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Volume 4

Department of Energy
FY 2022 Congressional Budget Request

Science

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May 2021 Office of Chief Financial Officer Volume 4

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FY 2022 Congressional Budget

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DEPARTMENT OF ENERGY
Appropriation Summary
FY 2022

(Dollars in Thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs. FY 2021 Enacted $	FY 2022 Request vs. FY 2021 Enacted %
Department of Energy Budget by Appropriation					
Energy Efficiency and Renewable Energy	2,777,277	2,861,760	4,732,000	+1,870,240	+65.35%
Electricity	190,000	211,720	327,000	+115,280	+54.45%
Cybersecurity, Energy Security and Emergency Response	156,000	156,000	201,000	+45,000	+28.85%
Strategic Petroleum Reserve	195,000	188,000	197,000	+9,000	+4.79%
Naval Petroleum and Oil Shale Reserve	14,000	13,006	13,650	+644	+4.95%
Strategic Petroleum Reserve Petroleum Account	10,000	1,000	7,350	+6,350	+635.00%
Northeast Home Heating Oil Reserve	10,000	6,500	0	-6,500	-100.00%
Total, Petroleum Reserve Accounts	229,000	208,506	218,000	+9,494	+4.55%
Total, Cybersecurity, Energy Security, and Emergency Response	385,000	364,506	419,000	+54,494	+14.95%
Nuclear Energy (270)	1,340,000	1,357,800	1,700,700	+342,900	+25.25%
Fossil Energy and Carbon Management	750,000	750,000	890,000	+140,000	+18.67%
Total, Fossil Energy Programs	**750,000**	**750,000**	**890,000**	**140,000**	**+18.67%**
Uranium Enrichment Decontamination and Decommissioning (D&D) Fund	881,000	841,000	831,340	-9,660	-1.15%
Energy Information Administration	126,800	126,800	126,800	+0	+0.00%
Non-Defense Environmental Cleanup	319,200	319,200	338,860	+19,660	+6.16%
Science	7,000,000	7,026,000	7,440,000	+414,000	+5.89%
Office of Technology Transitions (OTT)	0	0	19,470	+19,470	N/A
Office of Clean Energy Demonstration (OCED)	0	0	400,000	+400,000	N/A
Advanced Research Projects Agency - Energy	425,000	427,000	500,000	+73,000	+17.10%
Advanced Research Projects Agency - Climate	0	0	200,000	+200,000	N/A
Nuclear Waste Disposal	0	27,500	7,500	-20,000	-72.73%
Departmental Administration	161,000	166,000	321,760	+155,760	+93.83%
Indian Energy Policy and Programs	22,000	22,000	122,000	+100,000	+454.55%
Inspector General	54,215	57,739	78,000	+20,261	+35.09%
Title 17 Innovative Technology Loan Guarantee Program	29,000	-363,000	179,000	+542,000	-149.31%
Advanced Technology Vehicles Manufacturing Loan Program	5,000	-1,903,000	5,000	+1,908,000	-100.26%
Tribal Energy Loan Guarantee Program	2,000	2,000	2,000	+0	+0.00%
Total, Credit Programs	**36,000**	**-2,264,000**	**186,000**	**2,450,000**	**-108.22%**
Total, Energy Programs	**14,467,492**	**12,295,025**	**18,640,430**	**6,345,405**	**+51.61%**
Federal Salaries and Expenses	434,699	443,200	464,000	+20,800	+4.69%
Weapons Activities	12,457,097	15,345,000	15,484,295	+139,295	+0.91%
Defense Nuclear Nonproliferation	2,164,400	2,260,000	1,934,000	-326,000	-14.42%
Naval Reactors	1,648,396	1,684,000	1,860,705	+176,705	+10.49%
Total, National Nuclear Security Administration	**16,704,592**	**19,732,200**	**19,743,000**	**10,800**	**+0.05%**
Defense Environmental Cleanup	6,255,000	6,426,000	6,841,670	+415,670	+6.47%
Other Defense Activities	906,000	920,000	1,170,000	+250,000	+27.17%
Total, Environmental and Other Defense Activities	**7,161,000**	**7,346,000**	**8,011,670**	**665,670**	**+9.06%**
Nuclear Energy (050)	153,408	149,800	149,800	+0	+0.00%
Total, Atomic Energy Defense Activities	**24,019,000**	**27,228,000**	**27,904,470**	**676,470**	**+2.48%**
Southeastern Power Administration (SEPA)	0	0	0	+0	+0.00%
Southwestern Power Administration (SWPA)	10,400	10,400	10,400	+0	+0.00%
Western Area Power Administration	89,196	89,372	90,772	+1,400	+1.57%
Falcon and Amistad Operating and Maintenance Fund	228	228	228	+0	+0.00%
Colorado River Basins Power Marketing Fund *	-21,400	-21,400	-21,400	+0	+0.00%
Total, Power Marketing Administrations	**78,424**	**78,600**	**80,000**	**1,400**	**+1.78%**
Federal Energy Regulatory Commission	0	0	0	+0	+0.00%
Total, Energy and Water Development and Related Agencies	**38,564,916**	**39,601,625**	**46,624,900**	**7,023,275**	**+17.73%**
Excess Fees and Recoveries, FERC	-16,000	-9,000	-9,000	+0	+0.00%
Title XVII Loan Guar. Prog Section 1703 Negative Credit Subsidy Receipt	-15,000	0	-10,800	-10,800	N/A
UED&D Fund Offset	0	0	-415,670	-415,670	N/A
Discretionary Funding by Appropriation	**38,533,916**	**39,592,625**	**46,189,430**	**+6,596,805**	**+16.66%**
DOE Budget Function	**38,533,916**	**39,592,625**	**46,189,430**	**+6,596,805**	**+16.66%**
NNSA Defense (050) Total	16,704,592	19,732,200	19,743,000	+10,800	+0.05%
Non-NNSA Defense (050) Total	7,314,408	7,495,800	8,161,470	+665,670	+8.88%
Defense (050)	*24,019,000*	*27,228,000*	*27,904,470*	*676,470*	*2.48%*
Science (250)	7,000,000	7,026,000	7,440,000	+414,000	+5.89%
Energy (270)	7,514,916	5,338,625	10,844,960	+5,506,335	+103.14%
Non-Defense (Non-050)	*14,514,916*	*12,364,625*	*18,284,960*	*5,920,335*	*47.88%*

* Amount has been adjusted per Section 127 of Public Law 116-159, Continuing Appropriations Act, 2021 and Other Extensions Act.

Science

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Proposed Appropriation Language

For Department of Energy expenses including the purchase, construction, and acquisition of plant and capital equipment, and other expenses necessary for science activities in carrying out the purposes of the Department of Energy Organization Act (42 U.S.C. 7101 et seq.), including the acquisition or condemnation of any real property or any facility or for plant or facility acquisition, construction, or expansion, and purchase of not more than 35 passenger motor vehicles *including one ambulance* for replacement only, [$7,026,000,000] *$7,440,000,000*, to remain available until expended: provided, that of such amount, [$192,000,000] *$202,000,000* shall be available until September 30, [2022] *2023*, for program direction [: *Provided further*, That of the amount provided under this heading in this Act, $2,300,000,000 is designated by the Congress as being for an emergency requirement pursuant to section 251(b)(2)(A)(i) of the Balanced Budget and Emergency Deficit Control Act of 1985].
(Energy and Water Development and Related Agencies Appropriations Act, 2021)

Explanation of Change

Proposed appropriation language updates reflect the funding

Public Law Authorization

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

Isotope R&D and Production
- 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 2020 Enacted	FY 2021 Enacted	FY 2022 Request
$7,000,000	$7,026,000	$7,440,000

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 2020 enabled by the SC programs are described in the program budget narratives. Additional descriptions of recent science discoveries can be found at https://science.osti.gov/bes/Highlights/2020.

Highlights and Major Changes in the FY 2022 Request

The FY 2022 Request for SC is $7,440.0 million, an increase of 5.9 percent above the FY 2021 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. The FY 2022 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; isotope production; and basic research to advance new energy technologies.

The Request increases investments in Administration priorities including basic research on climate change and clean energy, fundamental science to transform manufacturing, and biopreparedness. SC initiates a new activity, Reaching a New Energy Sciences Workforce (RENEW), for targeted efforts to increase participation and retention of underrepresented groups in SC research activities. The request also supports ongoing investments in priority areas including microelectronics, critical materials, quantum information science (QIS), artificial intelligence (AI) and machine learning (ML), exascale computing, integrated computational and data infrastructure for scientific discovery, and accelerator science and technology. These new and ongoing initiatives position SC to meet new research demands through more collaborative, cross-program efforts.

The Request supports SC's basic research portfolio, which includes extramural grants and contracts supporting nearly 28,000 researchers located at over 300 institutions and the 17 DOE national laboratories, spanning all fifty states and the District of Columbia. In FY 2022, SC's suite of 28 scientific user facilities will continue to provide unmatched tools and capabilities for over 36,000 users per year from universities, national laboratories, industry, and international partners. The Request will also support the construction of new and upgraded user facilities and the R&D necessary for future facilities 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 2022 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 $1,040.0 million, is an increase of $25.0 million, or 2.5 percent, above the FY 2021 Enacted level. The Request will strengthen U.S. leadership in strategic computing with operation of the Nation's first exascale computing system, Frontier, at Oak Ridge National Laboratory, and deployment of a second system, Aurora, at Argonne National Laboratory. The Request also broadens the foundations of AI and QIS, and expands the infrastructure that enables data-driven science. The Request increases support for the Computational Science Graduate Fellowship and the initiation of a new activity, RENEW, to increase participation and retention of underrepresented groups in areas relevant to ASCR. The Request includes $404.0 million for SC's contribution to DOE's Exascale Computing Initiative (ECI) to deploy an exascale computing software ecosystem and mission critical applications to address national needs. A total of $275.0 million of this effort will go to the Leadership Computing Facilities to deploy and operate the exascale systems and testbeds, as well as support early science users and Exascale Computing Project (ECP) project teams. 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 and networking technologies, including QIS and a DOE quantum internet. The Request also supports the design of a state-of-the-art scientific high-performance computing data facility focused on the unique challenges of near real-time computing needed to support the explosion of SC scientific data that will serve as the anchor for the integrated computational and data infrastructure initiative efforts. The Request increases support for ASCR's Computational Partnerships and Research and Evaluation Prototypes with a focus on continuing strategic partnerships in quantum computing and networking including the partnerships with other Science programs to support the five QIS Research Centers selected in FY 2020 and other testbeds. New partnerships will enhance DOE's ability to rapidly respond to national emergencies, understand earth systems, develop new clean energy technologies, and facilitate research at DOE facilities. 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. This includes planning for an upgrade to National Energy Research Scientific Computing Center and continuing the ESnet-6 upgrade.

- *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 $2,300.0 million is an increase of $55.0 million, or 2.4 percent, above the FY 2021 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 clean energy research, critical materials/minerals research, manufacturing including microelectronics and polymer upcycling, national preparedness, QIS, data science and related infrastructure, exascale computing, and accelerator science and technology. The Request increases funding for the Energy Frontier Research Centers, with a focus on clean energy research. The Request continues support for the multi-disciplinary QIS Research Centers to promote basic research and early-stage development to accelerate the advancement of QIS. 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 and supports the Batteries and Energy Storage and the Fuels from Sunlight Energy Innovation Hub awards. The Request also provides funds for the DOE Established Program to Stimulate Competitive Research. BES maintains a balanced suite of complementary tools, including supporting operations of five x-ray light sources and two neutron sources at greater than 90 percent of optimal, and supports the five nanoscale science research centers. Funding is provided for projects nearing completion: the Advanced Photon Source Upgrade project and the Linac Coherent Light Source-II project. The Request provides continued support for the ongoing construction activities for the Advanced Light Source Upgrade project, the Linac Coherent Light Source-II High Energy project, the Proton Power Upgrade project, the Second Target Station project, and the Cryomodule Repair and

Maintenance Facility. 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. BES will participate in the RENEW activity with targeted efforts to increase participation and retention of underrepresented groups in areas relevant to BES.

- *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.
  - BER's support of basic research will contribute to a future of stable, reliable, and resilient energy sources and infrastructures, that will lead to climate solutions, strengthen economic prosperity, and assure environmental justice. The BER Request of $828.0 million is an increase of $75.0 million, or 10.0 percent, above the FY 2021 Enacted level. All BER research is also informed by the community and the federally chartered BER Advisory Committee. The Request for Biological Systems Science supports initiation of the Biopreparedness Research Virtual Environment (BRaVE) to provide a single portal through which a distributed network of capabilities and scientists can work together on multidisciplinary and multiprogram priorities. Support continues for the four Bioenergy Research Centers, performing new fundamental research underpinning the production of fuels and chemicals from sustainable biomass and developing new technological advances for translation of basic research results to industry. Computational Biosciences will integrate prior microbiome efforts within the DOE Systems Biology Knowledgebase to develop integrated networks and computational models of system dynamics and behavior. Research in Biomolecular Characterization and Imaging Science will develop QIS-enabled techniques and advanced sensors for biological research.
  - Earth and Environmental Systems Sciences research activities will focus on Earth system predictions. Urban Integrated Field Laboratories will be initiated, dedicated to the development of an integrated science framework to advance climate and energy research enabling the evaluation of the societal and environmental impacts of current and future energy policies. The Request establishes the National Virtual Climate Laboratory (NVCL) serving as a one stop portal to advance access to climate science from the DOE National Laboratories. The NVCL engagement with the science community will focus on access to local and regional climate science to Minority Serving Institutions (MSIs) and Historically Black Colleges or Universities (HBCUs), connecting frontline communities with the key climate science capabilities at the DOE national laboratories. Planning begins for the National Climate Laboratory or Center affiliated with an HBCU or MSI. The Energy Exascale Earth System Model (E3SM) will include advanced software for running on numerous processors, flexibility toward future DOE computer architectures including exascale systems. Environmental System Science integrates physical and hydrobiogeochemical sciences to provide a predictive understanding of above- and below-surface terrestrial ecosystems. Atmospheric System Research will investigate cloud-aerosol-precipitation interactions using a broad range of observations to support the E3SM capability at spatial scales of 10 km. The Data Management effort will enhance data archiving and management capabilities, including AI/ML tools. Across BER, the new Integrated Computational and Data Infrastructure for Scientific Discovery will deploy a flexible multi-tier data and computational management architecture, including new 5G capabilities. The Request supports operations of BER's three scientific user facilities: the DOE Joint Genome Institute, the Environmental Molecular Sciences Laboratory, and the Atmospheric Radiation Measurement Research Facility (ARM). The ARM user facility will continue acceptance testing and evaluation of the aerial capability Major Item of Equipment acquired in FY 2019. All BER facilities will begin a multiyear instrumentation refresh to ensure these facilities are delivering the state-of-the-art capabilities required by the scientific community. BER will participate in the RENEW activity with targeted efforts to increase participation and retention of underrepresented groups in areas relevant to BER.

- *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 $675.0 million is a increase of $3.0 million, or 0.4 percent, above the FY 2021 Enacted level. The Request is aligned with the recommendations of the recent Long-Range Plan developed by the Fusion Energy Sciences Advisory Committee. It supports research and facility operations at the DIII-D national fusion facility at 90% of the optimal run time to optimize the tokamak approach to magnetic confinement fusion; continues to support the recovery of the National Spherical Torus Experiment-Upgrade (NSTX-U) and enhanced collaborative research at other facilities to support NSTX-U research program priorities; and continues to support collaborations by U.S. scientists at overseas superconducting tokamaks and stellarators and other international facilities with unique capabilities. The Request supports research activities in Materials, Fusion Nuclear Science, and Enabling R&D; supports research in QIS both at the QIS Research Centers established in FY 2020 and for core research addressing FES priorities; and continues to support Scientific Discovery through Advanced Computing in partnership with ASCR, research in High-Energy-Density Laboratory Plasma science including LaserNetUS, and General Plasma Science including low-temperature plasmas and microelectronics. The Request expands partnerships with the private sector through the Innovation Network for Fusion Energy program; provides support for the U.S. Contributions to ITER project focusing on the design, fabrication, and delivery of in-kind hardware components and providing construction cash contributions to support the ITER Organization assembly and installation of the hardware contributions from all the ITER Members; and initiates an ITER Research program to start preparing the U.S. fusion community to take full advantage of ITER operations after First Plasma. The Request provides funding for the Matter in Extreme Conditions Petawatt Laser Facility upgrade project at the Linac Coherent Light Source; supports the Materials-Plasma Exposure eXperiment MIE project, which will be a world-leading facility for dedicated studies of reactor-relevant heat and particle loads on fusion materials; and addresses a key recommendation in the Long-Range Plan by supporting a new activity entitled "Future Facilities Studies" focused on the design of next step facilities like a Fusion Pilot Plant. FES will participate in the RENEW activity with targeted efforts to increase participation and retention of underrepresented groups in areas relevant to FES.

- *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 $1,061.0 million is an increase of $15.0 million, or 1.4 percent, above the FY 2021 Enacted level. The Request will focus support on the highest priority elements identified in the 2014 High Energy Physics Advisory Panel Particle Physics Project Prioritization Panel (P5) Report. Support for Research will prioritize efforts that address the P5 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. In coordination with SC, HEP will support the Integrated Computational and Data Infrastructure for Scientific Discovery development of data storage capabilities to handle tens of exabytes of data from future experiments; cross-cutting efforts in AI/ML and edge computing to seek solutions for real-time and extremely high data rate environments; and investments in software development to improve the interface with SC infrastructure and ASCR-supported middleware. HEP will increase QIS R&D and will continue support for multi-disciplinary QIS Research Centers initiated in FY 2020 to accelerate the advancement of QIS through integration between systems and theory, and hardware and software. In coordination with the Accelerator R&D and Production program, HEP will continue and increase support for the Accelerator Science and Technology Initiative to support mid- to long-term R&D to maintain a leading position in key accelerator technologies that define SC's competitive advantage. AI/ML research will continue to tackle the challenges of managing increasingly high volumes and complexity of HEP experimental and simulated data, and to address cross-cutting challenges across the HEP program in coordination with DOE investments in exascale computing and associated AI efforts. HEP research will continue support for multi-disciplinary microelectronics research, including 5G, with ASCR, BES and FES, to accelerate the advancement of microelectronic technologies. The P5 report identified the High-Luminosity Large Hadron Collider accelerator and A Toroidal LHC Apparatus and Compact Muon Solenoid Detector Upgrade Projects as the highest priority in the near-term, and Long-Baseline Neutrino Facility and Deep Underground Neutrino Experiment as the highest-priority large project in its timeframe. To continue SC's strong international partnership with CERN, the FY 2022 Request will support these high-priority projects, and the Proton Improvement Plan-II construction project. The Request will support a new MIE start for the Accelerator Controls Operations Research Network project and will continue support for the next generation Cosmic Microwave Background experiment. The Request will support the operation of the Fermilab Accelerator Complex at 90 percent of optimal, the SLAC Facility for Advanced Accelerator Experimental Tests II operations at 90 percent of optimal, and investments to enhance the Sanford Underground Research Facility to meet DOE expectations for reliable, efficient, and safe operations. Finally, in the FY 2022 Request, the Accelerator Stewardship subprogram moves to the Accelerator R&D and Production program. HEP will participate in the RENEW activity with targeted efforts to increase participation and retention of underrepresented groups in areas relevant to HEP.

- *Nuclear Physics (NP)* supports experimental and theoretical research to discover, explore, and understand all forms of nuclear matter. The NP Request of $720.0 million is a increase of $7.0 million, or 1.0 percent, above the FY 2021

Enacted level. The Request supports safe efficient, and cost-effective operations of four NP scientific user facilities. The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory recreates new forms of matter and phenomena that occurred in the infant universe. The Continuous Electron Beam Accelerator Facility (CEBAF) at Thomas Jefferson National Accelerator Facility (TJNAF or JLab) extracts information on quarks and gluons bound inside protons and neutrons that formed shortly after the universe began to cool. The Argonne Tandem Linear Accelerator System gently accelerates nuclei to energies typical of nuclear reactions in the cosmos to further our understanding of the ongoing synthesis of heavy elements such as gold and platinum. To maintain U.S. leadership throughout this century and to extend well beyond current scientific capabilities. NP also supports operations of the newly-constructed Facility for Rare Isotope Beams (FRIB) facility and research programs that will begin in FY 2022, and R&D and Preliminary Engineering Design for the Electron-Ion Collider project. The Request also supports non accelerator-based research using the nucleus as a laboratory to search for new physics by observing nature's fundamental symmetries and precision measurements to determine the properties of the neutron and whether the neutrino is its own anti-particle. The Request continues to support the construction of world-leading instrumentation, including the Gamma-Ray Energy Tracking Array, the super Pioneering High Energy Nuclear Interaction eXperiment at RHIC, High Rigidity Spectrometer to realize the full scientific potential of FRIB, and the Measurement of a Lepton-Lepton Electroweak Reaction MIE at JLab. The Request also 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. NP is the primary steward of the nation's fundamental nuclear physics research portfolio providing over 91 percent of the investment in U.S. nuclear physics basic research. The Request also supports the National Nuclear Data Center which collects, evaluates, curates, and disseminates nuclear physics data for basic nuclear research and applied nuclear technologies for global use. Efforts on QIS, in collaboration with other SC programs, for the development of quantum sensors and quantum control techniques continue, as do efforts on data analytics for autonomous decision making which can benefit nuclear physics research and NP accelerator operations. The Request supports the Accelerator Science and Technology initiative to pursue next generation electron ion source developments and advanced approaches in superconducting radio frequency technologies. The Request also supports participation in microelectronics and Integrated Computational & Data Infrastructure for cross-cutting cloud solutions to Big Data storage challenges in Nuclear Physics. NP will participate in the RENEW activity with targeted efforts to increase participation and retention of underrepresented groups in areas relevant to NP. Beginning in the FY 2022 Request, the Isotope Development and Production for Research and Applications subprogram is now a separate program. Funds are requested under the new Isotope R&D and Production Program within SC.

- *Isotope R&D and Production (IRP)* supports National Preparedness for critical isotope production and distribution to ensure functionality even during times of national crisis; efforts focus on mitigating U.S. dependence on foreign supply of key isotopes. The IRP Request is $90.0 million. Isotopes are high-priority commodities of strategic importance for the nation and are essential in medical diagnosis and treatment, discovery science, national security, industrial processes and manufacturing, space exploration and communications, biology, archeology, quantum science and other fields. The Request supports transformative research to develop new or improved production and separation techniques for high priority isotopes in short supply. A high priority remains the dedicated research effort to develop large scale production capabilities of the alpha-emitter actinium-225 (Ac-225), a high priority isotope that has shown stunning success in the treatment of diffuse cancers and infections. The implementation of the Stable Isotope Production Facility MIE continues, with support for pre-operations activities. The Request continues support for the U.S. Stable Isotope Production and Research Center, which will significantly enhance stable isotope production capacity for the nation. The Request continues the FRIB Isotope Harvesting research effort, which adds capabilities to extract and process significant quantities of isotopes from the beam dump of FRIB, supported by the Office of Nuclear Physics. The Request enables participation in the SC Fundamental Science to Transform Manufacturing Initiative to pursue transformative approaches to target manufacturing, such as ink jet printing of thin film targets for isotope production, and modular automated systems for radioisotope purification and processing. Research focusses on facilitating the translation of novel radioisotopes and targeted delivery agents from the laboratory to use in clinical trials for both diagnosis and treatment of disease. As part of the BRaVE Initiative, the program tackles what has become an obstacle and single point failure in the program, the processing of irradiated nuclear reactor targets. Funding will develop short-term reactor target processing capabilities at the University of Missouri Research Reactor and further develop the conceptual design of a new long-term facility at ORNL, the ORNL Radioisotope Processing Facility. Increased investment in the ongoing QIS initiative advances development of cutting-edge technology for the production of isotopes of interest to QIS. The Request continues the investment in an Isotope Program Traineeship in research to advance workforce development in areas requiring unique skillsets and broaden the diversity of the available workforce pipeline.

- *Accelerator R&D and Production (ARDAP)* supports cross-cutting basic R&D in accelerator science and technology, access to unique SC accelerator R&D infrastructure, workforce development, and public-private partnerships to advance new technologies for use in SC's scientific facilities and in commercial products. The ARDAP Request of $24.0 million will support fundamental research, operation and maintenance of a scientific user facility, and production of accelerator technologies in industry. The Request supports innovative R&D and deployment of accelerator technology, the formation of topically-focused multi-institutional collaborations for accelerator R&D, and workforce development. The Request supports operation of the Brookhaven National Laboratory Accelerator Test Facility for 2,500 hours (100 percent of optimal). Accelerator Production activities support public-private partnerships to develop advanced superconducting wire and cable, superconducting accelerators, and advanced radiofrequency power sources for accelerators.

Reorganization and Restructure Initiative

SC completed the implementation of a reorganization of SC Headquarters in FY 2020. The changes for this reorganization 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 established 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 was eliminated and the reporting offices and staff reassigned to other SC HQ elements. Also, this reorganization created two new research programs, the Isotope R&D and Production and the Accelerator R&D and Production programs. The FY 2022 Request is the first budget submission with these new research programs. 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. Advancing the frontiers of science also depends on the continued availability of state-of-the-art scientific facilities; SC constructs and operates national scientific facilities and instruments that comprise the world's most sophisticated suite of research capabilities. SC's basic research is integrated within program portfolios, projects, and individual awards; as such, it is not possible to quantitatively separate the funding contributions of particular experiments or theoretical studies that are high-risk, high-reward from other mission-driven research in a manner that is credible and auditable. SC incorporates high-risk, high-reward basic research elements in its research portfolios to drive innovation and challenge current thinking, using a variety of mechanisms to develop topics: Federal advisory committees, triennial Committees of Visitors, program and topical workshops, interagency working groups, National Academies' studies, and special SC program solicitations. Many of these topics are captured in formal reports, e.g., *Basic Energy Sciences Roundtable: Chemical Upcycling of Polymers,* Basic Energy Sciences report

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

(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]; *From Long-distance Entanglement to Building a Nationwide Quantum Internet: Report of the DOE Quantum Internet Blueprint Workshop,* ASCR workshop report (2020)[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]; *Basic Research Needs for Transformative Manufacturing* (2020)[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]; *Genome Engineering for Materials Synthesis*, BER workshop report (2018)[j]; *Plasma: at the Frontier of Scientific Discovery*, FES workshop report (2017)[k]; *Powering the Future: Fusion and Plasmas*, FES Advisory Committee Long Range Plan (2020)[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://www.osti.gov/biblio/1638794/
[f] https://science.osti.gov/~/media/bes/pdf/reports/2018/Quantum_computing.pdf
[g] https://science.osti.gov/-/media/bes/pdf/reports/2020/Transformative_Mfg_Brochure.pdf?la=en&hash=95094B9257DCFD506C04787D96EEDD942EB92EEC
[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] https://science.osti.gov/-/media/ber/pdf/community-resources/2019/GEMS_Report_2019.PDF?la=en&hash=0D7092AD5416A28207F0F95F94E00921D308A113
[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/2020/202012/FESAC_Report_2020_Powering_the_Future.pdf?la=en&hash=B404B643396D74CE7EDAB3F67317E326A891C09C
[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 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. The Request initiates a new activity, Reaching a New Energy Sciences Workforce (RENEW), for targeted efforts to increase participation and retention of underrepresented groups in SC research activities. The Office of Science administers and/or bestows several awards to recognize talented scientists and engineers that advance the Department's missions, including the Presidential Early Career Award for Scientists and Engineers (PECASE), Ernest Orlando Lawrence Award, Enrico Fermi Award, and Distinguished Scientist Fellow opportunity. In FY 2022, SC plans to confer up to 10 awards with honorariums of $20,000 each for the Ernest Orlando Lawrence Award.

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 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted ($)	FY 2022 Request vs FY 2021 Enacted (%)
Advanced Scientific Computing Research					
ASCR Research	791,265	846,055	911,000	+64,945	+7.68%
17-SC-20, SC Exascale Computing Project (ECP)	188,735	168,945	129,000	-39,945	-23.64%
Total, Advanced Scientific Computing Research	**980,000**	**1,015,000**	**1,040,000**	**+25,000**	**+2.46%**
Basic Energy Sciences					
BES Research	1,853,000	1,856,000	1,995,800	+139,800	+7.53%
Construction					
13-SC-10 - Linac Coherent Light Source-II (LCLS-II), SLAC	–	33,000	28,100	-4,900	-14.85%
18-SC-10, Advanced Photon Source Upgrade (APS-U), ANL	170,000	160,000	101,000	-59,000	-36.88%
18-SC-11, Spallation Neutron Source Proton Power Upgrade (PPU), ORNL	60,000	52,000	17,000	-35,000	-67.31%
18-SC-12, Advanced Light Source Upgrade (ALS-U), LBNL	60,000	62,000	75,100	+13,100	+21.13%
18-SC-13, Linac Coherent Light Source-II-High Energy (LCLS-II-HE), SLAC	50,000	52,000	50,000	-2,000	-3.85%
19-SC-14, Second Target Station (STS), ORNL	20,000	29,000	32,000	+3,000	+10.34%
21-SC-10, Cryomodule Repair & Maintenance Facility (CRMF)	–	1,000	1,000	–	–
Total, Construction	**360,000**	**389,000**	**304,200**	**-84,800**	**-21.80%**
Total, Basic Energy Sciences	**2,213,000**	**2,245,000**	**2,300,000**	**+55,000**	**+2.45%**

(dollars in thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted ($)	FY 2022 Request vs FY 2021 Enacted (%)
Biological and Environmental Research					
BER Research	750,000	753,000	828,000	+75,000	+9.96%
Total, Biological and Environmental Research	**750,000**	**753,000**	**828,000**	**+75,000**	**+9.96%**
Fusion Energy Sciences					
FES Research	414,000	415,000	449,000	+34,000	+8.19%
Construction					
20-SC-61, Matter in Extreme Conditions (MEC) Petawatt Upgrade, SLAC	15,000	15,000	5,000	-10,000	-66.67%
14-SC-60, U.S. Contributions to ITER	242,000	242,000	221,000	-21,000	-8.68%
Total, Construction	**257,000**	**257,000**	**226,000**	**-31,000**	**-12.06%**
Total, Fusion Energy Sciences	**671,000**	**672,000**	**675,000**	**+3,000**	**+0.45%**
High Energy Physics					
HEP Research	814,000	794,000	782,000	-12,000	-1.51%
Construction					
18-SC-42, Proton Improvement Plan II (PIP-II), FNAL	60,000	79,000	90,000	+11,000	+13.92%
11-SC-40, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment	171,000	171,000	176,000	+5,000	+2.92%
11-SC-41, Muon to Electron Conversion Experiment, FNAL	–	2,000	13,000	+11,000	+550.00%
Total, Construction	**231,000**	**252,000**	**279,000**	**+27,000**	**+10.71%**
Total, High Energy Physics	**1,045,000**	**1,046,000**	**1,061,000**	**+15,000**	**+1.43%**

(dollars in thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted ($)	FY 2022 Request vs FY 2021 Enacted (%)
Nuclear Physics					
NP Operation and Maintenance	660,000	690,700	700,000	+9,300	+1.35%
Construction					
14-SC-50, Facility for Rare Isotope Beams (FRIB), MSU	40,000	5,300	–	-5,300	-100.00%
20-SC-51, U.S. Stable Isotope Production and Research Center (SIPRC), ORNL	12,000	12,000	–	-12,000	-100.00%
20-SC-52, Electron Ion Collider (EIC), BNL	1,000	5,000	20,000	+15,000	+300.00%
Total, Construction	**53,000**	**22,300**	**20,000**	**-2,300**	**-10.31%**
Total, Nuclear Physics	**713,000**	**713,000**	**720,000**	**+7,000**	**+0.98%**
Isotope R&D and Production					
IRP Research	–	–	78,000	+78,000	–
Construction					
20-SC-51, U.S. Stable Isotope Production and Research Center (SIPRC), ORNL	–	–	12,000	+12,000	–
Total, Construction	**–**	**–**	**12,000**	**+12,000**	**–**
Total, Isotope R&D and Production	**–**	**–**	**90,000**	**+90,000**	**–**
Accelerator R&D and Production					
ARDAP Research	–	–	24,000	+24,000	–
Total, Accelerator R&D and Production	**–**	**–**	**24,000**	**+24,000**	**–**
Workforce Development for Teachers and Scientists					
WDTS	28,000	29,000	35,000	+6,000	+20.69%
Total, Workforce Development for Teachers and Scientists	**28,000**	**29,000**	**35,000**	**+6,000**	**+20.69%**

	(dollars in thousands)				
	FY 2020 Enacted	**FY 2021 Enacted**	**FY 2022 Request**	**FY 2022 Request vs FY 2021 Enacted ($)**	**FY 2022 Request vs FY 2021 Enacted (%)**
Science Laboratories Infrastructure					
PILT	4,540	4,650	4,820	+170	+3.66%
Oak Ridge Landlord	5,610	5,860	6,430	+570	+9.73%
SLI F&I	56,850	29,790	17,200	-12,590	-42.26%
OR Nuclear Operations	26,000	26,000	20,000	-6,000	-23.08%
Construction					
22-SC-71, Critical Infrastructure Modernization Project (CIMP), ORNL	–	–	1,000	+1,000	–
22-SC-72, Thomas Jefferson Infrastructure Improvements (TJII), TJNAF	–	–	1,000	+1,000	–
21-SC-71, Princeton Plasma Innovation Center (PPIC), PPPL	–	150	7,750	+7,600	+5,066.67%
21-SC-72, Critical Infrastructure Recovery & Renewal (CIRR), PPPL	–	150	2,000	+1,850	+1,233.33%
21-SC-73, Ames Infrastructure Modernization (AIM)	–	150	2,000	+1,850	+1,233.33%
20-SC-71, Critical Utilities Rehabilitation Project (CURP), BNL	20,000	20,000	26,000	+6,000	+30.00%
20-SC-72, Seismic and Safety Modernization (SSM), LBNL	10,000	5,000	27,500	+22,500	+450.00%
20-SC-73, CEBAF Renovation and Expansion (CEBAF), TJNAF	2,000	2,000	10,000	+8,000	+400.00%
20-SC-74, Craft Resources Support Facility (CRSF), ORNL	15,000	25,000	–	-25,000	-100.00%
20-SC-75, Large Scale Collaboration Center (LSCC), SLAC	11,000	11,000	12,000	+1,000	+9.09%
20-SC-76, Tritium System Demolition and Disposal (TSDD), PPPL	13,000	13,000	6,400	-6,600	-50.77%
20-SC-77, Argonne Utilities Upgrade (AU2), ANL	500	500	10,000	+9,500	+1,900.00%
20-SC-78, Linear Assets Modernization Project (LAMP), LBNL	500	500	12,850	+12,350	+2,470.00%
20-SC-79, Critical Utilities Infrastructure Revitalization (CUIR), SLAC	500	500	10,000	+9,500	+1,900.00%
20-SC-80, Utilities Infrastructure Project (UIP), FNAL	500	500	13,300	+12,800	+2,560.00%
19-SC-71, Science User Support Center (SUSC), BNL	20,000	20,000	38,000	+18,000	+90.00%

(dollars in thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted ($)	FY 2022 Request vs FY 2021 Enacted (%)
19-SC-72 - Electrical Capacity and Distribution Capability, ANL	30,000	–	–	–	–
19-SC-73, Translational Research Capability (TRC), ORNL	25,000	22,000	21,500	-500	-2.27%
19-SC-74, BioEPIC, LBNL	15,000	20,000	35,000	+15,000	+75.00%
18-SC-71, Energy Sciences Capability (ESC), PNNL	23,000	23,000	–	-23,000	-100.00%
17-SC-71, Integrated Engineering Research Center (IERC), FNAL	22,000	10,250	10,250	–	–
Total, Construction	**208,000**	**173,700**	**246,550**	**+72,850**	**+41.94%**
Total, Science Laboratories Infrastructure	**301,000**	**240,000**	**295,000**	**+55,000**	**+22.92%**
Safeguards and Security					
S&S	112,700	121,000	170,000	+49,000	+40.50%
Total, Safeguards and Security	**112,700**	**121,000**	**170,000**	**+49,000**	**+40.50%**
Program Direction					
PD	186,300	192,000	202,000	+10,000	+5.21%
Total, Program Direction	**186,300**	**192,000**	**202,000**	**+10,000**	**+5.21%**
Total, Office of Science	**7,000,000**	**7,026,000**	**7,440,000**	**+414,000**	**+5.89%**

SBIR/STTR funding:

- FY 2020 Enacted: SBIR $158,978,000 and STTR $22,435,000 (SC only)
- FY 2021 Enacted: SBIR $159,541,000 and STTR $22,440,000 (SC only)
- FY 2022 Request: SBIR $171,474,000 and STTR $24,139,000 (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 innovative 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 deploys and operates world-class, open access high performance computing facilities and a high performance network infrastructure 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 advanced computing systems and 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. 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 innovative clean energy technologies, medicines, industries and supply chains, and military capabilities. The U.S. will need to leverage investments in science for innovative new technologies, materials, and methods to build back better. Most of the modeling and prediction necessary to produce the next generation of breakthroughs in science will come from employing data-driven methods at extreme scale tightly coupled to the enormous increases in the volume and complexity of data generated by U.S. researchers and SC user facilities. The convergence of AI technologies with these existing investments creates a powerful accelerator for innovation.

The emerging field of 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. 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. However, 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.

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.

ASCR's proposed activities will advance AI, QIS, advanced communication networks, and strategic computing to accelerate progress in delivering a clean energy future, understanding and addressing climate change and increasing the competitive advantage of U.S. industry.

