,370 |
| Maintenance and Repair | 1,222 | 1,222 | 61,121 | 61,121 |
| Total, Operations and Maintenance | 2,249 | 2,249 | 112,480 | 112,480 |

[a] Other Project Costs (OPC) are funded through laboratory overhead.

## 7. D&D Information

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

| | Square Feet |
|---|---|
| New area being constructed by this project at Pacific Northwest National Laboratory ................ | 110,000 to 145,000 |
| Area of D&D in this project at Pacific Northwest National Laboratory .......................................... | None |
| Area at Pacific Northwest National Laboratory to be transferred, sold, and/or D&D outside the project, including area previously "banked" .................................................................................. | None[a] |
| Area of D&D in this project at other sites ........................................................................ | None |
| Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked" .......................................................................................................... | None |
| Total area eliminated .................................................................................................. | None |

## 8. Acquisition Approach

The PNNL Management and Operating (M&O) contractor, Battelle Memorial Institute, will perform the acquisition for this project, overseen by the Pacific Northwest Site Office. The M&O contractor considered various acquisition approaches and project delivery methods prior to achieving CD-1 and will be responsible for awarding and administering all subcontracts related to this project. The M&O contractor's annual performance evaluation and measurement plan will include project performance metrics on which they will be evaluated.

[a] With the implementation of OMB's Reduce the Footprint initiative, DOE no longer maintains the space bank. Footprint is managed using the Facility Information Management System, with decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

**17-SC-71, Integrated Engineering Research Center**
**Fermi National Accelerator Laboratory (FNAL)**
**Project is for Design and Construction**

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

### Summary

The FY 2021 Request for the Integrated Engineering Research Center (IERC) project is $12,000,000. The Total Estimated Cost (TEC) range for this project is $73,000,000 to $98,000,000. The Total Project Cost (TPC) range for this project is $74,000,000 to $99,000,000. The preliminary TPC estimate for this project is $86,000,000.

This project will construct new space to accommodate increased collaboration and interactions among Fermi National Accelerator Laboratory (FNAL) staff. The project is intended to close an infrastructure capability gap which will impede the establishment of an international neutrino campus as recommended by the Particle Physics Project Prioritization Panel (P5).

### Significant Changes

This project was initiated in FY 2017. The most recent DOE Order 413.3B Critical Decision (CD) is CD-3A, Long Lead Procurement, which was approved on July 16, 2019. FY 2021 funds will support the continuation of construction and associated activities after the appropriate CD approvals.

A Federal Project Director with the appropriate certification level (Level II: TPC greater than $50,000,000 and equal to or less than $100,000,000) has been assigned to this project.

### Critical Milestone History

| Fiscal Year | CD-0 | Conceptual Design Complete | CD-1 | CD-2 | Final Design Complete | CD-3 | D&D Complete | CD-4 |
|---|---|---|---|---|---|---|---|---|
| FY 2017 | 7/17/15 | N/A | 1Q FY 2017 | 3Q FY 2018[a] | N/A | 3Q FY 2019[a] | N/A | 4Q FY 2023[a] |
| FY 2018 | 7/17/15 | N/A | 4/18/17 | 3Q FY 2019[a] | N/A | 3Q FY 2020[a] | N/A | 4Q FY 2024[a] |
| FY 2019 | 7/17/15 | 3Q FY 2018 | 4/18/17 | 3Q FY 2019[a] | 3Q FY 2019 | 3Q FY 2020[a] | N/A | 4Q FY 2024[a] |
| FY 2020 | 7/17/15 | 4/18/17 | 4/18/17 | 3Q FY 2019[a] | 3Q FY 2019 | 3Q FY 2019[a] | N/A | 2Q FY 2024[a] |
| FY 2021 | 7/17/15 | 4/18/17 | 4/18/17 | 4Q FY 2020[a] | 2Q FY 2020 | 4Q FY 2020[a] | N/A | 3Q FY 2024[a] |

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

[a] This project is pre-CD-2; therefore, schedule estimates are preliminary.

| Fiscal Year | Performance Baseline Validation | CD-3A |
|---|---|---|
| FY 2017 | N/A | N/A |
| FY 2018 | N/A | N/A |
| FY 2019 | 3Q FY 2019 | N/A |
| FY 2020 | 4/18/18 | N/A |
| FY 2021 | 4/18/18 | 7/16/19 |

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

**Project Cost History**

(dollars in thousands)

| Fiscal Year | TEC, Design | TEC, Construction | TEC, Total | OPC[a], Except D&D | OPC, D&D | OPC, Total | TPC |
|---|---|---|---|---|---|---|---|
| FY 2017 | 10,000 | 75,000[b] | 85,000[b] | 2,000 | N/A | 2,000 | 87,000[b] |
| FY 2018 | 10,000 | 75,000[b] | 85,000[b] | 1,000 | N/A | 1,000 | 86,000[b] |
| FY 2019 | 7,000 | 78,000[b] | 85,000[b] | 1,000 | N/A | 1,000 | 86,000[b] |
| FY 2020 | 7,000 | 78,000 | 85,000[b] | 1,000 | N/A | 1,000 | 86,000[b] |
| FY 2021 | 7,000 | 78,000 | 85,000[b] | 1,000 | N/A | 1,000 | 86,000[b] |

**2. Project Scope and Justification**

**Scope**

The IERC project will construct an approximately 67,000 gross square feet (gsf) to 134,000 gsf building to accommodate increased collaboration and interactions among staff at Fermi National Accelerator Laboratory (FNAL), who will in turn be working with scientific collaborators and international partners in the design, construction, and operation of physics experiments.

**Justification**

In May 2014, the Particle Physics Project Prioritization Panel (P5) issued a report that included recommendations to "…develop a coherent short- and long-baseline neutrino program hosted at Fermilab," and to "reformulate the long-baseline neutrino program as an internationally designed, coordinated, and funded program with [Fermi National Accelerator Laboratory, FNAL or Fermilab] as host." SC and the High Energy Physics (HEP) program accepted the recommendations in the P5 report and are committed to implementing a successful program based on this new vision.

Implementing these recommendations will require significantly increased collaboration and interactions among FNAL staff, who will in turn be working with scientific collaborators and international partners in the design, construction, and operation of physics experiments. Currently, these staff and their associated manufacturing, assembly, engineering, and technical facilities are scattered among three parts of the campus – the Silicon Detector Complex, the Village, and Wilson Hall. As a result, they are unable to efficiently collaborate on ongoing and planned projects in support of the laboratory's mission.

Collocation of these staff will improve collaboration because it will increase interactions among the various groups and reduce down-time spent traveling across the site. From an infrastructure standpoint, however, FNAL currently lacks sufficient space to do this. Continuing the previous example, groups from the three Divisions noted above total approximately 300 staff occupying more than 170,000 square feet of laboratories, technical areas, and offices in 15 buildings and trailers. In addition, many of these spaces are inadequate to accommodate current and planned scientific

[a] Other project costs (OPC) are funded through laboratory overhead.
[b] This project has not received CD-2 approval; therefore, funding estimates are preliminary.

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 IERC will provide FNAL with a collaborative, multi-divisional, and interdisciplinary research center, which will close existing capability and infrastructure gaps by reducing the overall footprint of outdated facilities, and collocating engineering and associated research staff in a new or renovated facility near the central campus. This approach will complement the ongoing and planned renovations of Wilson Hall by establishing the main campus as the anchor point of the site. It will improve operational efficiency and collaboration because groups working on key projects would be in close proximity to one another. Such a facility will provide technical and engineering staff the necessary environment for interdisciplinary collaboration necessary to establish an international neutrino program and support other HEP science opportunities described in the P5 report.

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

Key Performance Parameters (KPPs)

The Key Performance Parameters (KPPs) are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve. The Objective KPPs represent the desired project performance. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

| Performance Measure | Threshold | Objective |
|---|---|---|
| Multistory Laboratory/Office Building | 67,000 gsf | 134,000 gsf |

**3. Financial Schedule**

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs[a] |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| FY 2017 | 2,500 | 2,500 | 38 |
| FY 2018 | 4,500 | 4,500 | 1,552 |
| FY 2019 | — | — | 3,190 |
| FY 2020 | — | — | 2,220 |
| Total, Design | 7,000 | 7,000 | 7,000 |
| Construction | | | |
| FY 2018 | 15,500 | 15,500 | — |
| FY 2019 | 20,000 | 20,000 | 4,810 |
| FY 2020 | 22,000 | 22,000 | 20,190 |
| FY 2021 | 12,000 | 12,000 | 25,000 |
| Outyears | 8,500 | 8,500 | 28,000 |
| Total, Construction | 78,000 | 78,000 | 78,000 |

[a] Costs through 2019 reflect actual Costs; costs for FY 2020 and the outyears are estimates.

(dollars in thousands)

| | Budget Authority (Appropriations) | Obligations | Costs[a] |
|---|---|---|---|
| Total Estimated Cost (TEC) | | | |
| FY 2017 | 2,500 | 2,500 | 38 |
| FY 2018 | 20,000 | 20,000 | 1,552 |
| FY 2019 | 20,000 | 20,000 | 8,000 |
| FY 2020 | 22,000 | 22,000 | 22,410 |
| FY 2021 | 12,000 | 12,000 | 25,000 |
| Outyears | 8,500 | 8,500 | 28,000 |
| **Total, TEC[a]** | **85,000** | **85,000** | **85,000** |
| **Other Project Cost (OPC)[b]** | | | |
| FY 2015 | 120 | 120 | 120 |
| FY 2016 | 510 | 510 | 510 |
| FY 2017 | 300 | 300 | 300 |
| Outyears | 70 | 70 | 70 |
| **Total, OPC** | **1,000** | **1,000** | **1,000** |
| **Total Project Cost (TPC)** | | | |
| FY 2015 | 120 | 120 | 120 |
| FY 2016 | 510 | 510 | 510 |
| FY 2017 | 2,800 | 2,800 | 338 |
| FY 2018 | 20,000 | 20,000 | 1,552 |
| FY 2019 | 20,000 | 20,000 | 8,000 |
| FY 2020 | 22,000 | 22,000 | 22,410 |
| FY 2021 | 12,000 | 12,000 | 25,000 |
| Outyears | 8,570 | 8,570 | 28,070 |
| **Total, TPC[b]** | **86,000** | **86,000** | **86,000** |

[a] This project has not received CD-2 approval; therefore, funding estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

## 4. Details of Project Cost Estimate

(dollars in thousands)

| | Current Total Estimate | Previous Total Estimate | Original Validated Baseline |
|---|---|---|---|
| **Total Estimated Cost (TEC)** | | | |
| Design | | | |
| Design | 6,000 | 6,000 | N/A |
| Contingency | 1,000 | 1,000 | N/A |
| Total, Design | 7,000 | 7,000 | N/A |
| Construction | | | |
| Construction | 63,000 | 63,000 | N/A |
| Contingency | 15,000 | 15,000 | N/A |
| Total, Construction | 78,000 | 78,000 | N/A |
| **Total, TEC[a]** | **85,000** | **85,000** | **N/A** |
| *Contingency, TEC* | *16,000* | *16,000* | *N/A* |
| **Other Project Cost (OPC)** | | | |
| OPC except D&D | | | |
| Conceptual Planning | 250 | 250 | N/A |
| Conceptual Design | 530 | 530 | N/A |
| Other OPC Costs | 150 | 150 | N/A |
| Contingency | 70 | 70 | N/A |
| **Total, OPC[b]** | **1,000** | **1,000** | **N/A** |
| *Contingency, OPC* | *70* | *70* | *N/A* |
| **Total Project Cost** | **86,000** | **86,000** | **N/A** |
| ***Total, Contingency (TEC+OPC)*** | ***16,070*** | ***16,070*** | ***N/A*** |