Highlights of the FY 2022 Request

The FY 2022 Request of $1,040.0 million for ASCR will strengthen U.S. leadership in strategic computing with operation of the Nation's first exascale computing system and deployment of a second system, broadening the foundations of AI and QIS, and expanding the infrastructure that enables data-driven science from climate to clean energy solutions.

Research

- To ensure ASCR is meeting SC's HPC and advanced networking mission needs during and after the exascale project, the Request prioritizes foundational research in Applied Mathematics and Computer Science. Investments will continue to emphasize the challenges of data intensive science, including AI/ML, and development of innovative computing and networking technologies. The Request increases support for ASCR's Computational Partnerships with a focus on developing partnerships that broaden the impact of both exascale and data infrastructure investments in areas of strategic importance to DOE and the Nation leading to new clean energy solutions, greater understanding of the earth's systems, new accelerator technologies, and enhancing our ability to respond to national emergencies. This includes partnering with other programs and key agencies to understand their simulation and modeling capabilities, data management and curation needs, and to identify and bridge gaps to enable DOE to provide appropriate resources. The Request also increases support for the Computational Sciences Graduate Fellowship (CSGF) to increase the number of fellows in AI and Quantum as well as outreach to and participation by under-represented groups.

- The Request provides robust support for Advanced Computing Research's quantum investments in the National Quantum Information Sciences (QIS) Research Centers, quantum internet and testbeds. ASCR will continue to partner with the other SC programs to support the multi-disciplinary National QIS Research 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 2022, ASCR will support early-stage research and development associated with the first steps to establishing a dedicated Quantum Network.

- The Office of Science is fully committed to advancing a diverse, equitable, and inclusive research community. This commitment is key to providing the scientific and technical expertise for U.S. leadership in high end computing, networking, and computational science. Toward that goal, ASCR will participate in the SC-wide Reaching a New Energy Sciences Workforce (RENEW) initiative that leverages SC's unique national laboratories, user facilities, and other research infrastructures to provide undergraduate and graduate training opportunities for students and academic institutions not currently well represented in the U.S. S&T ecosystem. This includes Historically Black Colleges and Universities (HBCUs) and Minority Serving Institutions (MSIs) and individuals from groups historically underrepresented in STEM, but also includes students from communities with environmental justice impacts and the EPSCoR jurisdictions. The hands-on experiences gained through the RENEW initiative will open new career avenues for the participants, forming a nucleus for a future pool of talented young scientists, engineers, and technicians with the critical skills and expertise needed for the full breadth of SC research activities, including DOE national laboratory staffing.

Facility Operations

- 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. Funding supports the baseline schedules for planned 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 at the facilities and provides robust support for the execution of ECI, which includes the SC-Exascale Computing Project (SC-ECP).

- Current ASCR high performance computing (HPC) resources and facilities are designed to efficiently execute large-scale simulations and are focused on minimizing users' wait-times in batch queues while maximizing use of these unique resources. However, the rate and volume of data from SC scientific user facilities is expected to grow exponentially in the future. ASCR will design a state-of-the-art Scientific HPC Data Facility focused on the unique challenges of near real-time computing needed to support the explosion of scientific data that will serve as the anchor for the integrated computational and data infrastructure efforts. To provide geographic diversity, this facility will be located on the East Coast.

Projects

- The ASCR FY 2022 Request includes $404.0 million for SC's contribution to DOE's Exascale Computing Initiative to deploy an exascale computing software ecosystem and mission critical applications on at least one exascale system in calendar year 2021 and a second in the 2021–2022 timeframe to address national needs. $275 million of this effort will go to the LCFs to deploy and operate the exascale systems and testbeds and support ECP project teams.

Advanced Scientific Computing Research
FY 2022 Research Initiatives

Advanced Scientific Computing Research supports the following FY 2022 Research Initiatives.

(dollars in thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Artificial Intelligence and Machine Learning	36,000	56,866	58,820	+1,954
Biopreparedness Research Virtual Environment (BRaVE)	–	–	5,183	+5,183
Exascale Computing Crosscut	463,735	438,945	404,000	-34,945
Integrated Computational & Data Infrastructure	–	11,974	15,328	+3,354
Microelectronics	–	5,182	5,183	+1
Quantum Information Science	54,680	98,402	107,649	+9,247
Reaching a New Energy Sciences Workforce (RENEW)	–	–	5,000	+5,000
Total, Research Initiatives	**554,415**	**611,369**	**601,163**	**-10,206**

Advanced Scientific Computing Research
Funding

(dollars in thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Advanced Scientific Computing Research				
Applied Mathematics Research	41,500	48,570	51,048	+2,478
Computer Sciences Research	38,700	46,827	49,773	+2,946
Computational Partnerships	69,142	76,194	86,029	+9,835
Advanced Computing Research	–	88,274	106,112	+17,838
Mathematical, Computational, and Computer Sciences Research, SBIR/STTR	5,658	–	–	–
Total, Mathematical, Computational, and Computer Sciences Research	**155,000**	**259,865**	**292,962**	**+33,097**
High Performance Production Computing	110,000	113,786	115,963	+2,177
Leadership Computing Facilities	375,000	381,075	408,113	+27,038
Research and Evaluation Prototypes	39,000	–	–	–
High Performance Network Facilities and Testbeds	90,000	91,329	93,962	+2,633
High Performance Computing and Network Facilities, SBIR/STTR	22,265	–	–	–
Total, High Performance Computing and Network Facilities	**636,265**	**586,190**	**618,038**	**+31,848**
17-SC-20 SC Exascale Computing Project	**188,735**	**168,945**	**129,000**	**-39,945**
Subtotal, Advanced Scientific Computing Research	**980,000**	**1,015,000**	**1,040,000**	**+25,000**
Total, Advanced Scientific Computing Research	**980,000**	**1,015,000**	**1,040,000**	**+25,000**

SBIR/STTR funding:

- FY 2020 Enacted: SBIR $25,160,000 and STTR $3,538,000
- FY 2021 Enacted: SBIR $25,736,000 and STTR $3,620,000
- FY 2022 Request: SBIR $30,753,000 and STTR $4,324,000

	(dollars in thousands) FY 2022 Request vs FY 2021 Enacted
Mathematical, Computational, and Computer Sciences Research	**+$33,097**

The Computer Science and Applied Mathematics activities will continue to increase their efforts on foundational research to address 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 quantum, AI and data infrastructure tools, into strategic applications, including areas such as revolutionizing microelectronics, accelerating the development of clean energy technologies, and understanding the earth's systems, to get the most out of the leadership computing systems and data infrastructure investments. In addition, the Computational Partnerships activity will increase investments in the development of algorithms, applications, and data infrastructure, focused on both AI 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 and new efforts with other agencies to enable rapid response to deliver research capabilities to address national emergencies. Computer Science for quantum information networks will continue to focus on addressing new opportunities and challenges of transporting and storing quantum information. The Advanced Computing Research activity continues to robustly support the National QIS Research Centers and quantum testbeds, in close coordination with the other SC programs. This includes early-stage R&D activities for a quantum network. The Research and Evaluation Prototype activity also continues to support fundamental research in cybersecurity, microelectronics and emerging technologies such as neuromorphic computing. This subprogram also supports the RENEW initiative to provide undergraduate and graduate training opportunities for students and academic institutions not currently well represented in the U.S. S&T ecosystem. In addition, the Computational Sciences Graduate Fellowship is increased to expand the skilled workforce necessary to maintain U.S. Leadership in high end computing, networking, and computational science.

High Performance Computing and Network Facilities	**+$31,848**

The LCFs will complete acceptance testing and early science/ECP access to the Frontier exascale computing system at Oak Ridge and the Aurora exascale system at Argonne through calendar year 2022. Both facilities will also provide testbed resources to the SC-ECP to continuously test and deploy software technologies. In addition, funding supports operation of the 125 petaflop NERSC-9 Perlmutter system, planning for NERSC-10, and the ESnet-6 upgrade to significantly increase capacity and security at all DOE sites. Funding for all facilities supports operations, including power, equipment, staffing, testbeds, and lease payments. To address the significant growth in the rate and volume of data from SC scientific user facilities, ASCR will design a state-of-the-art Scientific HPC Data Facility focused on the unique challenges of near real-time computing needed to support the explosion of data that will also serve as the anchor for the integrated computational and data infrastructure efforts.

	(dollars in thousands)
	FY 2022 Request vs FY 2021 Enacted
Exascale Computing The FY 2022 Request will support efforts to deploy SC-ECP applications and ecosystem on both exascale architectures in partnership with the ASCR facilities. The decrease represents transition from research to testing of applications and software on the exascale systems and testbeds.	**-$39,945**
Total, Advanced Scientific Computing Research	**+$25,000**

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 in AI, Future Advanced Computing 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 2016, 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 2022, cross-agency interactions and collaborations will continue in coordination with the Office of Science and Technology Policy.

Program Accomplishments

Supercomputing Versus COVID-19

In the early days of the pandemic it was clear that fighting COVID-19 would require extensive research in areas like bioinformatics, epidemiology, and molecular modeling to understand the threat and to develop strategies to address it. One of the earliest heavy hitters to join the research effort, OLCF's Summit supercomputer—at the time, the most powerful publicly ranked supercomputer in the world—quickly added projects to characterize the virus structure, understand the ways in which it infects cells and assess thousands of compounds for their ability to bind to SARS-CoV-2's spike protein. As allocation requests poured in and private and public computing resources from around the world offered help, the Department of Energy, with 16 founding partners, established the COVID-19 High Performance Computing Consortium in March 2020. This massive collaboration between government, academic, and industry partners from around the globe aimed to pool available resources—from small clusters to clouds and some of the worlds biggest supercomputers—and quickly match them to COVID researchers. IBM established a central portal for researchers to request resources and the consortium matched them with available computing resources from one of the partner institutions. An expert panel comprised of top scientists and computing researchers worked with proposers to assess the public health benefit of the work, with emphasis on projects that could ensure rapid results. The Consortium grew to 43 members with a computing capacity over 600 petaflops and received more than 175 research proposals from researchers in more than 15 countries. Projects used simulations to understand how the virus infects and the dynamics of COVID aerosols in various settings. They also used artificial intelligence to characterize the spread of the virus and identify effective countermeasures and to accelerate the discovery of promising treatments. The HPC consortium also worked with policymakers to manage the course of the infection and strategically deploy resources. The HPC consortium demonstrated how public-private partnerships can be quickly established to harness combined capabilities to address a global emergency and was recognized by HPC wire as the 2020 Editor's choice for "Best HPC Collaboration".

AI Joins the Fight Against COVID-19

To find a drug that can stop the SARS-CoV-2 virus, scientists want to screen billions of molecules for the right combination of properties. The process is usually risky and slow, often taking several years. However, a team of scientists led by Argonne National Laboratory found a way to make the process 50,000 times faster using artificial intelligence (AI). A related Argonne collaboration used a novel AI-driven workflow to elucidate the mechanism by which COVID infects cells in the paper, "AI-Driven Multiscale Simulations Illuminate Mechanisms of SARS-CoV-2 Spike Dynamics", which was awarded the 2020 Special Gordon Bell prize for COVID applications at Supercomputing 2020. With that understanding and an expanded team, Argonne developed a pipeline of AI and simulation techniques to hasten the discovery of promising drug candidates for COVID-19. The pipeline is named IMPECCABLE, short for Integrated Modeling PipelinE for COVID Cure by Assessing Better Leads. With it, the team has been able to screen four billion potential drug candidates in a day—a thousand times more compounds that with conventional methods. This effort was part of the Department's National Virtual Biotechnology Laboratory, funded by the CARES Act, and leveraged the capabilities of Argonne's Advanced Photon Source (APS), the CARES Act funded enhancements to the Leadership Computing Facilities, the COVID-19 HPC Consortium, and capabilities developed within the DOE-NCI collaboration and the Exascale Computing Project.

Exascale Computing Project: Advancing the Applications for Building Back Better
The Exascale Computing Project (ECP) has been accelerating progress in a wide array of hardware and software technologies to advance National goals from basic science to clean energy options. Within the project, ECP researchers work with the ASCR facilities and domain scientists in the application development teams from across the Department's national labs and missions. ECP supports six application areas (national security, energy security, economic security, earth systems, and health care) and 24 applications with a significant focus on simulation and data-driven (AI) approaches. These efforts involve more than 10 billion lines of existing code that span methodologies and engage large user communities with hundreds of thousands of scientists and engineers standing to benefit from these efforts. Working together, in large diverse teams, they prepare and optimize critical applications for exascale architectures through knowledge of the application domain as well as the hardware, software, and other features of the planned exascale systems. All projects have ported to the OLCF's Summit architecture and have performance increases between a factor of 20 and a factor of 300 from ECP software improvements. The software advances, coupled with the exascale systems deployed in 2021–22 will enable these applications to deliver accurate regional impact assessment from climate change, forecast water resources and severe weather with increased confidence, address food supply changes, optimize power grid planning with diverse green energy options, reliably guide safe long-term consequential decisions about waste storage and carbon sequestration, accelerate the widespread adoption of additive manufacturing by enabling routine fabrication of qualifiable metal parts, design more robust and selective biofuel catalysts orders of magnitude more efficient at temperatures hundreds of degrees lower, and enable atomistic simulations to assist in the development of novel materials for energy applications.

Exascale Computing Project: Partnering to Push U.S. Microelectronics Forward
For 50 years, steady progress in computing was described by "Moore's Law"—the observation that the number of transistors in an integrated circuit (IC) doubles about every two years. As feature sizes approached the width of individual atoms, the pace of progress was expected to slow. To sustain progress in scientific computing, ASCR initiated investments in joint research with U.S. chip makers to forge a new path forward. These "Forward" partnerships have, for example, enabled Advanced Micro Devices, Inc. (AMD) to provide immense computational power in America's pre-exascale and exascale supercomputers through innovative computing solutions, acceleration of key hardware and software technologies, the rejuvenation of the HPC hardware and software ecosystem, and joint research and co-design with the DOE National Laboratories. ECP partnered with AMD for collaborative research to accelerate and enhance the performance, power-efficiency, and capabilities of AMD's commercially available hardware and open-source software for high-performance computing and machine learning. One effort accelerated AMD's development and commercial use of its revolutionary chiplet architecture with an enhanced version of AMD's Infinity Fabric™ interconnect to link separate pieces of silicon, chiplets, within a single processor package. The use of chiplets provides higher performance and more cost-effective manufacturing than traditional monolithic chip designs, and enabled AMD to introduce the world's first high-performance x86 7nm CPUs. Chiplets and other technologies accelerated by the ECP "Forward" investments will be used to enable scientific breakthroughs in the Perlmutter pre-exascale supercomputer at the National Energy Research Scientific Computing Center (NERSC), the Frontier exascale supercomputer at the Oak Ridge Leadership Computing Facility, the NNSA's El Capitan exascale supercomputer at Lawrence Livermore National Laboratory (LLNL), and other supercomputers and datacenters across the Nation.

Exascale Computing Project: Accelerating the Future of U.S. Microelectronics
The demands of massive scientific datasets require ever increasing amounts of bandwidth to, within, and on High Performance Computers. Exascale systems, combined with the data from upgrades at many of the Office of Science scientific user facilities, push traditional interconnect technologies to their limits. Silicon Photonics, which uses photons of light to transmit information more rapidly and efficiently, offers the potential to be a disruptive technology for HPC, delivering significant performance gains similar to those realized by fiber optics in long-distance networks. This technology will also have significant impacts across microelectronics applications, leap-frogging foreign competition and helping to satisfy the increasing bandwidth demands of ubiquitous, online connectivity, including from 5G/6G deployment, and could even help deliver the promise of quantum computing, which would provide an additional disruptive technology. To address the challenges of data bottlenecks in exascale systems, ECP partnered with Intel to accelerate research in integrated Silicon Photonics. Intel improved the power efficiency of high-speed interconnects by developing co-packaged optical interconnect technology that integrates high-bandwidth Intel Silicon Photonic engines with next-generation high-bandwidth switches. The ECP-Intel "PathForward" project helped fund an intensive technology development effort that resulted in the demonstration of a fully functional Ethernet switch with co-packaged optics, demonstrating 400Gbps optical I/O links

interoperable with a commercial switching system. This demonstrates the technical viability of fully-integrated optical photonics with core compute silicon, and has motivated the formation of an Optical Interconnect Forum Co-Packaged Optical Working Group based upon the initial description published by leading data center partners (http://www.copackagedoptics.com/). The Working Group will publish industry-wide specifications for co-packaged optics by the end of 2021 to support a broad multi-vendor eco-system enabling broad technology deployment. The results of these efforts which will soon put the technology into HPCs, data centers, and telecommunication infrastructure that drive our modern information economy with performance and energy gains that are well beyond next-generation electrical-networking technologies.

Quantum Supremacy Milestone Harnesses OLCF Summit Supercomputer
While still in the early stages, quantum computers have the potential to be exponentially more powerful than today's leading high-performance computing systems with the promise to revolutionize research in materials, chemistry, high-energy physics, and across the science and technology spectrum. Quantum computers use the laws of quantum mechanics to increase greatly how information is processed. Demonstrating when this threshold in relative computational power is crossed has been an important event for the computing community known as quantum supremacy. A joint research team from Google Inc., NASA Ames Research Center, and Oak Ridge National Laboratory (ORNL) has demonstrated quantum supremacy using a Google quantum computer, Sycamore, which can outperform the world-class Summit supercomputer at the task of random circuit sampling (RCS). The RCS task was designed specifically to measure the performance of quantum devices by characterizing the rate at which a randomly selected distribution can be calculated. The Summit supercomputer was used to verify the accuracy and operation of the Google quantum computer against baseline RCS tasks. Then, running on more difficult case studies, Sycamore was shown to require 200 seconds to perform RCS whereas the same simulations on Summit was expected to require 10,000 years to complete. In addition, the calculation on Sycamore was found to be approximately 10 million times more energy efficient. These dramatic differences in performance have provided the first experimental evidence of quantum supremacy and give critical insights into the design of future quantum computers that can address scientific computing tasks inaccessible today.

The Power of Technology Convergence: HPC + AI + Physical Model = Gordan Bell Prize
Molecular dynamics modeling has become a primary tool in scientific inquiry, allowing scientists to analyze the movements of interacting atoms over a set period of time, which helps them determine the properties of different materials or organisms. These computer simulations often lead the way in designing everything from new drugs to improved alloys. However, the two most popular methodologies have tradeoffs between speed and accuracy and are limited by even the most powerful supercomputer. But what if there was a way to bridge the gap between these methods to produce complex simulations that are both large and accurate? With the power of OLCF's Summit supercomputer, researchers successfully tested a software package that offers a potential solution: DeePMD-kit, named for "deep potential molecular dynamics." The team refers to DeePMD-kit as a "HPC+AI+Physical Model" in that it combines high-performance computing (HPC), Artificial Intelligence (AI), and physical principles to achieve large-scale speed and accuracy. It uses a neural network to assist its calculations by approximating the physics, thereby reducing the computational complexity. Simulating a block of copper atoms, the team put DeePMD-kit to the test on Summit with the goal of seeing how far they could push the simulation's size and timescales. The team was able to simulate a system of 127.4 million atoms—more than 100 times larger than the current state of the art. Furthermore, the simulation achieved a time-to-solution mark of at least 1,000 times faster at 2.5 nanoseconds per day for mixed-half precision, with a peak performance of 275 petaflops (one thousand million million floating-point operations per second) for mixed-half precision. This result was awarded the 2020 Gordon Bell prize for outstanding achievements in high-performance computing at the 2020 Supercomputing Conference, SC20, and their methods will doubtless accelerate simulations in a wide array of applications.

DOE and NCI: Working Together Against Cancer
The mechanism and dynamics of how RAS proteins—a family of proteins whose mutations are linked to more than 30 percent of all human cancers—interact and promote cancer signaling are not well understood. A pilot project in the Joint Design of Advanced Computing Solutions for Cancer (JDACS4C) program, a collaboration between the Department of Energy (DOE) and National Cancer Institute (NCI) that is supported in part by the Cancer Moonshot™, was recognized with the Best Paper award at SC19 for a novel application of Artificial Intelligence to improve multi-scale Molecular Dynamics modeling. The paper describes a predictive approach to model the dynamics of RAS proteins and lipid membranes, as well

as the activation of oncogenic signaling through interaction with other proteins. The paper includes contributions from Lawrence Livermore National Laboratory (LLNL), Oak Ridge National Laboratory (ORNL), the Frederick National Laboratory for Cancer Research (FNLCR), and IBM. The team took a broad approach to modeling RAS protein interactions that validates the results of many smaller experiments and pushes toward a first of its kind model that fully describes all possible RAS interactions. They began with a macro-model capable of simulating the impact of a lipid membrane on RAS proteins at long timescales and incorporated a machine learning algorithm to determine which lipid "patches" were interesting enough to model in more detail with a molecular level micromodel. The result is a Massively parallel Multiscale Machine-Learned Modeling Infrastructure (MuMMI) that scales up efficiently on supercomputers like the OLCF's Summit. The models help NCI carry out experiments to test predictions and generate more data that will feed back into the machine learning model, creating a validation loop that will produce a more accurate model. The MuMMI tool is also being incorporated into DOE multiscale codes to improve predictive capability in energy and national security applications.

Machine Learning Accelerates Our Clean Energy Future
Magnetically confined fusion promises to deliver CO_2-free energy. Test runs on ITER is the next step in the development of fusion energy. The ITER walls surrounding the fusion plasma are made of tungsten because it can withstand the very high temperature of the plasma. However, the tungsten can also contaminate and subsequently degrade the plasma. Attempts to simulate the tungsten-plasma interactions, including the 74 different charge states in the ITER plasma, would require an entire exascale computing system. A new method, developed though a SciDAC collaboration between fusion physicists and applied mathematicians, uses machine learning to simulate the contamination process. This approach has been demonstrated to achieve the desired accuracy while significantly reducing the computing requirements from nearly all of an exascale computer to a few percent.

Toward Environmental Justice: How Urbanization and Pollution Increase Storm Activity Around Cities
A study led by scientists at Pacific Northwest National Laboratory (PNNL) used computing resources at the National Energy Research Scientific Computing Center (NERSC) to run detailed simulations of storm physics and found that urbanization, combined with human-produced (anthropogenic) aerosol air pollution, increased both storm strength and storm development in two major U.S. cities. The researchers used NERSC's Cori system to study two separate convective storms: a supercell near Kansas City, Missouri that produced hail, tornado, and strong wind; and a sea-breeze-induced thunderstorm occurring near Houston, Texas. To resolve convection patterns, a key part of the study, the simulations were run at very high resolution across the entire Cori supercomputer. With this resolution, researchers were able to gain a good understanding of how physical factors affect storms. They found that urban land modifies convective evolution, speeding up cloud state transitions and initiating surface rain earlier, all of which results from urban heating-induced stronger sea-breeze circulation. The anthropogenic aerosol effect became evident after the storm clouds evolved, accelerating convective intensity and precipitation mainly by activating numerous ultrafine particles at various cloud stages. The team is building on this understanding to build a more predictive modeling, with the goal of being able to foresee hazardous weather and prevent death and damages from severe storms.

Deep Learning Nurtures the Roots of Innovations
When engines fail, technicians struggle to know why. Understanding the root cause of scientific phenomena, or an industrial failure event, could significantly accelerate discoveries, save on maintenance costs, and drive innovative instrument/scientific simulation design. However, there are often long, complex, and nonlinear interactions that occur between the root causes and its effects, which makes it difficult to identify a true root cause. The ASCR-funded extreme-scale spatio-temporal learning team led by researchers at Brookhaven National Laboratory (BNL) formulated an approach to sort and understand complex interactions via high performance computing modeling and simulation of event relationships and interactions in a bidirectional (forward and backward) deep learning framework. The approach was evaluated on industrial applications, such as engine failure sensor data, and can be applicable to any space and time correlated datasets and experimental sensor networks.

Connecting the dots – From Instruments to HPC to Publications: Getting More Out of Our Investments in Science
Exponential increases in data volumes and velocities are overwhelming finite human capabilities. Continued progress in science and engineering demands that we automate a broad spectrum of currently manual research data manipulation tasks, from data transfer and sharing to acquisition, publication, and analysis. These needs are particularly evident in large-scale experimental science, in which researchers are typically granted short periods of instrument time and must maximize

experiment efficiency as well as output data quality and accuracy. To address the need for improved and automated workflows, the Robust Analytical Models for Extreme-Scale Systems (RAMSES) project is developing end-to-end analytical performance modeling that is transforming science workflows in extreme-scale science environments. In one example that was recognized at SC19, the team automated a real-world scientific workflow in which the Advanced Photon Source was used to image centimeter-scale mouse brains with sub-micrometer resolution acquiring real-time data that was automatically passed through a complex automation flow for reconstruction using HPC resources, human-in-the-loop coordination, and data publication and visualization. The team is building on lessons learned from that experiment to productionize the platform so it can be applied to a variety of use cases and scaled to a range of compute resources matched to the size of the datasets up to exascale computing for challenges such as the mouse brain connectome.

ESnet: Advancing the Democratization of Science
Over the last decade, the scientific community has experienced an unprecedented shift in the way research is performed and how discoveries are made. Highly sophisticated experimental instruments are creating massive datasets for diverse scientific communities that hold the potential for new insights that will have long-lasting impacts on society. However, scientists cannot make effective use of this data if they are unable to move, store, and analyze it. The Engagement and Performance Operations Center (EPOC) was established in 2018 as a collaborative focal point for operational expertise and analysis and is jointly led by Indiana University (IU) and the Energy Sciences Network (ESnet) with support from the National Science Foundation. EPOC provides researchers with a holistic set of tools and services needed to debug performance issues and enable reliable and robust data transfers. By considering the full end-to-end data movement pipeline, EPOC is uniquely able to support collaborative science, allowing researchers to make the most effective use of shared data, computing, and storage resources to accelerate the discovery process. Many researchers at larger educational institutions, or part of large-scale collaborations, already have access to significant in-house resources, so EPOC focuses on small or medium-sized institutions and collaborations that may lack the financial and human resource capacity for more advanced services. By working with regional networks to develop, teach, and make available additional instructive material to these institutions, EPOC is not only increasing the abilities of the teams they are in direct contact with, but is also providing a broad set of materials made freely available to the general public.

Advancing Research in Geothermal Resources Mapping Using Distributed Acoustic Sensing
At present, large portions of western basins relevant to geothermal energy production are poorly mapped using classical high-resolution geophysical methods due to the high costs of seismic surveys, the restricted availability of archival seismic lines in the same regions, and limited coverage by dense arrays required for ambient noise imaging. ESnet is collaborating with the scientists to explore the use of fiber optic sensing, particularly distributed acoustic sensing (DAS), to seismically characterize geothermal systems at the basin scale in California's Imperial Valley south of the Salton Sea, near Calipatria and El Centro. ESnet has leveraged its extensive experience in the telecom fiber marketplace to acquire access to specific dark fiber segments motivated by the research goals and rack space and power to house the DAS equipment. These efforts have led to a recent award under the DOE's Frontier Observatory for Research in Geothermal Energy (FORGE) initiative.

ESnet: Advancing Diversity in Network Engineering
2020 marked the five-year anniversary of the Women in IT Networking at SC (WINS) program. ESnet created the program with collaborators funded by the NSF, to address the gender diversity gap in the network engineering workforce. The program funds and mentors approximately 7 women each year to participate in the construction of SCinet, one of the world's most advanced networks, purpose-built for the annual Supercomputing Conference. SCinet provides these women the opportunity to work with ~150 leading engineers and top technology vendors to build a Terabit+ network. The awardees are selected through a competitive application process. Since its introduction, WINS has increased the female to male participation ratio in SCinet from 13 percent to over 30 percent as of 2020. In recent years, the program has funded women not just from large universities and DOE laboratories but also from community and tribal colleges.

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

Description

The Mathematical, Computational, and Computer Sciences Research subprogram supports research activities to effectively meet the 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. ASCR investments are not focused on the next quarter but on the next quarter century. The Computer Science and Applied Mathematics activities in ASCR provide the foundation for increasing the capability of the national HPC ecosystem and scientific 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 the Nation. 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 incorporating 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 all levels of computing, from the edge to HPC storage and networking resources;
- collaboration tools, data and compute infrastructure and partnerships to make scientific resources and data 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, DOE, and the Nation; and
- long-term, basic research on future computing technologies with relevance to the DOE missions.

Applied Mathematics Research

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 multi-physics 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. Historically, advances in these methods have contributed as much, if not more, to gains in computational science than hardware improvements alone. Forward-looking efforts by this activity anticipate DOE mission needs from the closer coupling and integration of scientific modeling, data and scientific AI/ML with advanced computing, for enabling greater capabilities for scientific discovery, design, and decision-support in complex systems and new algorithms to support data analysis at the edge of experiments and instruments.

Computer Sciences Research

The Computer Science research activity supports long-term, basic research on the software infrastructure that is essential for the effective use of the most powerful high performance computing and networking systems in the country as well as the tools and data infrastructure to enable the exploration and understanding of extreme scale and 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 Computer Science research plays a key role in developing and evolving the sophisticated software required for future Leadership Computers, including basic research focused on quantum computing and communication. Hardware and software vendors often take software developed with ASCR Computer Science investments and integrate it with their own software. ASCR-supported activities are entering a new paradigm driven by sharp increases in the heterogeneity and complexity of computing systems and their software ecosystems, support for large-scale data analytics, and by the incorporation of AI techniques. 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 comprehensive workflows—from the edge of experiments, through simulation and AI, to data analytics and visualization. This includes making research data and AI models findable, accessible, interoperable, and reusable to strengthen trust and maximize the impact of scientific research in society.

Computational Partnerships

The Computational Partnerships activity primarily supports the Scientific Discovery through Advanced Computing, or SciDAC, program, which is a recognized leader for the employment of HPC for scientific discovery. Established in 2001, SciDAC involves ASCR partnerships with the other SC programs, other DOE program offices, and other federal agencies in strategic areas 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, DOE, and the Nation.

The Computational Partnerships activity also supports collaborations in the areas of data analysis, microelectronics, and future computing. Collaborative 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. In addition, partnerships with BES, BER, FES, HEP, and NP enable development of new algorithms and applications targeted for future computing platforms, including quantum information systems.

Advanced Computing Research

This activity supports Quantum efforts, Research and Evaluation Prototypes (REP), and ASCR-specific workforce investments including the Computational Sciences Graduate Fellowship (CSGF) and the SC-wide Reaching a New Energy Sciences Workforce (RENEW) initiative.

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. In addition to REP, this activity supports ASCR's investments in the National QIS Research Centers, as well as quantum computing testbeds and building a quantum internet to connect the National QIS Research Centers and ultimately the 17 DOE National Laboratories.

SC is fully committed to advancing a diverse, equitable, and inclusive research community, key to providing the scientific and technical expertise for U.S. scientific leadership. Toward that goal, ASCR will participate in the SC-wide RENEW initiative that leverages SC's world-unique national laboratories, user facilities, and other research infrastructures to provide undergraduate and graduate training opportunities for students and academic institutions not currently well represented in the U.S. S&T ecosystem. This includes HBCUs and MSIs and individuals from groups historically underrepresented in STEM, but also includes students from communities with environmental justice impacts and the EPSCoR jurisdictions. The hands-on experiences gained through the RENEW initiative will open new career avenues for the participants, forming a nucleus for a future pool of talented young scientists, engineers, and technicians with the critical skills and expertise needed for the full breadth of SC research activities, including DOE national laboratory staffing.

Success in fostering and stewarding a highly skilled, diverse, equitable, and inclusive workforce is fundamental to SC's mission and key to also sustaining U.S. leadership in HPC and computational science. The high demand across DOE missions and the unique challenges of high-performance computational science and engineering led to the establishment of the CSGF in 1991. This program has delivered leaders in computational science both within the DOE national laboratories and across the private sector. With increasing demand for these highly skilled scientist and engineers, ASCR continues to partner with the NNSA to support the CSGF to increase the availability and diversity of a trained workforce for exascale, AI, and beyond Moore's Law capabilities such as QIS.

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Mathematical, Computational, and Computer Sciences Research	**$259,865**	**$292,962**	**+$33,097**
Applied Mathematics Research	$48,570	$51,048	+$2,478
Funding expands 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 Request will continue to 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. Request also supports planning for the transition of critical Applied Math efforts from the Exascale Computing Project (ECP) into core research areas.	Funding will continue support of core research efforts and incorporating ECP efforts into core research areas.
Computer Sciences Research	$46,827	$49,773	+$2,946
Funding continues 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 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 continue long-term basic research efforts that explore and prepare for emerging technologies, such as quantum networking, specialized and heterogeneous hardware and accelerators, and quantum information systems. Request also supports planning for the sustainability of software from the ECP.	Increased funding will support core investments and continue long-term basic research initiative efforts.

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Computational Partnerships	$76,194	$86,029	+$9,835
Funding continues 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 Request will continue support for the SciDAC Institutes and partnerships with SC and DOE applications. Partnerships on scientific data, AI, microelectronics research, Quantum Information Science, and an integrated computational and data infrastructure for science will continue. The partnership with NIH will increase to 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. New efforts will focus on enabling widespread use of DOE high performance computing resources by Federal agencies in support of emergency preparedness and response. The Request also supports planning for the transition of mission critical Exascale Computing Project applications into SciDAC.	The increase will support interagency efforts to maximize the public benefit of DOE infrastructure and accelerate development of AI techniques for science. The increase will also support investments in capabilities that allow DOE to rapidly respond to research needs in support of national emergencies. This includes partnering with key agencies to understand their simulation and modeling capabilities, data management and curation needs, and identify and bridge gaps necessary for DOE to provide resources on short notice.

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Advanced Computing Research	$88,274	$106,112	+$17,838
Funding continues to support quantum testbed efforts, with emphasis on partnerships with the new QIS centers. 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. Funding under this activity continues to support small investments in REP for cybersecurity and testbeds for advanced microelectronics research. In addition, funding provides support for the CSGF fellowship at $10,000,000, in partnership with NNSA. The goal of CSGF is to increase availability of a trained workforce for exascale, AI, and beyond Moore's Law capabilities such as QIS.		The Request will continue to support the National QIS Research Centers and quantum testbed efforts. Building on basic research in quantum information networks, this activity will continue to support early-stage research associated with the first steps to establishing a dedicated Quantum network. The Request allows REP to explore new strategic investments in emerging technologies and microelectronics. Small investments in cyber security will continue. The Request will increase support for the CSGF fellowship, in partnership with NNSA, to support increased tuition costs, to increase the number of fellows focused on emerging technologies, and to expand the participation of groups, fields, and institutions that are under-represented in high end computational science. The goal of CSGF is to increase availability of a trained workforce for exascale, AI, and beyond Moore's Law capabilities such as QIS. The Request also supports the RENEW initiative to provide undergraduate and graduate training opportunities for students and academic institutions not currently well represented in the U.S. S&T ecosystem to expand the pipeline for ASCR research and facilities workforce needs.	The increase will support early stage research for a quantum network, support for the National QIS Research Centers, selected in FY 2020, and user access to quantum resources at the quantum testbeds and other quantum computers through the quantum computing user program at ORNL. Funding will also support an increase in support for the CSGF and the RENEW initiative.

Note: Funding for the subprogram above, includes 3.65% of research and development (R&D) funding for the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Programs.

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.

ASCR regularly gathers requirements from the other SC research programs through formal processes, including workshops and technical reviews, to inform upgrade plans and user programs. 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 ASCR HPC facilities computing resources to users follows the merit review public-access model used by other SC scientific user facilities. The Innovative and Novel Computational Impact on Theory and Experiment (INCITE) program provides access to the LCFs and the ASCR Leadership Computing Challenge (ALCC) program provides an allocation path for critical DOE mission applications and to broaden the community of users on the LCFs and NERSC.

ASCR HPC facilities received CARES Act funding in FY 2020 to support COVID-19 research teams through the HPC Consortium. DOE deployed customized hardware to each HPC facility to better address specific COVID-19 research needs and dozens of projects used millions of hours of compute time to provide insights including how the virus infects cells, exploration of treatment options, understanding variation in patient outcomes, high throughput drug candidate screening, epidemiology and public health surveillance, and advanced data analytics. Several of these research teams were finalists for the special COVID-19 Gordon Bell Prize. Once the pandemic is over, this hardware will be integrated into the HPC resources available for peer-reviewed, competitive research and will continue to advance biological and medical research.

<u>High Performance Production Computing</u>
This activity supports NERSC at LBNL to deliver high-end production computing services for the SC research community. More than 8,000 computational scientists conducting about 700 projects use NERSC annually to perform scientific research across a wide range of disciplines including astrophysics, chemistry, earth systems modeling, materials science, engineering, 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, approximately one-third in DOE laboratories, and other users from government laboratories, non-profits, small businesses, 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 NERSC's HPC resources.

NERSC currently operates the 30 petaflops (pf) Intel/Cray NERSC-8 system (Cori), as well as the 125 pf HPE/AMD/NVIDIA NERSC-9 system (Perlmutter), that comes online in FY 2021. 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. In FY 2022, NERSC will initiate preparations for a NERSC-10 upgrade that is needed to meet SC's growing computational needs.

Current ASCR HPC resources and facilities are primarily designed to efficiently execute large-scale simulation data analysis applications on premises, with a focus on minimizing users' wait-times in batch queues. With the rate and volume of data generated at SC scientific user facilities growing exponentially, and the significant interest in coupling these facilities to HPC in real-time to drive scientific discovery, ASCR is exploring the resource requirements to enable HPC for a broadening set of mission essential computational science workflows. In FY 2022, ASCR will design a state-of-the-art Scientific High Performance Data Facility focused on the unique challenges and opportunities for data-intensive applications workflows and near real-time computing needed to support the explosion of SC scientific data that will serve as the anchor for the Integrated Computational and Data Infrastructure Initiative. To provide geographic diversity and operational resiliency, this facility will be located on the East Coast.

Leadership Computing Facilities

The LCFs enable open scientific applications, including industry applications, to harness the potential of leadership computing to advance science and engineering. The success of this effort is built on the gains made in REP and ASCR research efforts. Another strength of the ASCR facilities 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 OLCF-4 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. The OLCF will undertake final acceptance and operations of an HPE-Cray/AMD exascale system (Frontier), which was deployed in calendar year 2021.

The Argonne Leadership Computing Facility (ALCF) at ANL operates the 8.5 pf Intel/Cray ALCF-2 system (Theta) and testbeds such as Polaris (A-19) to prepare their users and SC-ECP applications and software technology for the ALCF-3 upgrade, to be known as Aurora. Aurora will be an exascale system when deployed in calendar year 2022 and is being designed by Intel/HPE-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 new sustainable materials to capture and convert solar energy; developing new solid-state energy storage systems; 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 manage enterprise risk and foster diverse capabilities that provide the Nation's HPC user community with the most effective resources.

The demand for 2021 INCITE allocations at the LCFs outpaced the available resources by more than a factor of three. Demand for 2020-2021 ALCC allocations outpaced resources by more than a factor of five.

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 executing a complete upgrade of its backbone network (the ESnet-6 upgrade).

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
High Performance Computing and Network Facilities	**$586,190**	**$618,038**	**+$31,848**
High Performance Production Computing	$113,786	$115,963	+$2,177
Funding supports 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.		The Request will support operations at the NERSC facility, including user support, power, space, system leases, and staff. The Request will also support full operations of Perlmutter, which will be installed and accepted in FY 2021.	Funding will support the operations of the Cori and Perlmutter systems as well as development of early-stage designs for the NERSC-10 upgrade. In addition, funding will also support the design of a Scientific High-Performance Data Facility located on the East Coast.
Leadership Computing Facilities	$381,075	$408,113	+$27,038
Funding supports 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.		The Request will support operations at the LCF facilities at ANL and ORNL, including user support, power, space, system leases, early access systems and testbeds, and operations staff. The Request also will support deployment, acceptance testing, early science and operations of exascale systems at OLCF and ALCF.	Funding will support the calendar year 2021–2022 deployment schedule for both LCF upgrades to the exascale.
Leadership Computing Facility at ANL	*$152,955*	*$159,047*	*+$6,092*
Funding continues 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.		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 calendar year 2022.	Funding will continue operations at the ALCF and support final preparations, deployment and early science access of the ALCF-3 exascale system.

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Leadership Computing Facility at ORNL	*$228,120*	*$249,066*	*+$20,946*
Funding continues 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 Request will continue support for the operation and competitive allocation of the Summit system and other testbeds. The OLCF will complete acceptance of the OLCF-5 exascale system, Frontier, which was deployed in calendar year 2021 and will provide access for early science applications and the Exascale Computing Project.	The increase in funding will support the operations of the exascale system deployed in calendar year 2021.
High Performance Network Facilities and Testbeds	$91,329	$93,962	+$2,633
Funding supports 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 on dark fiber with new equipment, increased capacity, and an advanced 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 ESnet-6 upgrade in accordance with the project baseline as well as continued operation of ESnet-5.

Note: Funding for the subprogram above, includes 3.65% of research and development (R&D) funding for the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Programs.

Advanced Scientific Computing Research
Exascale Computing

Description

SC and NNSA will continue to execute the Exascale Computing Initiative (ECI), which is an effort to develop and deploy an exascale-capable computing system with an emphasis on sustained performance for relevant applications and analytic computing to support DOE missions. The deployment of these systems includes necessary site preparations and non-recurring engineering (NRE) at the Leadership Computing Facilities (LCFs) 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 its major computing projects, including the LCFs at ANL and ORNL, and NERSC at LBNL.

SC conducts overall project management for the SC-ECP via a Project Office established at ORNL because of its considerable expertise in developing computational science and engineering applications and in managing HPC facilities, both for the Department and for other federal agencies; and its 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 2022 Request includes $129,000,000 for the SC-ECP. These funds will support test and deployment investments in the ECP technical focus areas—application development, software technology and hardware and integration—via testing and development on early access exascale hardware and exascale systems. Deployment of exascale systems in calendar years 2021-2022 will be through the LCFs as part of their usual upgrade processes.

Advanced Scientific Computing Research
Exascale Computing

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Construction	**$168,945**	**$129,000**	**-$39,945**
17-SC-20, SC Exascale Computing Project	$168,945	$129,000	-$39,945
Funding supports 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.		The Request will support project management; co-design activities between application and the software stack; and integration between SC-ECP and the LCFs to provide continuous integration and testing of the ECP funded applications and software on exascale testbed.	The funding decrease reflects the completion of research and development activities as the project moves into implementation of software technology and execution of application challenge problems on the actual exascale systems.

Advanced Scientific Computing Research
Capital Summary

(dollars in thousands)

	Total	Prior Years	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Capital Operating Expenses						
Capital Equipment	N/A	N/A	5,000	31,809	5,000	-26,809
Total, Capital Operating Expenses	**N/A**	**N/A**	**5,000**	**31,809**	**5,000**	**-26,809**

Capital Equipment

(dollars in thousands)

	Total	Prior Years	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Capital Equipment						
Total, Non-MIE Capital Equipment	N/A	N/A	5,000	31,809	5,000	-26,809
Total, Capital Equipment	**N/A**	**N/A**	**5,000**	**31,809**	**5,000**	**-26,809**

Advanced Scientific Computing Research
Funding Summary

(dollars in thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Research	405,000	428,810	421,962	-6,848
Facility Operations	575,000	586,190	618,038	+31,848
Total, Advanced Scientific Computing Research	**980,000**	**1,015,000**	**1,040,000**	**+25,000**

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.

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 2020 Enacted	FY 2020 Current	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Scientific User Facilities - Type A					
National Energy Research Scientific Computing Center	**110,000**	**109,224**	**111,245**	**115,963**	**+4,718**
Number of Users	7,500	8,329	8,329	8,500	+171
Achieved Operating Hours	–	8,293	–	–	–
Planned Operating Hours	8,585	8,585	8,585	8,585	–
Optimal Hours	8,585	8,585	8,585	8,585	–
Percent of Optimal Hours	100.0%	100.0%	100.0%	100.0%	–
Unscheduled Down Time Hours	–	292	–	–	–
Argonne Leadership Computing Facility	**150,000**	**150,000**	**153,818**	**159,047**	**+5,229**
Number of Users	950	1,174	1,174	1,300	+126
Achieved Operating Hours	–	6,923	–	–	–
Planned Operating Hours	7,008	7,008	7,008	7,008	–
Optimal Hours	7,008	7,008	7,008	7,008	–
Percent of Optimal Hours	100.0%	100.0%	100.0%	100.0%	–
Unscheduled Down Time Hours	–	84	–	–	–
Oak Ridge Leadership Computing Facility	**225,000**	**225,000**	**229,915**	**249,066**	**+19,151**
Number of Users	1,450	1,546	1,546	1,500	-46
Achieved Operating Hours	–	6,980	–	–	–
Planned Operating Hours	7,008	7,008	7,008	7,008	–
Optimal Hours	7,008	7,008	7,008	7,008	–
Percent of Optimal Hours	100.0%	100.0%	100.0%	100.0%	–
Unscheduled Down Time Hours	–	28	–	–	–

(dollars in thousands)

	FY 2020 Enacted	FY 2020 Current	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Energy Sciences Network	**90,000**	**90,000**	**91,212**	**93,962**	**+2,750**
Achieved Operating Hours	–	8,760	–	–	–
Planned Operating Hours	8,760	8,760	8,760	8,760	–
Optimal Hours	8,760	8,760	8,760	8,760	–
Percent of Optimal Hours	100.0%	100.0%	100.0%	100.0%	–
Total, Facilities	**575,000**	**574,224**	**586,190**	**618,038**	**+31,848**
Number of Users	9,900	11,049	11,049	11,300	+251
Achieved Operating Hours	–	30,956	–	–	–
Planned Operating Hours	31,361	31,361	31,361	31,361	–
Optimal Hours	31,361	31,361	31,361	31,361	–
Unscheduled Down Time Hours	–	404	–	–	–

Note: Achieved Operating Hours and Unscheduled Downtime Hours will only be reflected in the Congressional budget cycle which provides actuals.

Advanced Scientific Computing Research
Scientific Employment

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Number of Permanent Ph.Ds (FTEs)	683	814	825	+11
Number of Postdoctoral Associates (FTEs)	331	349	365	+16
Number of Graduate Students (FTEs)	438	520	535	+15
Number of Other Scientific Employment (FTEs)	212	217	220	+3

Note: Other Scientific Employment (FTEs) includes technicians, engineers, computer professionals and other support staff.

17-SC-20, SC Exascale Computing Project

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

Summary

The FY 2022 Request for the SC Exascale Computing Project (SC-ECP) is $129,000,000. The Total Estimated Cost (TEC) range for this project is between $1,500,000,000 and $1,900,000,000. The Total Project Cost (TPC) of the SC portion of ECP is $1,326,200,000 with the total combined SC and NNSA TPC of $1,812,300,000.

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.

Other activities included in the ECI but not the Office of Science-Exascale Computing Project (SC-ECP) include $275,000,000 in FY 2022 to support the final site preparations and the installation of the exascale system at the Argonne Leadership Computing Facility (ALCF) and the final acceptance of the exascale system deployed at the Oak Ridge Leadership Computing Facilities (OLCF) in calendar year 2021. Supporting parallel development at both Leadership Computing Facilities (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.

Significant Changes

This project was initiated in FY 2017. The FY 2022 Request supports investments in the ECP technical focus areas—application development, software technology and hardware and integration—to initiate test and deployment a capable exascale software ecosystem on exascale-capable systems deployed in the calendar year 2021 and 2022. Funding decreases in FY 2022 to reflect the completion of research and development activities as the project focus moves more to execution and implementation.

The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-2/3 Approve Performance Baseline, where definitive scope, schedule and cost baselines have been developed and the project is ready for implementation. The project achieved CD-2/3 on February 25, 2020. The Total Project Cost (TPC) of the SC portion of ECP is $1,326,200,000 with the total combined SC and NNSA TPC of $1,812,300,000.

Critical Milestone History

Fiscal Year	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	D&D Complete	CD-4
FY 2017	3Q FY 2016	TBD	TBD	TBD	TBD	N/A	TBD
FY 2018	7/28/16	2Q FY 2019	1/3/17	4Q FY 2019	3Q FY 2019	N/A	4Q FY 2023
FY 2019	7/28/16	2Q FY 2019	1/3/17	4Q FY 2019	3Q FY 2019	N/A	4Q FY 2023
FY 2020	7/28/16	2Q FY 2019	1/3/17	1Q FY 2020	3Q FY 2019	N/A	4Q FY 2023
FY 2021	7/28/16	3/22/16	1/3/17	2Q FY 2020	6/6/19	N/A	4Q FY 2024
FY 2022	7/28/16	3/22/16	1/3/17	2/25/20	6/6/19	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-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 2017	TBD	TBD	TBD
FY 2018	4Q FY 2019	1/3/17	4Q FY 2019
FY 2019	4Q FY 2019	1/3/17	4Q FY 2019
FY 2020	1Q FY 2020	1/3/17	1Q FY 2020
FY 2021	1Q FY 2020	1/3/17	2Q FY 2020
FY 2022	2/25/20	1/3/17	2/25/20

CD-3A – Approve Long Lead Time Procurements
CD-3B – Approve Remaining Construction Activities

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 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
FY 2022	N/A	700,843	700,843	625,363	N/A	625,363	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.

<u>Justification</u>

In 2015, the National Strategic Computing Initiative was established to maximize the benefits of HPC for U.S. economic competitiveness, scientific discovery, and national security. Within that initiative DOE, represented by a partnership between SC and NNSA, has the responsibility for executing a joint program focused on advanced simulation through an exascale–capable computing program, which will emphasize sustained performance and analytic computing to advance DOE missions. The objectives and the associated scientific challenges define a mission need for a computing capability of 2 – 10 ExaFLOPS (2 billion billion floating-point operations per second) in the early to mid-2020s. In FY 2017, SC initiated the 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.

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 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.

<u>Key Performance Parameters (KPPs)</u>

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 their KPP-1 stretch goal.
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 stretch goal
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

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
Construction (TEC)			
FY 2019	187,696	187,696	–
FY 2020	174,735	174,735	105,440
FY 2021	160,412	160,412	336,480
FY 2022	115,000	115,000	154,909
Outyears	63,000	63,000	104,014
Total, Construction (TEC)	**700,843**	**700,843**	**700,843**
Total Estimated Cost (TEC)			
FY 2019	187,696	187,696	–
FY 2020	174,735	174,735	105,440
FY 2021	160,412	160,412	336,480
FY 2022	115,000	115,000	154,909
Outyears	63,000	63,000	104,014
Total, TEC	**700,843**	**700,843**	**700,843**

[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.

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Other Project Cost (OPC)			
FY 2016	146,820	146,820	5,741
FY 2017	164,000	164,000	83,698
FY 2018	205,000	205,000	170,898
FY 2019	45,010	45,010	220,565
FY 2020	14,000	14,000	93,203
FY 2021	8,533	8,533	9,258
FY 2022	14,000	14,000	14,000
Outyears	28,000	28,000	28,000
Total, OPC	**625,363**	**625,363**	**625,363**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Project Cost (TPC)			
FY 2016	146,820	146,820	5,741
FY 2017	164,000	164,000	83,698
FY 2018	205,000	205,000	170,898
FY 2019	232,706	232,706	220,565
FY 2020	188,735	188,735	198,643
FY 2021	168,945	168,945	345,738
FY 2022	129,000	129,000	168,909
Outyears	91,000	91,000	132,014
Total, TPC	**1,326,206**	**1,326,206**	**1,326,206**

4. Details of Project Cost Estimate

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

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Application Development (TEC)	347,289	236,759	346,360
Production Ready Software	228,472	142,661	217,290
Hardware Partnership	125,082	128,260	131,726
Total, Other (TEC)	**700,843**	**507,680**	**695,376**
Total, TEC	**700,843**	**507,680**	**695,376**
Contingency, TEC	***N/A***	***N/A***	***N/A***
Other Project Cost (OPC)			
Planning Project Management	89,688	102,595	89,688
Application Development (OPC)	221,050	333,568	221,050
Software Research	118,517	199,754	118,517
Hardware Research	196,108	182,609	201,575
Total, Except D&D (OPC)	**625,363**	**818,526**	**630,830**
Total, OPC	**625,363**	**818,526**	**630,830**
Contingency, OPC	***N/A***	*N/A*	***N/A***
Total, TPC	**1,326,206**	**1,326,206**	**1,326,206**
Total, Contingency (TEC+OPC)	***N/A***	***N/A***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Request Year	Type	Prior Years[a]	FY 2020	FY 2021	FY 2022	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	707,524	14,000	—	—	42,000	763,524
	TPC	707,524	189,000	—	—	257,000	1,153,524

[a] 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.

(dollars in thousands)

Request Year	Type	Prior Years[a]	FY 2020	FY 2021	FY 2022	Outyears	Total
FY 2019	TEC	—	174,735	—	—	252,000	426,735
	OPC	751,230	14,000	—	—	42,000	807,230
	TPC	751,230	188,735	—	—	294,000	1,233,965
FY 2020	TEC	—	174,735	—	—	252,000	426,735
	OPC	759,650	14,000	—	—	56,000	829,650
	TPC	759,650	188,735	—	—	308,000	1,256,385
FY 2021	TEC	—	174,735	154,945	—	178,000	507,680
	OPC	748,526	14,000	14,000	—	42,000	818,526
	TPC	748,526	188,735	168,945	—	220,000	1,326,206
FY 2022	TEC	187,696	174,735	160,412	115,000	63,000	700,843
	OPC	560,830	14,000	8,533	14,000	28,000	625,363
	TPC	748,526	188,735	168,945	129,000	91,000	1,326,206

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 2022 Budget Request, $275,000,000, is included in the ALCF and OLCF 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	7 years
Expected Future Start of D&D of this capital asset	2029

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.

[a] 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.

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. BES research provides the foundations to develop new energy technologies, to mitigate the environmental impacts of energy generation/use, 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 clean 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. In response to the COVID pandemic, BES facilities were at the forefront of the research efforts to understand the virus and to provide therapeutics to combat it. 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 of accomplishment begins with rigorous community-based processes for conceptualization, planning, and execution in construction of facilities that continues in performance assessment for operating facilities.

Key to exploiting scientific discoveries for future clean 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. Materials will need to be more functional than today's energy materials, and new chemical processes will require ever-increasing control at the level of electronic structure and dynamics. 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 have been experimentally realized. 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 2022 Request

The BES FY 2022 Request of $2,300.0 million is an increase of $55.0 million, or 2.4 percent, above the FY 2021 Enacted level. The Request focuses resources on the highest priorities in early-stage fundamental research, in operation and maintenance of scientific user facilities, and in facility upgrades.

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

Key elements in the FY 2022 Request are summarized below.

Research

The Request continues funding for the Energy Frontier Research Centers (EFRCs), the Batteries and Energy Storage Energy Innovation Hub and the Fuels from Sunlight Hub awards, and the National Quantum Information Science (QIS) Research Centers. BES will build stronger programs with underrepresented institutions and regions, including strengthening awareness in order to address environmental justice issues.

Core research priorities in the FY 2022 Request include:

- Clean Energy: Research to provide understanding and foundations for clean energy crosses the entire portfolio. A few examples:
  - Direct air capture of carbon dioxide: Designing high-selectivity, high-capacity, and high-throughput chemical separations and materials;
  - Hydrogen, Solar: Improved conversion of solar energy to useful energy—and fuels, such as hydrogen by water splitting; and
  - Energy Storage: New materials and chemistries for next-generation electrical and thermal energy storage.
- Critical Materials/Minerals: Critical materials/minerals, including rare earth and platinum-group elements, are vital to the Nation's security and economic prosperity, as well as applications for clean energy. In BES, the Request continues support for research to advance our understanding of fundamental properties of these materials, to identify methodologies to reduce their use and to discover substitutes, and to enhance extraction, chemical processing and separation science for rare earths and platinum-group elements.
- Fundamental Science to Transform Advanced Manufacturing (Advanced Manufacturing): BES invests in fundamental science underpinning advanced manufacturing, partnering across SC, with thrusts in circular, clean, and scalable synthesis and processing; transformational operando characterization; multiscale models and tools; and co-design of materials, processes, and products for functionality and use.
- Revolutionizing Polymer Upcycling: Related to Advanced Manufacturing, BES continues its investment in fundamental research that 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.
- Microelectronics: Also related to Advanced Manufacturing, BES continues 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), Nuclear Physics (NP), 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.
- Artificial Intelligence and Machine Learning (AI/ML): The Request continues investments in data science and AI/ML to accelerate fundamental research for the discovery of new chemical mechanisms and material systems with exceptional properties and function and to apply these techniques for effective user facility operations and interpretation of massive data sets.
- Exascale Computing Crosscut: 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 Crosscut.
- Integrated Computational & Data Infrastructure: Partnering with ASCR, BES invests in cost-effective computational, networking, and storage capabilities to keep pace with exponential increases in data rates, volumes, and complexities, including those from scientific user facilities.
- Biopreparedness Research Virtual Environment (BRaVE): In support of the activity, which brings DOE laboratories together to tackle problems of pressing national importance, BES research will focus on developing and maintaining capabilities at user facilities related to biotechnology for responsiveness to biological threats and development of advanced instrumentation to address these research challenges.
- Quantum Information Science (QIS): In support of the National Quantum Initiative, SC QIS Research Centers established in FY 2020 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.

- Accelerator Science and Technology Initiative: Accelerator R&D is a core capability, which SC stewards for the Nation. Increased 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.
- Reaching a New Energy Sciences Workforce (RENEW): The Office of Science is fully committed to advancing a diverse, equitable, and inclusive research community key to providing the scientific and technical expertise for U.S. scientific leadership. Toward that goal, BES will participate in the SC-wide RENEW initiative that leverages SC's world-unique national laboratories, user facilities, and other research infrastructures to provide undergraduate and graduate training opportunities for students and academic institutions not currently well represented in the U.S. S&T ecosystem. This includes Minority Serving Institutions and individuals from groups historically underrepresented in STEM, but also includes students from communities with environmental justice impacts and the Established Program to Stimulate Competitive Research (EPSCoR) jurisdictions. The hands-on experiences gained through the RENEW initiative will open new career avenues for the participants, forming a nucleus for a future pool of talented young scientists, engineers, and technicians with the critical skills and expertise needed for the full breadth of SC research activities, including DOE national laboratory staffing.

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), Stanford Synchrotron Radiation Lightsource (SSRL), and Linac Coherent Light Source (LCLS) will continue operations and are supported at approximately 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 2022 and funded at approximately 96 percent of optimum. The Request provides funding for the five Nanoscale Science Research Centers (NSRCs) at a level of approximately 96 percent of optimal.

Projects

The Request provides continuing support for the Advanced Photon Source Upgrade (APS-U), Advanced Light Source Upgrade (ALS-U), Linac Coherent Light Source-II (LCLS-II), Linac Coherent Light Source-II High Energy (LCLS-II-HE), Proton Power Upgrade (PPU), Second Target Station (STS), and Cryomodule Repair and Maintenance Facility (CRMF) projects. The FY 2022 Request also continues two Major Item of Equipment projects: NSLS-II Experimental Tools-II (NEXT-II) and NSRC Recapitalization.

Basic Energy Sciences
FY 2022 Research Initiatives

Basic Energy Sciences supports the following FY 2022 Research Initiatives.

(dollars in thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Accelerator Science and Technology Initiative	–	5,000	13,000	+8,000
Artificial Intelligence and Machine Learning	10,000	20,000	20,000	–
Biopreparedness Research Virtual Environment (BRaVE)	–	–	9,500	+9,500
Critical Materials/Minerals	–	17,000	25,000	+8,000
Exascale Computing Crosscut	26,000	26,000	26,000	–
Fundamental Science to Transform Advanced Manufacturing	–	–	17,000	+17,000
Integrated Computational & Data Infrastructure	–	–	10,000	+10,000
Microelectronics	5,000	15,000	30,000	+15,000
Quantum Information Science	72,270	92,050	102,000	+9,950
Reaching a New Energy Sciences Workforce (RENEW)	–	–	5,000	+5,000
Revolutionizing Polymers Upcycling	–	8,250	8,250	–
Total, Research Initiatives	**113,270**	**183,300**	**265,750**	**+82,450**

Basic Energy Sciences
Funding

(dollars in thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Basic Energy Sciences				
Scattering and Instrumentation Sciences Research	71,235	74,031	85,675	+11,644
Condensed Matter and Materials Physics Research	144,963	170,200	187,769	+17,569
Materials Discovery, Design, and Synthesis Research	65,443	71,189	88,047	+16,858
Established Program To Stimulate Competitive Research EPSCoR	24,088	25,000	25,000	–
Energy Frontier Research Centers - Materials	57,500	57,500	64,678	+7,178
Materials Sciences and Engineering - Energy Innovation Hubs	24,088	24,088	25,000	+912
Computational Materials Sciences	13,000	13,000	13,492	+492
Materials Sciences and Engineering, SBIR/STTR	15,165	–	–	–
Total, Materials Sciences and Engineering	**415,482**	**435,008**	**489,661**	**+54,653**
Fundamental Interactions Research	101,567	107,904	124,415	+16,511
Chemical Transformations Research	97,836	112,292	117,725	+5,433
Photochemistry and Biochemistry Research	75,724	82,589	106,871	+24,282
Energy Frontier Research Centers - Chemical	57,500	57,500	64,678	+7,178
Chemical Sciences, Geosciences, and Biosciences - Energy Innovation Hubs	20,000	20,000	20,758	+758
Chemical Sciences, Geosciences, and Biosciences - General Plant Projects	1,000	1,000	1,000	–
Computational Chemical Sciences	13,000	13,000	13,492	+492
Chemical Sciences, Geosciences, and Biosciences, SBIR/STTR	13,851	–	–	–
Total, Chemical Sciences, Geosciences, and Biosciences	**380,478**	**394,285**	**448,939**	**+54,654**

(dollars in thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
X-Ray Light Sources	518,791	525,000	538,282	+13,282
High-Flux Neutron Sources	289,701	292,000	293,871	+1,871
Nanoscale Science Research Centers	138,687	139,000	142,387	+3,387
Other Project Costs	23,000	19,000	14,300	-4,700
Major Items of Equipment	10,500	10,500	30,000	+19,500
Scientific User Facilities, Research	39,879	41,207	38,360	-2,847
Scientific User Facilities, SBIR/STTR	36,482	–	–	–
Total, Scientific User Facilities (SUF)	**1,057,040**	**1,026,707**	**1,057,200**	**+30,493**
Subtotal, Basic Energy Sciences	**1,853,000**	**1,856,000**	**1,995,800**	**+139,800**
Construction				
21-SC-10, Cryomodule Repair & Maintenance Facility, (CRMF), SLAC	–	1,000	1,000	–
19-SC-14, Second Target Station (STS), ORNL	20,000	29,000	32,000	+3,000
18-SC-10, Advanced Photon Source Upgrade (APS-U), ANL	170,000	160,000	101,000	-59,000
18-SC-11, Spallation Neutron Source Proton Power Upgrade (PPU), ORNL	60,000	52,000	17,000	-35,000
18-SC-12, Advanced Light Source Upgrade (ALS-U), LBNL	60,000	62,000	75,100	+13,100
18-SC-13, Linac Coherent Light Source-II-High Energy (LCLS-II-HE), SLAC	50,000	52,000	50,000	-2,000
13-SC-10 - Linac Coherent Light Source-II (LCLS-II), SLAC	–	33,000	28,100	-4,900
Subtotal, Construction	**360,000**	**389,000**	**304,200**	**-84,800**
Total, Basic Energy Sciences	**2,213,000**	**2,245,000**	**2,300,000**	**+55,000**

SBIR/STTR funding:

- FY 2020 Enacted: SBIR $57,423,000 and STTR $8,075,000
- FY 2021 Enacted: SBIR $56,592,000 and STTR $7,963,000
- FY 2022 Request: SBIR $59,865,000 and STTR $8,432,000

Basic Energy Sciences
Explanation of Major Changes

	(dollars in thousands) FY 2022 Request vs FY 2021 Enacted
Materials Sciences and Engineering Research will continue to support fundamental scientific opportunities for materials innovations, including those identified in recent BESAC and Basic Research Needs workshop reports. Research priorities include clean energy (e.g., hydrogen, direct air capture, energy storage), critical materials/minerals, exascale (computational materials sciences), data science and AI/ML, integrated computational and data infrastructure, advanced manufacturing, microelectronics, BRaVE, QIS, strategic accelerator technology, and RENEW. The Request also includes funding for continued support of the EFRCs, the Batteries and Energy Storage Energy Innovation Hub, the National QIS Research Centers, and the Established Program to Stimulate Competitive Research (EPSCoR).	**+$54,653**
Chemical Sciences, Geosciences, and Biosciences Research will continue to support fundamental scientific opportunities for innovations in chemistry, geosciences and biosciences, including those identified in recent BESAC, Basic Research Needs, and Roundtable workshop reports. Research priorities include clean energy (e.g., energy efficient, sustainable cycles for carbon and hydrogen, and direct air capture of carbon dioxide), critical materials/minerals, exascale (computational chemical sciences), data science and AI/ML, integrated computational and data infrastructure, advanced manufacturing, polymer upcycling, microelectronics, QIS, and RENEW. The Request also includes funding for continued support of the EFRCs, the Fuels from Sunlight Hub awards, and the National QIS Research Centers.	**+$54,654**
Scientific User Facilities (SUF) The Advanced Light Source (ALS), Advanced Photon Source (APS), National Synchrotron Light Source-II (NSLS-II), Stanford Synchrotron Radiation Lightsource (SSRL), and Linac Coherent Light Source (LCLS) user facilities will operate at approximately 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 96 percent of optimum. These facilities will support the BRaVE initiative to maintain capabilities to tackle biological threats. The Request continues to support all five NSRCs at approximately 96 percent of optimum, with funding for continued QIS-related tools development. Research priorities include accelerator science and technology and applications of data science and AI/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.	**+$30,493**
Construction The Request provides continuing support for the Advanced Photon Source-Upgrade (APS-U), the Advanced Light Source Upgrade (ALS-U), the Linac Coherent Light Source-II (LCLS-II), the Linac Coherent Light Source-II High Energy (LCLS-II-HE), the SNS Proton Power Upgrade (PPU), the SNS Second Target Station (STS), and the Cryomodule Repair and Maintenance Facility at SLAC.	**-$84,800**
Total, Basic Energy Sciences	**+$55,000**

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; hydrogen production, storage, transport and use; carbon dioxide removal including direct air capture; energy storage; critical minerals/materials; advanced nuclear energy systems; vehicle technologies; biotechnology; and fundamental science to transform advanced manufacturing and industrial processes. These activities facilitate cooperation and coordination between BES and the DOE technology offices and defense programs. Additionally, DOE technology office personnel participate in reviews of BES research, and BES personnel participate in reviews of research funded by the technology offices. DOE leadership has established formal Science and Energy Technology Teams that cross the Department and meet on a regular basis to discuss R&D activities and goals.

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

Foundational understanding and characterization of novel materials and molecular systems for use in microelectronics and quantum information science.

Future generations of energy-efficient quantum, optical, and electronic devices will be built from advanced materials and molecules that have not previously been exploited technologically. Harnessing the full potential of these systems requires detailed understanding and control of their fundamental properties at the level of atoms and electrons.

- Using neutron diffraction and inelastic scattering, researchers discovered evidence of a long-sought quantum spin liquid (QSL) state that can be controlled with magnetic fields. QSLs are an exotic new phase of matter that may have use as quantum bits (qubits) in quantum information-based applications, and may help scientists understand high-temperature superconductivity and entangled correlated electrons. This discovery, enabled by the unique sensitivity of neutrons to magnetic properties, may provide a foundation to develop materials for applications such as topologically protected qubits, robust against local disorder and perturbations.
- A novel characterization method was used to correlate the optical properties of atomic-defect-based quantum emitters with their atomic and crystallographic structure. The work combined multiple characterization techniques: photoluminescence, cathodoluminescence, and nano-beam electron diffraction. Next-generation quantum and energy technologies will require bright, controllable emitter characteristics and placement. This research provides a foundation for creating such emitters based on atomic "defects-by-design".
- Using a new technology developed for scanning transmission electron microscopy, researchers produced the most accurate 3D images of 2D materials to date, mapping the materials' atomic structure to picometer-scale (one-trillionth of a meter) precision. They quantified defects and the effects of doping in the materials, both of which can affect the materials' electronic properties. This approach should enable scientists to better predict and discover new physical, chemical, and electronic properties of 2D materials at the single-atom level.
- Scientists developed a general, practical approach to test for the presence and degree of entanglement—a key quantum phenomenon exploited in QIS technologies—in continuous measurements of systems such as chemical reactions. An effective procedure to prepare and measure entanglement to uncover how chemical reactions work could enable innovative schemes to mimic or recreate the reactions in new technologies.

Ultrafast chemical and materials sciences.

Advances in science and technology over the past century have been driven by an improved understanding of matter on ever-decreasing length scales, reaching down to atomic dimensions. Understanding and controlling the interplay between atomic-scale structure and the associated ultrafast dynamical processes, which govern the macroscopic functionality observed in matter, are key to discovery and driving innovation in energy applications.

- Researchers used ultrafast x-ray free-electron-laser (XFEL) pulses to observe the initial ultrafast step in the radiolysis of water—the transfer of a proton from an ionized water molecule to form the chemically aggressive hydroxyl radical. Understanding the role of the molecular environment on the mechanism of this process is critical to developing strategies to suppress radiation damage in chemical and materials systems.
- Using a high-speed "electron camera", scientists simultaneously captured the movements of electrons and nuclei in a molecule after it was excited with light. This novel accomplishment used ultrafast electron diffraction, which scatters a short, powerful beam of electrons off matter to reveal tiny molecular motions.
- Information on how light is absorbed and on tracking of energy flows from light to electrons to atoms, including atomic distortions on ultrafast time scales, is needed to understand and control the novel properties of 2D materials. Atomic vibrations in a single molecular sheet were measured by intense pulses in a new time-resolved ultrafast technique using an XFEL. This is now possible at the time and distance limits of the ultrafast dynamics involving particles and arrangements that make up new materials and involve new properties.
- Scientists used ultra-broadband 2D electronic spectroscopy to uncover the ultrafast processes and energy-dissipating mechanisms that prevent damage to molecular systems in plant photosynthesis. This work confirmed a predicted pathway for energy transfer from chlorophyll to carotenoid and suggested a role for the local molecular environment in controlling light harvesting and energy dissipation. These insights could inspire innovative strategies to limit damage from excess energy in clean-energy technologies.

Electrochemical mechanisms in systems for energy generation, conversion, and storage.

Discovery of the electrochemical mechanisms in natural and man-made systems enables scientific design of chemical processes and materials to advance electrochemical systems for clean-energy applications, such as photo-electrochemical cells, batteries, and fuel cells, with the potential for significantly improved performance. Understanding the ingenious mechanisms that nature uses to manage such electrochemical processes provides inspiration for designing man-made systems that mimic these processes.

- Recent innovations in catalyst design for electrochemical reduction of CO_2 resulted in significantly higher activity and selectivity than existing catalysts and avoided the need for high pressures and temperatures. Controlling the catalyst microenvironment by introducing a second metal on palladium-based catalysts led to systematic improvements in the electrochemical conversion of CO_2 to synthesis gas with controllable CO/H_2 ratios. This versatile mixture can lead to a variety of environmentally sustainable chemicals.
- Scientists developed a theoretical model for electron bifurcation, an efficient and reversible electro-chemical reaction so far found only in biology. This process takes the energy of two electrons and splits it unequally, creating one electron with energy high enough to drive difficult reactions and one electron for easier ones. The model predicts that steep free energy gradients help nature avoid "short-circuits" and could guide development of innovative reversible and efficient chemical reactions for clean-energy applications.
- The electrochemical storage mechanism at high voltages for state-of-the-art lithium-ion batteries was elucidated using an array of x-ray structural and electronic characterization tools. Researchers identified two primary charge storage mechanisms for nickel-rich metal oxide electrodes. Below 4.25V, the charge is stored by the transition metal atoms, which lose electrons during charging. Above 4.25V, metal-oxygen bonds develop as electrons are removed from the transition metal. The formation of oxygen-oxygen bonds, which has been postulated as the high-voltage mechanism, was not observed. This fundamental understanding of microscopic mechanisms could help inform future battery design.
- Researchers developed an electrochemical mechanism to protect against unwanted reactions at the electrode-electrolyte interface in lithium-sulfur (Li-S) batteries. Adding small amounts of tellurium to the sulfur cathode or electrolyte significantly improved cycling efficiencies and the number of lifetime charge/discharge cycles (up to 7x improvement). This highlights the potential for a simple and scalable path forward to realize viable, long-lived, high-energy-density Li-S batteries.

New techniques and capabilities at BES facilities.
Recent developments and upgrades at the scientific user facilities provide users with advanced capabilities, especially adopting data science approaches, to conduct cutting-edge science.

- LCLS has successfully delivered coherent x-rays through the newly installed hard x-ray undulator. This new hard x-ray undulator system, developed by the Advanced Photon Source, is the world's first adjustable horizontal gap system for XFELs that can produce vertically polarized x-rays. The energy of the emitted x-rays can be easily changed by tuning the undulator gap to match the needs of an experiment. These unique capabilities provide new scientific research opportunities to a wide range of user communities.
- A data science algorithm was developed that learns from experience and from physical models to reduce the tuning time of a dozen instruments at once for XFEL systems, leading to an optimization of the photon energy that is 65% faster than conventional methods. The reduced machine tuning time frees operators to focus on critical tasks and potentially saves hundreds of hours per year that can be used for different experiments.
- Researchers at a BES neutron source have developed a state-of-the-art capability -- a new 14-tesla magnet with large scattering angle opening and cryogenics to chill samples down to 100 mK. This new sample environment will enable research previously not possible on a broad range of quantum materials and phenomena such as superconductivity, quantum magnetism, and spin liquids.
- A data science technique for nanoscale materials research was developed to visualize and quantify the atomic and molecular structures in three-dimensional samples in real time. The computational efficiency and error sensitivity of the method are suitable for future real-time analysis of data from large characterization facilities.

BES scientific user facilities assist industry to advance technology frontiers, including combating COVID-19.
Industrial researchers used unique capabilities provided by the scientific user facilities to improve advanced manufacturing technologies, and to develop new drugs and vaccines to combat the COVID-19 pandemic.

- Researchers at a BES nanoscale science research center working with their academic and industrial partners have developed and synthesized several designer peptoids (artificial peptides) as potential candidates for COVID-19 vaccines or lung therapeutics. One of these vaccine candidates showed encouraging results in initial testing with animals. Two other peptoid sequences have shown significant activity to prevent viral replication of SARS-CoV-2, which causes COVID-19, in air-interface lung cell cultures.
- X-ray scattering and imaging capabilities provided by BES light sources supported many COVID-19-related research experiments conducted by leading pharmaceutical companies. The most notable results are the structural studies of the proteins of the SARS-CoV-2 virus and their complexes with potential drug candidates. This atomic-resolution 3D structural information is crucial for the development of potential therapeutic drugs and vaccines to fight this pandemic.
- Neutron diffraction and imaging capabilities at a BES neutron source enabled nondestructive characterization of high-resolution structures related to residual stresses in manufactured components, such as complex 3D-printed automobile structures. This data is critical to refine and validate computational modeling as a function of the advanced manufacturing variables, leading to improved efficiency and reliability of the production processes.

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 clean 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, 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 and control 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, theoretical/computational, and instrumentation research that will enable the predictive design and discovery of new materials with novel structures, functions, and properties.