## 5. Schedule of Appropriations Requests

(dollars in thousands)

| Request Year | Type | Prior Years | FY 2019 | FY 2020 | FY 2021 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| FY 2017 | TEC | 2,500 | TBD | TBD | — | TBD | 85,000[a] |
| | OPC[b] | 500 | TBD | TBD | — | TBD | 2,000 |
| | TPC | 5,000 | TBD | TBD | — | TBD | 87,000[a] |
| FY 2018 | TEC | 4,000 | TBD | TBD | — | TBD | 85,000[a] |
| | OPC[b] | 1,000 | — | — | — | — | 1,000 |
| | TPC | 5,000 | TBD | TBD | — | TBD | 86,000[a] |
| FY 2019 | TEC | 4,000 | 5,000 | 20,000 | 28,096 | 27,904 | 85,000[a] |
| | OPC[b] | 930 | — | — | — | 70 | 1,000 |
| | TPC | 4,930 | 5,000 | 20,000 | 28,096 | 27,974 | 86,000[a] |

[a] This project has not received CD-2 approval; therefore, funding estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

(dollars in thousands)

| Request Year | Type | Prior Years | FY 2019 | FY 2020 | FY 2021 | Outyears | Total |
|---|---|---|---|---|---|---|---|
| FY 2020 | TEC | 22,500 | 20,000 | 10,000 | — | 32,500 | 85,000[a] |
| | OPC[b] | 930 | — | — | — | 70 | 1,000 |
| | TPC | 23,430 | 20,000 | 10,000 | — | 32,570 | 86,000[a] |
| FY 2021 | TEC | 22,500 | 20,000 | 22,000 | 12,000 | 8,500 | 85,000[a] |
| | OPC[b] | 930 | — | — | — | 70 | 1,000 |
| | TPC | 23,430 | 20,000 | 22,000 | 12,000 | 8,570 | 86,000[a] |

### 6. Related Operations and Maintenance Funding Requirements

| | |
|---|---|
| Start of Operation or Beneficial Occupancy | 3Q FY 2024 |
| Expected Useful Life | 50 years |
| Expected Future Start of D&D of this capital asset | 3Q FY 2074 |

Related Funding Requirements
(dollars in thousands)

| | Annual Costs | | Life Cycle Costs | |
|---|---|---|---|---|
| | Previous Total Estimate | Current Total Estimate | Previous Total Estimate | Current Total Estimate |
| Operations | 508 | 508 | 25,428 | 25,428 |
| Utilities | 94 | 94 | 4,670 | 4,670 |
| Maintenance and Repair | 1,525 | 1,525 | 76,285 | 76,285 |
| Total, Operations and Maintenance | 2,127 | 2,127 | 106,383 | 106,383 |

### 7. D&D Information

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

| | Square Feet |
|---|---|
| New area being constructed by this project at Fermi National Accelerator Laboratory.................. | 67,000 - 134,000 |
| Area of D&D in this project at Fermi National Accelerator Laboratory.......................................... | None |
| Area at Fermi National Accelerator Laboratory to be transferred, sold, and/or D&D outside the project, including area previously "banked" ................................................................................. | 55,200 |
| Area of D&D in this project at other sites ...................................................................................... | None |
| Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked" ........................................................................................................... | None[a] |
| Total area eliminated ...................................................................................................... | 55,200 |

[a] With the implementation of OMB's Reduce the Footprint initiative, DOE no longer maintains the space bank. Footprint is managed using the Facility Information Management System, with decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

## 8. Acquisition Approach

The FNAL Management and Operating (M&O) contractor, Fermi Research Alliance, LLC will perform the acquisition for this project, overseen by the Fermi Site Office. The M&O contractor evaluated various acquisition approaches and project delivery methods prior to achieving CD-1 and selected a Construction Manager/General Contractor (CM/GC) project delivery with best value procurement approach as the overall best delivery method with the lowest risk to DOE. The M&O contractor is responsible for awarding and administering all subcontracts related to this project. The annual performance evaluation and measurement plan includes project performance metrics on which they are evaluated.

## Safeguards and Security

### Overview
The Department of Energy's (DOE) Office of Science (SC) Safeguards and Security (S&S) program is designed to ensure appropriate security measures are in place to support the SC mission requirements of open scientific research and to protect critical assets within SC laboratories. Accomplishing this mission depends on providing physical controls that will mitigate possible risks to the laboratories' employees, nuclear and special materials, classified and sensitive information, and facilities. The SC S&S program also provides funding for cybersecurity for the laboratories' information technology systems to protect computers, networks, and data from unauthorized access.

### Highlights of the FY 2021 Request
The FY 2021 Request for S&S is $115,623,000. The FY 2021 Request supports sustained levels of operations in S&S program elements including Protective Forces, Security Systems, Information Security, Cyber Security, Personnel Security, Material Control and Accountability, and Program Management.

The FY 2021 Request ensures that the S&S program's highest priority is accomplished, which is to provide adequate security for the special nuclear material housed in Building 3019 at the Oak Ridge National Laboratory (ORNL). The Request also ensures the Cyber Security program can adequately detect, mitigate, and recover from cyber intrusions and attacks against DOE laboratories.

The 2018 revision of DOE's Design Basis Threat (DBT) and the then Deputy Secretary's DOE International Science and Technology Engagement Policy (S&T Policy) have shifted DOE's security direction. The DBT addresses protection measures for a more encompassing range of threats and assets than just special nuclear material and classified matter. This revised DBT mandates additional risk assessments and security planning for the protection of chemicals and radioactive sources that could affect persons on-site, whereas, the previous protection standard only addressed quantities that could have an impact off-site. The DBT also calls for "Active Shooter" and "Insider Threat" mitigation. The S&T Policy is designed to protect U.S.-funded research and technologies from sensitive nations who pose high security risks. This includes denying access to restricted areas within DOE laboratories as well as including foreign visitor's Curriculum Vitae (CV) in the Foreign Access Central Tracking System (FACTS).

Implementing both the revised DBT and the S&T Policy is the near- and long-term basis for S&S program and risk mitigating funding decisions at SC laboratories. SC completed implementation planning for the DBT in March 2019 through rigorous Security Risk Assessments and full compliance (based on the most complex laboratories milestones) is expected by September 30, 2022. The S&S program received funding in FY 2020 to begin initial implementation by installing and updating automated access controls to ensure the protection of personnel and intellectual property at SC laboratories. The FY 2021 Request includes an additional $2,923,000 in Security Systems to continue addressing the highest priority items of the DBT and the new S&T Policy.

### Description
The S&S program is organized into seven program elements: Protective Forces, Security Systems, Information Security, Cyber Security, Personnel Security, Material Control and Accountability, and Program Management.

<u>Protective Forces</u>
The Protective Forces program element supports security officers that control access and protect S&S interests, along with their related equipment and training. Activities within this program element include access control and security response operations as well as physical protection of the Department's critical assets and SC facilities. The Protective Forces mission includes providing effective response to emergency situations, random prohibited article inspections, security alarm monitoring, and performance testing of the protective force response to various event scenarios.

<u>Security Systems</u>
The Security Systems program element provides DBT and S&T policy implementation through the physical protection of Departmental personnel, material, equipment, property, and facilities, and includes fences, barriers, lighting, sensors,

surveillance devices, entry control devices, access control systems, and power systems operated and used to support the protection of people, DOE property, classified information, and other interests of national security.

Information Security

The Information Security program element provides support to ensure that sensitive and classified information is accurately, appropriately, and consistently identified, reviewed, marked, protected, transmitted, stored, and ultimately destroyed. Specific activities within this element include management, planning, training, and oversight for maintaining security containers and combinations, marking documents, and administration of control systems, operations security, special access programs, technical surveillance countermeasures, and classification and declassification determinations.

Cyber Security

SC is engaged in protecting the enterprise from a range of cyber threats that can adversely impact mission capabilities. The Cyber Security program element includes central coordination of the strategic and operational aspects of cybersecurity and facilitates cooperative efforts such as the Joint Cybersecurity Coordination Center (JC3) for incident response and the implementation of Department-wide Identity, Credentials, and Access Management (ICAM).

Personnel Security

The Personnel Security program element encompasses the processes for employee suitability and security clearance determinations at each site to ensure that individuals are trustworthy and eligible for access to classified information or matter. This element also includes the management of security clearance programs, adjudications, security education, awareness programs for Federal and contractor employees, and processing and hosting approved foreign visitors.

Material Control and Accountability (MC&A)

The MC&A program element provides assurance that Departmental materials are properly controlled and accounted for at all times. This element supports administration, including testing performance and assessing the levels of protection, control, and accountability required for the types and quantities of materials at each facility; documenting facility plans for materials control and accountability; assigning authorities and responsibilities for MC&A functions; and establishing programs to detect and report occurrences such as material theft, the loss of control or inability to account for materials, or evidence of malevolent acts.

Program Management

The Program Management program element coordinates the management of Protective Forces, Security Systems, Information Security, Personnel Security, Cyber Security, and MC&A to achieve and ensure appropriate levels of protections are in place.

**Safeguards and Security**
**Funding**

(dollars in thousands)

| | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|
| Protective Forces | 43,545 | 43,545 | 43,545 | — |
| Security Systems | 10,370 | 16,960 | 19,883 | +2,923 |
| Information Security | 4,356 | 4,356 | 4,356 | — |
| Cyber Security | 33,346 | 33,346 | 33,346 | — |
| Personnel Security | 5,444 | 5,444 | 5,444 | — |
| Material Control and Accountability | 2,431 | 2,431 | 2,431 | — |
| Program Management | 6,618 | 6,618 | 6,618 | — |
| **Total, Safeguards and Security** | **106,110** | **112,700** | **115,623** | **+2,923** |

**Safeguards and Security**
**Explanation of Major Changes**

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| **Safeguards and Security** | **$112,700** | **$115,623** | **+$2,923** |
| Protective Forces | $43,545 | $43,545 | $— |
| Funding supports security officers and their required equipment and training necessary to maintain proper protection levels at all SC laboratories. | | The Request will maintain support for security officers and their required equipment and training necessary to maintain proper protection levels at all SC laboratories. | Funding provides sustained support for the Protective Forces activity. |
| Security Systems | $16,960 | $19,883 | +$2,923 |
| Funding supports physical protection of Departmental personnel, material, equipment, property, and facilities, and security infrastructure and systems. Funding also supports initial implementation of security modifications identified in the revised DBT. | | The Request will maintain support for the security systems in place as well as continued implementation of security modifications that address both the revised DBT and S&T Policy. | Funding increases to continue implementation of DBT and S&T Policy mandated physical security modifications at SC laboratories. In an effort to address both new initiatives, automated access controls are the program's first priority to protect the workforce and intellectual property and mitigate active shooter and workplace violence threats. |
| Information Security | $4,356 | $4,356 | $— |
| Funding supports personnel, equipment, and systems necessary to ensure sensitive and classified information is safeguarded at SC laboratories. | | The Request will continue support for the personnel, equipment, and systems necessary to ensure sensitive and classified information is safeguarded at SC laboratories. | Funding provides sustained support for Information Security activities. |
| Cyber Security | $33,346 | $33,346 | $— |
| Funding supports protection of laboratory computers, networks, and data from unauthorized access. | | The Request will continue support for the protection of laboratory computers, networks, and data from unauthorized access. | Funding provides sustained support for Cybersecurity activities. |
| Personnel Security | $5,444 | $5,444 | $— |
| Funding supports Personnel Security efforts at SC laboratories. | | The Request will continue support for Personnel Security efforts at SC laboratories as well as SC Headquarters security investigations. | Funding provides sustained support for Personnel Security activities. |