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

- **Scattering and Instrumentation Sciences Research**—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 Research**—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 Research**—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 Request continues to focus resources toward the highest-priority fundamental research that supports the DOE mission, including priorities in support of clean energy. The portfolio emphasizes understanding of how to direct and control energy flow in materials systems over multiple time (femtoseconds to seconds) and length (nanoscale to mesoscale and beyond) scales, and translation of this understanding to prediction of material behavior, transformations, and processes in challenging real-world systems, establishing a foundational knowledge base for future advanced, clean energy technologies and advanced manufacturing processes, including extremes in temperature, pressure, stress, photon and radiation flux, electromagnetic fields, and chemical exposures. To maintain leadership in materials discovery, the research supported by this subprogram explores new frontiers of 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, chemical, and biological sciences to explore new approaches to novel materials design and advanced manufacturing, including understanding to enable polymer upcycling to higher-value molecular systems. In clean energy-related research, there is a growing emphasis on carbon dioxide removal, including direct capture of carbon dioxide from the air. Other topics in clean energy include a focus on low-carbon hydrogen research and long-duration energy storage. Also, critical materials/minerals research will provide foundational knowledge to enable secure and sustainable supply chains for key clean energy technologies.

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 quantum information science (QIS). Materials science for microelectronics will provide the needed advances for future computing, sensors, detectors, and communication 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 data science techniques to enhance the utility of both theoretical and experimental data for predictive design and discovery of materials. As an essential element of this research, this subprogram supports 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.

In addition to a diverse portfolio of single-investigator and small-group research projects, this subprogram supports Computational Materials Sciences, Energy Frontier Research Centers (EFRCs), the Batteries and Energy Storage Hub, and SC QIS Centers (in partnership with other SC programs). These research modalities support multi-investigator, multi-disciplinary research focused on forefront scientific challenges in support of the DOE energy mission. This subprogram also includes the DOE Established Program to Stimulate Competitive Research (EPSCoR). The DOE EPSCoR program will strengthen investments in early-stage clean energy research for U.S. states and territories that do not historically have large federally-supported academic research programs, expanding DOE research opportunities to a broad and diverse scientific community. This subprogram also supports the RENEW initiative to provide undergraduate and graduate training opportunities for students and academic institutions not currently well represented in the U.S. S&T ecosystem.

<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 about the relationship among structure, dynamics, and properties, generating scientific knowledge that is foundational to the BES mission. 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. This program is focused on open questions in materials science and physics, but these characterization tools are broadly applicable to other fields including chemistry, biology, and geoscience, and can be a key component in preparedness for biological threats.

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 link 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, as is the development and application of cryogenic electron microscopy for challenges in physical sciences. For example, to aid in the design of transformational new materials for clean energy technologies such as batteries, *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). Advances in cryogenic microscopy will support the BRaVE initiative since this instrumentation is heavily used to characterize biological threats. Information from these characterization tools is the foundation for the creation of new materials that have extraordinary tolerance and can function in extreme environments without property degradation.

<u>Condensed Matter and Materials Physics Research</u>
This activity supports fundamental experimental and theoretical research to discover, understand, and control novel phenomena in solid materials, generating scientific knowledge that is foundational to the BES mission. These electronic, magnetic, optical, thermal, and structural materials make up the infrastructure for clean energy technologies, as well as accelerator and detector technologies for SC facilities. Also supported is research to understand the role of rare earth and other critical materials in determining functionality, so that they can be reduced or eliminated from key energy technology supply chains.

Experimental research in this program emphasizes discovery and characterization of materials' properties that have the potential to be exploited for new technological functionalities. Complementary theoretical research aims to explain such properties across a broad range of length and time scales. Theoretical research also includes development and integration of predictive theory and modeling for discovery of materials with targeted properties. Advanced computational and data science techniques (including artificial intelligence and machine learning) are increasingly enabling knowledge to be extracted from large materials databases of theoretical calculations and experimental measurements. This program also supports the development of such databases as well as the computational tools that can take advantage of them.

This program continues to emphasize understanding and control of quantum materials whose properties result from interactions of the constituent electrons with each other, the atomic lattice, or light. Investigations include bulk materials as well as 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 electronic, magnetic, and optical properties relevant to energy-efficient microelectronics and quantum information science (QIS). The focus on QIS research couples experimental and theoretical expertise in quantum materials with prototypes of quantum structures that can be used to study the science of device functionality and performance.

Activities also emphasize research to understand how materials respond to temperature, light, radiation, corrosive chemicals, and other environmental conditions. This includes electrical and optical properties of materials related to solar energy as well as the effects of defects on electronic properties, strength, deformation, and failure over a wide range of length and time scales. A recent focus is on extending knowledge of radiation effects to enable predictive capabilities for the extreme environments expected in future nuclear reactors and accelerators for SC facilities.

In FY 2022, BES will continue to partner with other SC programs to support the QIS Centers initiated in FY 2020. These centers focus on a set of QIS applications and cross-cutting topics that span the development space that will impact SC programs, including sensors, communication, quantum emulators/simulators, and enabling technologies that will pave the path to exploit quantum computing in the longer term. Research supported by this program will include theory of materials for quantum applications in computing, communication, and sensing; device science for next-generation QIS systems, including interface science and modeling of materials performance; and synthesis, fabrication, and characterization of quantum materials, including integration into novel device architectures to explore QIS functionality.

In partnership with ASCR, HEP, FES, and NP, BES will continue activities begun in FY 2021 to support multi-disciplinary basic research to accelerate the advancement of microelectronic technologies in a co-design innovation ecosystem, as called for by the Basic Research Needs for Microelectronics report.[a] Among the challenges is discovery science that can lead to low-power microelectronics for edge computing as well as for exascale computers and beyond. Such computing capabilities will be necessary to analyze the vast volumes of data that will be generated by future SC facilities. Similarly, transforming power electronics and the electricity grid into a modern, agile, resilient, and energy-efficient system requires improvements in advanced microelectronics materials, and their integration within a co-design framework.

<u>Materials Discovery, Design, and Synthesis Research</u>
The discovery and development of new materials has long been recognized as the engine that drives science frontiers, technology innovations, and advanced manufacturing. 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, generating scientific knowledge that is foundational to the BES mission.

The BESAC report on transformative opportunities for discovery science reinforced the importance of the continued growth of synthesis science, recognizing the transformational opportunity to realize targeted functionality in materials by controlling the synthesis and assembly of hierarchical architectures and beyond equilibrium matter. In FY 2022 this program

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

will continue to expand the application of materials discovery and synthesis research to understand the unique properties of rare earth and other critical materials/minerals, with the goal of reducing their use. New research directions will be inspired by BES reports related to advanced manufacturing, including polymer upcycling. Understanding of synthesis science will enable design of new systems that are easier to efficiently convert into similar products with comparable or enhanced complexity, functionality, and value. Emphasis will include advancing the basic science of advanced manufacturing through innovative approaches for scalable assembly and integration of predictive modeling with characterization tools tuned to advanced manufacturing scale, complexity, and speed.

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. Major research directions include the controlled synthesis and assembly of nanoscale materials into functional materials with desired properties; 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 academic 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 and world-class national laboratories managed by the DOE. This research leverages DOE national user facilities and takes 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 in the EPSCoR jurisdictions. The FY 2022 program will focus on EPSCoR State-National Laboratory Partnership awards promoting single PI and small group interactions with the unique capabilities of the DOE national laboratory system and will focus on clean energy research, expanding this important research community. The program supports early career scientists from EPSCoR jurisdictions on an annual basis and provides complementary support for research grants to eligible institutions.

Energy Frontier Research Centers
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 and gas separation; quantum materials and quantum information science; microelectronics; and materials for future nuclear energy and waste storage.

After eleven years of research activity, the program has produced an impressive breadth of scientific accomplishments, including over 12,700 peer-reviewed journal publications.

BES 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. 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 scientific meetings of the EFRC researchers biennially.

In FY 2022 BES plans to issue a Funding Opportunity Announcement to re-compete the four-year EFRC awards that were made in FY 2018. Emphasis will be placed on clean energy topics and other program priorities.

Energy Innovation Hubs

The Joint Center for Energy Storage Research (JCESR), the Batteries and Energy Storage Hub, 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 identified critical scientific gaps to serve as a foundation for the research. The research directions are consistent with the priorities established in the 2017 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. JCESR is focusing on advances that 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 proving critical 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 are being 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, impactful research. In FY 2022, JCESR will receive the tenth and final year of funding.

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 physical 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 or functionalities, and in turn, create new advanced, innovative technologies. Given the importance of materials to virtually all technologies, including clean energy, computational materials sciences are critical for American competitiveness in advanced manufacturing and global leadership in innovation.

This paradigm shift will accelerate the design of revolutionary materials to enable the Nation's energy and quantum information security, tackle the climate challenge, and enhance economic competitiveness. Success will require extensive

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

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 or quantum materials with new functionalities. This research is performed by small groups and fully integrated teams. Large teams combine the skills of experts in materials theory, modeling, computation, synthesis, characterization, and fabrication. The research includes development of new ab initio theory, contributing the generated data to databases, as well as advanced characterization and controlled synthesis to validate the computational predictions. It uses the unique world-leading tools and instruments at DOE's user facilities. The computational codes will use DOE's leadership computational facilities and be positioned to take advantage of today's petascale and tomorrow's exascale high-performance computers. This will result in open source, robust, validated, user-friendly software that captures the essential physics of relevant materials systems. The goal is the use of these codes and generated 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 small and large team modalities. Management reviews by a peer review panel are held in the first year of the award for large teams. Mid-term peer reviews are held to assess scientific progress, with regular teleconferences, annual progress reports, and active oversight by BES throughout the performance period.

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Materials Sciences and Engineering	**$435,008**	**$489,661**	**+$54,653**
Scattering and Instrumentation Sciences Research	$74,031	$85,675	+$11,644
Funding continues 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 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 focuses on innovation that will enable assessment of new regimes not amenable to current characterization approaches.		The Request will continue to focus on the development and use of advanced characterization tools to address the most challenging fundamental questions in materials science, including quantum behavior and properties. The use of multiscale and multimodal techniques to extract information on multiple length and time scales is a growing emphasis, as is the development and application of cryogenic microscopy techniques to answer open questions in physical sciences. Advanced instrumentation research can be applied to diverse national priorities, including QIS, clean energy science, and preparedness for biological threats.	Funding will emphasize the advancement of novel measurement techniques and application of the tools to a broad range of science challenges, from quantum phenomena in energy materials to soft materials. Expanded investments will include a focus on clean energy research in underrepresented communities and institutions.

(dollars in thousands)

FY 2021 Enacted	FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Condensed Matter and Materials Physics Research $170,200	$187,769	+$17,569
Funding continues to support research to understand, 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 provides continued support for the QIS Centers established in FY 2020. Investments 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. Support increases for investigations of 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 includes AI/ML for data-driven science to enhance materials discovery.	The Request will continue to emphasize the understanding and control of the fundamental properties of materials that are central to their functionality in a wide range of clean energy-relevant technologies, including critical materials/minerals. Exploration of quantum materials remains a high priority, and particularly the role that these materials play in microelectronics, accelerators, and the broad emerging field of QIS. The program will continue to partner with other SC program offices to support the QIS Centers that were initiated in FY 2020. Additional focus areas include the response of materials to environmental conditions, including temperature, light, corrosive chemicals, and radiation. Integration of experimental techniques with theoretical and computational research is a key to success, with an emphasis on new data science techniques.	Funding will enhance clean energy research, critical materials/minerals as well as materials in high-radiation environments including future accelerators. Efforts will also support the development and integration of computational and data science tools to enable scientific discovery. Expanded investments will include a focus on clean energy research in underrepresented communities and institutions.

(dollars in thousands)

FY 2021 Enacted	FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Materials Discovery, Design, and Synthesis Research $71,189	$88,047	+$16,858
Funding continues for 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 is 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 emphasizes new approaches to replace or minimize the use of critical and rare earth materials in energy-relevant technologies.	The Request will continue support for the design, discovery, and synthesis of novel forms of matter with desired properties and functionalities with an emphasis on advancing the fundamental science relevant to future advanced manufacturing, including innovative approaches to scalable assembly and integration of characterization and predictive modeling. Research will continue to explore science-based solutions to materials criticality. Research on bio-mimetic and biology-inspired materials is relevant to energy technologies as well as other national priorities such as preparedness for and response to biological threats.	The scientific focus will continue to evolve in response to research directions identified in recent strategic planning activities, such as the 2020 Basic Research Needs Workshop for Transformative Manufacturing. Expanded investments will include a focus on clean energy research in underrepresented communities and institutions.
Established Program to Stimulate Competitive Research (EPSCoR) $25,000	$25,000	$ —
Funding continues 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 emphasizes implementation awards, larger multiple principal investigator grants that develop research capabilities in EPSCoR jurisdictions. The FY 2021 funding opportunity solicits both renewals of FY 2019 awards and new proposals. Investment continues 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 implementation awards, FY 2022 will emphasize state-lab partnership awards, single principal investigator and small group grants that promote interactions with the unique capabilities and expertise at the DOE National Labs with a technical focus on clean energy research. The FY 2022 funding opportunity will consider 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 will focus on State-National Laboratory Partnership awards focused on clean energy research and promoting single PI and small group interactions with the unique capabilities of the DOE national laboratory system.

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Energy Frontier Research Centers	$57,500	$64,678	+$7,178
Funding provides 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.		The Request will provide the third year of support for four-year EFRC awards that were made in FY 2020 in the following topical areas: environmental management, microelectronics, and QIS. In addition, BES plans to issue a solicitation in FY 2022 to re-compete the EFRC awards made in FY 2018, with emphasis on clean energy and other high-priority topics.	Technical emphasis for the EFRC program will include research directions identified in recent strategic planning activities and aligned with program priorities. Expanded investments will include a focus on clean energy research in underrepresented communities and institutions.
Energy Innovation Hubs	$24,088	$25,000	+$912
Funding continues 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 continues 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 closely integrates theory, simulation, and experimentation to elucidate the impact of coupled phenomena and enable predictive design of new materials for batteries.		The Request will provide the tenth and final year of funding for JCESR. JCESR is focusing on advancing understanding of scientific principles for electrochemical stability; transport in the bulk, at interfaces, and across membranes; coupling electrochemical and mechanical processes; and dynamics that control reversible and irreversible reactions. Tight coupling of theory, simulation, and characterization will accelerate understanding of the complex, coupled phenomena.	Funding will support the final year of funding for JCESR.

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Computational Materials Sciences	$13,000	$13,492	+$492
Funding continues to support 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 utilizes leadership class computers, and will be made available to the broad research community. The codes incorporate frameworks suited for future exascale computer systems.		The Request will continue research that focuses on development of computational codes and associated experimental and computational databases for the predictive design of functional materials. The research includes development of new ab initio theory, populating databases, and advanced characterization and controlled synthesis to validate the computational predictions. The goal is open source, validated software that uses today's DOE's leadership computational facilities and is poised to take advantage of tomorrow's exascale high-performance computers.	Funding will continue to support research in ongoing CMS Awards.

Note: Funding for the subprogram above, includes 3.65% of research and development (R&D) funding for the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Programs.

Basic Energy Sciences
Chemical Sciences, Geosciences, and Biosciences

Description

Understanding and ultimately controlling transformations of energy among forms, and rearrangements of matter across multiple scales starting at the atomic level, are essential to development of innovative clean-energy technologies. 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, separations, and light-induced chemical transformations. The 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 Research**—Discover the foundational factors controlling chemical reactivity and dynamics in the gas phase, in condensed phases, and at interfaces, based upon a quantum description of the interactions among photons, electrons, atoms, and molecules.
- **Chemical Transformations Research**—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 Research**—Elucidate the molecular mechanisms of the capture of light energy and its conversion into electrical and chemical energy through biological and chemical pathways.

The Request continues the highest-priority fundamental research, including support of clean energy such as chemistry for low-carbon, efficient, sustainable, and circular approaches to advanced manufacturing. Related research emphasizes chemical upcycling of polymers and the chemistry of rare earth and platinum-group elements important in manufacturing supply chains (critical materials/minerals). Fundamental biochemistry will develop models and datasets for discovery of principles to enable biomimetic and biohybrid clean energy systems. Research focused on molecular science will enable new microelectronics and lead to understanding of the phenomena relevant to QIS and quantum computing. Bringing simulation and experiments together, integration of data science and computational chemistry will provide the needed tools and infrastructure for shared data repositories.

The following five synergistic, foundational research themes are at the intersections of multiple research focus areas in this portfolio. Ultrafast Chemistry probes electron and atom dynamics to understand energy and chemical conversions. Chemistry at Complex Interfaces advances understanding of how the dynamics of interfaces as well as their structural and functional disorder influence chemical phenomena. Charge Transport and Reactivity explores how charge dynamics contribute to energy flow and chemical conversions. Reaction Pathways in Diverse Environments discovers the influence of nonequilibrium, heterogeneous, nanoscale, and extreme environments on complex reaction mechanisms. Chemistry in Aqueous Environments addresses water’s unique properties, and the role aqueous systems play in energy and chemical conversions.

The subprogram supports a diverse portfolio of research efforts including single investigators, small groups, and larger multi-investigator, cross-disciplinary teams—through EFRCs, the Fuels from Sunlight Energy Innovation Hub program, Computational Chemical Sciences, Data Science, and QIS—to advance foundational science for development of clean-energy technologies. The subprogram also supports, in partnership with other SC programs, SC QIS Research Centers that were established in FY 2020. This subprogram also supports the RENEW initiative to provide undergraduate and graduate training opportunities for students and academic institutions not currently well represented in the U.S. S&T ecosystem.

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, in condensed phases, and at interfaces. This activity provides leadership for ultrafast chemistry, supporting research that advances ultrafast tools and approaches, as well as their application to probe and control chemical processes. Research supports theory and computation for accurate and efficient descriptions of molecular reactions and chemical dynamics.

The principal research thrusts in this activity are atomic, molecular, and optical sciences (AMOS), gas phase chemical physics (GPCP), condensed phase and interfacial molecular science (CPIMS), and computational and theoretical chemistry (CTC). AMOS research emphasizes the fundamental interactions of atoms and molecules with ultrafast electrons and photons, to characterize and control their behavior. Novel attosecond sources, x-ray free electron laser sources such as the LCLS, and ultrafast electron diffraction are used to image the dynamics of electrons and charge transport. CPIMS research emphasizes foundational research at the boundary of chemistry and physics, pursuing a molecular-level understanding of chemical, physical, and electron- and photon-driven processes in liquids and at interfaces. Experimental, theoretical, and computational investigations in the condensed phase and at interfaces aim to elucidate the molecular-scale chemical and physical properties and interactions that govern condensed phase structure and dynamics. The GPCP program supports research on fundamental gas-phase chemical processes important in energy applications. Research in this program explores chemical reactivity, kinetics, and dynamics in the gas phase at the level of electrons, atoms, molecules, and nanoparticles. The CTC program supports development, improvement and integration of new and existing theoretical and massively parallel computational or data-driven strategies for the accurate and efficient prediction or simulation of processes and mechanisms. 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 open-source computational chemistry codes and databases. In the context of SC QIS Centers, this research also lays the groundwork for applications of future quantum computers to computational quantum chemistry.

In FY 2022, BES, in partnership with other SC programs, will continue support for the multi-disciplinary multi-institutional QIS centers, initiated in FY 2020. The SC QIS centers will focus on a set of QIS applications or cross-cutting topics including innovative research on sensors, quantum emulators/simulators, and enabling technologies that will pave the path to exploit quantum computing in the longer term. Research initiated in FY 2021 in microelectronics will continue with a focus on unraveling complex mechanisms of chemical reactions at interfaces to inform the design and synthesis of new materials.[a] The Fundamental Interactions activity will continue to advance data science and computational approaches for chemical sciences with a focus on integration of databases and computational chemistry tools for the generation of scientific knowledge that is foundational to the BES mission.

Chemical Transformations Research

This activity seeks fundamental understanding of chemical reactivity, matter and charge transport, and chemical separation and stabilization processes that are foundational in core research areas—catalysis science, separation science, heavy element chemistry, and geosciences—which are critical for developing future clean-energy and advanced manufacturing technologies. The research entails use of ultrafast spectroscopy to follow transient species during reactions; advances understanding of charge transport and reactivity, which determine the kinetics of electrocatalytic, separations, and geochemical processes; explores the influence of complex interfaces on chemical transformations; and develops understanding of chemistry in aqueous environments that influence many sustainable chemical processes. Understanding reaction pathways in diverse catalytic, separation and geological environments is a major focus in this activity.

Catalysis science research is focused on understanding reaction mechanisms, precise synthesis, *operando* characterization, manipulation of catalytic active sites and their environments, and control of reaction conditions for efficiency and selectivity. A primary goal is the molecular-level control of chemical transformations relevant to the sustainable conversion of energy resources, with emphasis on thermal and electrochemical conversions. Separation science research seeks to understand and ultimately predict and control the atomic and molecular interactions and energy exchanges determining the efficiency and viability of chemical separations, with emphasis on critical elements and atmospheric CO_2. The major

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

focus is to advance discovery of principles and predictive design of future chemical separation approaches with improved efficiencies. Heavy element chemistry provides foundational knowledge on the influence of complex environments, such as multiple phases and extreme conditions of temperature and radiation, on the dynamic behavior of actinide compounds. A primary goal is to advance understanding of the unique chemistry of f-electron systems that is required to design new ligands for actinide separations processes, to predict the chemical evolution of actinides in nuclear wastes and next-generation reactors, and to improve models of actinide environmental transport. Geosciences research provides the fundamental science underlying the subsurface chemistry and physics of natural substances under extreme conditions of pressure or confined environments. 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 subject to chemo-mechanical stress corrosion and strain localization.

In FY 2022, this activity will continue to support efforts central to transformative approaches to advanced manufacturing,[a] including predictive design of catalytic and separations processes for circular use of natural and synthetic resources with atom and energy efficiency, as exemplified by polymer upcycling—the selective chemical deconstruction of polymers that make up plastics followed by reassembly into high-value products.[b] This activity will increase focus on discovery and design of sustainable cycles for carbon and hydrogen, by means of enhanced carbon separation from dilute as well as concentrated sources and clean-energy cycles of hydrogen generation and use. This activity will also continue to address challenges in critical materials with focus on novel approaches for selective separation, and substitution and use of rare earth and platinum-group elements. Research will continue to investigate the unique quantum phenomena enabled by f-electron elements, which could lead to novel approaches for QIS. Research will develop fundamental knowledge of subsurface processes across spatial and temporal scales—such as mineralization, crack propagation, and rock fracture – that are critical for innovative methods of resource extraction, including critical minerals. The use of data science and AI/ML approaches will continue to be emphasized in research across the portfolio to accelerate the generation of scientific knowledge that is foundational to the BES mission.

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. Innovative research on absorption, transfer, and conversion of energy across spatial and temporal scales and on redox interconversion of small molecules (e.g., carbon dioxide/methane, nitrogen/ammonia, and protons/hydrogen) advances basic understanding of dynamic mechanisms of charge transport and reactivity. Studies of ultrafast chemistry and photo-driven quantum coherence probe the short time-scales critical in natural photosynthesis and artificial molecular systems and can provide insights into the role of quantum phenomena in chemical and biochemical reactions. Crosscutting research on the dynamics and function of enzymes, natural and artificial membranes, and nano- to meso-scale structures provides mechanistic understanding of how complex interfaces and aqueous environments influence reaction pathways and can inspire new strategies for clean energy conversions.

This activity integrates multidisciplinary research at the interface of chemistry, physics, and biology. Research of biological systems provides insights for understanding and enhancing man-made chemical systems. In a reciprocal manner, studies of chemical (non-biological) systems provide insights on the dynamics and reactivity underlying biochemical processes. Research in natural photosynthesis advances knowledge of biological mechanisms of solar energy capture and conversion and can inspire development of bio-hybrid, biomimetic, and artificial photosynthetic systems for clean-energy production. Studies of complex multielectron redox reactions, electron bifurcation, and quantum phenomena in biological systems can suggest innovative approaches to energy conversion and storage strategies for clean-energy applications. Complementary research on the elementary steps of light absorption, charge separation, and charge transport of solar energy conversion in man-made systems provides foundational knowledge for the use of solar energy for fuel production and electricity generation. Research also addresses fundamental effects resulting from ionizing radiation to understand chemical reactions in extreme environments and to provide insights for remediation, fuel-cycle separation, and design of nuclear reactors.

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

In FY 2022, research will continue to establish a molecular-level understanding of biochemical processes. Efforts will build on BES biochemistry and biophysics research to discover and design chemical processes and complex structures that can enable clean energy innovations for advanced manufacturing and microelectronics, such as bio-inspired, biohybrid, and biomimetic systems with desired functions and properties. Studies of photo-driven quantum coherence in natural photosynthesis and artificial molecular systems will continue with the goal of inspiring new approaches in QIS. Research will also address challenges such as reducing the use of critical and rare earth elements in light absorbers and catalysts for clean energy. Efforts across this research portfolio will continue to generate scientific knowledge that is foundational to the BES mission.

Energy Frontier Research Centers

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 processes for improved electrochemical conversion and storage of energy; the understanding of catalytic chemistry and biochemistry that are foundational for fuels, chemicals, separations, and polymer upcycling; interdependent energy-water issues; quantum information science; future nuclear energy and the chemistry of waste processing; and advanced interrogation and characterization of the earth's subsurface. After eleven years of research activity, the program has produced an impressive breadth of scientific accomplishments, including over 12,700 peer-reviewed journal publications.

BES 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. Each EFRC undergoes a review of its management structure and approach in the first year of the award and a mid-term assessment by outside experts 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.

In FY 2022 BES plans to issue a Funding Opportunity Announcement to re-compete the four-year EFRC awards that were made in FY 2018. Emphasis will be placed on clean energy topics and other program priorities.

Energy Innovation Hubs

The two multi-investigator, cross-disciplinary solar fuels research awards for the Fuels from Sunlight Hub program build on the unique accomplishments of the first Fuels from Sunlight Hub and address both new directions and long-standing challenges in the use of solar energy, water, and carbon dioxide as the only inputs for fuels production for clean energy. The FY 2022 Request will continue support for these early-stage fundamental research efforts that target innovative solutions to key scientific challenges for solar fuels (as identified in the strategic planning report from the Roundtable on Liquid Solar Fuels), including how to overcome degradation mechanisms to increase durability of solar fuel-generating components and systems, design catalytic microenvironments to selectively produce energy-rich solar fuels, take advantage of the direct coupling of light-driven phenomena and chemical processes to improve component and system performance, and tailor complex phenomena that interact and affect function of integrated multicomponent assemblies for solar fuels production.[a]

BES uses a variety of methods to regularly assess the progress of the awards, including annual progress reports, regular phone calls with the Directors, periodic Directors' meetings to ensure coordination and communication, and on-site visits and reviews. Each award undergoes a review of its management structure and approach in the first year and beginning in the second year will have an annual peer review of research progress against its scientific goals.

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

Computational Chemical Sciences

The computational chemical sciences program (CCS) supports basic research to develop validated, open-source codes and associated experimental/computational databases for modeling and simulation of complex chemical processes and phenomena that allow full use of emerging exascale and future planned DOE leadership-class computing capabilities. BES launched CCS research awards in FY 2017 and additional awards were initiated in FY 2018. The FY 2017 awards were recompeted in FY 2021. The FY 2018 awards will be recompeted in FY 2022. This research supports a publicly accessible website[a] of open source, robust, validated, user-friendly software that captures the essential physics and chemistry of relevant chemical systems. The goal is use of these codes/data by the broader research community and by industry to dramatically accelerate chemical research in the U.S.

BES uses a variety of methods to regularly assess the progress of the CCS awards, including annual progress reports, regular phone calls with the Directors, and periodic meetings of funded activities to ensure coordination and communication. Large team awards undergo a review of management structure and approach in the first year and a mid-term review by outside experts to evaluate scientific progress compared to the project's scientific goals.

General Plant Projects

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.

[a] https://ccs-psi.org/

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Chemical Sciences, Geosciences, and Biosciences	**$394,285**	**$448,939**	**+$54,654**
Fundamental Interactions Research	$107,904	$124,415	+$16,511
Funding continues to develop forefront ultrafast approaches, with emphasis on the use of x-ray free electron lasers, including LCLS and its upgrades. Gas-phase research continues studies of how reactive intermediates in heterogeneous environments impact reaction pathways, and quantum phenomena underlying QIS in tailored molecules. Research extends 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 increases with the aim of understanding the energy and chemical conversion mechanisms for clean-energy applications and of designing and synthesizing new materials relevant to microelectronics. This activity continues to develop advanced theoretical and computational approaches that can be scaled to operate on exascale computers. Development of AI/ML methods increases to enable novel data science approaches for knowledge discovery. Research emphasizes efforts to drive advances in the application of quantum information science for understanding and exploiting quantum phenomena in chemical systems. This activity provides continuing support for the QIS Research Centers established in FY 2020.		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 impact reaction pathways. Increased emphasis will be placed on quantum phenomena underlying QIS, such as coherence and entanglement. Research will extend efforts to understand and control chemical processes and quantum phenomena at the molecular level. Research to understand and control interfacial chemical reactions will continue with the aim of understanding the energy and chemical conversion mechanisms for clean-energy applications and 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 data science methods will increase to enable novel approaches for knowledge discovery. This activity provides continued support for the QIS Research Centers established in FY 2020.	Technical emphasis will include new efforts to unravel the fundamental mechanisms of energy and chemical conversions underlying clean-energy applications, to understand and exploit quantum phenomena important for QIS, and to understand and control interfacial chemical reactions that can enable new materials for microelectronics. Support will continue for the development of advanced theoretical and computational approaches, with focus on integration of data science and computational chemistry tools for the generation of scientific knowledge that is foundational to the BES mission. Expanded investment will include a focus on clean energy research in underrepresented communities and institutions.

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Chemical Transformations Research	$112,292	$117,725	+$5,433
Funding continues 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 important in clean-energy applications and chemical upcycling of polymers. Separation science research continues to focus on novel approaches to separate complex chemical mixtures with high efficiency, with increased focus on separation of carbon dioxide from dilute mixtures. Geosciences research continues 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 continues to deepen understanding of actinide speciation and reactivity, fundamental theories of f-electron systems, and approaches to synthesize and separate actinide compounds. Research on the chemistry of rare earth elements, including heavy elements such as lanthanides, focuses on understanding their reactivity to limit their use in catalytic processes, their interactions and chemical processes in multiphase systems relevant to separations, and their behavior in rare-earth containing minerals that are relevant to extraction in geological environments.		The Request will continue supporting fundamental research to understand catalytic mechanisms for thermo- and electro-chemical conversions important in clean-energy applications. Separation science research will continue to focus on innovative separation mechanisms for high-efficiency processes, including reactive and electro-separations, and novel solvents. Heavy element research will continue to deepen understanding of actinide speciation and reactivity and fundamental theories of f-electron systems. Geosciences research will continue to elucidate subsurface phenomena, such as mineralization and rock fracture propagation under extreme subsurface conditions. Areas for increased emphasis in FY 2022 include advances in atomically precise synthesis of new catalysts and in chemical processes that will gain the knowledge required to develop transformative, sustainable approaches in advanced manufacturing, such as combined catalysis and separations research for chemical upcycling of polymers; understanding of multiscale phenomena in extreme and constrained environments in the subsurface; and research on rare earth elements focused on advanced approaches to separations from complex and dilute mixtures, and discovery of alternative approaches that reduce their use.	Funding will emphasize research on catalysis and separation science research to provide the foundational knowledge needed for advanced manufacturing, including chemical upcycling of polymers, and microelectronics; for studies of the chemistry of rare earth and platinum-group elements important in critical materials to enable their improved separation, substitution, and reduction in use; and for development of innovative approaches to sustainable carbon and hydrogen cycles. The use of data science and AI/ML approaches will continue to be emphasized in research across the portfolio to accelerate the generation and sharing of scientific knowledge and its impact in clean-energy technologies. Expanded investment will include a focus on clean energy research in underrepresented communities and institutions.

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Photochemistry and Biochemistry Research	$82,589	$106,871	+$24,282
Funding continues 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 provide fundamental knowledge to guide the design of new clean-energy systems. Funding increases 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, informs bioinspired design of catalysts and reaction pathways, for instance to guide new approaches for clean-energy applications and polymer upcycling. Research on metal uptake and use by biological systems informs bio-inspired separation processes. Studies also increase understanding of how rare elements can be minimized in photo-absorbers and catalysts for solar fuels. Advances in solar fuels 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 address the relationship between quantum phenomena and the efficiency and fidelity of energy transfer and conversion.		The Request will continue support of core research to understand physical, chemical, biophysical, and biochemical processes of light energy capture and conversion in biological and chemical systems. Studies of light absorption, energy transfer, charge transport, separation processes, and photocatalysis in natural and artificial systems will provide fundamental insights that can lead to innovations in the design of new clean-energy systems and processes. Knowledge of the molecular mechanisms of biocatalysis will guide the bio-inspired design of efficient catalysts and reaction pathways. Study of biochemical processes and structures will provide a foundation for bio-inspired, biohybrid, and biomimetic systems with desired functions and properties. Solar fuels research will continue to address the molecular mechanisms of photon capture, charge transport, product selectivity and separation from non-target molecules, and the reduction of rare elements and critical material use in photoabsorbers and catalysts. Biological and chemical studies will discover how quantum phenomena affect energy conversion efficiency and fidelity.	Technical emphasis will include research that targets fundamental science for innovation in advanced manufacturing, microelectronics, and clean-energy technologies through advances in fundamental biochemical, chemical, and biophysical principles; bio-inspired design and development of biomimetic and biohybrid energy systems and processes; and the discovery and understanding of mechanisms and processes of energy capture and conversion in both natural and artificial systems. Expanded investment will include a focus on clean energy research in underrepresented communities and institutions.

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Energy Frontier Research Centers	$57,500	$64,678	+$7,178
Funding provides 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.		The Request will provide the third year of support for four-year EFRC awards that were made in FY 2020 in the following topical areas: environmental management, polymer upcycling, and QIS. In addition, BES plans to issue a solicitation in FY 2022 to re-compete the EFRC awards made in FY 2018, with an emphasis on clean energy topics and other program priorities.	Technical emphasis for the EFRC program will include research directions identified in recent strategic planning activities. Expanded investment will include a focus on clean energy research in underrepresented communities and institutions.
Energy Innovation Hubs	$20,000	$20,758	+$758
Funding continues 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 continues 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 into principles for solar energy capture and conversion into liquid fuels. Efforts that integrate experiment and theory and couple high-throughput experimentation with artificial intelligence continue to be emphasized.		The Request will continue support of early-stage fundamental research to address both long-standing and emerging new scientific challenges for solar fuels generation. Research will continue to focus on innovative artificial photosynthesis approaches to generate liquid fuels using only sunlight, carbon dioxide, and water as inputs. Experiment and theory are integrated for the design of processes, components, and systems for selective, stable, and efficient liquid solar fuels production for clean energy.	Funding will support priority research areas.

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Computational Chemical Sciences	$13,000	$13,492	+$492
Funding continues 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 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.		The Request will continue CCS awards made in FY 2021, with ongoing focus on developing public, open-source codes for future exascale computer platforms. In addition, FY 2022 funds will support a recompetition of CCS awards made in FY 2018 and will make awards for development of new theoretical and computational approaches and open-source codes and databases 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. New investments will include a focus on clean energy research in underrepresented communities and institutions.
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.

Note: Funding for the subprogram above, includes 3.65% of research and development (R&D) funding for the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Programs.

Basic Energy Sciences
Scientific User Facilities (SUF)

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 a wide diversity of universities, industry, and government laboratories to advance a broad 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 electrons, x-rays, 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 facilities, 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 with improved computational and data analysis infrastructure, improved nanoscience 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 data science 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 instrument) to save the highest-value data from user experiments.

The BES user 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 and delivery systems 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.

In FY 2019, more than 16,000 scientists and engineers in many fields of science and technology used BES scientific facilities. Due to the COVID-19 pandemic, BES scientific user facilities were under curtailed user operations, available mainly through remote access for the majority of the instruments during the second half of FY 2020. Additional funds provided through the CARES Act supported extraordinary operations of the light and neutron sources and nanoscale science research centers for COVID-specific research during curtailed operations. Light sources and neutron sources were able to provide critical support to the development of potential therapeutic drugs and vaccines through structural studies of the proteins of the SARS CoV-2 virus, which causes COVID-19. The BES facilities stand ready to continue to support ongoing research efforts to combat COVID-19 and future public health challenges. In FY 2022, continued support for biological threats at the light and neutron sources is recognized by the BRaVE initiative.

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 their 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 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 uniquely distinguished via isotope substitution experiments, for example substitution of deuterium for hydrogen 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 instruments for inelastic scattering, small angle scattering, powder and single crystal diffraction, neutron imaging, and engineering diffraction.

The Spallation Neutron Source (SNS) at ORNL uses a different 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, cascades of 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 large suite of capabilities for high and low temperature, high magnetic field, and high-pressure sample environment equipment is available for the instruments. All the SNS instruments are in high demand by researchers world-wide in a range of disciplines from biology to materials sciences and condensed matter physics.

Nanoscale Science Research Centers

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 while they interact with their physical and chemical environments. 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 Nanoscale Science Research Centers (NSRCs) focus on interdisciplinary discovery research at the nanoscale, serving as the basis for a national program that encompasses new science, new tools, and new computing capabilities. Distinct from the x-ray and neutron sources, NSRCs comprise of a suite of smaller unique tools and expert scientific staff. The five NSRCs 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 and scanning probe microscopy; and nanostructure fabrication and integration. Selected thematic areas include catalysis, electronic materials, nanoscale photonics, and soft and biological materials. The centers are typically near BES facilities for x-rays or neutrons, or near SC-supported computation facilities, which complement and leverage each other's capabilities. These custom-designed laboratories contain clean rooms, nanofabrication resources, one-of-a-kind signature instruments, and other instruments generally available only at major user facilities. The NSRC electron and scanning probe microscopy capabilities provide superior atomic-scale spatial resolution and simultaneously obtain structural, chemical, and other types of information from sub-nanometer regions at short time scales. They house one of the highest resolution electron microscopes in the world. Data science approaches are enabling large and fast data acquisition, real-time analysis, and autonomous experiments. Operating funds enable cutting-edge research, provide technical support, and administer the user program at these facilities, which serve academic, government, and industry researchers with access determined through external peer review of user proposals.

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 comprises two major components—the total estimated cost (TEC) and other project costs (OPC). The TEC includes project costs incurred after Critical Decision-1, such as costs associated with all engineering design and inspection; the acquisition of land and land rights; direct and indirect construction/fabrication; 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 NSRC 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 that is specific to BES facility needs and directions. BES coordinates with the SC Office of Accelerator R&D and Production on crosscutting research and technology areas. Accelerator research is the cornerstone for the development of new technologies that will improve performance of accelerator-based light sources and neutron scattering facilities, in support of the Accelerator Science and Technology Initiative. 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 the most advanced Artificial Intelligence (AI)/Machine Learning (ML) 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 BES 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 supports training in the field of particle beams and their associated accelerator applications.

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Scientific User Facilities (SUF)	**$1,026,707**	**$1,057,200**	**+$30,493**
X-Ray Light Sources	$525,000	$538,282	+$13,282
The funding supports operations at five BES light sources (LCLS, APS, ALS, NSLS-II, and SSRL).		The Request will support operations at five BES light sources (LCLS, APS, ALS, NSLS-II, and SSRL).	Funding will support LCLS, APS, ALS, NSLS-II and SSRL operations at 97 percent of optimal.
High-Flux Neutron Sources	$292,000	$293,871	+$1,871
The funding supports operations at SNS and HFIR.		The Request will support operations at SNS and HFIR.	Funding will support operations for SNS and HFIR at approximately 96 percent of optimal.
Nanoscale Science Research Centers	$139,000	$142,387	+$3,387
The funding supports operations for the five NSRCs (CFN, CNM, CNMS, TMF, and CINT). The NSRCs continue to develop nanoscience and QIS-related research infrastructure and capabilities for materials synthesis, device fabrication, metrology, modeling and simulation.		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 at 96 percent of optimal, including support to develop QIS-related research infrastructure and capabilities.
Other Project Costs	$19,000	$14,300	-$4,700
Other Project Costs continue for the LCLS-II-HE project at SLAC National Accelerator Laboratory, PPU at Oak Ridge National Laboratory, Second Target Station project at Oak Ridge National Laboratory, and the Cryomodule Repair and Maintenance Facility (CRMF) project at SLAC.		The Request will support Other Project Costs for the LCLS-II-HE project at SLAC National Accelerator Laboratory, PPU at Oak Ridge National Laboratory, the Second Target Station project at Oak Ridge National Laboratory, and the Cryomodule Repair and Maintenance Facility (CRMF) project at SLAC.	Other Project Costs follow project plans.

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Major Items of Equipment	$10,500	$30,000	+$19,500
The funding supports 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 also continues with R&D, design, engineering, prototyping, other supporting activities, and possible procurements. The project received CD-1/3A approval on 4/15/2021.		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, long lead procurements and construction/equipment procurements. The project is planning for CD-2/3 approval early in FY 2022. The recapitalization project for the NSRCs will also continue with R&D, design, engineering, prototyping, other supporting activities, and possibly long-lead procurements. The project is planning for CD-2/3 approval in FY 2022.	Funding will support the NEXT-II and NSRC Recapitalization MIE projects.
Research	$41,207	$38,360	-$2,847
The funding supports 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.		The Request will support high-priority research activities for advanced seeded FEL schemes that provide several orders of magnitude performance enhancement, detectors with high read out rate, optics that can handle high heat load and preserve the coherent wave front, and applications of data science 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 data science methods and tools to address data and information challenges at the BES user facilities, including accelerator optimization, control, prognostics, and experiment automation and real time data analysis.

Note: Funding for the subprogram above, includes 3.65% of research and development (R&D) funding for the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Programs.

Basic Energy Sciences
Construction

Description

Accelerator-based x-ray light sources, accelerator-based pulsed neutron sources, and reactor-based neutron sources are essential user facilities that enable critical DOE mission-driven science, including research in support of clean energy, as well as research in response to national priorities such as the COVID-19 pandemic. 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.

<u>21-SC-10, Cryomodule Repair & Maintenance Facility (CRMF), SLAC</u>

The CRMF project will provide a much needed capability to maintain, repair, and test superconducting radiofrequency (SRF) accelerator components. These components include but are not limited to superconducting RF cavities and cryomodules that make up the new superconducting accelerator being constructed by the LCLS-II and LCLS-II-HE projects, high brightness electron injectors, and superconducting undulators. 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.

<u>19-SC-14, Second Target Station (STS), ORNL</u>

The STS project will expand SNS capabilities for neutron scattering research by exploiting part of the higher SNS accelerator proton beam 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 beam power density 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 15 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-1, Approve Alternative Selection and Cost Range, on November 23, 2020, which established the approved TPC range of $1,800,000,000–$3,000,000,000.

<u>18-SC-10, Advanced Photon Source Upgrade (APS-U), ANL</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 x-ray brightness and coherent flux. Nine new x-ray beamlines will be installed and several existing beamlines will be upgraded to take advantage of the enhanced x-ray properties. 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, projected in 2Q FY 2026.

<u>18-SC-11, Spallation Neutron Source Proton Power Upgrade (PPU), ORNL</u>

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 by fabricating and installing seven new superconducting radio frequency (SRF) cryomodules and supporting RF equipment, upgrade the first target station to accommodate beam power up to 2 MW, and deliver a 2 MW-qualified target. 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. The improved target performance at the increased beam power of 2 MW is enabled by the addition of a new gas injection system and a redesigned mercury target vessel. The project received CD-3, Approve Start of Construction, on October 6, 2020, with a Total Project Cost (TPC) of $271,567,000 and CD-4, Approve Project Completion, expected in 4Q FY 2028.

18-SC-12, Advanced Light Source Upgrade (ALS-U), LBNL

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 project received CD-2, Approve Performance Baseline, on April 2, 2021. The project CD-2 Total Project Cost (TPC) is $590,000,000 with a projected CD-3, Approve Start of Construction, in 3Q of FY 2022.

18-SC-13, Linac Coherent Light Source-II-High Energy (LCLS-II-HE), SLAC

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-3A, Approve Long Lead Procurements, on May 12, 2020, with the TPC range of $290,000,000–$480,000,000. Between CD-3A and the current budget process, the TPC estimate has increased to $660,000,000 as a result of a maturing design effort that identified additional costs across the project scope, added scope for a new superconducting electron source, and increased the project’s contingency to address several future risks. The LCLS-II-HE project is currently assessing the impact of COVID-19 on the project’s cost and schedule. The key milestones have been delayed and the combined CD-2/3 approval is now projected for 4Q FY 2022 and CD-4 now projected for 2Q FY 2030.

13-SC-10, Linac Coherent Light Source II (LCLS-II), SLAC

The LCLS-II project will provide a second source of electrons at LCLS by constructing a 4 GeV, high repetition rate, superconducting linear accelerator in addition to adding two new variable gap undulators to generate an unprecedented high-repetition-rate free-electron laser. This new x-ray source will solidify the LCLS complex as the world leader in ultrafast x-ray science for decades to come. The project received approval for CD-2, Approve Performance Baseline, and CD-3, Approve Start of Construction, on March 21, 2016, establishing a Total Project Cost (TPC) of $1,045,000,000 and a CD-4, Project Completion date of June 30, 2022. Due largely to COVID impacts, the project suffered a Baseline Deviation in FY 2020. The Baseline Change Proposal was approved on October 13, 2020, establishing a new TPC of $1,136,400,000 and a new CD-4 date of January 2024.

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 sheets.

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Construction	**$389,000**	**$304,200**	**-$84,800**
21-SC-10, Cryomodule Repair & Maintenance Facility (CRMF), SLAC	$1,000	$1,000	$ —
Funding supports conducting a conceptual design and an Analysis of Alternatives to determine a revised cost range for the project at SLAC. Engineering and design activities may begin.		The FY 2022 Request will continue to support the conceptual design effort and possibly the initial engineering design work depending on progress and CD approvals.	Funding will advance progress on the CRMF project.
19-SC-14, Second Target Station (STS), ORNL	$29,000	$32,000	+$3,000
Funding continues to support planning, R&D, and engineering activities to assist in maturing the project preliminary design, scope, cost, schedule and key performance parameters with emphasis on advancing the accelerator, target, instrument, controls, and conventional civil construction subsystems.		In FY 2022, the project will continue the FY 2021 activities of planning, R&D, and engineering to assist in maturing the project preliminary design, scope, cost, schedule and key performance parameters with continued emphasis on advancing the accelerator, target, instrument, controls, and conventional civil construction subsystems.	Funding will advance progress on the STS project.

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
18-SC-10, Advanced Photon Source Upgrade (APS-U), ANL	$160,000	$101,000	-$59,000
Funding continues to support advancing the final designs, engineering, prototyping, testing, fabrication, procurement of baseline and spare hardware, integration, and installation for the storage ring and experimental facilities, and site preparation and civil construction associated with the long beamlines.		The FY 2022 Request will support ongoing activities to advance the final designs, engineering, prototyping, testing, fabrication, procurement of baseline and spare hardware, integration, and installation for the storage ring and experimental facilities. Further civil construction associated with the long beamline building 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.	Funding will advance progress on the APS-U project. The APS-U current baseline (from the CD-2 approval) does not include potential COVID impacts that could increase the baseline cost and extend the schedule; this situation is being carefully monitored.
18-SC-11, Spallation Neutron Source Proton Power Upgrade (PPU), ORNL	$52,000	$17,000	-$35,000
Funding continues to support R&D, engineering, prototyping, design, testing, fabrication, procurement of baseline and spare hardware, component integration and installation, and civil construction. Advancing the target R&D, engineering, design, and prototyping in conjunction with SNS operations target improvement plans will be a high priority.		In FY 2022, the project will prioritize continuing activities of R&D, engineering, prototyping, design, testing, fabrication, procurement of baseline and spare hardware, component integration and installation, and civil construction site preparation with priority on continuing RF equipment installation in the klystron gallery, cryomodule assembly, first complete cryomodule receipt, and advancing the target knowledge base by running the first PPU test target during SNS operations.	Funding will advance progress on the PPU project.
18-SC-12, Advanced Light Source Upgrade (ALS-U), LBNL	$62,000	$75,100	+$13,100
Funding continues to support engineering, design, R&D prototyping and long lead procurements of construction items and other tasks as required.		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 early FY 2022.	Funding will advance progress on the ALS-U project.

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request		Explanation of Changes FY 2022 Request vs FY 2021 Enacted	
18-SC-13, Linac Coherent Light Source-II-High Energy (LCLS-II-HE), SLAC	$52,000		$50,000		-$2,000
Funding continues to support engineering, design, R&D prototyping, and long lead procurements of construction items as authorized along with other tasks as required.		Funding will support engineering, design, R&D prototyping, continuing long lead procurements of construction items and preparation of the project baseline. Other tasks as required.		Funding will advance progress on the LCLS-II-HE project.	
13-SC-10 - Linac Coherent Light Source-II (LCLS-II), SLAC	$33,000		$28,100		-$4,900
Funding continues to support installation of all remaining major accelerator and x-ray systems and equipment commissioning activities.		Funding will be used to complete installation of any remaining major accelerator and x-ray systems and equipment commissioning activities.		Funding will support completion of the LCLS II project.	

Basic Energy Sciences
Capital Summary

	(dollars in thousands)					
	Total	Prior Years	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Capital Operating Expenses						
Capital Equipment	N/A	N/A	46,825	46,950	65,800	+18,850
Minor Construction Activities						
General Plant Projects	N/A	N/A	1,000	10,000	11,500	+1,500
Accelerator Improvement Projects	N/A	N/A	10,700	30,539	42,820	+12,281
Total, Capital Operating Expenses	**N/A**	**N/A**	**58,525**	**87,489**	**120,120**	**+32,631**

Capital Equipment

	(dollars in thousands)					
	Total	Prior Years	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Capital Equipment						
Major Items of Equipment						
Scientific User Facilities (SUF)						
NSLS-II Experimental Tools-II (NEXT-II), BNL	94,500	–	5,500	5,500	15,000	+9,500
NSRC Recapitalization	80,000	–	5,000	5,000	15,000	+10,000
Total, MIEs	N/A	N/A	10,500	10,500	30,000	+19,500
Total, Non-MIE Capital Equipment	N/A	N/A	36,325	36,450	35,800	-650
Total, Capital Equipment	**N/A**	**N/A**	**46,825**	**46,950**	**65,800**	**+18,850**

Note: GPP activities less than $5M include design and construction for additions and/or improvements to land, buildings, replacements or addition to roads, and general area improvements. AIP activities less than $5M include minor construction at an existing accelerator facility.

Minor Construction Activities

(dollars in thousands)

	Total	Prior Years	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
General Plant Projects (GPP)						
GPPs (greater than or equal to $5M and less than $20M)						
HFIR Guide Hall Extension	18,000	–	–	9,000	9,000	–
Total GPPs (greater than or equal to $5M and less than $20M)	N/A	N/A	–	9,000	9,000	–
Total GPPs less than $5M	N/A	N/A	1,000	1,000	2,500	+1,500
Total, General Plant Projects (GPP)	**N/A**	**N/A**	**1,000**	**10,000**	**11,500**	**+1,500**
Accelerator Improvement Projects (AIP)						
AIPs (greater than or equal to $5M and less than $20M)						
Storage Ring HVAC System Upgrade, ALS	6,900	650	6,250	–	–	–
3rd Harmonic Cavity, NSLS-II	5,211	–	–	–	5,211	+5,211
Spallation Neutron Source Cold Box-Engineering	500	–	–	–	500	+500
Spare Cold Box for RF Cryoplant	5,200	–	–	5,200	–	-5,200
Cold Source Helium Refrigerator System	9,339	–	–	9,339	–	-9,339
Moderator Test Stand (SNS)	6,250	–	–	–	6,250	+6,250
160kW Solid State Amplifier Hardware and Utilities - Phase 2 (APS)	10,958	–	–	–	10,958	+10,958
Total AIPs (greater than or equal to $5M and less than $20M)	N/A	N/A	6,250	14,539	22,919	+8,380
Total AIPs less than $5M	N/A	N/A	4,450	16,000	19,901	+3,901
Total, Accelerator Improvement Projects (AIP)	**N/A**	**N/A**	**10,700**	**30,539**	**42,820**	**+12,281**
Total, Minor Construction Activities	**N/A**	**N/A**	**11,700**	**40,539**	**54,320**	**+13,781**

Basic Energy Sciences
Major Items of Equipment Description(s)

Scientific User Facilities (SUF) 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-1, Approve Alternative Selection and Cost Range, on September 30, 2020. The CD-1 approved total project cost range is $65,000,000 to $95,000,000 with a point estimate of $89,000,000. The FY 2022 Request of $15,000,000 will continue R&D, prototyping, other supporting activities, and construction/equipment procurements. The project is planning for CD-2/3 approval early in FY 2022.

Nanoscale Science Research Center (NSRC) Recapitalization Project

The NSRCs started early operations in 2006-2007 and now, a decade later, instrumentation recapitalization is needed 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 a combined CD-1, Approve Alternative Selection and Cost Range, and CD-3A, Approve Long-Lead Procurements, on April 15, 2021. The current total project cost range is $70,000,000 to $95,000,000 with a point estimate of $80,000,000. The FY 2022 Request of $15,000,000 will continue R&D, design, engineering, prototyping, other supporting activities, and construction/equipment procurements. The project is planning for CD-2/3 approval in FY 2022.

Basic Energy Sciences
Construction Projects Summary

(dollars in thousands)

	Total	Prior Years	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
21-SC-10, Cryomodule Repair & Maintenance Facility (CRMF), SLAC						
Total Estimated Cost (TEC)	88,000	–	–	1,000	1,000	–
Other Project Cost (OPC)	10,000	–	–	1,000	2,000	+1,000
Total Project Cost (TPC)	**98,000**	**–**	**–**	**2,000**	**3,000**	**+1,000**
19-SC-14, Second Target Station, ORNL						
Total Estimated Cost (TEC)	2,143,000	1,000	20,000	29,000	32,000	+3,000
Other Project Cost (OPC)	99,000	15,805	17,000	13,000	–	-13,000
Total Project Cost (TPC)	**2,242,000**	**16,805**	**37,000**	**42,000**	**32,000**	**-10,000**
18-SC-10, Advanced Photon Source Upgrade, ANL						
Total Estimated Cost (TEC)	796,500	363,300	170,000	160,000	101,000	-59,000
Other Project Cost (OPC)	18,500	8,500	–	–	5,000	+5,000
Total Project Cost (TPC)	**815,000**	**371,800**	**170,000**	**160,000**	**106,000**	**-54,000**
18-SC-11, Spallation Neutron Source Proton Power Upgrade, ORNL						
Total Estimated Cost (TEC)	257,802	96,000	60,000	52,000	17,000	-35,000
Other Project Cost (OPC)	13,798	10,798	–	3,000	–	-3,000
Total Project Cost (TPC)	**271,600**	**106,798**	**60,000**	**55,000**	**17,000**	**-38,000**
18-SC-12, Advanced Light Source Upgrade, LBNL						
Total Estimated Cost (TEC)	562,000	76,000	60,000	62,000	75,100	+13,100
Other Project Cost (OPC)	28,000	26,000	2,000	–	–	–
Total Project Cost (TPC)	**590,000**	**102,000**	**62,000**	**62,000**	**75,100**	**+13,100**

(dollars in thousands)

	Total	Prior Years	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
18-SC-13, Linac Coherent Light Source-II-High Energy, SLAC						
Total Estimated Cost (TEC)	644,543	33,200	50,000	52,000	50,000	-2,000
Other Project Cost (OPC)	32,000	8,000	4,000	2,000	3,000	+1,000
Total Project Cost (TPC)	**676,543**	**41,200**	**54,000**	**54,000**	**53,000**	**-1,000**
13-SC-10, Linac Coherent Light Source II (LCLS-II), SLAC						
Total Estimated Cost (TEC)	1,060,856	999,756	–	33,000	28,100	-4,900
Other Project Cost (OPC)	56,200	51,900	–	–	4,300	+4,300
Total Project Cost (TPC)	**1,117,056**	**1,051,656**	**–**	**33,000**	**32,400**	**-600**
Total, Construction						
Total Estimated Cost (TEC)	**N/A**	**N/A**	**360,000**	**389,000**	**304,200**	**-84,800**
Other Project Cost (OPC)	**N/A**	**N/A**	**23,000**	**19,000**	**14,300**	**-4,700**
Total Project Cost (TPC)	**N/A**	**N/A**	**383,000**	**408,000**	**318,500**	**-89,500**

Basic Energy Sciences
Funding Summary

(dollars in thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Research	871,321	869,500	975,960	+106,460
Facility Operations	947,179	956,000	974,540	+18,540
Projects				
Line Item Construction (LIC)	383,000	408,000	318,500	-89,500
Major Items of Equipment (MIE)	10,500	10,500	30,000	+19,500
Total, Projects	**393,500**	**418,500**	**348,500**	**-70,000**
Other	1,000	1,000	1,000	–
Total, Basic Energy Sciences	**2,213,000**	**2,245,000**	**2,300,000**	**+55,000**

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.

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 2020 Enacted	FY 2020 Current	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Scientific User Facilities - Type A					
Advanced Light Source	**68,093**	**68,393**	**68,908**	**70,704**	**+1,796**
Number of Users	1,800	1,816	1,800	1,400	-400
Achieved Operating Hours	–	3,239	–	–	–
Planned Operating Hours	3,880	3,880	3,168	3,300	+132
Optimal Hours	3,880	–	4,100	3,400	-700
Percent of Optimal Hours	100.0%	83.5%	93.2%	97.1%	+3.9%
Advanced Photon Source	**140,477**	**140,627**	**142,158**	**146,226**	**+4,068**
Number of Users	4,900	4,323	4,300	4,000	-300
Achieved Operating Hours	–	5,436	–	–	–
Planned Operating Hours	5,000	5,000	5,000	3,980	-1,020
Optimal Hours	5,000	–	5,000	4,100	-900
Percent of Optimal Hours	100.0%	108.7%	100.0%	97.1%	-2.9%
National Synchrotron Light Source	**117,244**	**117,394**	**118,647**	**121,243**	**+2,596**
Number of Users	1,700	1,356	1,300	1,600	+300
Achieved Operating Hours	–	5,416	–	–	–
Planned Operating Hours	5,000	5,000	4,500	4,850	+350
Optimal Hours	5,000	–	5,000	5,000	–
Percent of Optimal Hours	100.0%	108.3%	93.8%	97.0%	+3.2%

(dollars in thousands)

	FY 2020 Enacted	FY 2020 Current	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Stanford Synchrotron Radiation Light Source	**44,017**	**44,167**	**44,544**	**46,447**	**+1,903**
Number of Users	1,500	963	950	1,350	+400
Achieved Operating Hours	–	4,467	–	–	–
Planned Operating Hours	5,090	5,090	5,020	5,050	+30
Optimal Hours	5,090	–	5,400	5,200	-200
Percent of Optimal Hours	100.0%	87.8%	93.0%	97.1%	+4.1%
Linac Coherent Light Source	**148,960**	**160,875**	**150,743**	**153,662**	**+2,919**
Number of Users	500	291	800	800	–
Achieved Operating Hours	–	705	–	–	–
Planned Operating Hours	2,800	2,500	4,500	4,560	+60
Optimal Hours	2,800	–	4,600	4,700	+100
Percent of Optimal Hours	100.0%	28.2%	97.8%	97.0%	-0.8%
Spallation Neutron Source	**187,048**	**182,638**	**183,532**	**185,081**	**+1,549**
Number of Users	800	611	730	800	+70
Achieved Operating Hours	–	4,829	–	–	–
Planned Operating Hours	4,600	4,600	4,600	4,350	-250
Optimal Hours	4,600	–	5,000	4,600	-400
Percent of Optimal Hours	100.0%	105.0%	93.9%	94.6%	+0.7%
High Flux Isotope Reactor	**102,653**	**107,579**	**108,468**	**108,790**	**+322**
Number of Users	520	280	500	560	+60
Achieved Operating Hours	–	3,631	–	–	–
Planned Operating Hours	3,900	3,900	3,100	3,900	+800
Optimal Hours	3,900	–	4,000	4,000	–
Percent of Optimal Hours	100.0%	93.1%	93.9%	97.5%	+3.6%

	FY 2020 Enacted	FY 2020 Current	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
	(dollars in thousands)				
Scientific User Facilities - Type B					
Center for Nanoscale Materials	**28,461**	**28,562**	**28,275**	**28,555**	**+280**
Number of Users	530	484	500	480	-20
Center for Functional Nanomaterials	**24,807**	**24,907**	**25,113**	**26,864**	**+1,751**
Number of Users	510	546	500	520	+20
Molecular Foundry	**32,090**	**32,191**	**32,162**	**32,484**	**+322**
Number of Users	800	740	700	750	+50
Center for Nanophase Materials Sciences	**27,818**	**27,920**	**28,131**	**28,412**	**+281**
Number of Users	630	578	500	580	+80
Center for Integrated Nanotechnologies	**25,511**	**25,612**	**25,319**	**26,072**	**+753**
Number of Users	700	654	600	660	+60
Total, Facilities	**947,179**	**960,865**	**956,000**	**974,540**	**+18,540**
Number of Users	14,890	12,642	13,180	13,500	+320
Achieved Operating Hours	–	27,723	–	–	–
Planned Operating Hours	30,270	29,970	29,888	29,990	+102
Optimal Hours	30,270	–	33,100	31,000	-2,100

Note: Achieved Operating Hours and Unscheduled Downtime Hours will only be reflected in the Congressional budget cycle which provides actuals.

Basic Energy Sciences
Scientific Employment

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Number of Permanent Ph.Ds (FTEs)	4,950	4,860	5,370	+510
Number of Postdoctoral Associates (FTEs)	1,370	1,340	1,530	+190
Number of Graduate Students (FTEs)	2,140	2,090	2,420	+330
Number of Other Scientific Employment (FTEs)	3,100	3,050	3,250	+200

Note: Other Scientific Employment (FTEs) includes technicians, engineers, computer professionals and other support staff.

21-SC-10, Cryomodule Repair & Maintenance Facility (CRMF), SLAC
SLAC National Accelerator Laboratory
Project is for Design and Construction

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

Summary

The FY 2022 Request for the Cryomodule Repair and Maintenance Facility (CRMF) project at SLAC National Accelerator Laboratory is $1,000,000 of Total Estimated Cost (TEC) funding and $2,000,000 in Other Projects Costs (OPC) funding. This project has a preliminary Total Estimated Cost (TEC) range of $60,000,000 to $88,000,000 and a preliminary Total Project Cost (TPC) range of $70,000,000 to $98,000,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The preliminary TPC estimate for this project is $98,000,000.

Significant Changes

CRMF was initiated in FY 2021. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-0, Approve Mission Need, approved on December 5, 2019.

In FY 2021, both a conceptual design for the facility and an Analysis of Alternatives (AoA) based on that conceptual design will be conducted to determine a revised cost range for the project. Engineering and design activities may begin. The FY 2022 Request will support ongoing activities to support the conceptual design effort and possibly the initial engineering design work depending on progress and CD approvals.

A Federal Project Director 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	12/5/19	1Q FY 2021	1Q FY 2021	1Q FY 2022	4Q FY 2022	1Q FY 2023	N/A	1Q FY 2027
FY 2022	12/5/19	4Q FY 2022	4Q FY 2022	4Q FY 2023	2Q FY 2024	2Q FY 2024	N/A	4Q 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

Fiscal Year	Performance Baseline Validation	CD-3A
FY 2021	4Q FY 2021	1Q FY 2022
FY 2022	4Q FY 2023	4Q FY 2023

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

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D	OPC, D&D	OPC, Total	TPC
FY 2021	4,000	66,000	70,000	10,000	N/A	10,000	80,000
FY 2022	7,000	81,000	88,000	10,000	N/A	10,000	98,000

2. Project Scope and Justification

Scope

The preliminary scope of the CRMF project is to construct a building to support the repair, maintenance, and testing of superconducting radiofrequency (SRF) accelerator components. These components include but are not limited to SRF cavities and cryomodules, high brightness electron injectors, and superconducting undulators. 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 cryogenic refrigerator and distribution box, cryomodules handling 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 for inclusion in the project includes a dedicated SRF electron injector development and test area, which requires extending the envisioned building length by 30 feet, a 40 mega-electronvolt (MeV) SRF linac to provide the equipment and diagnostics necessary for an integrated injector test stand, and equipment to refurbish and test the niobium SRF cavities.

Justification

SC, through the two current BES construction projects, LCLS-II and LCLS-II-HE, is making over a $1,800,000,000 capital investment in an 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 20-22 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. FNAL and TJNAF produce the cryomodules making use of specialized fabrication, assembly, and test capabilities available there. To make any repairs, the facilities must currently send the cryomodules 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, during construction of the LCLS-II facility it was determined that cryomodules could be damaged during transportation; transportation of cryomodules for repairs during operations would pose a risk to reliable facility operations. This approach also assumed that either FNAL or TJNAF would have the maintenance capabilities available when needed. 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 is designed to meet these challenges and will provide the capability to repair, maintain, 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.

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. The lack of an appropriate research and development (R&D) facility with testing capabilities has hindered progress in this area at SLAC. The CRMF project will provide this needed support to SLAC when constructed.

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 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 (TEC)			
FY 2021	1,000	1,000	–
FY 2022	1,000	1,000	1,650
Outyears	5,000	5,000	5,350
Total, Design (TEC)	**7,000**	**7,000**	**7,000**
Construction (TEC)			
Outyears	81,000	81,000	81,000
Total, Construction (TEC)	**81,000**	**81,000**	**81,000**
Total Estimated Cost (TEC)			
FY 2021	1,000	1,000	–
FY 2022	1,000	1,000	1,650
Outyears	86,000	86,000	86,350
Total, TEC	**88,000**	**88,000**	**88,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Other Project Cost (OPC)			
FY 2021	1,000	1,000	880
FY 2022	2,000	2,000	1,870
Outyears	7,000	7,000	7,250
Total, OPC	**10,000**	**10,000**	**10,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Project Cost (TPC)			
FY 2021	2,000	2,000	880
FY 2022	3,000	3,000	3,520
Outyears	93,000	93,000	93,600
Total, TPC	**98,000**	**98,000**	**98,000**

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design	5,650	3,500	**N/A**
Design - Contingency	1,350	500	**N/A**
Total, Design (TEC)	**7,000**	**4,000**	**N/A**
Site Preparation	8,000	1,000	**N/A**
Equipment	7,400	35,000	**N/A**
Other Construction	46,850	15,500	**N/A**
Construction - Contingency	18,750	14,500	**N/A**
Total, Construction (TEC)	**81,000**	**66,000**	**N/A**
Total, TEC	**88,000**	**70,000**	**N/A**
Contingency, TEC	*20,100*	*15,000*	***N/A***
Other Project Cost (OPC)			
R&D	N/A	1,000	**N/A**
Conceptual Planning	500	1,000	**N/A**
Conceptual Design	5,500	2,000	**N/A**
Start-up	1,500	3,000	**N/A**
OPC - Contingency	2,500	3,000	**N/A**
Total, Except D&D (OPC)	**10,000**	**10,000**	**N/A**
Total, OPC	**10,000**	**10,000**	**N/A**
Contingency, OPC	*2,500*	*3,000*	***N/A***
Total, TPC	**98,000**	**80,000**	**N/A**
Total, Contingency (TEC+OPC)	***22,600***	***18,000***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Request Year	Type	Prior Years	FY 2021	FY 2022	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
FY 2022	TEC	—	1,000	1,000	86,000	88,000
	OPC	—	1,000	2,000	7,000	10,000
	TPC	—	2,000	3,000	93,000	98,000

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	FY 2028
Expected Useful Life	25 years
Expected Future Start of D&D of this capital asset	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, Maintenance and Repair	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 22,000 to 25,000 gsf building may be constructed as part of this project.

8. Acquisition Approach

The CRMF Project will be sited at the SLAC National Accelerator Laboratory and will be acquired under the existing DOE Management and Operations contract for that laboratory.

SLAC 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.

SLAC may choose to 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 and/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 (STS), ORNL
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 2022 Request for Second Target Station (STS) project is $32,000,000 of Total Estimated Cost (TEC) funding. This project has a preliminary Total Project Cost (TPC) range of $1,800,000,000 to $3,000,000,000. This cost range encompasses the most feasible preliminary alternatives. The preliminary TPC estimate is $2,242,000,000.

Significant Changes

STS was initiated in FY 2019. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range, approved on November 23, 2020. This Construction Project Data Sheet (CPDS) is an update of the FY 2021 CPDS and does not include a new start for FY 2022. Compared to the CD-0 estimates in FY 2009, there was a significant increase in the estimated TPC at CD-1. The increase is the result in escalation (CD-0 assumed CD-1 in FY 2013, CD-1 was actually granted in FY 2021), evolution in scope due to a deeper understanding of requirements and systems as a result of conceptual design, including project management and site preparation, and increased contingency (25 percent of CD-0 estimate vs. 39 percent of current estimate) due to understanding of pandemic impacts and better estimates of project risks.

In FY 2020, 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 2021, the project received CD-1 and continued planning, R&D, design, engineering, and other activities required to advance the STS project toward CD-2. The focus will be on maturing the accelerator, target, instrument, controls, and conventional civil construction subsystems. A commercial Architect/Engineer (AE) firm will be contracted to assist in advancing the planning, engineering, and design. Proposals from scientific community teams for world-class instrument concepts will be reviewed and eight will be included in the project. In FY 2022, the project will continue the FY 2021 activities of planning, R&D, and engineering to assist in maturing the project design, scope, cost, schedule and key performance parameters with continued emphasis on advancing the accelerator, target, instrument, controls, and conventional civil construction subsystems. A commercial Construction Manager/General Contractor firm will be contracted to work with the AE firm to assist in maturing the planning, engineering, and design with emphasis on the conventional civil construction plans and site preparation.

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 2020	1/7/09	2Q FY 2022	2Q FY 2022	2Q FY 2023	2Q FY 2025	2Q FY 2024	N/A	4Q FY 2031
FY 2021	1/7/09	2Q FY 2021	2Q FY 2021	3Q FY 2024	3Q FY 2026	3Q FY 2025	N/A	2Q FY 2032
FY 2022	1/7/09	4/30/21	11/23/20	2Q FY 2025	4Q FY 2029	2Q FY 2025	N/A	2Q FY 2037

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	65,500	1,158,200	1,223,700	45,300	N/A	45,300	1,269,000
FY 2022[a]	333,000	1,810,000	2,143,000	99,000	N/A	99,000	2,242,000

2. Project Scope and Justification

Scope
To address the gap in advanced neutron sources and instrumentation, the STS project will design, build, install, and test the equipment necessary to provide the four primary elements of the new Spallation Neutron Source (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 Key Performance Parameters (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 350,000 ft^2 of new buildings, making conventional facility construction a major contributor to project costs.

Justification
The Basic Energy Sciences (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 in part 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 Oak Ridge National Laboratory (ORNL), the SNS has been fulfilling this need. In accordance with the 1996 Basic Energy Sciences Advisory Committee (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

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

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 a proton beam that is highly concentrated to produce a very high density beam of protons that strikes a rotating solid tungsten target. The produced neutron beam illuminates moderators located above and below the target that will feed up to 22 experimental beamlines (eight within the STS project scope) with neutron beams 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, requested separately, will double the power of the SNS accelerator complex to 2.8 MW so that STS can use one out of every four proton pulses to produce cold neutron beams with the highest peak brightness 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, which currently operates at 60 Hz, but will operate at 45 pulses/second when STS is operating) 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 fourth 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 eight best-in-class instruments, 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*.

<u>Key Performance Parameters (KPPs)</u>
The 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
Demonstrate independent control of the proton beam on the two target stations	Operate beam to FTS at 45 pulses/s, with no beam to STS. Operate beam to STS at 15 Hz, with no beam to FTS. Operate with beam to both target stations 45 pulses/s at FTS and 15 Hz at STS.	Operate beam to FTS at 45 pulses/s, with no beam to STS. Operate beam to STS at 15 Hz, with no beam to FTS. Operate with beam to both target stations 45 pulses/s at FTS and 15 Hz at STS.
Demonstrate proton beam power on STS at 15 Hz	100 kW beam power	700 kW beam power
Measure STS neutron brightness	peak brightness of 2×10^{13}n/cm^2/sr/Å/s at 5 Å	peak brightness of 2×10^{14}n/cm^2/sr/Å/s at 5 Å
Beamlines transitioned to operations	8 beamlines successfully passed the integrated functional testing per the transition to operations parameters acceptance criteria	≥ 8 beamlines successfully passed the integrated functional testing per the transition to operations parameters acceptance criteria

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
Design (TEC)			
FY 2019	1,000	1,000	–
FY 2020	20,000	20,000	–
FY 2021	29,000	29,000	37,000
FY 2022	32,000	32,000	37,500
Outyears	251,000	251,000	258,500
Total, Design (TEC)	**333,000**	**333,000**	**333,000**
Construction (TEC)			
Outyears	1,810,000	1,810,000	1,810,000
Total, Construction (TEC)	**1,810,000**	**1,810,000**	**1,810,000**
Total Estimated Cost (TEC)			
FY 2019	1,000	1,000	–
FY 2020	20,000	20,000	–
FY 2021	29,000	29,000	37,000
FY 2022	32,000	32,000	37,500
Outyears	2,061,000	2,061,000	2,068,500
Total, TEC	**2,143,000**	**2,143,000**	**2,143,000**

(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	10,917
FY 2021	13,000	13,000	19,750
FY 2022	–	–	2,739
Outyears	53,195	53,195	53,195
Total, OPC	**99,000**	**99,000**	**99,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
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	10,917
FY 2021	42,000	42,000	56,750
FY 2022	32,000	32,000	40,239
Outyears	2,114,195	2,114,195	2,121,695
Total, TPC	**2,242,000**	**2,242,000**	**2,242,000**

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design	256,500	48,500	**N/A**
Design - Contingency	76,500	17,000	**N/A**
Total, Design (TEC)	**333,000**	**65,500**	**N/A**
Construction	1,291,500	864,700	**N/A**
Construction - Contingency	518,500	293,500	**N/A**
Total, Construction (TEC)	**1,810,000**	**1,158,200**	**N/A**
Total, TEC	**2,143,000**	**1,223,700**	**N/A**
Contingency, TEC	*595,000*	*310,500*	***N/A***
Other Project Cost (OPC)			
R&D	22,875	4,502	**N/A**
Conceptual Design	24,750	20,852	**N/A**
Start-up	20,250	8,621	**N/A**
OPC - Contingency	31,125	11,325	**N/A**
Total, Except D&D (OPC)	**99,000**	**45,300**	**N/A**
Total, OPC	**99,000**	**45,300**	**N/A**
Contingency, OPC	*31,125*	*11,325*	***N/A***
Total, TPC	**2,242,000**	**1,269,000**	**N/A**
Total, Contingency (TEC+OPC)	***626,125***	***321,825***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Request Year	Type	Prior Years	FY 2020	FY 2021	FY 2022	Outyears	Total
FY 2020	TEC	1,000	1,000	1,000	—	1,201,000	1,204,000
	OPC	11,500	—	1,000	—	32,800	45,300
	TPC	12,500	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	15,805	17,000	1,000	—	11,495	45,300
	TPC	16,805	37,000	2,000	—	1,213,195	1,269,000
FY 2022	TEC	1,000	20,000	29,000	32,000	2,061,000	2,143,000
	OPC	15,805	17,000	13,000	—	53,195	99,000
	TPC	16,805	37,000	42,000	32,000	2,114,195	2,242,000

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	FY 2037
Expected Useful Life	25 years
Expected Future Start of D&D of this capital asset	FY 2062

Related Funding Requirements
(dollars in thousands)

	Annual Costs		Life Cycle Costs	
	Previous Total Estimate	Current Total Estimate	Previous Total Estimate	Current Total Estimate
Operations, Maintenance and Repair	N/A	59,000	N/A	1,475,000

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.