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes<br>FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| Materials Control and Accountability | $2,431 | $2,431 | $— |
| Funding supports functions ensuring Departmental materials are properly controlled and accounted for at all times. | | The Request will maintain support for functions ensuring Departmental materials are properly controlled and accounted for at all times. | Funding provides sustained support for MC&A activities. |
| Program Management | $6,618 | $6,618 | $— |
| Funding supports oversight, administration, and planning for security programs at SC laboratories and will support security procedures and policy support for SC Research missions. | | The Request will maintain support for oversight, administration, and planning for security programs at SC laboratories and will support security procedures and policy support for SC Research missions. | Funding provides sustained support for Program Management activities. |

**Safeguards and Security**
**Funding Summary**

(dollars in thousands)

| | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|
| Other | 106,110 | 112,700 | 115,623 | +2,923 |
| **Total, Safeguards and Security** | **106,110** | **112,700** | **115,623** | **+2,923** |

**Safeguards and Security**
**Estimates of Cost Recovered for Safeguards and Security Activities**

In addition to the direct funding received from S&S, sites recover Safeguards and Security costs related to Strategic Partnerships Projects (SPP) activities from SPP customers, including the cost of any unique security needs directly attributable to the customer. Estimates of those costs are shown below.

| | (dollars in thousands) | | |
|---|---|---|---|
| | **FY 2019 Actual Costs** | **FY 2020 Planned Costs** | **FY 2021 Planned Costs** |
| Ames National Laboratory | 70 | 75 | 70 |
| Argonne National Laboratory | 1,000 | 1,000 | 1,000 |
| Brookhaven National Laboratory | 851 | 836 | 835 |
| Lawrence Berkeley National Laboratory | 749 | 751 | 1,297 |
| Oak Ridge Institute for Science and Education | 571 | 572 | 577 |
| Oak Ridge National Laboratory | 5,163 | 5,396 | 5,396 |
| Pacific Northwest National Laboratory | 5,500 | 5,100 | 5,000 |
| Princeton Plasma Physics Laboratory | 55 | 30 | 30 |
| SLAC National Accelerator Laboratory | 179 | 190 | 308 |
| **Total, Security Cost Recovered** | **14,138** | **13,950** | **14,513** |

## Program Direction

### Overview

The Office of Science (SC) Program Direction (PD) budget supports a highly skilled federal workforce to develop and oversee SC investments in basic research, and construction and operation of scientific user facilities, which are critical to the American scientific enterprise. SC research and facility investments transform our understanding of nature and advance the energy, economic, and national security of the United States. In addition, SC accelerates discovery and innovation by providing broad public access to all DOE research and development findings.

SC requires sophisticated and experienced scientific and technical program and project managers, as well as experts in acquisition; finance; legal; construction management; and environmental, safety, and health oversight. The SC basic research portfolio includes extramural grants and contracts supporting over 23,000 researchers located at over 300 institutions and the 17 DOE national laboratories, spanning all 50 states and the District of Columbia. The portfolio of 28 scientific user facilities serves over 33,000 users per year. SC also oversees ten of DOE's 17 national laboratories.

Headquarters (HQ)

The SC HQ includes the six SC research program offices (Advanced Scientific Computing Research, Basic Energy Sciences, Biological and Environmental Research, Fusion Energy Sciences, High Energy Physics, and Nuclear Physics), and the Workforce Development for Teachers and Scientists, Project Assessment, and SBIR/STTR Programs Offices, as well as several resource management functions, and HQ-based field management functions. The SC HQ federal staff:

- Conduct scientific program and research infrastructure planning, execution, and management across SC, in part by extensive engagement with the scientific community to identify research opportunities and develop priorities.
- Establish and maintain competitive research portfolios, which include high-risk, high-reward research, to achieve mission goals and objectives.
- Conduct rigorous external peer review of research proposals and ongoing programs. Each year, SC manages nearly 5,000 ongoing laboratory, university, non-profit, and private industry research awards and conducts nearly 20,000 peer reviews of new and renewal proposals.
- Provide safety, security, and infrastructure oversight and management of all SC user facilities and other current research investments.
- Provide oversight and management of all line item construction projects and other capital asset projects.
- Provide oversight and management of the maintenance and operational integrity of the ten SC-stewarded national laboratories.
- Provide policy, strategy, and resource management in the areas of laboratory oversight, information technology, grants and contracts, budget, and human capital.

Office of Scientific and Technical Information (OSTI)

OSTI fulfills the Department's responsibilities for providing public access to the unclassified results of its research investments and limited access to classified research results. DOE researchers produce over 50,000 research publications, datasets, software, and patents annually. OSTI's physical and electronic collections exceed one million research outputs from the 1940s to the present, providing access to the results of DOE's research investments. OSTI implements DOE's public access mandates, including the government-wide requirement that peer-reviewed publications resulting from federal funding is made available to the public within 12 months of publication in a journal.

Consolidated Service Center (CSC)

The CSC provides business management to support SC's federal responsibilities. These functions include legal and technical support; financial management; grant and contract processing; safety, security, and health management; intellectual property and patent management; environmental compliance; facility infrastructure operations and maintenance; and information systems development and support. As part of this, the CSC:

- Monitors the multi-appropriation, multi-program funding allocations for all ten SC national laboratories through administration of laboratory Management and Operating (M&O) contracts and is responsible for over 3,000 financial

assistance awards (grants and cooperative agreements) per year to university, non-profit, and small business-based researchers.
- Provides support to SC and other DOE programs for solicitations and funding opportunity announcements, as well as the negotiation, award, administration, and closeout of contracts and financial assistance awards using certified contracting officers and professional acquisition staff.

Site Offices
SC site offices provide contract management and critical support for the scientific mission execution at the ten SC national laboratories. This includes day to-day business management; approvals to operate hazardous facilities; safety and security oversight; leases; property transfers; sub-contracts; and activity approvals required by laws, regulations, and DOE policy. As part of this, the site offices:

- Maintain a comprehensive contract management program to ensure contractual mechanisms are managed effectively and consistently with guidelines and regulations.
- Evaluate laboratory activities including nuclear, radiological, and other complex hazards.
- Provide federal project directors to oversee construction projects and other major capital asset projects.

**Highlights of the FY 2021 Request**
The FY 2021 Request is $190,306,000 and will support a total level of approximately 785 FTEs. SC will utilize available human capital workforce reshaping tools to manage federal staff in a manner consistent with its long-term workforce restructuring plan as part of the DOE Agency Reform Plan[a]. SC will continue to review, analyze, and prioritize mission requirements and identify those organizations and functions aligning with Administration and Department program objectives and SC strategic goals while maximizing efficiency through functional consolidation.

The FY 2021 Request supports:

- Three-hundred (300) SC HQ federal staff, spread among the six research program offices, Workforce Development for Teachers and Scientists, Project Assessment, and SBIR/STTR Programs Offices, as well as several resource management functions, and HQ-based field management functions.
- Two (2) FTEs in the DOE Office of Planning and Management Oversight to support the Office of the Under Secretary for Science.
- Twenty-five (25) FTEs in the Office of the Chief Human Capital Officer operating the Shared Service Center (SSC) and supporting HR Advisory Offices.
- Two (2) FTEs supporting the President’s Council of Advisors on Science and Technology (PCAST).[b]
- Forty-two (42) OSTI federal staff to manage SC’s public access program.
- Three-hundred and seventy-seven (377) Consolidated Service Center (CSC) and site office federal staff.
- Thirty-seven (37) FTEs in Office of Chief Council within the Field Offices activity.

[a] OMB Memo M-17-22
[b] PCAST is required by Executive Order 13539, as amended by Executive Order 13596.

**Program Direction**
**Funding**

(dollars in thousands)

| | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|
| **Program Direction** | | | | |
| Salaries and Benefits | 134,139 | 135,611 | 138,597 | +2,986 |
| Travel | 4,200 | 4,300 | 4,470 | +170 |
| Support Services | 23,437 | 24,626 | 25,640 | +1,014 |
| Other Related Expenses | 13,074 | 13,188 | 13,024 | -164 |
| Working Capital Fund | 8,150 | 8,575 | 8,575 | — |
| **Total, Program Direction** | **183,000** | **186,300** | **190,306** | **+4,006** |
| Federal FTE | 810 | 785 | 785 | — |

**Program Direction**

**Activities and Explanation of Changes**

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | Explanation of Changes<br>FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|
| **Program Direction** | **$186,300** | **$190,306** | **+$4,006** |
| Salaries and Benefits | $135,611 | $138,597 | +$2,986 |
| Funding supports 785 FTEs to perform scientific oversight, program and project management, essential operations support associated with science program portfolio management, and support for the Office of the Chief Human Capital Officer operating the SSC and supporting HR Advisory Offices.<br><br>Funding supports Federal employees salary and benefits, including health insurance costs and retirement allocations in the Federal Employees Retirement System (FERS). | | The Request will support 785 FTEs to perform scientific oversight, program and project management, essential operations support associated with science program portfolio management, and support for the Office of the Chief Human Capital Officer operating the SSC and supporting HR Advisory Offices.<br><br>The Request will support costs associated with Federal employee benefits, including health insurance costs and retirement allocations in FERS. | The increase will support the projected salary and benefit requirements for the requested FTE levels. Also, the increase reflects a one percent pay raise for federal staff in 2021, a FERS contribution increase, and increased awards pool funding. |
| Travel | $4,300 | $4,470 | +$170 |
| Funding supports facility visits where the use of electronic telecommunications is not practical for mandated on-site inspections and facility operations reviews. Ensuring scientific management, compliance, safety oversight, and external review of research funding across all SC programs requires staff to travel, since SC senior program managers are not co-located with grantees or at national laboratories. | | The Request will support facility visits where the use of electronic telecommunications is not practical for mandated on-site inspections and facility operations reviews. Ensuring scientific management, compliance, safety oversight, and external review of research funding across all SC programs requires staff to travel, since SC senior program managers are not co-located with grantees or at national laboratories. | The increase will support the projected travel requirements for FY 2021. |

(dollars in thousands)

| FY 2020 Enacted | FY 2021 Request | Explanation of Changes FY 2021 Request vs FY 2020 Enacted |
|---|---|---|
| Funding also supports travel for the SC Federal Advisory Committees, which will include over 170 representatives from universities, national laboratories, and industry, representing a diverse balance of disciplines, professional experience, and geography. Each of the six advisory committees provides valuable, independent advice to the Department regarding the complex scientific and technical issues that arise in the planning, management, and implementation of SC programs. | The Request will also support travel for the SC Federal Advisory Committees, which will include over 170 representatives from universities, national laboratories, and industry, representing a diverse balance of disciplines, professional experience, and geography. Each of the six advisory committees provides valuable, independent advice to the Department regarding the complex scientific and technical issues that arise in the planning, management, and implementation of SC programs. | |
| Funding supports the PCAST advisory committee travel. | The Request will support the PCAST advisory committee travel. | |
| Support Services $24,626 | $25,640 | +$1,014 |
| Funding supports select administrative and professional services including: support for the SBIR/STTR program; grants and contract processing and close-out activities; accessibility to DOE's corporate multi-billion dollar R&D program through information systems managed and administered by OSTI; travel processing; correspondence control; select reports or analyses directed toward improving the effectiveness, efficiency, and economy of services and processes; and safeguards and security oversight functions. | The Request will support select administrative and professional services including: support for the Small Business Innovation Research/Small Business Technology Transfer program; grants and contract processing and close-out activities; accessibility to DOE's corporate multi-billion dollar R&D program through information systems managed and administered by OSTI; travel processing; correspondence control; select reports or analyses directed toward improving the effectiveness, efficiency, and economy of services and processes; and safeguards and security oversight functions. | The increase will support annual escalation in contract labor rates. |
| Funding supports essential information technology infrastructure; necessary upgrades to SC's financial management system; ongoing operations and maintenance of IT systems; and safety management support. | The Request will support essential information technology infrastructure; necessary upgrades to SC's financial management system; ongoing operations and maintenance of IT systems; and safety management support. | The increase will support the projected costs associated with the use of the Department's Office of the Chief Information Officer Business Operations Support Services (CBOSS) contract. |

(dollars in thousands)

| FY 2020 Enacted | | FY 2021 Request | | Explanation of Changes FY 2021 Request vs FY 2020 Enacted | |
|---|---|---|---|---|---|
| Funding supports federal staff training and education to maintain appropriate certification and update skills. | | The Request will fund federal staff training and education to maintain appropriate certification and update skills. | | | |
| Other Related Expenses | $13,188 | | $13,024 | | -$164 |
| Funding supports fixed requirements associated with rent, utilities, and telecommunications; building and grounds maintenance; computer/video maintenance and support; IT equipment leases, purchases, and maintenance; and site-wide health care units. It also includes miscellaneous purchases for supplies, materials, and subscriptions. | | The Request will support fixed requirements associated with rent, utilities, and telecommunications; building and grounds maintenance; computer/video maintenance and support; IT equipment leases, purchases, and maintenance; and site-wide health care units. It will also include miscellaneous purchases for supplies, materials, and subscriptions. | | The decrease will account for projected fixed requirements for FY 2021. | |
| Working Capital Fund | $8,575 | | $8,575 | | $— |
| Funding supports the SC contribution to the WCF for business lines: building occupancy, supplies, printing and graphics, health services, corporate training services, and corporate business systems. SC research programs also contribute to WCF. | | The Request will support the SC contribution to the WCF for business lines: building occupancy, supplies, printing and graphics, health services, corporate training services, and corporate business systems. SC research programs also contribute to WCF. | | Projections for Working Capital Fund costs are unchanged. | |

## Program Direction
## Funding

| | (dollars in thousands) | | | |
|---|---|---|---|---|
| | **FY 2019 Enacted** | **FY 2020 Enacted** | **FY 2021 Request** | **FY 2021 Request vs FY 2020 Enacted** |
| **Headquarters** | | | | |
| Salaries and Benefits | 58,995 | 63,672 | 65,604 | +1,932 |
| Travel | 2,383 | 2,432 | 2,553 | +121 |
| Support Services | 17,171 | 17,884 | 19,437 | +1,553 |
| Other Related Expenses | 5,407 | 5,339 | 5,357 | +18 |
| Working Capital Fund | 8,150 | 8,575 | 8,575 | — |
| **Total, Headquarters** | **92,066** | **97,902** | **101,526** | **+3,624** |
| | | | | |
| **Office of Scientific and Technical Information** | | | | |
| Salaries and Benefits | 6,109 | 6,216 | 6,384 | +168 |
| Travel | 100 | 73 | 100 | +27 |
| Support Services | 1,931 | 2,081 | 2,010 | -71 |
| Other Related Expenses | 980 | 1,027 | 980 | -47 |
| **Total, Office of Scientific and Technical Information** | **9,120** | **9,397** | **9,474** | **+77** |
| | | | | |
| **Field Offices** | | | | |
| Salaries and Benefits | 69,075 | 65,723 | 66,609 | +886 |
| Travel | 1,717 | 1,795 | 1,817 | +22 |
| Support Services | 4,335 | 4,661 | 4,193 | -468 |
| Other Related Expenses | 6,687 | 6,822 | 6,687 | -135 |
| **Total, Field Offices** | **81,814** | **79,001** | **79,306** | **+305** |
| | | | | |
| **Total Program Direction** | | | | |
| Salaries and Benefits | 134,139 | 135,611 | 138,597 | +2,986 |
| Travel | 4,200 | 4,300 | 4,470 | +170 |
| Support Services | 23,437 | 24,626 | 25,640 | +1,014 |
| Other Related Expenses | 13,074 | 13,188 | 13,024 | -164 |
| Working Capital Fund | 8,150 | 8,575 | 8,575 | — |
| **Total, Program Direction** | **183,000** | **186,300** | **190,306** | **+4,006** |
| Federal FTE | 810 | 785 | 785 | — |

## Program Direction
## Funding Detail

(dollars in thousands)

| | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|
| **Technical Support** | | | | |
| System review and reliability analyses | 973 | 2,051 | 1,000 | -1,051 |
| | | | | |
| **Management Support** | | | | |
| Automated data processing | 9,080 | 10,500 | 12,500 | +2,000 |
| Training and education | 740 | 954 | 797 | -157 |
| Reports and analyses, management, and general administrative services | 12,644 | 11,121 | 11,343 | +222 |
| **Total, Management Support** | **22,464** | **22,575** | **24,640** | **+2,065** |
| **Total, Support Services** | **23,437** | **24,626** | **25,640** | **+1,014** |
| | | | | |
| **Other Related Expenses** | | | | |
| Rent to GSA | 637 | 637 | 637 | — |
| Rent to others | 1,424 | 1,412 | 1,424 | +12 |
| Communications, utilities, and miscellaneous | 2,653 | 3,234 | 2,653 | -581 |
| Other services | 2,181 | 1,978 | 2,131 | +153 |
| Operation and maintenance of equipment | 2 | — | 2 | +2 |
| Operation and maintenance of facilities | 1,512 | 1,515 | 1,512 | -3 |
| Supplies and materials | 690 | 426 | 690 | +264 |
| Equipment | 3,975 | 3,986 | 3,975 | -11 |
| **Total, Other Related Expenses** | **13,074** | **13,188** | **13,024** | **-164** |
| | | | | |
| **Working Capital Fund** | **8,150** | **8,575** | **8,575** | **—** |

**Program Direction**
**Funding Summary**

(dollars in thousands)

| | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|
| Other | 183,000 | 186,300 | 190,306 | +4,006 |
| **Total, Program Direction** | **183,000** | **186,300** | **190,306** | **+4,006** |

**Public Access**[a]

The Department of Energy's Public Access Plan, issued in July 2014 in response to policy memorandum issued by the White House Office of Science and Technology Policy (OSTP), outlines DOE's model and policy for increasing public access to scholarly publications and digital data resulting from DOE research funding. DOE's enabling authorization and subsequent legislation require DOE to provide publicly available collections of unclassified R&D results; the DOE Public Access Plan added peer-reviewed, final accepted manuscripts to the types of unclassified scientific and technical information already made publicly accessible as required by these longstanding statutes. For digital data resulting from sponsored research (as defined by OMB Circular A-110), the Plan requires the submission of data management plans with funding proposals to DOE and provides guidelines for preserving and provide access to digital research data as appropriate.

Implementation of the Plan has been carried out through DOE internal agency policy directive, with requirements specified in national labs management & operating contracts and annual performance plans, and in the terms and conditions of DOE financial assistance awards (grants and cooperative agreements). Under the DOE policy, DOE-funded researchers are required to submit metadata and final accepted manuscripts to DOE or to their institutional repositories, and DOE makes these research papers freely accessible to the public within 12 months of publication through the portal DOE PAGES (Public Access Gateway for Energy and Science). DOE's public access model also includes cooperation with the publishing community and with other federal agencies. Since implementation of the DOE policy, DOE is among the top agencies in implementing public access, with DOE PAGES providing free access to over 86,400 scholarly publications resulting from DOE research funding. To promote discovery, DOE enables broad indexing of this content by commercial search engines, provides an application programming interface (API) to DOE PAGES, and includes this collection in the cross-agency search portal Science.gov.

[a] Responds to the reporting requirement specified by the FY 2018 House Energy and Water Development Appropriations Committee Report 115-230 to provide an update on the DOE Public Access Plan; https://www.energy.gov/downloads/doe-public-access-plan; https://www.osti.gov/public-access-policy; https://www.energy.gov/datamanagement/doe-policy-digital-research-data-management.

## Science
## Facilities Maintenance and Repair

The Department's Facilities Maintenance and Repair activities are tied to its programmatic missions, goals, and objectives. The Facilities Maintenance and Repair activities funded by the budget and displayed below and are intended to ensure that the scientific community has the facilities required to conduct cutting edge scientific research now and in the future to meet Department of Energy (DOE) goals and objectives.

### Costs for Direct-Funded Maintenance and Repair (including Deferred Maintenance Reduction)

| | (dollars in thousands) | | | |
|---|---|---|---|---|
| | **FY 2019 Planned Cost** | **FY 2019 Actual Cost** | **FY 2020 Planned Cost** | **FY 2021 Planned Cost** |
| Brookhaven National Laboratory | 4,870 | 5,991 | 4,821 | 4,917 |
| Lawrence Berkeley National Laboratory | 8,532 | 4,273 | 8,612 | 3,900 |
| Notre Dame Radiation Laboratory | 130 | 185 | 124 | 125 |
| Oak Ridge National Laboratory | 18,441 | 26,435 | 18,994 | 19,564 |
| Oak Ridge Office | 4,492 | 4,007 | 6,479 | 6,673 |
| Office of Scientific and Technical Information | 364 | 343 | 382 | 421 |
| SLAC National Accelerator Laboratory | 3,150 | 3,497 | 3,276 | 3,407 |
| Thomas Jefferson National Accelerator Facility | 191 | 122 | 195 | 198 |
| **Total, Direct-Funded Maintenance and Repair** | **40,170** | **44,853** | **42,883** | **39,205** |

General purpose infrastructure includes multiprogram research laboratories, administrative and support buildings, as well as cafeterias, power plants, fire stations, utilities, roads, and other structures. Together, the Office of Science (SC) laboratories have over 1,400 operational buildings and real property trailers, with nearly 20 million gross square feet of space.

Generally, facilities maintenance and repair expenses are funded through an indirect overhead charge. In some cases, however, a laboratory may charge maintenance directly to a specific program. One example would be when maintenance is performed in a building used only by a single program. Such direct-funded charges are not directly budgeted.

### Indirect-Funded Maintenance and Repair (including Deferred Maintenance Reduction)

Facilities maintenance and repair activities funded indirectly through overhead charges at SC laboratories are displayed in the table above. Since this funding is allocated to all work done at each laboratory, the cost of these activities is 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 costs across all SC laboratories.