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	~350,000
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"	~350,000
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 Conceptual 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 design and procure the key technical subsystem components. Some technical system designs will require research and development activities. Preliminary cost estimates for most of these systems are based on operating experience of SNS and vendor estimates, while some first-of-a-kind systems are based on expert judgement. 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 (APS-U), ANL
Argonne National Laboratory
Project is for Design and Construction

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

Summary
The FY 2022 Request for the Advanced Photon Source-Upgrade (APS-U) project is $106,000,000. The project has a Total Project Cost (TPC) of $815,000,000.

Significant Changes
The APS-U became a line item project in FY 2018. The most recent approved DOE Order 413.3B critical decision is CD-3 (Approve Start of Construction), which was approved on July 25, 2019. CD-4, Approve Project Completion is projected for mid-FY 2026. There are no significant changes.

In FY 2020, 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. Off-site space for storage was leased. Deliveries of the production first articles arrived for inspection and successfully passed acceptance testing. FY 2021 funding enables the advancement of the storage ring and experimental facilities final design, engineering, prototyping, testing, fabrication, procurement of baseline and spare hardware, integration, and installation, and enables site preparation and civil construction activities for the long beamline building. The project will continue receiving and inspecting hardware for the storage ring and experimental facilities and advance the integrated magnet module assembly. The FY 2022 Request will support continuing FY 2021 activities to advance the design, engineering, prototyping, testing, fabrication, procurement of baseline and spare hardware, integration, and installation for the storage ring and experimental facilities. Further civil construction associated with the long beamline building will occur. Completing final designs, system integration, testing, and assembly in preparation for the storage ring removal and installation during the experimental dark time, tentatively scheduled to begin in late June 2022, will be a high priority. COVID-19 may delay progress.

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 2018	4/22/10	9/18/15	2/4/16	1Q FY 2019	2Q FY 2020	4Q FY 2019	N/A	1Q FY 2026
FY 2019	4/22/10	9/18/15	2/4/16	2Q FY 2019	4Q FY 2021	1Q FY 2020	N/A	2Q FY 2026
FY 2020	4/22/10	9/18/15	2/4/16	12/9/18	1Q FY 2022	1Q FY 2020	N/A	2Q FY 2026
FY 2021	4/22/10	9/18/15	2/4/16	12/9/18	1Q FY 2022	7/25/19	N/A	2Q FY 2026
FY 2022	4/22/10	9/18/15	2/4/16	12/9/18	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 Start of Operations or Project Closeout

Fiscal Year	Performance Baseline Validation	CD-3A	CD-3B
FY 2018	1Q FY 2019	8/30/12	10/6/16
FY 2019	2Q FY 2019	8/30/12	10/6/16
FY 2020	12/9/18	8/30/12	10/6/16
FY 2021	12/9/18	8/30/12	10/6/16
FY 2022	12/9/18	8/30/12	10/6/16

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
FY 2022	189,638	606,862	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 project's scope includes a new very low emittance multi-bend achromat (MBA) lattice storage ring in the existing tunnel, new permanent magnet and superconducting insertion devices optimized for brightness and flux, 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 (ESRF) in France, PETRA-III in Germany, and SPring-8 in Japan are well into campaigns of major upgrades of beamlines and are also incorporating technological advancements in accelerator science to enhance performance for hard x-ray energies (>20 keV). In 2019, China initiated construction of the High Energy Photon Source (HEPS), a next-generation six giga-electronvolt (GeV) hard x-ray synchrotron light source. The ESRF upgrade, ESRF-EBS, was completed in early 2020.

The APS upgrade will provide a world-class hard x-ray synchrotron radiation facility, with 100 to 1000 times increased brightness and coherent flux over the current APS, and will be a unique asset in the U.S. portfolio of scientific user facilities. The APS-U is a critical and cost-effective next step in the photon science strategy that will keep the U.S. at the forefront of scientific research, combining with other facilities to give the U.S. a complementary set of storage ring and free-electron laser x-ray light sources.

The high-brightness, high-energy penetrating hard x-rays will provide a unique scientific capability directly relevant to probing real-world materials and applications in energy, the environment, new and improved materials, and biological studies. The APS upgrade 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 x 10^{20}	1 x 10^{22}
Brightness @ 60 keV[1]	> 1 x 10^{19}	1 x 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 (TEC)			
FY 2012	19,200	19,200	9,095
FY 2013	15,000	15,000	17,825
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	26,000	26,000	23,829
FY 2019	14,650	14,650	23,985
FY 2020	22,988	22,988	28,486
FY 2021	–	–	7,227
FY 2022	–	–	118
Total, Design (TEC)	**189,638**	**189,638**	**189,638**
Construction (TEC)			
FY 2012	800	800	–
FY 2013	5,000	5,000	3,391
FY 2014	2,985	2,985	4,534
FY 2015	–	–	573
FY 2017	7,715	7,715	389
FY 2018	67,000	67,000	6,307
FY 2019	113,150	113,150	24,425
FY 2020	147,012	147,012	55,859
FY 2021	160,000	160,000	229,709
FY 2022	101,000	101,000	232,058
Outyears	2,200	2,200	49,617
Total, Construction (TEC)	**606,862**	**606,862**	**606,862**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
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	93,000	93,000	30,136
FY 2019	127,800	127,800	48,410
FY 2020	170,000	170,000	84,345
FY 2021	160,000	160,000	236,936
FY 2022	101,000	101,000	232,176
Outyears	2,200	2,200	49,617
Total, TEC	**796,500**	**796,500**	**796,500**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Other Project Cost (OPC)			
FY 2010	1,000	1,000	587
FY 2011	7,500	7,500	3,696
FY 2012	–	–	4,217
FY 2022	5,000	5,000	4,400
Outyears	5,000	5,000	5,600
Total, OPC	**18,500**	**18,500**	**18,500**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Project Cost (TPC)			
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	93,000	93,000	30,136
FY 2019	127,800	127,800	48,410
FY 2020	170,000	170,000	84,345
FY 2021	160,000	160,000	236,936
FY 2022	106,000	106,000	236,576
Outyears	7,200	7,200	55,217
Total, TPC	**815,000**	**815,000**	**815,000**

Note – In FY 2021, the Office of Science reprogrammed $2,200,000 of FY 2019 funds to the LCLS-II project at SLAC. The FY 2019 Budget Authority in the table above reflects this reprogramming and additional funds are required in the outyears to maintain the project profile.

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design	187,921	182,825	166,962
Design - Contingency	1,717	7,600	9,696
Total, Design (TEC)	**189,638**	**190,425**	**176,658**
Equipment	478,809	461,675	465,180
Other Construction	17,000	17,000	17,000
Construction - Contingency	111,053	127,400	137,662
Total, Construction (TEC)	**606,862**	**606,075**	**619,842**
Total, TEC	**796,500**	**796,500**	**796,500**
Contingency, TEC	*112,770*	*135,000*	*147,358*
Other Project Cost (OPC)			
Conceptual Planning	1,000	1,000	1,000
Conceptual Design	7,500	7,500	7,500
Start-up	7,570	7,100	7,100
OPC - Contingency	2,430	2,900	2,900
Total, Except D&D (OPC)	**18,500**	**18,500**	**18,500**
Total, OPC	**18,500**	**18,500**	**18,500**
Contingency, OPC	*2,430*	*2,900*	*2,900*
Total, TPC	**815,000**	**815,000**	**815,000**
Total, Contingency (TEC+OPC)	***115,200***	***137,900***	***150,258***

5. Schedule of Appropriations Requests

(dollars in thousands)

Request Year	Type	Prior Years	FY 2020	FY 2021	FY 2022	Outyears	Total
	TEC	244,272	152,419	160,000	—	162,309	719,000
FY 2018	OPC	8,500	—	5,000	—	37,500	51,000
	TPC	252,772	152,419	165,000	—	199,809	770,000
	TEC	222,500	150,000	159,780	—	224,820	757,100
FY 2019	OPC	8,500	—	—	—	4,400	12,900
	TPC	231,000	150,000	159,780	—	229,220	770,000
	TEC	365,500	150,000	160,000	—	121,000	796,500
FY 2020	OPC	8,500	—	5,000	—	5,000	18,500
	TPC	374,000	150,000	165,000	—	126,000	815,000
	TEC	365,500	170,000	150,000	—	111,000	796,500
FY 2021	OPC	8,500	—	—	—	10,000	18,500
	TPC	374,000	170,000	150,000	—	121,000	815,000
	TEC	363,300	170,000	160,000	101,000	2,200	796,500
FY 2022	OPC	8,500	—		5,000	5,000	18,500
	TPC	371,800	170,000	160,000	106,000	7,200	815,000

Note – In FY 2021, the Office of Science reprogrammed $2,200,000 of FY 2019 funds to the LCLS-II project at SLAC. The FY 2022 Request in the table above reflects this reprogramming and additional funds are required in the outyears to maintain the project profile.

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	FY 2026
Expected Useful Life	25 years
Expected Future Start of D&D of this capital asset	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, Maintenance and Repair	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	23,000-27,000
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"	23,000-27,000
Area of D&D in this project at ANL	—
Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked"	—
Total area eliminated	—

Approximately 23,000-27,000 square feet of new construction is anticipated for the long beamline building, which will house two APS-U beamlines extending beyond the current APS experimental facilities and the support laboratories.

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 Environment, Safety and Health (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, Spallation Neutron Source Proton Power Upgrade (PPU), ORNL
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 2022 Request for the Proton Power Upgrade (PPU) project is $17,000,000 of Total Estimated Cost (TEC) funding. The Total Project Cost (TPC) is $271,600,000.

Significant Changes
PPU was initiated in FY 2018. The most recent DOE Order 413.3B approved Critical Decision (CD) is a combined CD-2, Approve Performance Baseline and CD-3, Approve Start of Construction, approved on October 6, 2020. CD-4, Approve Project Completion, is anticipated at the end of FY 2028.

In FY 2020, the project held successful CD-2/3 cost and project reviews for baseline and start of construction readiness and continued target development in coordination with Spallation Neutron Source (SNS) operations target management plans. All CD-3A long-lead procurement contracts have been placed and are ~75% complete. 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) and high voltage procurements, and cryomodule hardware procurements, delivery and assembly. In FY 2021, the project will continue R&D, engineering, prototyping, preliminary and final design, testing, fabrication, procurement of baseline and spare hardware, and component integration and installation and civil construction, focusing on initial target procurement, initial cryomodule production, and continued RF equipment procurement, and will initiate equipment installation in the klystron gallery. In FY 2022, the project will prioritize these continuing activities of R&D, engineering, prototyping, final design, testing, fabrication, procurement of baseline and spare hardware, component integration and installation, and civil construction site preparation, with priority on continuing RF equipment installation in the klystron gallery, cryomodule assembly, first complete cryomodule receipt, and advancing the target knowledge base by running the first PPU test target during SNS operations.

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	1/7/09	8/1/17	4/4/18	2Q FY 2021	4Q FY 2022	3Q FY 2022	N/A	3Q FY 2027
FY 2021	1/7/09	8/1/17	4/4/18	2Q FY 2021	4Q FY 2022	2Q FY 2021	N/A	3Q FY 2027
FY 2022	1/7/09	8/1/17	4/4/18	10/6/20	1Q FY 2023	10/6/20	N/A	4Q 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

Fiscal Year	Performance Baseline Validation	CD-3A	CD-3B
FY 2020	2Q FY 2021	10/5/18	2Q FY 2020
FY 2021	2Q FY 2021	10/5/18	9/3/19
FY 2022	10/6/20	10/5/18	9/3/19

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	46,700	189,502	236,202	13,798	N/A	13,798	250,000
FY 2022	40,000	217,802	257,802	13,798	N/A	13,798	271,600

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.

Justification

The Basic Energy Sciences (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 in part by operating large-scale user facilities consisting of a complementary set of intense x-ray 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 Oak Ridge National Laboratory (ORNL) in 2007, currently fulfills the need. The SNS was designed to be upgradeable so as to maintain its position of scientific leadership in the future, in accordance with the 1996 Basic Energy Sciences Advisory Committee (BESAC) (Russell Panel) Report recommendation, and many technical margins were built into the SNS systems to facilitate a power upgrade into the 2 - 4 MW range with the ability to extract some of that power to a second target station.

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

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

Key Performance Parameters (KPPs)

The Threshold KPPs, 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
Beam power on target	1.7 MW at 1.25 giga-electron volts (GeV)	2.0 MW at 1.3 GeV
Beam energy	1.25 GeV	1.3 GeV
Target reliability lifetime without target failure	1,250 hours at 1.7 MW	1,250 hours at 2.0 MW
Stored beam intensity in ring	≥ 1.6×10^{14} protons at 1.25 GeV	≥ 2.24×10^{14} protons at 1.3 GeV

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
Design (TEC)			
FY 2018	5,000	5,000	2,655
FY 2019	16,000	16,000	13,109
FY 2020	14,700	14,700	12,510
FY 2021	3,300	3,300	7,360
FY 2022	1,000	1,000	3,480
Outyears	–	–	886
Total, Design (TEC)	**40,000**	**40,000**	**40,000**
Construction (TEC)			
FY 2018	31,000	31,000	1,794
FY 2019	44,000	44,000	8,018
FY 2020	45,300	45,300	28,564
FY 2021	48,700	48,700	68,670
FY 2022	16,000	16,000	64,950
Outyears	32,802	32,802	45,806
Total, Construction (TEC)	**217,802**	**217,802**	**217,802**
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	41,074
FY 2021	52,000	52,000	76,030
FY 2022	17,000	17,000	68,430
Outyears	32,802	32,802	46,692
Total, TEC	**257,802**	**257,802**	**257,802**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
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	–	–	124
FY 2021	3,000	3,000	517
FY 2022	–	–	489
Outyears	–	–	3,057
Total, OPC	**13,798**	**13,798**	**13,798**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
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	41,198
FY 2021	55,000	55,000	76,547
FY 2022	17,000	17,000	68,919
Outyears	32,802	32,802	49,749
Total, TPC	**271,600**	**271,600**	**271,600**

4. **Details of Project Cost Estimate**

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design	32,000	38,800	32,000
Design - Contingency	8,000	7,900	8,000
Total, Design (TEC)	**40,000**	**46,700**	**40,000**
Construction	163,452	137,702	163,452
Construction - Contingency	54,350	51,800	54,350
Total, Construction (TEC)	**217,802**	**189,502**	**217,802**
Total, TEC	**257,802**	**236,202**	**257,802**
Contingency, TEC	*62,350*	*59,700*	*62,350*
Other Project Cost (OPC)			
R&D	2,408	2,800	2,408
Conceptual Design	7,250	6,498	7,250
Other OPC Costs	3,480	1,300	3,480
OPC - Contingency	660	3,200	660
Total, Except D&D (OPC)	**13,798**	**13,798**	**13,798**
Total, OPC	**13,798**	**13,798**	**13,798**
Contingency, OPC	*660*	*3,200*	*660*
Total, TPC	**271,600**	**250,000**	**271,600**
Total, Contingency (TEC+OPC)	***63,010***	***62,900***	***63,010***

5. **Schedule of Appropriations Requests**

(dollars in thousands)

Request Year	Type	Prior Years	FY 2020	FY 2021	FY 2022	Outyears	Total
FY 2020	TEC	96,000	5,000	30,000	—	106,300	237,300
	OPC	10,300	—	—	—	2,400	12,700
	TPC	106,300	5,000	30,000	—	108,700	250,000
FY 2021	TEC	96,000	60,000	5,000	—	75,202	236,202
	OPC	10,798	—	3,000	—	—	13,798
	TPC	106,798	60,000	8,000	—	75,202	250,000
FY 2022	TEC	96,000	60,000	52,000	17,000	32,802	257,802
	OPC	10,798	—	3,000	—		13,798
	TPC	106,798	60,000	55,000	17,000	32,802	271,600

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	FY 2028
Expected Useful Life	40 years
Expected Future Start of D&D of this capital asset	FY 2068

Related Funding Requirements
(dollars in thousands)

	Annual Costs		Life Cycle Costs	
	Previous Total Estimate	**Current Total Estimate**	**Previous Total Estimate**	**Current Total Estimate**
Operations, Maintenance and Repair	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. 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 (ALS-U), LBNL
Lawrence Berkeley National Laboratory
Project is for Design and Construction

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

Summary

The FY 2022 Request for the Advanced Light Source Upgrade (ALS-U) project is $75,100,000 of Total Estimated Cost (TEC) funding. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-2, Approve Performance Baseline, approved on April 2, 2021. The project has a Total Project Cost (TPC) of $590,000,000.

Significant Changes

The ALS-U was initiated in FY 2019. In FY 2020, the project initiated long lead procurements as approved at CD-3A, and continued with planning, engineering, design, research and development (R&D), and prototyping activities. FY 2021 funding continues the support of planning, engineering, design, R&D, prototyping activities, and long-lead procurements. FY 2022 funding will continue support of planning, engineering, design, R&D, prototyping, and procurements of both long-lead and normal construction items.

The project took on additional scope which included adding radiation shielding and safety-mandated seismic structural upgrades to the ALS facility to protect the ALS-U investment. The additional scope, along with maturing designs, increased the project cost point estimate to $590,000,000.

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	9/27/16	4/30/18	9/21/18	2Q FY 2021	4Q FY 2021	1Q FY 2022	N/A	2Q FY 2028
FY 2022	9/27/16	4/30/18	9/21/18	4/2/21	2Q FY 2022	3Q FY 2022	N/A	4Q 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
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	4Q FY 2020
FY 2020	2Q FY 2021	4Q FY 2019
FY 2021	2Q FY 2021	12/19/19
FY 2022	4/2/21	12/19/19

CD-3A – Approve Long-Lead Procurements scope included the equipment required for the electron accumulator ring.

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	89,750	290,450	380,200	30,000	N/A	30,000	410,200
FY 2022	135,711	426,289	562,000	28,000	N/A	28,000	590,000

2. Project Scope and Justification

Scope

The ALS-U project will upgrade the existing ALS facility by replacing the existing electron storage ring with a new electron storage ring based on a multi-bend achromat (MBA) lattice design to provide a soft x-ray source that is orders of magnitude 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 inner shield wall to enable on- and off-axis, swap-out injection and extraction into and from the new storage ring 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 two new undulator beamlines that are optimized for the novel science made possible by the beam's new high coherent flux. The project intends to reuse the existing building, utilities, electron gun, linac, and booster synchrotron equipment currently at ALS. Prior to CD-2, the scope was increased to include radiation shielding and safety-mandated seismic structural upgrades to the ALS facility. 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 but not above that. NSLS-II is somewhat lower in brightness than the new Swedish light source, MAX-IV, which began user operations in 2017 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 the 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 is possible with LCLS-II 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 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 x 10^{19}	≥ 2 x 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 (TEC)			
FY 2018	16,000	16,000	–
FY 2019	35,000	35,000	22,054
FY 2020	10,000	10,000	33,101
FY 2021	40,000	40,000	39,146
FY 2022	34,711	34,711	35,000
Outyears	–	–	6,410
Total, Design (TEC)	**135,711**	**135,711**	**135,711**
Construction (TEC)			
FY 2019	25,000	25,000	–
FY 2020	50,000	50,000	3,520
FY 2021	22,000	22,000	35,000
FY 2022	40,389	40,389	40,000
Outyears	288,900	288,900	347,769
Total, Construction (TEC)	**426,289**	**426,289**	**426,289**
Total Estimated Cost (TEC)			
FY 2018	16,000	16,000	–
FY 2019	60,000	60,000	22,054
FY 2020	60,000	60,000	36,621
FY 2021	62,000	62,000	74,146
FY 2022	75,100	75,100	75,000
Outyears	288,900	288,900	354,179
Total, TEC	**562,000**	**562,000**	**562,000**

(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	963
Outyears	–	–	6,739
Total, OPC	**28,000**	**28,000**	**28,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
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	37,584
FY 2021	62,000	62,000	74,146
FY 2022	75,100	75,100	75,000
Outyears	288,900	288,900	360,918
Total, TPC	**590,000**	**590,000**	**590,000**

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design	95,702	69,800	**N/A**
Design - Contingency	40,009	19,950	**N/A**
Total, Design (TEC)	**135,711**	**89,750**	**N/A**
Equipment	300,615	230,400	**N/A**
Construction - Contingency	125,674	60,050	**N/A**
Total, Construction (TEC)	**426,289**	**290,450**	**N/A**
Total, TEC	**562,000**	**380,200**	**N/A**
Contingency, TEC	*165,683*	*80,000*	***N/A***
Other Project Cost (OPC)			
R&D	8,200	8,000	**N/A**
Conceptual Planning	2,000	2,000	**N/A**
Conceptual Design	12,100	12,100	**N/A**
Start-up	2,000	2,000	**N/A**
OPC - Contingency	3,700	5,900	**N/A**
Total, Except D&D (OPC)	**28,000**	**30,000**	**N/A**
Total, OPC	**28,000**	**30,000**	**N/A**
Contingency, OPC	*3,700*	*5,900*	***N/A***
Total, TPC	**590,000**	**410,200**	**N/A**
Total, Contingency (TEC+OPC)	***169,383***	***85,900***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Request Year	Type	Prior Years	FY 2019	FY 2020	FY 2021	FY 2022	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
FY 2022	TEC	16,000	60,000	60,000	62,000	75,100	288,900	562,000
	OPC	24,000	2,000	2,000	—	—	—	28,000
	TPC	40,000	62,000	62,000	62,000	75,100	288,900	590,000

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	FY 2029
Expected Useful Life	25 years
Expected Future Start of D&D of this capital asset	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, Maintenance and Repair	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 provided a Preliminary 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. 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 (LCLS-II-HE), SLAC
SLAC National Accelerator Laboratory
Project is for Design and Construction

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

Summary

The FY 2022 Request for the Linac Coherent Light Source-II High Energy (LCLS-II-HE) project is $50,000,000 of Total Estimated Cost (TEC) funding and $3,000,000 of Other Project Costs (OPC). The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-3A, Approve Long-Lead Procurements, which was approved on May 12, 2020. This project at CD-1 established a preliminary Total Project Cost (TPC) range of $290,000,000 to $480,000,000. This cost range encompassed the most feasible preliminary alternatives at CD-1. The CD-1 preliminary TPC point estimate for this project was $368,000,000. Pending CD-2 reviews, the project's current TPC estimate is $660,000,000.

Significant Changes

The LCLS-II HE project was initiated in FY 2019. The project's Total Project Cost (TPC) estimate has increased from $428,000,000 to $660,000,000 between CD-3A and the current budget request as a result of a maturing design effort that identified additional costs across the project scope, added scope for a new superconducting electron source, and increased contingency to address several future risks. A major risk concerns the ability to operate the LCLS-II cryomodules above their design accelerating gradient and their ability to meet their design operating gradient, which is significantly higher than previously achieved with current technology. The R&D program in progress for the LCLS-II-HE cryomodules has shown promise and is nearly complete. Due to delays caused by the coronavirus pandemic (COVID-19), the performance of the LCLS-II cryomodules will not be known until sometime in FY 2022 when the LCLS-II project begins the accelerator commissioning. Both risks can be mitigated by adding additional cryomodules to the project at additional cost. The LCLS-II-HE project is currently assessing the impact of COVID-19 on the project's cost, schedule, and project milestones. The combined CD-2/3 approval is now projected for 4Q FY 2022 and CD-4 is now projected for 2Q FY 2030.

FY 2020 funding continued the support of planning, engineering, design, R&D prototyping, and long-lead procurements.
FY 2021 funding continues engineering, design, R&D, prototyping, and long-lead procurements of construction items.
FY 2022 funding will support engineering, design, R&D, prototyping, continuing long-lead procurements, and preparations for baselining the project.

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	12/15/16	3/23/18	9/21/18	2Q FY 2023	1Q FY 2023	2Q FY 2023	N/A	1Q FY 2029
FY 2022	12/15/16	3/23/18	9/21/18	4Q FY 2022	3Q FY 2022	4Q FY 2022	N/A	2Q 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 2019	1Q FY 2021	4Q FY 2019
FY 2020	2Q FY 2023	4Q FY 2019
FY 2021	2Q FY 2023	2Q FY 2020
FY 2022	4Q FY 2022	5/12/20

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	34,000	374,000	408,000	20,000	N/A	20,000	428,000
FY 2022	39,000	589,000	628,000	32,000	N/A	32,000	660,000

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. Recently added scope includes a new, superconducting electron source and increased contingency to address several future risks. Additional scope is being considered to address several risks associated with the linac performance, operation reliability and scientific mission capability.

Justification

The leadership position of LCLS-II will be challenged by the European x-ray free electron laser (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- 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 2022-2024 is the first step to address this capability gap. LCLS-II will be the premier 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 fully address the capability gaps and 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 > 10^{10} @ 12.8 keV (20 μJ)

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
Design (TEC)			
FY 2018	2,000	2,000	–
FY 2019	10,000	10,000	130
FY 2020	8,000	8,000	2,884
FY 2021	8,000	8,000	8,000
FY 2022	6,000	6,000	12,000
Outyears	5,000	5,000	15,986
Total, Design (TEC)	**39,000**	**39,000**	**39,000**
Construction (TEC)			
FY 2018	6,000	6,000	–
FY 2019	15,200	15,200	4,270
FY 2020	25,457	25,457	19,620
FY 2021	44,000	44,000	32,000
FY 2022	44,000	44,000	70,000
Outyears	454,343	454,343	463,110
Total, Construction (TEC)	**589,000**	**589,000**	**589,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
FY 2018	8,000	8,000	–
FY 2019	25,200	25,200	4,400
FY 2020	33,457	33,457	22,504
FY 2021	52,000	52,000	40,000
FY 2022	50,000	50,000	82,000
Outyears	459,343	459,343	479,096
Total, TEC	**628,000**	**628,000**	**628,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
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	4,081
FY 2021	2,000	2,000	3,000
FY 2022	3,000	3,000	4,000
Outyears	15,000	15,000	17,687
Total, OPC	**32,000**	**32,000**	**32,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Project Cost (TPC)			
FY 2018	10,000	10,000	1,191
FY 2019	31,200	31,200	6,441
FY 2020	37,457	37,457	26,585
FY 2021	54,000	54,000	43,000
FY 2022	53,000	53,000	86,000
Outyears	474,343	474,343	496,783
Total, TPC	**660,000**	**660,000**	**660,000**

Note – In FY 2021, the Office of Science reprogrammed $19,343,211.24 of prior year funds to the LCLS-II project at SLAC. The Prior Year Budget Authority in the table above reflects this reprogramming and additional funds are included in the outyears to maintain the project profile.

4. **Details of Project Cost Estimate**

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design	35,000	30,500	**N/A**
Design - Contingency	4,000	3,500	**N/A**
Total, Design (TEC)	**39,000**	**34,000**	**N/A**
Site Preparation	8,000	3,000	**N/A**
Equipment	410,000	250,700	**N/A**
Other Construction	29,000	9,000	**N/A**
Construction - Contingency	142,000	111,300	**N/A**
Total, Construction (TEC)	**589,000**	**374,000**	**N/A**
Total, TEC	**628,000**	**408,000**	**N/A**
Contingency, TEC	*146,000*	*114,800*	***N/A***
Other Project Cost (OPC)			
R&D	12,000	4,000	**N/A**
Conceptual Planning	2,000	1,500	**N/A**
Conceptual Design	2,000	2,000	**N/A**
Start-up	8,000	6,500	**N/A**
OPC - Contingency	8,000	6,000	**N/A**
Total, Except D&D (OPC)	**32,000**	**20,000**	**N/A**
Total, OPC	**32,000**	**20,000**	**N/A**
Contingency, OPC	*8,000*	*6,000*	***N/A***
Total, TPC	**660,000**	**428,000**	**N/A**
Total, Contingency (TEC+OPC)	***154,000***	***120,800***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Request Year	Type	Prior Years[a]	FY 2020	FY 2021	FY 2022	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	36,000	14,000	60,000	—	238,000	348,000
	OPC	8,000	4,000	—	—	8,000	20,000
	TPC	44,000	18,000	60,000	—	246,000	368,000
FY 2021	TEC	36,000	50,000	14,000	—	308,000	408,000
	OPC	8,000	4,000	2,000	—	6,000	20,000
	TPC	44,000	54,000	16,000	—	314,000	428,000
FY 2022	TEC	33,200	33,457	52,000	50,000	459,343	628,000
	OPC	8,000	4,000	2,000	3,000	15,000	32,000
	TPC	41,200	37,457	54,000	53,000	474,343	660,000

Note – In FY 2021, the Office of Science reprogrammed $19,343,211.24 of prior year funds to the LCLS-II project at SLAC. The FY 2022 Request in the table above reflects this reprogramming and additional funds are included in the outyears to maintain the project profile.

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	FY 2030
Expected Useful Life	25 years
Expected Future Start of D&D of this capital asset	FY 2055

Related Funding Requirements
(dollars in thousands)

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

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.

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

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 has started preliminary design activities, identifying 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.

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

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

Summary

The FY 2022 Request is $32,400,000 including $28,100,000 in Total Estimated Cost funds and $4,300,000 in Other Project Costs funds. Following a baseline change in FY 2021, the Total Project Cost (TPC) is $1,136,400,000.

The most recent DOE Order 413.3B approved Critical Decisions (CD) are CD-2/3, Approve Performance Baseline and Approve Start of Construction, that were approved on March 21, 2016. A Baseline Change Proposal (BCP) was approved on October 13, 2020, by the Project Management Executive.

Significant Changes

This Construction Project Data Sheet (CPDS) is an update of the FY 2019 CPDS and does not include a new start for the budget year. The project was impacted by the coronavirus (COVID-19) pandemic which caused a baseline deviation. The new CD-4 milestone is projected for January 2024.

FY 2021 funding was used to continue the installation of all major accelerator and x-ray systems and equipment commissioning activities that were halted due to the COVID-19 Shelter in Place order issued by the local and state authorities on March 16, 2020. FY 2022 funding will support the completion of installation and commissioning activities for the project. The remaining work will follow all appropriate COVID-19 protocols and procedures to ensure the safety and health of project and subcontractor staff.

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 2013	4/22/10	-	10/14/11	1Q FY 2013	4Q FY 2016	3Q FY 2013	N/A	4Q FY 2019
FY 2014	4/22/10	-	10/14/11	4Q FY 2013	4Q FY 2016	4Q FY 2013	N/A	4Q FY 2019
FY 2015	4/22/10	-	10/14/11	4Q FY 2015	4Q FY 2017	4Q FY 2016	N/A	4Q FY 2021
FY 2016	4/22/10	1/21/14	8/22/14	2Q FY 2016	4Q FY 2017	2Q FY 2016	N/A	4Q FY 2021
FY 2017	4/22/10	1/21/14	8/22/14	2Q FY 2016	4Q FY 2017	2Q FY 2016	N/A	3Q FY 2022
FY 2018	4/22/10	1/21/14	8/22/14	3/21/16	4Q FY 2017	3/21/16	N/A	3Q FY 2022
FY 2019	4/22/10	1/21/14	8/22/14	3/21/16	4Q FY 2018	3/21/16	N/A	3Q FY 2022
FY 2020	4/22/10	1/21/14	8/22/14	3/21/16	4Q FY 2018	3/21/16	N/A	3Q FY 2022
FY 2021	4/22/10	1/21/14	8/22/14	3/21/16	4Q FY 2018	3/21/16	N/A	2Q FY 2024
FY 2022	4/22/10	1/21/14	8/22/14	3/21/16	9/28/18	3/21/16	N/A	2Q 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-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 2013	1Q FY 2013	3/14/12	-
FY 2014	4Q FY 2013	3/14/12	-
FY 2015	4Q FY 2015	3/14/12	-
FY 2016	2Q FY 2016	3/14/12	3Q FY 2015
FY 2017	2Q FY 2016	3/14/12	5/28/15
FY 2018	3/21/16	3/14/12	5/28/15
FY 2019	3/21/16	3/14/12	5/28/15
FY 2020	3/21/16	3/14/12	5/28/15
FY 2021	3/21/16	3/14/12	5/28/15
FY 2022	3/21/16	3/14/12	5/28/15

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

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D[a]	OPC, D&D	OPC, Total	TPC
FY 2013	18,000	367,000	385,000	20,000	N/A	20,000	405,000
FY 2014	18,000	367,000	385,000	20,000	N/A	20,000	405,000
FY 2015	47,000	799,400	846,400	48,600	N/A	48,600	895,000
FY 2016	47,000	869,400	916,400	48,600	N/A	48,600	965,000
FY 2017	47,000	946,100	993,100	51,900	N/A	51,900	1,045,000
FY 2018	47,000	946,100	993,100	51,900	N/A	51,900	1,045,000
FY 2019	47,000	946,100	993,100	51,900	N/A	51,900	1,045,000
FY 2020	47,000	946,100	993,100	51,900	N/A	51,900	1,045,000
FY 2021	47,000	1,033,200	1,080,200	59,800	N/A	59,800	1,140,000
FY 2022	47,000	1,033,200	1,080,200	56,200	N/A	56,200	1,136,400

[a] Other Project Costs (OPC) are funded through laboratory overhead.

2. Project Scope and Justification

Scope

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

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

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

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

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

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

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

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

Prior to implementing the revised LCLS-II project, the original LCLS-II scope included construction of the Sector 10 Annex with a total cost of $8,200,000. The construction costs were included in the Total Project Cost of $1,045M, and are maintained in the revised BCP Total Project Cost of $1,136.4M.

Justification

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

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

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

Key Performance Parameters (KPPs)

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

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

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

Performance Measure	Threshold	Objective
FEL photon quantity (10^{-3} BW[a])	10^{10} (lasing @ 15,000 eV)	> 10^{12} @ 15,000 eV

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
Design (TEC)			
FY 2012	2,000	2,000	2,000
FY 2013	5,000	5,000	5,000
FY 2014	4,000	4,000	2,040
FY 2015	21,000	21,000	9,089
FY 2016	15,000	15,000	20,500
FY 2017	–	–	6,040
FY 2018	–	–	2,331
Total, Design (TEC)	**47,000**	**47,000**	**47,000**
Construction (TEC)			
FY 2006	277	277	–
FY 2008	158	158	–
FY 2012	42,503	20,003	13,862
FY 2013	18,544	41,044	33,423
FY 2014	71,798	71,798	28,929
FY 2015	117,704	117,704	65,897
FY 2016	185,372	185,372	125,476
FY 2017	190,000	190,000	224,606
FY 2018	192,100	192,100	209,060
FY 2019	134,300	134,300	159,240
FY 2020	16,543	16,543	65,166
FY 2021	35,801	35,801	65,000
FY 2022	28,100	28,100	38,000
Outyears	–	–	4,541
Total, Construction (TEC)	**1,033,200**	**1,033,200**	**1,033,200**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
FY 2006	277	277	–
FY 2008	158	158	–
FY 2012	44,503	22,003	15,862
FY 2013	23,544	46,044	38,423
FY 2014	75,798	75,798	30,969
FY 2015	138,704	138,704	74,986
FY 2016	200,372	200,372	145,976
FY 2017	190,000	190,000	230,646
FY 2018	192,100	192,100	211,391
FY 2019	134,300	134,300	159,240
FY 2020	16,543	16,543	65,166
FY 2021	35,801	35,801	65,000
FY 2022	28,100	28,100	38,000
Outyears	–	–	4,541
Total, TEC	**1,080,200**	**1,080,200**	**1,080,200**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Other Project Cost (OPC)			
FY 2010	1,126	1,126	938
FY 2011	9,474	9,474	8,033
FY 2012	8,000	8,000	8,893
FY 2013	–	–	116
FY 2014	10,000	10,000	8,581
FY 2015	9,300	9,300	2,660
FY 2016	–	–	34
FY 2017	–	–	758
FY 2018	7,900	7,900	2,204
FY 2019	6,100	6,100	3,038
FY 2020	–	–	3,545
FY 2021	–	–	5,500
FY 2022	4,300	4,300	6,500
Outyears	–	–	5,400
Total, OPC	**56,200**	**56,200**	**56,200**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Project Cost (TPC)			
FY 2006	277	277	–
FY 2008	158	158	–
FY 2010	1,126	1,126	938
FY 2011	9,474	9,474	8,033
FY 2012	52,503	30,003	24,755
FY 2013	23,544	46,044	38,539
FY 2014	85,798	85,798	39,550
FY 2015	148,004	148,004	77,646
FY 2016	200,372	200,372	146,010
FY 2017	190,000	190,000	231,404
FY 2018	200,000	200,000	213,595
FY 2019	140,400	140,400	162,278
FY 2020	16,543	16,543	68,711
FY 2021	35,801	35,801	70,500
FY 2022	32,400	32,400	44,500
Outyears	–	–	9,941
Total, TPC	**1,136,400**	**1,136,400**	**1,136,400**

Note – In FY 2021, the Office of Science reprogrammed $23,199,000 of prior year funds and $2,801,000 of FY 2021 funds to the LCLS-II project at SLAC. The Budget Authority in the table above reflects this reprogramming.