**Science**
**Costs for Indirect-Funded Maintenance and Repair (including Deferred Maintenance Reduction)**

(dollars in thousands)

| | FY 2019 Planned Cost | FY 2019 Actual Cost | FY 2020 Planned Cost | FY 2021 Planned Cost |
|---|---|---|---|---|
| Ames Laboratory | 2,300 | 1,962 | 2,700 | 2,400 |
| Argonne National Laboratory | 44,900 | 42,699 | 45,823 | 46,768 |
| Brookhaven National Laboratory | 31,747 | 33,858 | 29,619 | 30,211 |
| Fermi National Accelerator Laboratory | 20,759 | 15,829 | 20,994 | 21,704 |
| Lawrence Berkeley National Laboratory | 27,683 | 24,923 | 28,778 | 29,749 |
| Notre Dame Radiation Laboratory | — | 53 | — | — |
| Oak Ridge Institute for Science and Education | 387 | 598 | 468 | 480 |
| Oak Ridge National Laboratory and Y-12 | 69,592 | 55,928 | 71,680 | 73,830 |
| Oak Ridge Office | 1,511 | 1,498 | 1,492 | 1,537 |
| Pacific Northwest National Laboratory | 8,622 | 7,499 | 10,591 | 10,322 |
| Princeton Plasma Physics Laboratory | 6,450 | 6,856 | 6,644 | 6,843 |
| SLAC National Accelerator Laboratory | 13,124 | 12,525 | 13,649 | 14,195 |
| Thomas Jefferson National Accelerator Facility | 8,366 | 6,986 | 9,988 | 10,188 |
| **Total, Indirect-Funded Maintenance and Repair** | **235,441** | **211,214** | **242,426** | **248,227** |

**Report on FY 2019 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 DOE to provide an annual year-end report on maintenance expenditures to the Committees on Appropriations. This report compares the actual maintenance expenditures in FY 2019 to the amount planned for FY 2019, including Congressionally directed changes.

**Science**
**Total Costs for Maintenance and Repair**

(dollars in thousands)

| | FY 2019 Planned Costs | FY 2019 Actual Costs |
|---|---|---|
| Ames Laboratory | 2,300 | 1,962 |
| Argonne National Laboratory | 44,900 | 42,699 |
| Brookhaven National Laboratory | 36,617 | 39,849 |
| Fermi National Accelerator Laboratory | 20,759 | 15,829 |
| Lawrence Berkeley National Laboratory | 36,215 | 29,196 |
| Notre Dame Radiation Laboratory | 130 | 238 |
| Oak Ridge Institute for Science and Education | 387 | 598 |
| Oak Ridge National Laboratory and Y-12 | 88,033 | 82,363 |
| Oak Ridge Office | 6,003 | 5,505 |
| Office of Scientific and Technical Information | 364 | 343 |
| Pacific Northwest National Laboratory | 8,622 | 7,499 |
| Princeton Plasma Physics Laboratory | 6,450 | 6,856 |
| SLAC National Accelerator Laboratory | 16,274 | 16,022 |
| Thomas Jefferson National Accelerator Facility | 8,557 | 7,108 |
| **Total, Maintenance and Repair** | **275,611** | **256,067** |

**Science**

**Excess Facilities**

Excess Facilities are facilities no longer required to support the Department's needs, present or future missions or functions, or the discharge of its responsibilities. The table below reports the funding to deactivate and dispose of excess infrastructure, including stabilization and risk reduction activities at high-risk excess facilities. These activities result in surveillance and maintenance cost avoidance and reduced risk to workers, the public, the environment, and programs. This includes reductions in costs related to maintenance of excess facilities (including high-risk excess facilities) necessary to minimize the risk posed by those facilities prior to disposition. SC has no direct funded excess facilities costs to report.

**Costs for Indirect-Funded Excess Facilities**

| | (dollars in thousands) | | | |
|---|---|---|---|---|
| | **FY 2019 Planned Cost** | **FY 2019 Actual Cost** | **FY 2020 Planned Cost** | **FY 2021 Planned Cost** |
| Argonne National Laboratory | 400[a] | 400 | 400 | 400 |
| Brookhaven National Laboratory | 893 | 965 | 958 | 978 |
| Fermi National Accelerator Laboratory | 243 | 20 | 20 | 20 |
| Lawrence Berkeley National Laboratory | 66 | 47 | 16 | 16 |
| Oak Ridge National Laboratory | 1,000 | 500 | 500 | 500 |
| SLAC National Accelerator Laboratory | 50 | 52 | 54 | 56 |
| **Total, Indirect-Funded Excess Facilities** | **2,652** | **1,984** | **1,948** | **1,970** |

[a] This figure was reported erroneously as 6,750 in the FY 2020 Congressional Budget Justification.

**Science**
**Research and Development**

(dollars in thousands)

| | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|
| Basic | 4,964,670 | 5,324,920 | 4,734,211 | -590,709 |
| Applied | — | — | — | — |
| Subtotal, R&D | 4,964,670 | 5,324,920 | 4,734,211 | -590,709 |
| Equipment | 277,069 | 217,526 | 198,332 | -19,194 |
| Construction | 1,275,310 | 1,380,554 | 827,763 | -552,791 |
| **Total, R&D** | **6,517,049** | **6,923,000** | **5,760,306** | **-1,162,694** |

**Science**
**Small Business Innovative Research/Small Business Technology Transfer (SBIR/STTR)**

| | (dollars in thousands) | | | |
|---|---|---|---|---|
| | **FY 2019 Enacted** | **FY 2020 Enacted** | **FY 2021 Request** | **FY 2021 Request vs FY 2020 Enacted** |
| Office of Science | | | | |
| Advanced Scientific Computing Research | | | | |
| SBIR | 22,329 | 25,160 | 26,051 | +891 |
| STTR | 3,140 | 3,538 | 3,664 | +126 |
| Basic Energy Sciences | | | | |
| SBIR | 52,617 | 57,423 | 53,080 | -4,343 |
| STTR | 7,400 | 8,075 | 7,464 | -611 |
| Biological and Environmental Research | | | | |
| SBIR | 21,702 | 23,687 | 16,318 | -7,369 |
| STTR | 3,052 | 3,330 | 2,295 | -1,035 |
| Fusion Energy Sciences | | | | |
| SBIR | 12,992 | 12,348 | 8,469 | -3,879 |
| STTR | 1,827 | 1,737 | 1,191 | -546 |
| High Energy Physics | | | | |
| SBIR | 21,124 | 22,265 | 18,763 | -3,502 |
| STTR | 2,971 | 3,131 | 2,558 | -573 |
| Nuclear Physics | | | | |
| SBIR | 17,500 | 18,257 | 17,220 | -1,037 |
| STTR | 2,461 | 2,468 | 2,218 | -250 |
| **Total, Office of Science SBIR[a]** | **148,264** | **159,140** | **139,901** | **-19,239** |
| **Total, Office of Science STTR** | **20,851** | **22,279** | **19,390** | **-2,889** |

[a] The other DOE programs SBIR/STTR funding amounts are listed in the other DOE budget volumes.

**Science**
**Safeguards and Security Crosscut**

(dollars in thousands)

| | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request | FY 2021 Request vs FY 2020 Enacted |
|---|---|---|---|---|
| Protective Forces | 43,545 | 43,545 | 43,545 | — |
| Security Systems | 10,370 | 16,960 | 19,883 | +2,923 |
| Information Security | 4,356 | 4,356 | 4,356 | — |
| Cyber Security | 33,346 | 33,346 | 33,346 | — |
| Personnel Security | 5,444 | 5,444 | 5,444 | — |
| Material Control and Accountability | 2,431 | 2,431 | 2,431 | — |
| Program Management | 6,618 | 6,618 | 6,618 | — |
| **Total, Safeguards and Security** | **106,110** | **112,700** | **115,623** | **+2,923** |

**DEPARTMENT OF ENERGY**
**Funding by Site Detail Science FY 2021**
**(Dollars in Thousands)**

| | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request Detail |
|---|---|---|---|
| **Ames Laboratory** | | | |
| Research - Basic Energy Sciences | 17,620 | 17,578 | 17,578 |
| Basic Energy Sciences | 17,620 | 17,578 | 17,578 |
| Biological & Environmental Research | 1,250 | 1,250 | 0 |
| Workforce Development for Teachers & Scientists | 538 | 0 | 0 |
| 21-SC-78, Ames Infrastructure Modernization | 0 | 0 | 2,000 |
| Construction - Science Laboratories Infrastructure | 0 | 0 | 2,000 |
| Science Laboratories Infrastructure | 0 | 0 | 2,000 |
| Safeguards and Security - SC | 1,231 | 1,231 | 1,231 |
| **Total, Ames Laboratory** | **20,639** | **20,059** | **20,809** |
| **Ames Site Office** | | | |
| Program Direction - SC | 658 | 678 | 690 |
| **Total, Ames Site Office** | **658** | **678** | **690** |
| **Argonne National Laboratory** | | | |
| Research - Advanced Scientific Computing Research | 153,798 | 160,042 | 154,856 |
| Advanced Scientific Computing Research | 153,798 | 160,042 | 154,856 |
| Research - Basic Energy Sciences | 230,799 | 239,274 | 228,709 |
| 18-SC-10, Advanced Photon Source Upgrade (APS-U), ANL | 130,000 | 170,000 | 150,000 |
| Construction - Basic Energy Sciences | 130,000 | 170,000 | 150,000 |
| Basic Energy Sciences | 360,799 | 409,274 | 378,709 |
| Biological & Environmental Research | 32,250 | 30,852 | 20,222 |
| Research - Fusion Energy Sciences | 0 | 181 | 189 |
| Fusion Energy Sciences | 0 | 181 | 189 |
| Research - High Energy Physics | 15,695 | 13,913 | 9,670 |
| High Energy Physics | 15,695 | 13,913 | 9,670 |
| Operations and Maintenance - Nuclear Physics | 33,384 | 31,433 | 29,506 |
| Nuclear Physics | 33,384 | 31,433 | 29,506 |
| Workforce Development for Teachers & Scientists | 1,494 | 0 | 0 |
| Facilities and Infrastructure (SLI) | 23,393 | 10,800 | 0 |
| 20-SC-77, Argonne Utilities Upgrade, ANL (20-SC-79) | 0 | 500 | 2,000 |
| 19-SC-72, Electrical Capacity and Distribution Capability, ANL | 30,000 | 30,000 | 0 |
| Construction - Science Laboratories Infrastructure | 30,000 | 30,500 | 2,000 |
| Science Laboratories Infrastructure | 53,393 | 41,300 | 2,000 |
| Safeguards and Security - SC | 9,996 | 10,019 | 10,019 |
| **Total, Argonne National Laboratory** | **660,809** | **697,014** | **605,171** |
| **Argonne Site Office** | | | |
| Program Direction - SC | 4,415 | 4,424 | 4,590 |
| **Total, Argonne Site Office** | **4,415** | **4,424** | **4,590** |
| **Bay Area Site Office** | | | |
| Program Direction - SC | 0 | 5,834 | 5,947 |
| **Total, Bay Area Site Office** | **0** | **5,834** | **5,947** |
| **Berkeley Site Office** | | | |
| Program Direction - SC | 3,588 | 0 | 0 |
| **Total, Berkeley Site Office** | **3,588** | **0** | **0** |
| **Brookhaven National Laboratory** | | | |
| Research - Advanced Scientific Computing Research | 1,590 | 1,228 | 1,233 |
| Advanced Scientific Computing Research | 1,590 | 1,228 | 1,233 |

| | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request Detail |
|---|---|---|---|
| Research - Basic Energy Sciences | 169,571 | 182,858 | 169,475 |
| Basic Energy Sciences | 169,571 | 182,858 | 169,475 |
| Biological & Environmental Research | 17,306 | 11,998 | 9,448 |
| Research - High Energy Physics | 79,255 | 80,167 | 67,847 |
| 11-SC-40, LBNF/DUNE, FNAL | 3,000 | 2,942 | 17,000 |
| Construction - High Energy Physics | 3,000 | 2,942 | 17,000 |
| High Energy Physics | 82,255 | 83,109 | 84,847 |
| Operations and Maintenance - Nuclear Physics | 209,914 | 222,778 | 211,353 |
| 20-SC-52, Electron Ion Collider, BNL | 0 | 1,000 | 1,000 |
| Construction - Nuclear Physics | 0 | 1,000 | 1,000 |
| Nuclear Physics | 209,914 | 223,778 | 212,353 |
| Workforce Development for Teachers & Scientists | 2,506 | 0 | 0 |
| 20-SC-71, Critical Utilities Rehabilitation Project, BNL | 0 | 20,000 | 15,000 |
| 19-SC-71, Science User Support Center, BNL | 7,000 | 20,000 | 7,000 |
| 17-SC-73, Core Facility Revitalization, BNL | 42,200 | 0 | 0 |
| Construction - Science Laboratories Infrastructure | 49,200 | 40,000 | 22,000 |
| Science Laboratories Infrastructure | 49,200 | 40,000 | 22,000 |
| Safeguards and Security - SC | 13,933 | 14,013 | 14,013 |
| **Total, Brookhaven National Laboratory** | **546,275** | **556,984** | **513,369** |
| | | | |
| **Brookhaven Site Office** | | | |
| Program Direction - SC | 4,905 | 4,575 | 4,546 |
| **Total, Brookhaven Site Office** | **4,905** | **4,575** | **4,546** |
| | | | |
| **Chicago Office** | | | |
| Research - Advanced Scientific Computing Research | 16,885 | 17,464 | 15,060 |
| Advanced Scientific Computing Research | 16,885 | 17,464 | 15,060 |
| Research - Basic Energy Sciences | 339,965 | 363,064 | 368,906 |
| Basic Energy Sciences | 339,965 | 363,064 | 368,906 |
| Biological & Environmental Research | 154,065 | 158,308 | 94,476 |
| Research - Fusion Energy Sciences | 140,519 | 104,123 | 91,793 |
| Fusion Energy Sciences | 140,519 | 104,123 | 91,793 |
| Research - High Energy Physics | 110,234 | 95,238 | 81,822 |
| High Energy Physics | 110,234 | 95,238 | 81,822 |
| Operations and Maintenance - Nuclear Physics | 78,940 | 109,474 | 105,924 |
| 14-SC-50, Facility for Rare Isotope Beams, MSU | 75,000 | 40,000 | 5,300 |
| Construction - Nuclear Physics | 75,000 | 40,000 | 5,300 |
| Nuclear Physics | 153,940 | 149,474 | 111,224 |
| Safeguards and Security - SC | 50 | 50 | 50 |
| Program Direction - SC | 24,546 | 0 | 0 |
| Payment In Lieu of Taxes PILT | 1,713 | 1,650 | 1,650 |
| **Total, Chicago Office** | **941,917** | **889,371** | **764,981** |
| | | | |
| **Consolidated Service Center** | | | |
| Program Direction - SC | 0 | 45,242 | 45,377 |
| **Total, Consolidated Service Center** | **0** | **45,242** | **45,377** |
| | | | |
| **Fermi National Accelerator Laboratory** | | | |
| Research - Advanced Scientific Computing Research | 174 | 874 | 874 |
| Advanced Scientific Computing Research | 174 | 874 | 874 |
| Research - Basic Energy Sciences | 135 | 135 | 135 |
| Basic Energy Sciences | 135 | 135 | 135 |
| Research - High Energy Physics | 342,303 | 323,994 | 271,514 |
| 18-SC-42, Proton Improvement Plan II (PIP-II), FNAL | 20,000 | 60,000 | 20,000 |
| 11-SC-40, LBNF/DUNE, FNAL | 127,000 | 168,058 | 83,500 |
| 11-SC-41, Muon to Electron Conversion Experiment, FNAL | 30,000 | 0 | 0 |
| Construction - High Energy Physics | 177,000 | 228,058 | 103,500 |
| High Energy Physics | 519,303 | 552,052 | 375,014 |
| Operations and Maintenance - Nuclear Physics | 0 | 500 | 0 |

| | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request Detail |
|---|---|---|---|
| Nuclear Physics | 0 | 500 | 0 |
| Workforce Development for Teachers & Scientists | 257 | 0 | 0 |
| 20-SC-80, Utilities Infrastructure Project, FNAL (20-SC-82) | 0 | 500 | 2,000 |
| 17-SC-71, Integrated Engineering Research Center, FNAL | 20,000 | 22,000 | 12,000 |
| Construction - Science Laboratories Infrastructure | 20,000 | 22,500 | 14,000 |
| Science Laboratories Infrastructure | 20,000 | 22,500 | 14,000 |
| Safeguards and Security - SC | 7,037 | 7,877 | 7,877 |
| **Total Fermi National Accelerator Laboratory** | **546,906** | **583,938** | **397,900** |
| | | | |
| **Fermi Site Office** | | | |
| Program Direction - SC | 2,581 | 3,070 | 2,937 |
| **Total, Fermi Site Office** | **2,581** | **3,070** | **2,937** |
| | | | |
| **Idaho National Laboratory** | | | |
| Research - Advanced Scientific Computing Research | 70 | 70 | 70 |
| Advanced Scientific Computing Research | 70 | 70 | 70 |
| Research - Basic Energy Sciences | 4,592 | 3,723 | 3,723 |
| Basic Energy Sciences | 4,592 | 3,723 | 3,723 |
| Research - Fusion Energy Sciences | 5,510 | 2,500 | 2,500 |
| Fusion Energy Sciences | 5,510 | 2,500 | 2,500 |
| Workforce Development for Teachers & Scientists | 384 | 0 | 0 |
| **Total, Idaho National Laboratory** | **10,556** | **6,293** | **6,293** |
| | | | |
| **Idaho Operations Office** | | | |
| Research - Basic Energy Sciences | 0 | 369 | 369 |
| Basic Energy Sciences | 0 | 369 | 369 |
| **Total, Idaho Operations Office** | **0** | **369** | **369** |
| | | | |
| **Lawrence Berkeley National Laboratory** | | | |
| Research - Advanced Scientific Computing Research | 213,107 | 215,822 | 176,028 |
| Advanced Scientific Computing Research | 213,107 | 215,822 | 176,028 |
| Research - Basic Energy Sciences | 165,806 | 170,004 | 161,728 |
| 18-SC-12, Advanced Light Source Upgrade (ALS-U), LBNL | 60,000 | 60,000 | 13,000 |
| Construction - Basic Energy Sciences | 60,000 | 60,000 | 13,000 |
| Basic Energy Sciences | 225,806 | 230,004 | 174,728 |
| Biological & Environmental Research | 161,607 | 162,828 | 122,887 |
| Research - Fusion Energy Sciences | 895 | 1,525 | 765 |
| Fusion Energy Sciences | 895 | 1,525 | 765 |
| Research - High Energy Physics | 82,427 | 68,664 | 52,868 |
| High Energy Physics | 82,427 | 68,664 | 52,868 |
| Operations and Maintenance - Nuclear Physics | 26,121 | 25,138 | 19,801 |
| Nuclear Physics | 26,121 | 25,138 | 19,801 |
| Workforce Development for Teachers & Scientists | 1,298 | 0 | 0 |
| 20-SC-72, Seismic and Safety Modernization, LBNL | 0 | 10,000 | 10,000 |
| 20-SC-78, Linear Assets Modernization Project, LBNL (20-SC-80) | 0 | 500 | 2,000 |
| 19-SC-74, BioEPIC, LBNL | 5,000 | 15,000 | 6,000 |
| Construction - Science Laboratories Infrastructure | 5,000 | 25,500 | 18,000 |
| Science Laboratories Infrastructure | 5,000 | 25,500 | 18,000 |
| Safeguards and Security - SC | 7,155 | 7,175 | 7,175 |
| **Total, Lawrence Berkeley National Laboratory** | **723,416** | **736,656** | **572,252** |
| | | | |
| **Lawrence Livermore National Laboratory** | | | |
| Research - Advanced Scientific Computing Research | 5,531 | 2,472 | 1,724 |
| Advanced Scientific Computing Research | 5,531 | 2,472 | 1,724 |
| Research - Basic Energy Sciences | 1,804 | 2,948 | 2,948 |
| Basic Energy Sciences | 1,804 | 2,948 | 2,948 |
| Biological & Environmental Research | 31,587 | 29,558 | 18,036 |
| Research - Fusion Energy Sciences | 8,819 | 8,062 | 8,537 |

| | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request Detail |
|---|---|---|---|
| Fusion Energy Sciences | 8,819 | 8,062 | 8,537 |
| Research - High Energy Physics | 2,315 | 3,750 | 3,445 |
| High Energy Physics | 2,315 | 3,750 | 3,445 |
| Operations and Maintenance - Nuclear Physics | 1,728 | 1,769 | 1,484 |
| Nuclear Physics | 1,728 | 1,769 | 1,484 |
| Workforce Development for Teachers & Scientists | 423 | 0 | 0 |
| **Total, Lawrence Livermore National Laboratory** | **52,207** | **48,559** | **36,174** |
| | | | |
| **Los Alamos National Laboratory** | | | |
| Research - Advanced Scientific Computing Research | 3,626 | 2,930 | 2,071 |
| Advanced Scientific Computing Research | 3,626 | 2,930 | 2,071 |
| Research - Basic Energy Sciences | 23,337 | 27,422 | 26,585 |
| Basic Energy Sciences | 23,337 | 27,422 | 26,585 |
| Biological & Environmental Research | 32,034 | 30,291 | 20,321 |
| Research - Fusion Energy Sciences | 3,087 | 3,910 | 3,410 |
| Fusion Energy Sciences | 3,087 | 3,910 | 3,410 |
| Research - High Energy Physics | 2,640 | 2,040 | 1,145 |
| High Energy Physics | 2,640 | 2,040 | 1,145 |
| Operations and Maintenance - Nuclear Physics | 9,360 | 8,314 | 8,821 |
| Nuclear Physics | 9,360 | 8,314 | 8,821 |
| Workforce Development for Teachers & Scientists | 532 | 0 | 0 |
| **Total, Los Alamos National Laboratory** | **74,616** | **74,907** | **62,353** |
| | | | |
| **National Renewable Energy Laboratory** | | | |
| Research - Basic Energy Sciences | 12,600 | 12,109 | 12,109 |
| Basic Energy Sciences | 12,600 | 12,109 | 12,109 |
| Biological & Environmental Research | 827 | 848 | 877 |
| Workforce Development for Teachers & Scientists | 1,368 | 0 | 0 |
| **Total National Renewable Energy Laboratory** | **14,795** | **12,957** | **12,986** |
| | | | |
| **Oak Ridge Institute for Science & Education** | | | |
| Biological & Environmental Research | 4,103 | 3,187 | 2,102 |
| Research - Fusion Energy Sciences | 750 | 700 | 700 |
| Fusion Energy Sciences | 750 | 700 | 700 |
| Operations and Maintenance - Nuclear Physics | 467 | 697 | 636 |
| Nuclear Physics | 467 | 697 | 636 |
| Workforce Development for Teachers & Scientists | 11,176 | 0 | 0 |
| Safeguards and Security - SC | 1,892 | 1,894 | 1,894 |
| **Total Oak Ridge Institute for Science & Education** | **18,388** | **6,478** | **5,332** |
| | | | |
| **Oak Ridge National Laboratory** | | | |
| Research - Advanced Scientific Computing Research | 213,837 | 235,031 | 228,092 |
| 17-SC-20, Office of Science Exascale Computing Project (SC-ECP) | 232,706 | 188,735 | 168,945 |
| Advanced Scientific Computing Research | 446,543 | 423,766 | 397,037 |
| Research - Basic Energy Sciences | 349,799 | 374,486 | 330,118 |
| 19-SC-14, Second Target Station (STS), ORNL | 1,000 | 20,000 | 1,000 |
| 18-SC-11, Spallation Neutron Source Proton Power Upgrade (PPU), ORNL | 60,000 | 60,000 | 5,000 |
| Construction - Basic Energy Sciences | 61,000 | 80,000 | 6,000 |
| Basic Energy Sciences | 410,799 | 454,486 | 336,118 |
| Biological & Environmental Research | 82,294 | 78,923 | 59,393 |
| Research - Fusion Energy Sciences | 30,283 | 31,362 | 29,272 |
| 14-SC-60, U.S. Contributions to ITER (U.S. ITER) | 132,000 | 242,000 | 107,000 |
| Construction - Fusion Energy Sciences | 132,000 | 242,000 | 107,000 |
| Fusion Energy Sciences | 162,283 | 273,362 | 136,272 |
| Research - High Energy Physics | 920 | 697 | 407 |
| High Energy Physics | 920 | 697 | 407 |
| Operations and Maintenance - Nuclear Physics | 18,206 | 18,263 | 16,879 |
| 20-SC-51, U.S. Stable Isotope Production and Research Center, ORNL | 0 | 12,000 | 12,000 |
| Construction - Nuclear Physics | 0 | 12,000 | 12,000 |

| | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request Detail |
|---|---|---|---|
| Nuclear Physics | 18,206 | 30,263 | 28,879 |
| Oak Ridge Nuclear Operations | 26,000 | 26,000 | 6,000 |
| 20-SC-74, Craft Resources Support Facility, ORNL (19-SC-74) | 0 | 15,000 | 25,000 |
| 19-SC-73, Translational Research Capability, ORNL | 25,000 | 25,000 | 10,000 |
| Construction - Science Laboratories Infrastructure | 25,000 | 40,000 | 35,000 |
| Science Laboratories Infrastructure | 51,000 | 66,000 | 41,000 |
| Safeguards and Security - SC | 12,864 | 29,973 | 29,973 |
| **Total Oak Ridge National Laboratory** | **1,184,909** | **1,357,470** | **1,029,079** |
| | | | |
| **Oak Ridge National Laboratory Site Office** | | | |
| Program Direction - SC | 5,551 | 5,934 | 6,074 |
| **Total Oak Ridge National Laboratory Site Office** | **5,551** | **5,934** | **6,074** |
| | | | |
| **Oak Ridge Office** | | | |
| Operations and Maintenance - Nuclear Physics | 50 | 0 | 0 |
| Nuclear Physics | 50 | 0 | 0 |
| Oak Ridge Landlord | 6,434 | 5,610 | 5,860 |
| Facilities and Infrastructure (SLI) | 0 | 7,272 | 0 |
| Science Laboratories Infrastructure | 6,434 | 12,882 | 5,860 |
| Safeguards and Security - SC | 23,472 | 4,558 | 4,558 |
| Program Direction - SC | 24,177 | 0 | 0 |
| Payment In Lieu of Taxes PILT | 0 | 2,890 | 3,000 |
| **Total Oak Ridge Office** | **54,133** | **20,330** | **13,418** |
| | | | |
| **Office of Scientific & Technical Information** | | | |
| Research - Advanced Scientific Computing Research | 155 | 157 | 155 |
| Advanced Scientific Computing Research | 155 | 157 | 155 |
| Biological & Environmental Research | 296 | 177 | 159 |
| Research - High Energy Physics | 0 | 189 | 0 |
| High Energy Physics | 0 | 189 | 0 |
| Operations and Maintenance - Nuclear Physics | 285 | 285 | 128 |
| Nuclear Physics | 285 | 285 | 128 |
| Workforce Development for Teachers & Scientists | 200 | 0 | 0 |
| Facilities and Infrastructure (SLI) | 0 | 200 | 200 |
| Science Laboratories Infrastructure | 0 | 200 | 200 |
| Safeguards and Security - SC | 759 | 759 | 759 |
| Program Direction - SC | 9,120 | 9,397 | 9,515 |
| **Total Office of Scientific & Technical Information** | **10,815** | **11,164** | **10,916** |
| | | | |
| **Pacific Northwest National Laboratory** | | | |
| Research - Advanced Scientific Computing Research | 5,597 | 4,360 | 1,915 |
| Advanced Scientific Computing Research | 5,597 | 4,360 | 1,915 |
| Research - Basic Energy Sciences | 33,216 | 33,838 | 33,838 |
| Basic Energy Sciences | 33,216 | 33,838 | 33,838 |
| Biological & Environmental Research | 141,297 | 107,127 | 84,114 |
| Research - Fusion Energy Sciences | 250 | 650 | 1,663 |
| Fusion Energy Sciences | 250 | 650 | 1,663 |
| Research - High Energy Physics | 1,460 | 1,855 | 1,160 |
| High Energy Physics | 1,460 | 1,855 | 1,160 |
| Operations and Maintenance - Nuclear Physics | 500 | 830 | 287 |
| Nuclear Physics | 500 | 830 | 287 |
| Workforce Development for Teachers & Scientists | 1,022 | 0 | 0 |
| 18-SC-71, Energy Sciences Capability, PNNL | 24,000 | 23,000 | 23,000 |
| Construction - Science Laboratories Infrastructure | 24,000 | 23,000 | 23,000 |
| Science Laboratories Infrastructure | 24,000 | 23,000 | 23,000 |
| Safeguards and Security - SC | 12,459 | 12,759 | 12,759 |
| **Total Pacific Northwest National Laboratory** | **219,801** | **184,419** | **158,736** |

| | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request Detail |
|---|---|---|---|
| **Pacific Northwest Site Office** | | | |
| Program Direction - SC | 5,084 | 5,186 | 5,036 |
| **Total Pacific Northwest Site Office** | **5,084** | **5,186** | **5,036** |
| | | | |
| **Princeton Plasma Physics Laboratory** | | | |
| Research - Advanced Scientific Computing Research | 385 | 335 | 335 |
| Advanced Scientific Computing Research | 385 | 335 | 335 |
| Research - Fusion Energy Sciences | 107,770 | 83,350 | 74,499 |
| Fusion Energy Sciences | 107,770 | 83,350 | 74,499 |
| Workforce Development for Teachers & Scientists | 512 | 0 | 0 |
| 21-SC-75, Princeton Plasma Innovation Center, PPPL | 0 | 0 | 2,000 |
| 21-SC-76, Critical Infrastructure Recovery & Renewal, PPPL | 0 | 0 | 2,000 |
| 20-SC-76, Tritium System Demolition and Disposal, PPPL (20-SC-78) | 0 | 13,000 | 19,400 |
| Construction - Science Laboratories Infrastructure | 0 | 13,000 | 23,400 |
| Science Laboratories Infrastructure | 0 | 13,000 | 23,400 |
| Safeguards and Security - SC | 3,354 | 3,358 | 3,358 |
| **Total Princeton Plasma Physics Laboratory** | **112,021** | **100,043** | **101,592** |
| | | | |
| **Princeton Site Office** | | | |
| Program Direction - SC | 1,862 | 1,910 | 1,950 |
| **Total Princeton Site Office** | **1,862** | **1,910** | **1,950** |
| | | | |
| **Sandia National Laboratories** | | | |
| Research - Advanced Scientific Computing Research | 17,331 | 14,920 | 12,455 |
| Advanced Scientific Computing Research | 17,331 | 14,920 | 12,455 |
| Research - Basic Energy Sciences | 28,219 | 26,900 | 26,128 |
| Basic Energy Sciences | 28,219 | 26,900 | 26,128 |
| Biological & Environmental Research | 11,149 | 10,160 | 6,639 |
| Research - Fusion Energy Sciences | 1,265 | 1,669 | 1,614 |
| Fusion Energy Sciences | 1,265 | 1,669 | 1,614 |
| Research - High Energy Physics | 100 | 0 | 50 |
| High Energy Physics | 100 | 0 | 50 |
| Workforce Development for Teachers & Scientists | 130 | 0 | 0 |
| **Total Sandia National Laboratories** | **58,194** | **53,649** | **46,886** |
| | | | |
| **Savannah River National Laboratory** | | | |
| Research - Basic Energy Sciences | 420 | 410 | 410 |
| Basic Energy Sciences | 420 | 410 | 410 |
| Biological & Environmental Research | 150 | 150 | 150 |
| Research - Fusion Energy Sciences | 0 | 400 | 400 |
| Fusion Energy Sciences | 0 | 400 | 400 |
| **Total Savannah River National Laboratory** | **570** | **960** | **960** |
| | | | |
| **SLAC National Accelerator Laboratory** | | | |
| Research - Advanced Scientific Computing Research | 1,366 | 1,170 | 670 |
| Advanced Scientific Computing Research | 1,366 | 1,170 | 670 |
| Research - Basic Energy Sciences | 232,553 | 231,945 | 226,323 |
| 18-SC-13, Linac Coherent Light Source-II-High Energy (LCLS-II-HE), SLAC | 28,000 | 50,000 | 14,000 |
| 13-SC-10, Linac Coherent Light Source-II (LCLS-II), SLAC | 129,300 | 0 | 0 |
| Construction - Basic Energy Sciences | 157,300 | 50,000 | 14,000 |
| Basic Energy Sciences | 389,853 | 281,945 | 240,323 |
| Biological & Environmental Research | 7,394 | 4,100 | 3,600 |
| Research - Fusion Energy Sciences | 2,340 | 6,800 | 5,000 |
| 20-SC-61, Matter in Extreme Conditions (MEC) Petawatt Upgrade, SLAC | 0 | 15,000 | 5,000 |
| Construction - Fusion Energy Sciences | 0 | 15,000 | 5,000 |
| Fusion Energy Sciences | 2,340 | 21,800 | 10,000 |
| Research - High Energy Physics | 64,007 | 66,589 | 57,496 |