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design	47,000	47,000	42,125
Design - Contingency	N/A	N/A	4,875
Total, Design (TEC)	**47,000**	**47,000**	**47,000**
Site Preparation	24,700	24,700	24,700
Equipment	902,100	902,100	678,205
Other Construction	76,471	76,471	58,500
Construction - Contingency	29,929	29,929	184,695
Total, Construction (TEC)	**1,033,200**	**1,033,200**	**946,100**
Total, TEC	**1,080,200**	**1,080,200**	**993,100**
Contingency, TEC	*29,929*	*29,929*	*189,570*
Other Project Cost (OPC)			
R&D	1,972	1,972	1,972
Conceptual Planning	1,980	1,980	1,980
Conceptual Design	23,408	23,408	23,408
Start-up	22,190	22,190	15,790
OPC - Contingency	6,650	10,250	8,750
Total, Except D&D (OPC)	**56,200**	**59,800**	**51,900**
Total, OPC	**56,200**	**59,800**	**51,900**
Contingency, OPC	*6,650*	*10,250*	*8,750*
Total, TPC	**1,136,400**	**1,140,000**	**1,045,000**
Total, Contingency (TEC+OPC)	***36,579***	***40,179***	***198,320***

5. Schedule of Appropriations Requests

(dollars in thousands)

Request Year	Type	Prior Years	FY 2020	FY 2021	FY 2022	Outyears	Total
FY 2012 (MIE)	TEC	22,000	TBD	TBD	TBD	TBD	TBD
	OPC	18,600	TBD	TBD	TBD	TBD	TBD
	TPC	40,600	TBD	TBD	TBD	TBD	TBD
FY 2013 (MIE)	TEC	385,000	—	—	—	—	385,000
	OPC	20,000	—	—	—	—	20,000
	TPC	405,000	—	—	—	—	405,000
FY 2014	TEC	385,000	—	—	—	—	385,000
	OPC	20,000	—	—	—	—	20,000
	TPC	405,000	—	—	—	—	405,000
FY 2015	TEC	846,400	—	—	—	—	846,400
	OPC	48,600	—	—	—	—	48,600
	TEC	895,000	—	—	—	—	895,000
FY 2016	TEC	916,400	—	—	—	—	916,400
	OPC	48,600	—	—	—	—	48,600
	TPC	965,000	—	—	—	—	965,000
FY 2017	TEC	993,100	—	—	—	—	993,100
	OPC	51,900	—	—	—	—	51,900
	TPC	1,045,000	—	—	—	—	1,045,000
FY 2018	TEC	993,100	—	—	—	—	993,100
	OPC	51,900	—	—	—	—	51,900
	TPC	1,045,000	—	—	—	—	1,045,000
FY 2019	TEC	993,100	—	—	—	—	993,100
	OPC	51,900	—	—	—	—	51,900
	TPC	1,045,000	—	—	—	—	1,045,000
FY 2020	TEC	993,100	—	—	—	—	993,100
	OPC	51,900	—	—	—	—	51,900
	TPC	1,045,000	—	—	—	—	1,045,000
FY 2021	TEC	993,100	—	—	—	—	993,100
	OPC	51,900	—	—	—	—	51,900
	TPC	1,045,000	—	—	—	—	1,045,000
FY 2022	TEC	999,756	16,543	35,801	28,100	—	1,080,200
	OPC	51,900	—	—	4,300	—	56,200
	TPC	1,051,656	16,543	35,801	32,400	—	1,136,400

Note – In FY 2021, the Office of Science reprogrammed $23,199,000 of prior year funds and $2,801,000 of FY 2021 funds to the LCLS-II project at SLAC. The FY 2022 Request in the table above reflects this reprogramming.

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	FY 2024
Expected Useful Life	25 years
Expected Future Start of D&D of this capital asset	FY 2049

Related Funding Requirements
(dollars in thousands)

	Annual Costs		Life Cycle Costs	
	Previous Total Estimate	**Current Total Estimate**	**Previous Total Estimate**	**Current Total Estimate**
Operations	N/A	TBD	N/A	TBD
Utilities	N/A	TBD	N/A	TBD
Maintenance and Repair	N/A	TBD	N/A	TBD
Total, Operations and Maintenance	$38.6M	$38.6M	$1,317M	$1,317M

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

8. Acquisition Approach

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

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

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

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

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

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. This fundamental research, conducted at universities, DOE national laboratories, and research institutions across the country, explores organisms and ecosystems that can influence the U.S. energy system and advances understanding of the relationships between energy and environment from local to global scales, including a focus on climate change modeling. BER's support of basic research will contribute to a future of stable, reliable, and resilient energy sources and infrastructures that will contribute to climate solutions with a focus on environmental justice while strengthening economic prosperity. Research within BER can be categorized into biological systems and Earth and environmental systems. Biological systems research seeks to characterize and predictively understand microbial and plant systems using genomic science, computational analyses, and experimental approaches. Foundational knowledge of the structure and function of these systems underpins the ability to leverage natural processes for energy production, including the sustainable development of biofuels and other bioproducts, as well as natural carbon sequestration capabilities. Characterization of microbial communities will lead to understanding the impacts of how vulnerable environments will respond to climate change. Earth and environmental systems research seeks to characterize and understand the feedback between Earth and energy systems, which includes studies on atmospheric physics and chemistry, ecosystem ecology and biogeochemistry, and development and validation of Earth system models extending from regional to global scales. These models integrate information on the biosphere, atmosphere, terrestrial land masses, oceans, sea ice, subsurface, and human components. To promote world-class research in these areas, BER supports user facilities that enable observation and measurement of atmospheric, biological, and biogeochemical processes using the latest technologies. All BER activities are informed by community and the federally chartered BER Advisory Committee engagement.

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 and clean energy technologies to underpin a burgeoning bioeconomy.

Since the 1950s, BER and its predecessor organizations have been critical contributors to the fundamental scientific understanding of climate change and 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 climate and Earth System models that are in use today. Presently, BER research contributes to reducing the greatest uncertainties in model predictions, e.g., involving clouds and aerosols. In the last decade, DOE research has made considerable advances in increasing the reliability and predictive capabilities of these models using applied mathematics, access to DOE's fastest computers, and systematic comparisons with observational data to improve confidence in model predictions.

BER-supported research has also produced the software and algorithms that enable the productive application of models that span genomics, systems biology, environmental, and Earth system science. These mission-driven models that are run on DOE's fastest supercomputers, are game-changing and among the most capable in the world. For example, BER's models of biological and environmental processes are exploring the systems level complexity of genomics, protein structures, and microbial dynamics that will serve the basis of future bioenergy sources. BER's Joint Genome Institute (JGI) and Environmental Molecular Sciences Laboratory (EMSL) provide the necessary information to achieve these goals. Model developments in climate and Earth system science are shifting to ultra-high resolution to better represent the processes that limit prediction uncertainty, e.g., in the most climate-sensitive regions. Cloud-aerosol data provided by the Atmospheric Radiation Measurement Research Facility (ARM) as well as environmental data provided by BER's long term observatories are necessary in developing, testing, and validating climate and Earth systems.

Highlights of the FY 2022 Request

The FY 2022 Request for BER is $828.0 million. BER will enhance its research on climate modeling by: 1) initiating new Urban Integrated Field Laboratories (Urban IFLs) that will build integrated models and tools that improve our understanding of the interdependence of the natural and human components of the climate system; 2) establishing the National Virtual Climate Laboratory (NVCL), which will serve as a one stop portal to advance access to climate science from the DOE National Laboratories; and 3) initiating planning for a Climate Laboratory, which is included in the American Jobs Plan, or a center award, affiliated with a Historically Black College or University (HBCU) or other Minority Serving Institution (MSI). BER research will also support new activities to examine the global carbon carrying capacity of terrestrial ecosystems; continue investment in artificial intelligence (AI); enhance support for novel quantum sensors for biological systems and continued support of crosscutting SC QIS Research Centers; launch a new Biopreparedness Research Virtual Environment (BRaVE); and support new activities in advanced manufacturing for novel polymer upcycling approaches as well as new bio-based materials and foundational bioenergy research underpinning new biotechnology and the bioeconomy. BER will continue a pilot project to study complex coastal estuaries, including Puget Sound.

Key elements in the FY 2022 Request include:

<u>Research</u>

- Within Genomic Sciences, the Biopreparedness Research Virtual Environment (BRaVE) will provide the cyber infrastructure, computational platforms, and next generation experimental research capabilities within a single portal allowing distributed networks of scientists to work together on multidisciplinary research priorities and/or national emergency challenges. The overall goals of BRaVE are to understand the function of whole biological systems, effectively integrating knowledge from distributed datasets, individual process components, and individual component models in an AI/ML-enabled, open access computational environment. BER also prioritizes the four BRCs, which perform new fundamental research underpinning the production of clean energy and chemicals from sustainable biomass resources for translation of basic research results to industry. BER will initiate efforts to translate biodesign rules to functional properties of novel biological polymers and efforts to understand the key factors controlling soil carbon residence time through detailed characterization of soil-plant-microbe-environment processes governing carbon turnover. Computational Biosciences efforts will include a new initiative on Integrated Computational and Data Infrastructure for Scientific Discovery to deploy a flexible multi-tier data and computational management architecture for microbiome system dynamics and behavior. Research in Biomolecular Characterization and Imaging Science will develop QIS enabled techniques and sensors for predictive understanding of biological processes.
- Earth and Environmental Systems Sciences research will focus on improving the representation of physical and biogeochemical processes to enhance the predictability of Earth system models. Environmental System Science integrates physical and hydrobiogeochemical sciences to provide scale-aware predictive understanding of above- and below-surface terrestrial ecosystems. Atmospheric System Research will investigate cloud-aerosol-precipitation interactions to improve fine resolution cloud resolving models and to enhance the Energy Exascale Earth System Model (E3SM) down to spatial scales of 3 km. The E3SM system will include advanced software and AI/ML for running on future DOE computer architectures. The Data Management effort will continue to enhance data archiving and management capabilities, including using AI. Research on coastal estuaries will be continued, with a focus on the Chesapeake Bay, Puget Sound, and the Great Lakes. Research involving field-based observing and modeling will be initiated under new Urban Integrated Field Laboratories to incorporate environmental justice as a key tenet of research involving climate-sensitive regions. Additionally, the new NVCL will provide unified access to climate science to MSIs and HBCUs, connecting frontline communities with the key climate science capabilities at the DOE national laboratories. Planning efforts are initiated for a competition pending the AJP funding for a Climate Laboratory/Center affiliated with an HBCU or MSIs; the lab or center will serve as the translational agent connecting BER climate science with broader socioeconomic and environmental justice issues for equitable solutions. This will enhance research capacity at the affiliated universities and bring interdisciplinary strength and diversity to DOE’s climate research.
- The Office of Science is fully committed to advancing a diverse, equitable, and inclusive research community. This commitment is key to providing the scientific and technical expertise for U.S. leadership in biological and environmental sciences. Toward that goal, BER will participate in the SC-wide Reaching a New Energy Sciences Workforce (RENEW) initiative that leverages SC’s unique national laboratories, user facilities, and other research infrastructures to provide undergraduate and graduate training opportunities for students and academic institutions not currently well represented in the U.S. S&T ecosystem. This includes MSIs and individuals from groups historically

underrepresented in STEM, but also includes students from communities with environmental justice impacts and the EPSCoR jurisdictions. The hands-on experiences gained through the RENEW initiative will open new career avenues for the participants, forming a nucleus for a future pool of talented young scientists, engineers, and technicians with the critical skills and expertise needed for the full breadth of SC research activities, including DOE national laboratory staffing.

Facility Operations

- The DOE JGI will continue providing high quality genome sequence data and analysis techniques for a wide variety of plants and microbial communities.
- ARM will continue to provide new observations to advance Earth System models. A mobile facility will continue to be deployed near Houston, TX to conduct the aerosol-convection interactions experiment. Another mobile unit will continue the study on water and energy cycles in mountainous watersheds. A third will relocate to the south eastern U.S. for operation starting in FY 2023. Acceptance testing and evaluation will be completed on the manned aircraft.
- 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.
- All BER facilities will begin a multiyear instrumentation refresh to ensure these facilities are delivering the capabilities required by the scientific community.

Biological and Environmental Research
FY 2022 Research Initiatives

Biological and Environmental Research supports the following FY 2022 Research Initiatives.

(dollars in thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Artificial Intelligence and Machine Learning	3,000	3,000	3,000	–
Biopreparedness Research Virtual Environment (BRaVE)	–	–	5,000	+5,000
Exascale Computing Crosscut	15,000	15,000	15,000	–
Fundamental Science to Transform Advanced Manufacturing	–	–	5,000	+5,000
Integrated Computational & Data Infrastructure	–	–	5,183	+5,183
Quantum Information Science	12,000	12,000	14,500	+2,500
Reaching a New Energy Sciences Workforce (RENEW)	–	–	3,000	+3,000
Revolutionizing Polymers Upcycling	–	6,250	6,250	–
Total, Research Initiatives	**30,000**	**36,250**	**56,933**	**+20,683**

Biological and Environmental Research
Funding

(dollars in thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Biological and Environmental Research				
Genomic Science	268,235	277,574	277,000	-574
Biomolecular Characterization and Imaging Science	45,000	45,000	45,000	–
Biological Systems Facilities & Infrastructure	77,000	80,000	84,500	+4,500
Biological Systems Science, SBIR/STTR	14,544	–	–	–
Total, Biological Systems Science	**404,779**	**402,574**	**406,500**	**+3,926**
Atmospheric System Research	35,000	36,000	39,000	+3,000
Environmental System Sciences	77,638	87,777	119,500	+31,723
Earth and Environmental Systems Modeling	97,000	100,674	108,000	+7,326
Earth and Environmental Systems Sciences Facilities and Infrastructure	123,110	125,975	155,000	+29,025
Earth and Environmental Systems Sciences, SBIR/STTR	12,473	–	–	–
Total, Earth and Environmental Systems Sciences	**345,221**	**350,426**	**421,500**	**+71,074**
Subtotal, Biological and Environmental Research	**750,000**	**753,000**	**828,000**	**+75,000**
Total, Biological and Environmental Research	**750,000**	**753,000**	**828,000**	**+75,000**

SBIR/STTR funding:
- FY 2020 Enacted: SBIR $23,687,000 and STTR $3,330,000
- FY 2021 Enacted: SBIR $23,851,000 and STTR $3,352,000
- FY 2022 Request: SBIR $25,504,000 and STTR $3,589,000

Biological and Environmental Research
Explanation of Major Changes

	(dollars in thousands)
	FY 2022 Request vs FY 2021 Enacted
Biological Systems Science	**+$3,926**

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. Continued 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. New activities will be initiated to understand the key molecular processes governing soil-microbe-plant interactions with the environment that control carbon turnover. Environmental Genomics research is focused on understanding environmentally relevant microbiomes and the interdependencies between plants and microbes in a sustainable and resilient ecosystem. This research will be enhanced with the Biopreparedness Research Virtual Environment (BRaVE) providing the integrated computational and experimental platforms for multidisciplinary research and the Fundamental Science to Transform Advanced Manufacturing Initiative that will focus on novel polymer recycling approaches as well as new bio-based materials. Computational Bioscience will focus on an integrated computational platform, building out the National Microbiome Data Collaborative and continuing to add functionality to the Systems Biology Knowledgebase. The Request fully supports the four DOE BRCs in their fifth year of bioenergy research to underpin efforts to produce innovative clean energy and bioproducts from sustainable biomass resources, including augmented data dissemination to the broader community. 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.

	(dollars in thousands) FY 2022 Request vs FY 2021 Enacted
Earth and Environmental Systems Sciences The Request enhances support for 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 to understand and model the fate and transport of nutrients. Research on coastal estuaries will be continued, with a focus on the Chesapeake Bay, Puget Sound, and the Great Lakes. New integrated field laboratories focused on urban regions will be initiated, as will establishment of the National Virtual Climate Laboratory (NVCL) to serve as a unified access point for engagement with key climate science capabilities at the DOE labs. Planning begins for a new Climate Laboratory or Center. 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 continue deployment to the Houston, TX area; the second unit will continue observations in the upper Colorado River watershed; and the third unit will be deployed to the south eastern U.S. for operation in FY 2023. Acceptance testing and evaluation will be completed on the recently acquired manned aircraft. EMSL will focus on biological and environmental molecular science. Data management activities will include applying advanced analytics to observations and environmental field data.	**+$71,074**
Total, Biological and Environmental Research	**+$75,000**

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

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.

BER supports some interagency projects to manage databases (such as the Protein Data Bank) through interagency awards and funding for complementary community resources (such as beamlines and cryo-electron microscopy), mostly with NIH and NSF. BER also serves on a government advisory committee for DoD's latest Manufacturing Innovation Institute, the BioMADE project researching synthetic biology applications.

All Earth systems research activities are specifically coordinated through the interagency U.S. Global Change Research Program and other NSTC subcommittees. For example, the DOE E3SM has evolved to become the world's highest resolution Earth system model, that in turn serves as an integrating platform for the scientific community to develop and test system-level scientific concepts. The new version will add advanced capabilities for exploring cryosphere-ocean dynamics' impacts of climate variability, 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 Interagency Council for Advancing Meteorological Services (ICAMS). The ICAMS is co-led by OSTP and NOAA with DOE as a member. The Intelligence Community has indicated significant interest in E3SM, as a platform to incorporate their data to address national security problems. The E3SM research is tightly coordinated with BER's large scale experimental activities and has 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 focus on plant-microbe interactions in soil.
Researchers at Lawrence Livermore National Laboratory investigating RNA viruses in soil found that most RNA viruses infect soil fungi. Furthermore, the presence of root litter influenced viral community composition, and the RNA viral communities responded rapidly to resource availability. This work helped identify the potential role viruses play in soil microbial community dynamics with the potential to influence carbon cycling and/or sequestration in soil.

Bioenergy Research Centers' research continues to highlight significant basic science advances in clean energy technology underpinning biofuels and bioproduct production from sustainable plant biomass.
Notable accomplishments include:
- engineering of a soil bacterium with plant-derived amino acids boosted methyl ketone production, a biodiesel blendstock, nine-fold compared to the control experiment without plant-derived amino acids;
- use of genome-scale metabolic models to predict carbon use efficiency (CUE) in bacteria across soil types, provided a predictive link between genomics and carbon sequestration in soil;
- identification of new gene variations in the genomes of Poplar trees are now available as molecular targets for precision genome-editing to improve biomass feedstock characteristics for biofuel and bioproduct production;
- results from a long term field experiment indicate reduced nitrate pollution in agricultural landscapes over seven years from established perennial bioenergy crops.

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 climate variability, change, and the evolution of extreme events.
At Los Alamos National Laboratory, Arctic ice and permafrost dynamics were coded into a numerical model to understand how climate change will impact the growth of Arctic deltas, stream flow, and sediment delivery to the coastal ocean. Researchers concluded from new model results that reduced ice cover may make Arctic deltas more vulnerable due to sea level rise and increased coastal erosion, and increased sediment delivery to the ocean will likely lead to altered biogeochemistry and turbidity on coastal ocean shelves.

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.
Notable accomplishments from the User Facilities include:

- the Joint Genome Institute (JGI) developed a new technology, chassis-independent recombinase-assisted genome engineering (CRAGE), that enables up to 48,000 basepairs to be inserted into a bacterial host in a single step enabling more successful and efficient biomanufacturing;
- the Environmental Molecular Sciences Laboratory (EMSL) developed an approach to image and view interactions between bacteria and plants at the molecular level for the very first time, thereby offering insights for improving agricultural production; and
- the Atmospheric Radiation Measurement (ARM) user facility observed that evaporating precipitation from stratocumulus clouds cools and moistens the sub-cloud layer and decreases air turbulence below the clouds. This new measured observation will need to be accurately represented in Earth system models to improve climate simulations of radiation balance over the ocean.

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 and how does this information explain the functional characteristics of cells, organisms, and whole biological systems?
- How do interactions among cells regulate the functional behavior of living systems and how can those interactions be understood dynamically and predictively?
- How do plants, microbes, and communities of organisms adapt and respond to changing environmental conditions (e.g., temperature, water and nutrient availability, and ecological interactions), and how can their behavior be manipulated toward desired outcomes?
- What organizing biological principles need to be understood to facilitate the design and engineering of new biological systems for beneficial purposes?

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 and bioeconomy-related 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.

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 biological research for solutions to clean energy production, breakthroughs in genome-based biotechnology underpinning a broader bioeconomy, 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 understand genotype to phenotype translations 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 in support of the ongoing Revolutionizing Polymer Upcycling research initiative. The Fundamental Science to Transform Advanced Manufacturing Initiative will support new approaches and systems to support biomanufacturing, especially with respect to genome-enabled engineering and design of biomaterials. 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.

The new Biopreparedness Research Virtual Environment (BRaVE) will provide a single portal through which a distributed network of capabilities and scientists can work together on multidisciplinary and multiprogram priorities to tackle significant DOE mission-relevant science priorities and quickly address urgent national challenges when needed. The overall goals of the virtual environment are to understand the function of whole biological systems, effectively integrating knowledge from distributed datasets, individual process components, and individual component models in an AI/ML-enabled, open access computational environment.

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 bioenergy and environmental 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 analyses techniques and simulation capabilities on high performance computing platforms to accelerate collaborative and reproducible systems biology research within the Genomic Sciences. The activity supports the Integrated Computational and Data Infrastructure for Scientific Discovery initiative.

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 integrative approaches to detecting, visualizing, and measuring systems biology processes engaged in 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 holistic and 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 governing phenotypic expression in plants and microbes. The activity will include new efforts to incorporate QIS-enabled concepts into new approaches for imaging and characterization and to advance design of sensors and detectors based on correlated materials for real-time biological and environmental sensing technology. This information is crucial for developing an understanding of the impact of various environmental and/or biosystems designs on whole cell or community function.

Biological Systems Facilities and Infrastructure

The DOE JGI is the only federally funded major genome sequencing center focused on genome discovery and analysis in plants and microbes for energy and environmental applications, and is widely used by researchers in academia, the national laboratories, and industry. High-throughput DNA sequencing underpins modern systems biology research, providing fundamental biological data on organisms and groups of organisms. By understanding shared features of multiple genomes, scientists can identify key genes that may link to biological function. These functions include microbial metabolic pathways and enzymes that are used to generate a range of different chemicals, 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.

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Biological Systems Science	**$402,574**	**$406,500**	**+$3,926**
Genomic Science	$277,574	$277,000	-$574
Foundational Genomics research supports 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 initiated in biological-based polymer recycling and upcycling research. Environmental Genomics focuses on research to understand environmentally relevant microbiomes and the interdependencies between plants and microbes in a sustainable and resilient ecosystem.		Foundational Genomics research will support new biosystems design research to accelerate the ability to design plants and microorganisms with specific beneficial functions for renewable bioenergy, bioproduct and biomaterials production, or carbon sequestration. Environmental Genomics will support new plant genomics research to elucidate genotype to phenotype translations leading to beneficial bioenergy or bioproduct traits in potential bioenergy crops and new environmental microbiome science to understanding the functions of environmentally relevant microbial communities in a variety of ecosystems. The Biopreparedness Research Virtual Environment (BRaVE) will provide a single platform through which a distributed network of data and experimental capabilities can be accessed by multidisciplinary teams of scientists working together on urgent multiprogram priorities requiring science-informed insights.	Funding will support new concepts in biosystems design for programmable production (and/or deconstruction) of organic/inorganic/hybrid materials in modified plants and microorganisms. These efforts will contribute towards knowledge of soil-microbe-plant interactions governing carbon sequestration in terrestrial systems. Also, new efforts in plant genomics and environmental microbiome science will extend advances in plant genome science and the ability to predictively understand the activity of microbial communities in relevant environmental microbiomes. These efforts, building on knowledge gained from breaking down plant cell wall polymers for bioenergy, will be explored in engineered microbial and fungal systems relevant to support the ongoing Revolutionizing Polymer Upcycling initiative. The Advanced Manufacturing Initiative will support new approaches and systems to support biomanufacturing to genome-enabled engineering and design of biomaterials. Funding will also initiate the BRaVE.

(dollars in thousands)

FY 2021 Enacted	FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Computational Bioscience supports open computational platform development for microbiome science integrative with the JGI and the DOE Systems Biology Knowledgebase for bioenergy, bioproduct and programmable biomaterials design.	Computational Bioscience will support microbiome science through the National Microbiome Data Collaborative and provide capabilities within KBase to enable the design of microbes and plants for a variety of bioenergy, bioproduct and biomaterial production purposes. Platform integration among these two projects will continue in close coordination with the JGI.	Funding will support new computational techniques for new biosystems design, plant genomics and environmental microbiome tools supporting broader genomic science efforts within the portfolio. The activity will also support the Integrated Computational and Data Infrastructure for Scientific Discovery.
The four BRCs began 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 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.	The four BRCs will begin their fifth year of operations on multidisciplinary clean energy research underpinning a broader bio-based economy. The BRCs will identify the genomic underpinnings of complex plant traits in crops with promising bioenergy/bioproduct characteristics, streamline biomass deconstruction processes to funnel plant components into defined process streams, design new pathways in microorganisms to convert plant biomass components to a range of fuels, chemicals and products, and develop the needed agronomic understanding of how to manage bioenergy crops for sustainable production on marginal lands.	The four BRCs will expand the knowledge needed to further advance a broadening bioeconomy by developing a range of dedicated crops for bioenergy and bioproduct production; developing methods to breakdown and convert plant biomass to a range of fuels, chemicals and products, and how to sustain broader scale efforts in bioenergy/bioproduct production at larger agronomic scales. Funding supports acceleration of bioenergy data curation, deposition, and dissemination to the broader community.

(dollars in thousands)

FY 2021 Enacted	FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Biomolecular Characterization and Imaging Science $45,000	$45,000	$ —
Development of new bioimaging, measurement and characterization approaches through the Biomolecular Characterization and Imaging Science activity includes expanded integrative imaging and analysis platforms and biosensors, including quantum science-enabled techniques, to understand and validate hypotheses of cellular metabolism and/or test pathway design relevant to bioenergy, bioproduct and biomaterials production in plants and microorganisms.	New quantum-enabled science concepts will be explored for application in bioimaging, measurement and characterization techniques through the Biomolecular Characterization and Imaging Science activity. Multimodal imaging concepts will also be pursued to create integrative systems to validate hypotheses of cellular function or design of new process.	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. New instrumentation based on these techniques will enhance capabilities to image biological processes dynamically and repeatedly without damage to the plant or microorganism under study.
Biological Systems Facilities & Infrastructure $80,000	$84,500	+$4,500
JGI provides 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.	JGI will provide users with high quality genome production and new analysis techniques for complex plant and microbiome samples. Integrative activities with the DOE Systems Biology Knowledgebase will provide new cross-platform capabilities for users and the NMDC. New methods for natural product identification and characterization of microbial isolates will be explored in concert with expanded metagenomics analysis techniques.	Funding will support integrative computational platforms among JGI, KBase, and NMDC which 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. A multi-year instrument and equipment refresh will be initiated to ensure that existing capabilities are state-of-the-art and to bring on new capabilities needed by the research community.

Note: Funding for the subprogram above, includes 3.65% of research and development (R&D) funding for the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Programs.

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 climate, environmental, and Earth system research, in support of DOE's mission goals for transformative science for energy and national security. This includes research on atmospheric, terrestrial, and human components of the Earth system; modeling of component interdependencies under a variety of natural and anthropogenic forcings; studies involving the interdependence and perturbations involving cloud, aerosol, marine, ecological, hydrological, biogeochemical, and cryospheric processes; analysis of the vulnerabilities that affect the resilience of the full suite of energy and related infrastructures as well as the vulnerabilities of other human systems and to extreme events; and uncertainty quantification. This integrated portfolio of research extends from molecular-level to field-scales, spans time scales from seasonal to centennial, and emphasizes the coupling of multidisciplinary experimentation with increasingly sophisticated computer models. The ultimate goal of new science is to develop and enhance a predictive, systems-level understanding of the fundamental science that addresses environmental and energy-related challenges associated with extreme phenomena. Investments will emphasize the most difficult challenges limiting prediction uncertainty, including cloud-aerosol interactions; terrestrial systems experiencing rapid transitions; the role of human activities as they couple with the natural system; and opportunities provided by machine learning and emerging technologies.

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 Atmospheric Radiation Measurement (ARM) user facility and the Environmental Molecular Sciences Laboratory (EMSL). ARM provides unique, multi-instrumented, high resolution capabilities for continuous, three-dimensional, long-term observations that researchers need in order to improve scientific understanding of atmospheric and climate processes involving clouds, aerosols, and the Earth's energy balance. ARM also contains a sophisticated model-simulation component that scientists use to augment field observations. EMSL provides integrated experimental and computational resources that researchers utilize 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 dedicated environmental field experiments; on behalf of the DOE and the international community, this activity also archives information generated world-wide by climate and Earth system models of variable complexity and sophistication.

<u>Atmospheric System Research</u>

Atmospheric System Research (ASR) is the primary U.S. research activity addressing the main source of uncertainty in climate and Earth system models: the interdependence of clouds, atmospheric aerosols, and precipitation that in turn influences the Earth's radiation balance. ASR coordinates with ARM, using the facility's continuous long-term datasets that in turn provide three-dimensional measurements of a variety of aerosol types that span natural to black carbon; cloud and precipitation microphysics under a variety of dynamical conditions; and turbulence and thermodynamics over a range of environmental conditions. Collected at diverse climate-sensitive geographic locations, the long-term observational datasets are supplemented with shorter-duration, ground-based and airborne field campaigns as well as laboratory studies to target specific atmospheric processes. Using integrated, scalable test-beds that incorporate process-level understanding, climate and Earth system models incorporate ASR research results to assure greater confidence in system level understanding and predictions that span local to global.

<u>Environmental System Science</u>

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. Short-term extreme events that act on spatial scales that span from molecular to global are of particular interest. New multi-scale data are essential to advance basic understanding and improve climate and Earth system models that can and are being used to achieve broad benefits ranging from planning and development of energy infrastructure 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, terrestrial-aquatic interfaces, and urban-rural transitions that are present in, e.g., the Arctic, midlatitude boreal zone, the Tropics, mountainous zones, and coastal regions that include the Delaware and Susquehanna watersheds, the Great Lakes, and Puget sound.

Using decadal-scale investments, such as the Next Generation Ecosystem Experiments (NGEEs), to study the variety of time scales and processes associated with ecological change, 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 climate and 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.

Urban Integrated Field Laboratories (IFLs) for climate science will be initiated. The Urban IFLs will be dedicated to developing the science framework for advancing observational and prediction capabilities to tackle the following interdependent challenges: constraining climate changes and its impacts on all scales across urban regions; evaluating the mitigation-potential for emerging energy technologies in urban regions and beyond; and addressing environmental justice by enabling neighborhood scale evaluation of climate impacts and energy needs. The Urban IFL scope will initially target a focused set of urban regions, integrate field data with a next generation Earth System Modeling framework, and create a science capability to advance climate and energy research as a unified co-dependent system. The scope will provide DOE, its stakeholders, and impacted communities with the best possible science-based tools that enable the evaluation of the societal and environmental benefits of current and future energy policies.

The National Virtual Climate Laboratory (NVCL) will provide access to climate science to MSIs and HBCUs, connecting frontline communities with the key climate science capabilities at the DOE national laboratories. Planning will also begin to establish a Climate Laboratory or center (pending AJP) affiliated with an HBCU or MSI.

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 air-surface exchanges 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.

<u>Earth and Environmental Systems Modeling</u>

Earth and Environmental Systems Modeling develops the physical, biogeochemical, and dynamical underpinning of fully coupled climate and Earth System Models (ESMs), in coordination with other Federal efforts. The research specifically focuses on quantifying and reducing the uncertainties in these system models, based on more advanced process representations, sophisticated software, robust couplers, diagnostics, performance metrics, and advanced data analytics. Priority model components include the ocean, sea-ice, land-ice, atmosphere, terrestrial ecosystems, and human activities, where these 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 within each of the world's leading climate and Earth system modeling 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.

<u>Earth and Environmental Systems Sciences Facilities and Infrastructure</u>

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. Both facilities will begin a multi-year instrumentation refresh.

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, radiative transfer, and related meteorological information. These observations provide new data to address the main source of uncertainty in climate and Earth system models: the interdependence of clouds, atmospheric aerosols, and precipitation that in turn influences the Earth's 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 2022, 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), where scientists will use a sophisticated precipitation radar together with radiosonde and aerosol measurements to learn more about cloud and aerosol interactions in deep convection. A second mobile unit will continue deployment in central Colorado to study how water and energy budgets in a heterogeneous mountain environment affect precipitation patterns. The third mobile unit will be moved from its Oliktok site to the southeastern U.S. with operations beginning in FY 2023. 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 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. Acceptance testing and evaluation on the recently acquired manned aircraft will be completed, including modifications to the air frame as needed to install numerous existing and new atmospheric aerosol, cloud, turbulence, and other sensors. Research flight operations will begin in FY 2023.

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 models, combines with advanced data analytics such as machine learning 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 for scientific discovery, technological innovation, decision-making, 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 coastal and watershed systems.

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted	FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Earth and Environmental Systems Sciences $350,426	**$421,500**	**+$71,074**
Atmospheric System Research $36,000	$39,000	+$3,000
ASR continues 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 continues to make use of data generated by Large Eddy Simulations at the ARM Oklahoma site.	The Request for ASR will enhance 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 and initial data from the TRACER campaign. ASR will continue to make use of data generated by Large Eddy Simulations at the ARM Oklahoma site.	The increase will support research focused on using the new observations from ARM field studies including the FY 2020 Arctic campaign and initial TRACER data to inform Earth system model development.

(dollars in thousands)

FY 2021 Enacted	FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Environmental System Science $87,777	$119,500	+$31,723
ESS focuses research on permafrost and maintains 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, and Puget Sound.	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, and Puget Sound. Urban Integrated Field Laboratories (IFLs) for climate science as a single portal to DOE lab climate capabilities. Planning will begin for a Climate Laboratory or center. The Request also supports the RENEW initiative to provide undergraduate and graduate training opportunities for students and academic institutions not currently well represented in the U.S. S&T ecosystem.	The increase for ESS will enhance investments in field experiments and process modeling activities associated with the terrestrial-aquatic project located in the mid-Atlantic, Great Lakes, and Puget Sound. The Urban IFLs will initially target a diverse set of urban regions, integrate field data with a next generation Earth System Modeling framework, and create a science capability to advance climate and energy research as a unified co-dependent system. The research will provide DOE, its stakeholders, and impacted communities with the best possible tools that enable the evaluation of the societal and environmental impacts of current and future energy policies. The NVCL will provide a single portal to partner the capabilities at the DOE national labs with key stakeholders from underrepresented and impacted communities through training and outreach for equitable climate resilience solutions. Planning initiates for establishment of a Climate Laboratory or center affiliated with an HBCU or MSI. Funding also supports the RENEW initiative.

(dollars in thousands)

FY 2021 Enacted	FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Earth and Environmental Systems Modeling $100,674	$108,000	+$7,326
Earth and Environmental Systems Modeling focuses investments on further refinement of the science underpinning nonhydrostatic 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.	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 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 enhance deployment of a higher resolution and more sophisticated version of E3SM and affiliate models to the scientific community in support of broad-based basic research as well as to energy sector stakeholders who require projections.
Focus is on core research in model intercomparisons and diagnostics. In addition, research incorporates limited fine scale physics and dynamics that can be applied to metrics for application to coastal zones and mid-latitude-Arctic interactions.	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 for application to coastal zones (including the Great Lakes and Puget Sound) and mid-latitude-Arctic interactions.	Funding will support research with a shift in emphasis from the science of Arctic-midlatitude interactions to examine boundary regions that also include coastal zones, the Great Lakes, and Puget Sound.

(dollars in thousands)

FY 2021 Enacted	FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Earth and Environmental Systems Sciences Facilities and Infrastructure $125,975	$155,000	+$29,025
ARM continues to provide new observations through long term measurements at fixed sites in Alaska, Oklahoma, and 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. ARM activities are prioritized for critical observations needed to improve the E3SM model. ARM initiates deployment of its second mobile facility to Houston, TX. The newly acquired aircraft continues 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.	The Request for ARM will continue to provide new observations through long term measurements at fixed sites in Alaska, Oklahoma, and the Eastern North Atlantic site. An ARM mobile unit will begin deployment to a location in the southeastern U.S. with operations beginning in FY 2023. The Request prioritizes all ARM activities for critical observations needed to improve the E3SM model. ARM will continue deployment of its first and second mobile facilities, i.e., to Houston, TX, and Colorado. Scientists will use the precipitation radars together with sophisticated meteorological instrumentation to learn more about cloud and aerosol interactions in urbanized coastal regions and mountainous terrain. Acceptance testing and evaluation will be completed on the recently acquired aircraft, including modifications to the air frame as needed to install numerous existing and new atmospheric aerosol, cloud, turbulence, and other sensors.	Increased funding will support ARM site operations, and a mobile facility will be deployed to the southeastern U.S. and configured to begin operations in FY 2023. ARM will begin a multi-year instrumentation refresh. The ARM support for the Urban IFL for climate science will be developed.
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 will complete construction of the Dynamic Transmission Electron Microscope (DTEM) and provide some new capabilities 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. The Dynamic Transmission Electron Microscope (DTEM) will provide some new capabilities in support of BER science.	Funding will support the multiple experimental capabilities of the new DTEM and initiate planning for a high throughput multiomics pipeline. EMSL will begin a multi-year instrumentation refresh.

(dollars in thousands)

FY 2021 Enacted	FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Earth and Environmental Sciences Data Management activity continues to provide support to maintain existing critical software and data archives for ongoing experimental and modeling research. Essential data archiving and storing protocols, capacity, and provenance continues. Advanced analytical methodologies such as Machine Learning (ML) is used to improve the predictability of extreme events more rapidly using Earth system models.	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 the combination of field observations with Earth system models.	Funding will support the incorporation of new analytical methodologies to advance scientific insight based on the fusion of model generated and observed data.