| | FY 2019 Enacted | FY 2020 Enacted | FY 2021 Request Detail |
|---|---|---|---|
| High Energy Physics | 64,007 | 66,589 | 57,496 |
| Operations and Maintenance - Nuclear Physics | 1,015 | 1,336 | 1,005 |
| Nuclear Physics | 1,015 | 1,336 | 1,005 |
| Workforce Development for Teachers & Scientists | 460 | 0 | 0 |
| Facilities and Infrastructure (SLI) | 9,400 | 0 | 0 |
| 20-SC-75, Large Scale Collaboration Center, SLAC (19-SC-75) | 0 | 11,000 | 8,000 |
| 20-SC-79, Critical Utilities Infrastructure Revitalization, SLAC (20-SC-81) | 0 | 500 | 2,000 |
| Construction - Science Laboratories Infrastructure | 0 | 11,500 | 10,000 |
| Science Laboratories Infrastructure | 9,400 | 11,500 | 10,000 |
| Safeguards and Security - SC | 4,304 | 4,328 | 4,328 |
| **Total SLAC National Accelerator Laboratory** | **480,139** | **392,768** | **327,422** |
| | | | |
| **Stanford Site Office** | | | |
| Program Direction - SC | 2,476 | 0 | 0 |
| **Total Stanford Site Office** | **2,476** | **0** | **0** |
| | | | |
| **Thomas Jefferson National Accelerator Facility** | | | |
| Research - Advanced Scientific Computing Research | 387 | 382 | 360 |
| Advanced Scientific Computing Research | 387 | 382 | 360 |
| Research - High Energy Physics | 350 | 750 | 400 |
| High Energy Physics | 350 | 750 | 400 |
| Operations and Maintenance - Nuclear Physics | 129,017 | 133,267 | 128,609 |
| Nuclear Physics | 129,017 | 133,267 | 128,609 |
| Workforce Development for Teachers & Scientists | 200 | 0 | 0 |
| 20-SC-73, CEBAF Renovation and Expansion, TJNAF (19-SC-73) | 0 | 2,000 | 2,000 |
| Construction - Science Laboratories Infrastructure | 0 | 2,000 | 2,000 |
| Science Laboratories Infrastructure | 0 | 2,000 | 2,000 |
| Safeguards and Security - SC | 3,021 | 3,037 | 3,037 |
| **Total Thomas Jefferson National Accelerator Facility** | **132,975** | **139,436** | **134,406** |
| | | | |
| **Thomas Jefferson Site Office** | | | |
| Program Direction - SC | 1,971 | 2,148 | 2,241 |
| **Total Thomas Jefferson Site Office** | **1,971** | **2,148** | **2,241** |
| | | | |
| **Washington Headquarters** | | | |
| Research - Advanced Scientific Computing Research | 68,955 | 134,008 | 223,208 |
| Advanced Scientific Computing Research | 68,955 | 134,008 | 223,208 |
| Research - Basic Energy Sciences | 147,264 | 165,937 | 142,591 |
| 21-SC-10, Cryomodule Repair and Maintenance Facilty | 0 | 0 | 1,000 |
| Construction - Basic Energy Sciences | 0 | 0 | 1,000 |
| Basic Energy Sciences | 147,264 | 165,937 | 143,591 |
| Biological & Environmental Research | 27,391 | 120,243 | 74,510 |
| Research - Fusion Energy Sciences | 130,512 | 168,768 | 92,809 |
| Fusion Energy Sciences | 130,512 | 168,768 | 92,809 |
| Research - High Energy Physics | 98,294 | 156,154 | 149,807 |
| High Energy Physics | 98,294 | 156,154 | 149,807 |
| Operations and Maintenance - Nuclear Physics | 106,013 | 105,916 | 110,594 |
| Nuclear Physics | 106,013 | 105,916 | 110,594 |
| Workforce Development for Teachers & Scientists | 0 | 28,000 | 20,500 |
| Facilities and Infrastructure (SLI) | 11,500 | 38,578 | 6,000 |
| Science Laboratories Infrastructure | 11,500 | 38,578 | 6,000 |
| Safeguards and Security - SC | 4,583 | 11,669 | 14,592 |
| Program Direction - SC | 92,066 | 97,902 | 101,403 |
| **Total Washington Headquarters** | **686,578** | **1,027,175** | **937,014** |
| **Y-12 National Security Complex** | | | |
| Facilities and Infrastructure (SLI) | 1,250 | 0 | 0 |
| Science Laboratories Infrastructure | 1,250 | 0 | 0 |
| **Total Y-12 National Security Complex** | **1,250** | **0** | **0** |
| | | | |
| **Total, Science** | **6,585,000** | **7,000,000** | **5,837,806** |

## GENERAL PROVISIONS—DEPARTMENT OF ENERGY
### (INCLUDING TRANSFER AND CANCELLATION 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)*, and (h)*, 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 Act).

(e) The amounts made available by this title may be reprogrammed for any program, project, or activity, and the Department shall notify, and obtain the prior approval of, the Committees on Appropriations of both Houses of Congress at least 30 days prior to the use of any proposed reprogramming that would cause any program, project, or activity funding level to increase or decrease by more than $5,000,000 or 10 percent, whichever is less, during the time period covered by this Act.

(f) None of the funds provided in this title shall be available for obligation or expenditure through a reprogramming of funds that—

(1) creates, initiates, or eliminates a program, project, or activity;

(2) increases funds or personnel for any program, project, or activity for which funds are denied or restricted by this Act; or

(3) reduces funds that are directed to be used for a specific program, project, or activity by this Act.

(g) (1) The Secretary of Energy may waive any requirement or restriction in this section that applies to the use of funds made available for the Department of Energy if compliance with such requirement or restriction would pose a substantial risk to human health, the environment, welfare, or national security.

(2) The Secretary of Energy shall notify the Committees on Appropriations of both Houses of Congress of any waiver under paragraph (1) as soon as practicable, but not later than 3 days after the date of the activity to which a requirement or restriction would otherwise have applied. Such notice shall include an explanation of the substantial risk under paragraph (1) that permitted such waiver.

(h) *EXCLUSIONS.—Subsections (d), (e), and (f) shall not apply to applied energy program funds transferred or reprogrammed under —*

(1) *the small business innovation research program under section 9 of the Small Business Act (15 U.S.C 638); or*

(2) *the small business technology transfer program under that section.*

(**[**h**]***i*) The unexpended balances of prior appropriations provided for activities in this Act may be available to the same appropriation accounts for such activities established pursuant to this title. Available balances may be merged with funds in the applicable established accounts and thereafter may be accounted for as one fund for the same time period as originally enacted.

SEC. 302. Funds appropriated by this or any other Act, or made available by the transfer of funds in this Act, for intelligence activities are deemed to be specifically authorized by the Congress for purposes of section 504 of the National Security Act of 1947 (50 U.S.C. 3094) during fiscal year 2020 until the enactment of the Intelligence Authorization Act for fiscal year 2020.

SEC. 303. None of the funds made available in this title shall be used for the construction of facilities classified as high-hazard nuclear facilities under 10 CFR Part 830 unless independent oversight is conducted by the Office of Enterprise Assessments to ensure the project is in compliance with nuclear safety requirements.

SEC. 304. None of the funds made available in this title may be used to approve critical decision–2 or critical decision–3 under Department of Energy Order 413.3B, or any successive departmental guidance, for construction projects where the total project cost exceeds $100,000,000, until a separate independent cost estimate has been developed for the project for that critical decision.

SEC. 305. (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. 306. Notwithstanding section 161 of the Energy Policy and Conservation Act (42 U.S.C. 6241), upon a determination by the President in this fiscal year that a regional supply shortage of refined petroleum product of significant scope and duration exists, that a severe increase in the price of refined petroleum product will likely result from such shortage, and that a draw down and sale of refined petroleum product would assist directly and significantly in reducing the adverse impact of such shortage, the Secretary of Energy may draw down and sell refined petroleum product from the Strategic Petroleum Reserve. Proceeds from a sale under this section shall be deposited into the SPR Petroleum Account established in section 167 of the Energy Policy and Conservation Act (42 U.S.C. 6247), and such amounts shall be available for obligation, without fiscal year limitation, consistent with that section.

**[**SEC. 307. Of the offsetting collections, including unobligated balances of such collections, in the "Department of Energy-Power Marketing Administration-Colorado River Basins Power Marketing Fund, Western Area Power Administration", $21,400,000 shall be transferred to the "Department of Interior-Bureau of Reclamation-Upper Colorado River Basin Fund" for the Bureau of Reclamation to carry out environmental stewardship and endangered species recovery efforts.**]**

**[**SEC. 308. (a) Of the unobligated balances available from amounts appropriated in prior Acts under the heading "Title III-Department of Energy-Energy Programs", $12,723,000 is hereby rescinded.

(b) No amounts may be rescinded under (a) 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. 309. Beginning in fiscal year 2021 and for each fiscal year thereafter, fees collected pursuant to subsection (b)(1) of section 6939f of title 42, United States Code, shall be deposited in "Department of Energy-Energy Programs-Non-Defense Environmental Cleanup" as discretionary offsetting collections.**]**

**[**SEC. 310. During fiscal year 2020 and each fiscal year thereafter, notwithstanding any provision of title 5, United States Code, relating to classification or rates of pay, the Southeastern Power Administration shall pay any power system dispatcher employed by the Administration a rate of basic pay and premium pay based on those prevailing for similar occupations in the electric power industry. Basic pay and premium pay may not be paid under this section to any individual during a calendar year so as to result in a total rate in excess of the rate of basic pay for level V of the Executive Schedule (section 5316 of such title).**]**

*SEC. 307. Section 611 of the Energy and Water Development Appropriations Act, 2000 (P.L. 106–60; 10 U.S.C 2701 note) is amended as follows:*

(a) *In subsection (a) in the matter preceding paragraph (1), by striking "the Army, acting through the Chief of Engineers" and inserting "Energy".*

(b) *In subsection (a)(6), by striking "by the Secretary of the Army, acting through the Chief of Engineers," and striking ", which may be transferred upon completion of remediation to the administrative jurisdiction of the Secretary of Energy".*

(c) *In subsection (a), by adding after paragraph (6) the following undesignated matter: "Upon completion of remediation of a site acquired by the Secretary of the Army prior to fiscal year 2021, the Secretary of the Army may transfer administrative jurisdiction of such site to the Secretary of Energy.".*

(d) *In subsection (b), by striking "the Army, acting through the Chief of Engineers," and inserting "Energy".*

(e) *In subsection (c), by striking "amounts made available to carry out that program and shall be available until expended for costs of response actions for any eligible site" and inserting "'Other Defense Activities' appropriation account or successor appropriation account and shall be available until expended for costs of response actions for any eligible Formerly Utilized Sites Remedial Action Program Site".*

(f) *By redesignating subsection (f) as subsection (g).*

(g) *By inserting after subsection (e) the following new subsection:*

*"(f) The Secretary of Energy, in carrying out subsection (a), shall enter into an agreement with the Secretary of the Army to carry out the remediation functions and activities described in subsections (a)(1) through (a)(6).".*

*SEC. 308. Section 2307 of the Energy Policy Act of 1992 (42 U.S.C 13526) is repealed.*

*SEC. 309. Notwithstanding section 161 of the Energy Policy and Conservation Act (42 U.S.C. 6241), the Secretary of Energy shall draw down and sell 15 million barrels of refined petroleum product from the Strategic Petroleum Reserve during fiscal year 2021. Proceeds from sales under this section shall be deposited into the general fund of the Treasury during fiscal year 2021, with the exception of $242,000,000 from such proceeds to be deposited in the "Naval Petroleum and Oil Shale Reserves" account for comprehensive remediation of the Naval Petroleum Reserve–1 site near Elk Hills, California, to remain available until expended.*

*SEC. 310. 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) of this section, no later than 150 days after the date of the enactment of this Act. Such regulations shall be consistent with the Federal Acquisition Regulation 48 C.F.R. 31.205–22.*

*SEC. 311. Pursuant to a request by the Secretary of Defense, and upon determination by the Director of the Office of Management and Budget in consultation with the Secretary of Energy that such action is necessary, the Secretary of Energy may, with the approval of the Office of Management and Budget, transfer not to exceed $2,500,000,000 of funds made available in this Act to the Department of Energy for National Nuclear Security Administration functions to the Department of Defense, to be merged with and to be available for the same purposes, and for the same time period, as the appropriation or fund to which transferred: Provided, That the Secretary of Energy shall notify the Congress promptly of all transfers made pursuant to this authority or any other authority in this Act: Provided further, That this transfer authority is in addition to any other transfer authority provided in this Act.*

## TITLE V—GENERAL PROVISIONS
### (INCLUDING TRANSFER OF FUNDS)

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. None of the funds made available by this Act may be used in contravention of Executive Order No. 12898 of February 11, 1994 (Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations).

SEC. 504. (a) None of the funds made available in this Act may be used to maintain or establish a computer network unless such network blocks the viewing, downloading, and exchanging of pornography.

(b) Nothing in subsection (a) shall limit the use of funds necessary for any Federal, State, tribal, or local law enforcement agency or any other entity carrying out criminal investigations, prosecution, or adjudication activities.