Note: Funding for the subprogram above, includes 3.65% of research and development (R&D) funding for the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Programs.

Biological and Environmental Research
Capital Summary

(dollars in thousands)

	Total	Prior Years	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Capital Operating Expenses						
Capital Equipment	N/A	N/A	9,800	7,700	28,000	+20,300
Total, Capital Operating Expenses	**N/A**	**N/A**	**9,800**	**7,700**	**28,000**	**+20,300**

Capital Equipment

(dollars in thousands)

	Total	Prior Years	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Capital Equipment						
Total, MIEs	N/A	N/A	–	–	–	–
Total, Non-MIE Capital Equipment	N/A	N/A	9,800	7,700	28,000	+20,300
Total, Capital Equipment	**N/A**	**N/A**	**9,800**	**7,700**	**28,000**	**+20,300**

Biological and Environmental Research
Funding Summary

(dollars in thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Research	570,500	571,089	627,000	+55,911
Facility Operations	179,500	181,911	201,000	+19,089
Total, Biological and Environmental Research	**750,000**	**753,000**	**828,000**	**+75,000**

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 2020 Enacted	FY 2020 Current	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Scientific User Facilities - Type B					
Environmental Molecular Sciences Laboratory	**45,000**	**45,000**	**45,000**	**56,000**	**+11,000**
Number of Users	577	766	525	715	+190
Joint Genome Institute	**77,000**	**77,000**	**80,000**	**84,500**	**+4,500**
Number of Users	1,925	2,038	1,550	2,115	+565
Atmospheric Radiation Measurement Research Facility	**70,110**	**70,110**	**72,672**	**90,000**	**+17,328**
Number of Users	1,100	1,001	900	1,250	+350
Total, Facilities	**192,110**	**192,110**	**197,672**	**230,500**	**+32,828**
Number of Users	3,602	3,805	2,975	4,080	+1,105

Biological and Environmental Research
Scientific Employment

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Number of Permanent Ph.Ds (FTEs)	1,500	1,510	1,600	+90
Number of Postdoctoral Associates (FTEs)	370	375	410	+35
Number of Graduate Students (FTEs)	520	530	580	+50
Number of Other Scientific Employment (FTEs)	370	375	395	+20

Note: Other Scientific Employment (FTEs) 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 of plasma 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 northern and southern aurora. Practical applications of plasmas are found in lighting and semiconductor manufacturing. High-temperature fusion plasmas at hundreds of millions of degrees are being exploited in the laboratory to become the basis for a future clean energy source. Once developed, fusion energy will provide a clean energy source that is especially well-suited for baseload electricity production, supplementing intermittent renewables and fission. Energy from fusion will be carbon-free, inherently safe, without the production of long-lived radioactive waste, and relying on a virtually inexhaustible fuel supply that is available worldwide. Developing fusion energy 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 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, 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. U.S. scientists take advantage of international partnerships to conduct research on overseas tokamaks and stellarators with unique capabilities. In addition, the development of novel materials 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 creation of strongly self-heated fusion burning plasmas, to be enabled by the ITER facility, will allow the discovery and study of new scientific phenomena relevant to fusion as a future clean energy source. At the same time, partnerships with the emerging fusion private sector can shorten the time for developing fusion energy by combining forces to resolve common scientific and technological challenges.

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, including applications that are relevant to multiple clean energy sources.

The FES program invests in several SC cross-cutting transformational technologies such as artificial intelligence and machine learning (AI/ML), quantum information science (QIS), microelectronics, advanced manufacturing, and high-performance computing. Finally, the unique scientific challenges and rigor of fusion and plasma physics research lead to the development of a well-trained STEM workforce, guided by the principles of diversity, equity, and inclusion.

Decisions about the direction of the FES program and its activities are driven by science. They are informed by reports from the National Academies of Sciences, Engineering, and Medicine (NASEM), the Fusion Energy Sciences Advisory Committee

(FESAC), and community workshops. Specific projects are selected through rigorous peer review and the application of validated standards.

Highlights of the FY 2022 Request

The FY 2022 Request is $675.0 million. The Request is aligned with the recommendations in the recent FESAC Long-Range Plan.[a] Priorities include keeping SC fusion user facilities world-leading, building a new research portfolio of high-performance computing fusion applications, continuing to explore the potential of QIS and AI/ML, supporting high-impact research in fusion nuclear science and materials, maintaining partnerships for access to international facilities with unique capabilities, continuing stewardship of discovery plasma science, continuing to seek opportunities with public-private partnerships, initiating an ITER Research program, and supporting studies of future facilities. Key elements in the FY 2022 Request include:

<u>Research</u>

- DIII-D research: Investigate the role of divertor geometry, optimize plasma performance using non-axisymmetric magnetic fields and plasma shaping, and exploit innovative current drive systems.
- NSTX-U research: Support focused efforts on plasma startup and initial machine commissioning and collaborative research at other facilities for addressing program priorities.
- Partnerships with private fusion efforts: Continue to expand public-private partnerships in critical fusion research areas through the Innovation Network for Fusion Energy (INFUSE) program.
- Enabling technology, fusion nuclear science, and materials: Support research on high-temperature superconductors, advanced materials, and blanket/fuel cycle research. Continue exploring options for a neutron source to test materials in fusion-relevant environments and support the Accelerator Science and Technology and Fundamental Science to Transform Manufacturing initiatives.
- Scientific Discovery through Advanced Computing: A new portfolio of SciDAC projects will continue development of an integrated simulation capability expanding it from whole-device to whole-facility modeling, in partnership with the ASCR program.
- Long-pulse tokamak and stellarator research: Enable U.S. scientists to work on superconducting tokamaks with world-leading capabilities and allow U.S. teams to exploit U.S. hardware investments on the Wendelstein 7-X stellarator.
- Discovery plasma science: Continue support for small- and intermediate-scale basic plasma science and HEDLP facilities including LaserNetUS, and microelectronics research.
- QIS: In support of the National Quantum Initiative, the Request continues support for the SC QIS Research Centers established in FY 2020 along with a core research portfolio to advance developments in QIS and related technology.
- ITER research: Support a national team for ITER research to ensure the U.S. fusion community takes full advantage of ITER research operations after First Plasma.
- Future Facilities Studies: Initiate a program in future facilities studies to address one of the highest-priority recommendations in the FESAC Long-Range Plan for the design of a Fusion Pilot Plant (FPP).
- Reaching a New Energy Sciences Workforce (RENEW): The Office of Science is fully committed to advancing a diverse, equitable, and inclusive research community. This commitment is key to providing the scientific and technical expertise for U.S. leadership in fusion energy sciences. Toward that goal, FES will participate in the SC-wide RENEW initiative that leverages SC's world-unique national laboratories, user facilities, and other research infrastructures to provide undergraduate and graduate training opportunities for students and academic institutions not currently well represented in the U.S. S&T ecosystem. This includes Minority Serving Institutions and individuals from groups historically underrepresented in STEM, but also includes students from communities with environmental justice impacts and the EPSCoR jurisdictions. The hands-on experiences gained through the RENEW initiative will open new career avenues for the participants, forming a nucleus for a future pool of talented young scientists, engineers, and technicians with the critical skills and expertise needed for the full breadth of SC research activities, including DOE national laboratory staffing.

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[a] https://science.osti.gov/-/media/fes/fesac/pdf/2020/202012/FESAC_Report_2020_Powering_the_Future.pdf

Facility Operations

- DIII-D operations: Support 20 weeks of facility operations, representing 90% of the optimal run time, and completion of ongoing machine and infrastructure refurbishments and improvements.
- NSTX-U recovery and operations: Continue the recovery and repair project, whose completion date may slip beyond FY 2022 due to COVID-19 related schedule delays. NSTX-U Operations will support the remaining machine assembly and hardware commissioning.

Projects

- U.S. hardware development and delivery to ITER: 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.
- Petawatt laser facility upgrade for HEDLP science: Support design activities for a significant upgrade to the Matter in Extreme Conditions (MEC) instrument on the Linac Coherent Light Source-II (LCLS-II) facility at SLAC.
- Major Item of Equipment (MIE) project for fusion materials research: Continue to support the Materials Plasma Exposure eXperiment (MPEX) MIE project with efforts focused on highest-priority items, including the establishment of the project baseline and continuation of long-lead procurements.

Other

- General Plant Projects/General Purpose Equipment (GPP/GPE): Support Princeton Plasma Physics Laboratory (PPPL) and Oak Ridge National Laboratory (ORNL) infrastructure improvements and repairs.

Fusion Energy Sciences
Research Initiatives

Fusion Energy Sciences supports the following FY 2022 Research Initiatives.

(dollars in thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Accelerator Science and Technology Initiative	–	–	3,073	+3,073
Artificial Intelligence and Machine Learning	7,000	7,000	7,000	–
Fundamental Science to Transform Advanced Manufacturing	–	–	3,000	+3,000
Integrated Computational & Data Infrastructure	–	–	4,037	+4,037
Microelectronics	–	5,000	5,000	–
Quantum Information Science	7,520	9,520	10,000	+480
Reaching a New Energy Sciences Workforce (RENEW)	–	–	3,000	+3,000
Total, Research Initiatives	**14,520**	**21,520**	**35,110**	**+13,590**

Fusion Energy Sciences
Funding

(dollars in thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Fusion Energy Sciences				
Advanced Tokamak	123,500	127,038	124,390	-2,648
Spherical Tokamak	101,000	104,331	101,000	-3,331
Theory & Simulation	44,000	42,000	53,037	+11,037
GPP/GPE Infrastructure	7,000	2,640	1,500	-1,140
Public-Private Partnerships	4,000	5,000	6,000	+1,000
Artificial Intelligence and Machine Learning	–	7,000	7,000	–
Strategic Accelerator Technology	–	–	3,073	+3,073
Total, Burning Plasma Science: Foundations	**279,500**	**288,009**	**296,000**	**+7,991**
Long Pulse: Tokamak	14,000	15,000	15,000	–
Long Pulse: Stellarators	8,500	8,500	8,500	–
Materials & Fusion Nuclear Science	47,500	49,000	59,500	+10,500
Future Facilities Studies	–	–	3,000	+3,000
Total, Burning Plasma Science: Long Pulse	**70,000**	**72,500**	**86,000**	**+13,500**
ITER	–	–	2,000	+2,000
Total, Burning Plasma Science: High Power	**–**	**–**	**2,000**	**+2,000**
Plasma Science and Technology	42,500	32,700	40,000	+7,300
Measurement Innovation	3,000	3,000	3,000	–
Quantum Information Science (QIS)	–	9,520	10,000	+480
Advanced Microelectronics	–	5,000	5,000	–
Other FES Research	4,915	4,271	4,000	-271
Reaching a New Energy Sciences Workforce	–	–	3,000	+3,000
FES SBIR/STTR	14,085	–	–	–
Total, Discovery Plasma Science	**64,500**	**54,491**	**65,000**	**+10,509**
Subtotal, Fusion Energy Sciences	**414,000**	**415,000**	**449,000**	**+34,000**

(dollars in thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Construction				
20-SC-61, Matter in Extreme Conditions (MEC) Petawatt Upgrade, SLAC	15,000	15,000	5,000	-10,000
14-SC-60, U.S. Contributions to ITER	242,000	242,000	221,000	-21,000
Subtotal, Construction	**257,000**	**257,000**	**226,000**	**-31,000**
Total, Fusion Energy Sciences	**671,000**	**672,000**	**675,000**	**+3,000**

SBIR/STTR funding:

- FY 2020 Enacted: SBIR $12,348,000 and STTR $1,737,000
- FY 2021 Enacted: SBIR $12,352,000 and STTR $1,740,000
- FY 2022 Request: SBIR $13,360,000 and STTR $1,885,000

Fusion Energy Sciences
Explanation of Major Changes

	(dollars in thousands) FY 2022 Request vs FY 2021 Enacted
Burning Plasma Science: Foundations	**+7,991**

The Request for DIII-D supports 20 weeks of research operations which is 90 percent of the optimal run time, as well as continued facility enhancements to ensure the world-leading status of the facility. Funding for the NSTX-U program will support the NSTX-U Recovery project and maintain collaborative research at other facilities to support NSTX-U research program priorities. SciDAC will maintain and expand its emphasis toward whole-facility modeling following a recompetition of the portfolio, and will continue to increase its readiness to capture the power of exascale computing. Enabling R&D will focus attention on high-temperature superconductor development. Funding is provided for GPP/GPE to support critical infrastructure improvements and repairs at PPPL and ORNL where fusion research is conducted. Public-private partnership collaborations through the INFUSE program will expand.

Burning Plasma Science: Long Pulse	**+13,500**

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 and blanket and fuel cycle research. The Request will also support new activities in relation to the Fundamental Science to Transform Manufacturing Initiative. The Request supports design and R&D activities for the MPEX MIE project, expected to be baselined in FY 2022, and initiates long-lead major procurements. The Request establishes a Future Facilities Studies program to address one of the highest recommendations in the FESAC Long-Range Plan (LRP) for the design of a Fusion Pilot Plant.

Burning Plasma Science: High Power	**+$2,000**

The Request establishes an ITER Research program to start preparing the U.S. fusion community to take full advantage of ITER Operations after First Plasma.

	(dollars in thousands) FY 2022 Request vs FY 2021 Enacted
Discovery Plasma Science 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 in Basic Plasma Science and Engineering. For High Energy Density Laboratory Plasmas (HEDLP), the focus remains on supporting research utilizing the MEC instrument of the LCLS user facility at SLAC and supporting research on the ten LaserNetUS network facilities. For QIS, the Request continues to support the crosscutting SC QIS Research Centers established in FY 2020 and the core research portfolio stewarded by FES. FES will continue to support the SC initiative on advanced microelectronics. This subprogram also supports the RENEW initiative to provide undergraduate and graduate training opportunities for students and academic institutions not currently well represented in the U.S. S&T ecosystem and aligns with a recommendation in the FESAC LRP.	**+10,509**
Construction 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, including the central solenoid superconducting magnet modules.	**-31,000**
Total, Fusion Energy Sciences	**+3,000**

Basic and Applied R&D Coordination
FES participates in coordinated intra- and inter-agency initiatives within DOE and with other federal agencies on science and technology issues related to fusion and plasma science. Within SC, FES operates the MEC instrument at the SLAC LCLS user facility operated by BES, supports high-performance computing research with ASCR, uses the BES-supported High Flux Isotope Reactor (HFIR) facility at ORNL for fusion materials irradiation research, and supports the construction of a high field magnet vertical test facility at Fermilab with HEP. 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
DIII-D expands the range of accessible stable plasma profiles in the tokamak.
Traditionally, tokamak experiments inject microwaves from outside the tokamak toward the core of the plasma to drive electrical currents in the plasma that are necessary for long-pulse or steady-state operation. Recent computer modeling at DIII-D predicted that moving the injection point toward the top of the tokamak and carefully directing it toward precise locations away from the core would dramatically improve efficiency. Based on that modeling, researchers at DIII-D designed and installed a new system with the top-launch configuration that aligns the microwave trajectory with both the magnetic field and the energy distribution of electrons in the plasma. This means the microwaves selectively interact with only the most energetic electrons in the plasma. This approach was experimentally demonstrated to be twice as efficient as that of traditional configurations, helping to bring practical fusion energy closer to reality.

Collaboration between sister spherical tokamaks accelerates plasma startup development.
Through collaborative research, physicists at the Princeton Plasma Physics Laboratory (PPPL) in the U.S. and the Culham Centre for Fusion Energy (CCFE) in the U.K., have developed a specialized simulation framework for developing and testing the plasma startup techniques for both the National Spherical Torus Experiment-Upgrade (NSTX-U) at PPPL and the Mega Ampere Spherical Tokamak-Upgrade (MAST-U) at CCFE. The new simulation capability first required extensive validation work through comparison of predictions with previously collected experimental data. With the validation work now complete, this capability will enable the experimental operators of both facilities to quickly determine the right balance of applied voltages, magnetic field, and gas injection needed to start the plasmas even before the first attempt, significantly reducing the amount of time spent running experiments to successfully fire up the plasma.

Scientists offer new explanation for pressure oscillations in fusion devices.
High-performance computer simulations performed at the National Energy Research Scientific Computing Center (NERSC) by scientists supported by the PPPL-led SciDAC Center for Tokamak Transients Simulations, have largely reproduced the periodic pressure oscillations seen in all tokamak fusion experiments. These oscillations, known as sawtooth oscillations and thought by many to be due to magnetic reconnection, have been shown to occur due to pressure-driven instabilities. When the central pressure increases to a critical value, many localized instabilities develop, leading the magnetic field in the center of the device to become stochastic. This causes the central pressure to drop and the magnetic surfaces to re-form, and the process repeats. A better understanding of the origin of these oscillations is essential for their effective control in order to prevent them potentially disrupting the discharge.

Machine Learning for image correlation to advance materials science.
Crystallographic defects play a vital role in determining the physical and mechanical properties of a wide range of material systems. Although computer vision has demonstrated success in recognizing feature patterns in images with well-defined contrast, automated identification of nanometer scale crystallographic defects in electron micrographs governed by complex contrast mechanisms is still a challenging task. Building upon an advanced defect imaging mode that offers high feature clarity, a team of researchers led by Pacific Northwest National Laboratory (PNNL) developed a new neural network architecture that can identify a number of crystallographic defects important in structural alloys. Results from supervised

training on a small set of high-quality images of steels show high accuracy, with predictions outperforming human experts, promising a new workflow for fast and statistically meaningful quantification of materials defects.

Quantum leap for fusion: First-ever quantum simulation of nonlinear plasma interactions.
The first-ever quantum simulation of nonlinear plasma dynamics was performed on the LLNL Quantum Design and Integration Testbed (QuDIT) quantum computing hardware platform. QuDIT was able to simulate multiple cycles of the dynamics of the three-wave equations of plasma physics with >10x more time steps than other state-of-the-art quantum computing platforms using a novel approach to the codesign of quantum hardware and software. These results provide a first demonstration of the ability of quantum computing hardware to perform useful plasma physics calculations. The new codesign approach represents an advancement for both quantum information science and for fusion energy science.

FES and HEP collaborate on high field vertical magnet test facility development.
Recent advances in high temperature superconductors (HTS) hold the potential for significant breakthroughs for magnet applications, and a world-class test facility is urgently needed by the U.S. community to identify, understand, and resolve technical hurdles associated with the application of HTS materials for high-field magnets, which are critical for future fusion facility development. FES partnered with the High Energy Physics (HEP) program in FY 2020 to jointly pursue the research and development of a novel high-field magnet, designed and fabricated by Lawrence Berkeley National Laboratory, and the installation of this magnet at Fermi National Accelerator Laboratory for usage as a High Field Vertical Magnet Test Facility. The purpose of the new facility is to support research interests, and leverage resources, of both HEP and FES to further science and technology related to high-field magnets and their usage for DOE.

First demonstration of power-law electron energy distribution in 3D magnetic reconnection.
Scientists at the Los Alamos National Laboratory have demonstrated for the first time the formation process of power-law electron energy distribution during 3D magnetic reconnection. The new sophisticated analysis capabilities enabled researchers to identity the self-generated turbulence and chaotic magnetic field lines produced by micro-instabilities associated with 3D magnetic reconnection. The 3D effects allow the high-energy electrons to transport themselves across the reconnection layer and access many main acceleration regions. A new model was developed to explain the observed power-law behavior in terms of the dynamical balance between particle acceleration and escape from the acceleration regions. This finding could provide an explanation for particle acceleration in solar flares and could also contribute to a deeper understanding of how the accelerated electron population interacts with the background turbulent plasma, a physical regime found also in laboratory fusion plasmas.

An international collaboration on the JET facility provides an important test for ITER.
The U.S., through a multilateral international collaboration with the European Union, the U.K., and the ITER Organization, successfully installed, commissioned, and operated a tokamak disruption mitigation system (DMS) on the Joint European Torus (JET), located at the Culham Centre for Fusion Energy in the U.K. Because JET is currently the largest tokamak in the world and has walls like those designed for ITER, this is providing an important test of the planned system for the ITER facility. The DMS is designed to minimize the effects of transient thermal excursions, mechanical forces, and runaway electrons that may result when the plasma current in a tokamak is interrupted abruptly. The planned system is a shattered pellet injector (SPI), originally developed by the Oak Ridge National Laboratory and successfully deployed on the DIII-D tokamak in San Diego and the Korea Superconducting Tokamak Advanced Research (KSTAR) facility in Korea. The SPI test results on JET are expanding the database needed to improve the physics understanding of disruption mitigation, validate the DMS simulation codes, and ready the SPI technology for operation on ITER.

Shock waves mimic supernova particle accelerators.
When stars explode as supernovas, shock waves are produced in the plasma that surrounds them. These shocks blast streams of high-energy particles, called cosmic rays, out into the universe at relativistic speeds approaching the speed of light. Yet how exactly they do that remains a mystery. New experiments using powerful lasers have recreated a miniature version of these supernova shocks in the laboratory. Scientists discovered that small-scale turbulence produced at the shock is key to boosting electrons to these incredible speeds. The results shed new light on the long-standing question of how cosmic accelerators work. Understanding the fundamental science of the cosmic acceleration could pave the way to better particle accelerators on Earth for applications in science, industry, and medicine.

Progress continues on high priority components for ITER.
The U.S. Contributions to ITER project successfully delivered twelve Central Solenoid structural components and Assembly Tooling to the ITER site in France. The structural components and Assembly Tooling are needed for the installation and assembly of the Central Solenoid magnet modules in the center of the ITER tokamak. Design of hardware components needed to achieve First Plasma is progressing with the project team completing six Final Design Reviews (FDR) for various systems. This is a significant achievement since several of the FDR's were accomplished virtually, due to COVID-19 restrictions. Work on the high-priority Central Solenoid modules and Tokamak Cooling Water System continued to make significant progress, with the final preparations being made to ship the first magnet module to the ITER site in early FY 2021. The ITER project is expected to demonstrate the viability of fusion as a significant energy source and will help inform the ongoing and increasingly aggressive efforts to develop demonstration power plants in the U.S. and around the globe.

Fusion Energy Sciences
Burning Plasma Science: Foundations

Description
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 user facilities aimed at resolving fundamental advanced tokamak and spherical tokamak science issues.
- Research on small-scale magnetic confinement experiments for rapid and cost-effective development of new techniques and exploration of new concepts underlying toroidal confinement.
- 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 continued improvement and capabilities of the experimental program and current and future facilities.
- Support of the Accelerator Science and Technology initiative to advance research and development of high-temperature superconducting (HTS) magnets for future fusion facilities.
- Support for infrastructure improvements at Princeton Plasma Physics Laboratory (PPPL) and other DOE laboratories where fusion research is ongoing.
- Research on artificial intelligence and machine learning (AI/ML) relevant to fusion and plasma science.
- Support for public-private partnerships through the Innovation Network for Fusion Energy (INFUSE) activity.

Research in the Burning Plasma Science: Foundations area in FY 2022 will focus on high-priority scientific issues in alignment with the recommendations in the recent FESAC Long-Range Plan.

<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.

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 2022, NSTX-U recovery activities will continue. This recovery effort will ensure reliable plasma operations of the facility.

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 & 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. 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 three interrelated but distinct elements: Theory, SciDAC, and Integrated Computational & Data Infrastructure for Fusion.

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 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.

The Integrated Computational & Data Infrastructure for Fusion element supports efforts that address the growing data needs of fusion research resulting both from experimental and large-scale simulation efforts. This program element is part of the SC crosscutting initiative in this area.

GPP-GPE 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.

Public-Private Partnerships

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. Established in FY 2019, this public-private research partnership program, the first of its kind in SC, is modeled after the successful DOE's Office of Nuclear Energy Gateway for Accelerated Innovation in Nuclear (GAIN) Energy Voucher program. The INFUSE program does not provide direct funding to the private companies, but instead provides support to DOE laboratories to enable them to collaborate with their industrial partners. The private companies are expected to contribute 20 percent cost share. Among the areas supported by INFUSE are the development of new and improved magnets; materials science, including engineered materials, testing and qualification; plasma diagnostic development; modeling and simulation; and access to fusion experimental capabilities. The program is managed for FES by two SC laboratories, ORNL and PPPL, which solicit and collect the Request for Assistance (RFA) proposals and carry out the merit reviews.

Artificial Intelligence and Machine Learning

The objective of the FES Artificial Intelligence and Machine Learning (AI/ML) activity is to support research on the development and application of AI/ML techniques that can have a transformative impact on FES mission areas. Research in this area addresses recommendations from the 2018 FESAC report on “Transformative Enabling Capabilities for Efficient Advance toward Fusion Energy,”[a] is informed by the findings of the joint 2019 FES-ASCR workshop on “Advancing Fusion with Machine Learning,”[b] and is often conducted in partnership with computational scientists through the establishment of multi-institutional, interdisciplinary collaborations.

Among the areas supported by the FES AI/ML activity are prediction of key plasma phenomena and plant states; plasma optimization and active plasma control augmented by AI/ML; plasma diagnostics enhanced by AI/ML methods; extraction of models from experimental and simulation data; and extreme data algorithms able to handle the amount and rate of data generated by fusion simulations and experiments at both existing and planned fusion user facilities. Supported activities encompass multiple FES areas, including magnetic fusion, materials science, and discovery plasma science.

Strategic Accelerator Technology

The objective of this initiative is to leverage expertise across SC to maximize research and development progress in high-temperature superconducting magnets for future fusion facilities. One area supported by FES, in collaboration with High Energy Physics (HEP), is the High Field Vertical Magnet Test Facility Project at Fermi National Laboratory, which will be utilized to test HTS magnet conductor for future fusion facilities.

[a] https://science.osti.gov/-/media/fes/fesac/pdf/2018/TEC_Report_15Feb2018.pdf
[b] https://science.osti.gov/-/media/fes/pdf/workshop-reports/FES_ASCR_Machine_Learning_Report.pdf

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Burning Plasma Science: Foundations	**$288,009**	**$296,000**	**+$7,991**
Advanced Tokamak	$127,038	$124,390	-$2,648
Funding supports 18 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 supports research in enabling technologies, including high-temperature superconducting magnet technology and plasma fueling and heating technologies. Funding supports small-scale 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.		The Request will support 20 weeks of operations at the DIII-D facility, which is 90% of optimal. Research will utilize newly installed capabilities including innovative current drive systems to assess their potential as actuators for a pilot plant. Divertor configurations will be studied to understand the role of divertor geometry on power exhaust strategies. New flexible power supplies will be used to optimize performance using non-axisymmetric magnetic fields and plasma shaping. The Request will support continuing research in high-temperature superconducting magnet technology, plasma fueling, heating, and other fusion enabling technologies. The Request will continue support for flexible small-scale experiments developing advanced tokamak control schemes, validating predictive plasma models, and training early career scientists.	Funding will support high-priority DIII-D research activities, enabling research and development, and small-scale experiments, and provide resources for increased DIII-D facility operations, while support for facility enhancements is reduced.

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Spherical Tokamak	$104,331	$101,000	-$3,331
Funding supports recovery procurements, fabrication, and machine reassembly activities that are necessary to resume robust research operations. Research efforts are focused on analysis and modeling activities at other facilities that support NSTX-U program priorities. Funding also supports 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.		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, as well as the development and installation of additional diagnostic instrumentation on NSTX-U. The Request will continue to support small-scale ST 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.	Operations funding will support the continuation of NSTX-U Recovery activities at a reduced level as the Recovery nears completion. Research funding will be focused on the highest-priority scientific objectives that are aligned with the FESAC Long-Range Plan.
Theory & Simulation	$42,000	$53,037	+$11,037
Funding supports theory and modeling efforts focusing on advancing the scientific understanding of the fundamental physical processes governing the behavior of magnetically confined plasmas. This activity emphasizes 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. In addition, funding supports the nine SciDAC partnerships, now in their fifth and final year. Emphasis on whole-device modeling and Exascale readiness continues.		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 Request will support a new SciDAC portfolio from the SC-wide SciDAC-5 recompetition in FY 2022. Emphasis on whole-device modeling and exascale readiness will continue, but will expand to include domains outside the plasma and first wall, as a first step toward whole-facility modeling. The Request will also support Integrated Computational & Data Infrastructure for fusion research activities.	Research efforts in theory will focus on the highest-priority activities. The increase will enhance the SciDAC portfolio to expand toward whole-facility modeling and will support the Integrated Computational & Data Infrastructure activity.

(dollars in thousands)

FY 2021 Enacted	FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
GPP-GPE Infrastructure $2,640	$1,500	-$1,140
Funding supports PPPL as well as other DOE laboratories infrastructure improvements, repair, maintenance and environmental monitoring.	The Request will support PPPL as well as other DOE laboratories infrastructure improvements, repair, maintenance, and environmental monitoring.	Funding efforts will focus on the highest-priority activities.
Public-Private Partnerships $5,000	$6,000	+$1,000
Funding enables the INFUSE program to provide funding opportunities for partnerships with the private-sector through DOE laboratories at a level consistent with FY 2020. This includes two Request for Assistance calls and an estimated 20 awards.	The Request will support the INFUSE program to continue providing private-sector entities collaborative opportunities through its voucher program.	The increase will allow for further expansion of the INFUSE collaborative voucher program. This will include the possibility of adding universities to the INFUSE network, which is being explored.
Artificial Intelligence and Machine Learning $7,000	$7,000	$ —
Funding supports five multi-institutional teams applying artificial intelligence and machine learning to high-priority areas including real-time plasma behavior prediction, materials modeling, plasma equilibrium reconstruction, radio frequency modeling, and optimization of experiments using high-repetition-rate lasers.	The Request will support the third and final year of the FES AI/ML research efforts selected in FY 2020.	Research activities will continue at the same level of effort.
Strategic Accelerator Technology $ —	$3,073	+$3,073
N/A	The request will support the Accelerator Science and Technology initiative to develop high-temperature superconducting magnets for future fusion facilities. Additionally, the request will support the High Field Vertical Magnet Test Facility Project.	Funding will support the SC initiative.

Note: Funding for the subprogram above, includes 3.65% of research and development (R&D) funding for the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Programs.

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, materials research, and future facilities studies.

Long Pulse: Tokamak

This activity 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. aims at building the science and technology required to confine and sustain a burning plasma as described in the 2020 FESAC Long-Range Plan.[a] Multidisciplinary teams work together to close key gaps in the design basis for a fusion pilot plant, especially in the areas of plasma-material interactions, transients control, and current drive for steady-state operation. 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: Stellarators

This activity supports research on stellarators, which 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 the Wendelstein 7-X (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. is developing 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, which was invented in the U.S. According to the 2020 FESAC Long-Range Plan, the quasi-symmetric stellarator is the leading U.S. approach to develop disruption-free, low-recirculating-power fusion configurations.

Materials & Fusion Nuclear Science

The Materials and Fusion Nuclear Science activity seeks to address the significant scientific and technical gaps between current-generation fusion experiments and a future Fusion Pilot Plant (FPP), as recommended by the 2020 FESAC Long-Range Plan. An FPP will produce heat, particle, and neutron fluxes that significantly exceed those in present confinement facilities, and new approaches and materials need to be developed and engineered for the anticipated extreme reactor conditions. The goal of the Materials subactivity is to develop a scientific understanding of how the properties of materials evolve and degrade due to fusion neutron and plasma exposure to safely predict the behavior of materials in fusion reactors. Before an FPP is constructed, materials and components must be qualified and a system design must ensure the compatibility of all components. The goal of the Fusion Nuclear Science subactivity is to advance the balance-of-plant equipment, remote handling, tritium breeding, and safety systems that are required to safely harness fusion power in an

[a] https://usfusionandplasmas.org/

FPP. The new SC initiative on Fundamental Science to Transform Manufacturing, which has implications for both the Materials and Fusion Nuclear Science subactivities, is also part of this activity.

Developing solutions for this scientifically challenging area requires innovative types of research along with new experimental capabilities. In the near term, this includes the Material Plasma Exposure eXperiment (MPEX) Major Item of Equipment (MIE) project, which will enable solutions for new plasma-facing materials, and the Fusion Prototypic Neutron Source (FPNS), which will provide unique material irradiation capabilities for understanding materials degradation in the fusion nuclear environment. In the longer term, capabilities like the Blanket Component Test Facility will be needed to provide the scientific understanding and basis to qualify fusion blankets. These experimental capabilities will lead to an increased understanding of materials and of component and system performance in support of an FPP.

Future Facilities Studies

The Future Facilities Studies activity seeks to identify approaches for an integrated fusion plant design, like an FPP, as recommended by the 2020 FESAC Long-Range Plan.

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Burning Plasma Science: Long Pulse	**$72,500**	**$86,000**	**+$13,500**
Long Pulse: Tokamak	$15,000	$15,000	$ —
Funding supports 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.		The Request will support multidisciplinary U.S. teams, as identified through competitive solicitation, to conduct research on international facilities with unique capabilities. Ongoing diagnostic contributions to the JT-60SA facility in Japan will continue.	Research efforts will emphasize the highest-priority topics while leveraging unique capabilities on long-pulse superconducting tokamaks.
Long Pulse: Stellarators	$8,500	$8,500	$ —
Funding supports research on W7-X to further the understanding of core and edge transport optimization for stellarators by utilizing U.S. developed state-of-the-art diagnostics and components. Funding also supports experiments on domestic stellarators 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.		The Request will support U.S. scientists to utilize the continuous pellet fueling system, which will be 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. The Request will also support research on compact domestic experimental devices that are providing data in regimes relevant to mainline stellarator confinement and experimental validation of theoretical models and codes.	Funding will continue to support research activities at the same level of effort.

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Materials & Fusion Nuclear Science	$49,000	$59,500	+$10,500
Funding supports the core research areas of tritium fuel cycle, breeder blanket technologies, safety, plasma-facing components, and structural and functional materials development, as well as the MPEX MIE project. The research program continues expanding efforts into the areas of novel fusion blanket and tritium fuel cycle research, innovative plasma facing component, novel materials, and advanced manufacturing. In addition, funding continues to support the MPEX MIE project.		The Request will enable expansion of the program, with a focus on critical enabling technologies for an FPP, as recommended by the 2020 FESAC Long-Range Plan. This includes plasma-facing components, structural and functional materials, and breeding-blanket and tritium-handling systems. The Request will also support an expansion of research into additive manufacturing technology, consistent with the new SC initiative. Finally, the request will continue to support the MPEX MIE project, with efforts focused on initiating construction following the combined baselining and approval of construction in FY 2022.	The Request is aimed at enhancing the materials and fusion nuclear science program, consistent with the FESAC Long-Range Plan, which considers this area in need of being strengthened in the fusion mission portfolio. Priority in the materials subactivity will be given to developing key materials required to enable an FPP, as well as increased emphasis on foundational fusion materials. Priority in the fusion nuclear science subactivity will be given to expanding the blanket and tritium fuel cycle research program.
Future Facilities Studies	$ —	$3,000	+$3,000
N/A		The Request will support the Future Facilities Studies activity, which seeks to identify methods for an integrated fusion plant design, as recommended by the FESAC Long-Range Plan.	Funding will support the Future Facilities Studies.

Note: Funding for the subprogram above, includes 3.65% of research and development (R&D) funding for the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Programs.

Fusion Energy Sciences
Burning Plasma Science: High Power

Description

The Burning Plasma Science: High Power subprogram supports research on experimental facilities that can produce large amounts of fusion power and maintain self-heated plasmas for hundreds of seconds, allowing scientists to study the burning plasma state. In a burning or self-heated plasma, at least half of the power needed to maintain the plasma at thermonuclear temperatures is provided by heating sources within the plasma. For the most common deuterium-tritium (D-T) fuel cycle, this internal heating source is provided by the energy of the helium nuclei (alpha particles) which are produced by the D-T reaction itself. A common figure of merit characterizing the proximity of a plasma to burning plasma conditions is the fusion gain or "Q", which is defined as the ratio of the fusion power produced by the plasma to the heating power injected into the plasma that is necessary to bring it, and keep it, at thermonuclear temperatures. No existing or past experiment has reached this regime or even produced more fusion power than it consumed, with the current record of Q=0.67 held by the Joint European Torus in 1997.

ITER will be the world's first burning plasma experiment that is expected to produce 500 MW of fusion power for pulses of 400 seconds, attaining a fusion gain Q of 10. It is a seven-Member international collaborative project to design, build, operate, and decommission a first-of-a-kind international fusion research facility in St. Paul-lez-Durance, France, aimed at demonstrating the scientific and technological feasibility of fusion energy. In addition to the U.S., the six other ITER Members are China, the European Union, India, Japan, South Korea, and Russia. More information about the U.S. Contributions to the ITER project is provided in the FES Construction section.

<u>ITER Research</u>

Presently, ITER is expected to achieve the First Plasma milestone in December 2025, however, because of COVID-19 impacts, this date will most likely be delayed. During the construction of ITER, U.S. contributes ~9 percent and gets 100 percent of the intellectual discovery during ITER research operations. To ensure the U.S. fusion community takes full advantage of ITER research operations after first plasma, it is necessary to organize a U.S. ITER research team to be ready on day one to benefit from the scientific and technological opportunities offered by ITER. Building such a team was also among the highest recommendations in the recent Long-Range Plan developed by FESAC.

Fusion Energy Sciences
Burning Plasma Science: High Power

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Burning Plasma Science: High Power	**$ —**	**$2,000**	**+$2,000**
ITER Research	$ —	$2,000	+$2,000
N/A		The Request will initiate support of a national team for ITER research, to ensure the U.S. fusion community takes full advantage of ITER research operations after achievement of First Plasma.	The FY 2022 funding will support establishing an ITER research team.

Note: Funding for the subprogram above, includes 3.65% of research and development (R&D) funding for the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Programs.

Fusion Energy Sciences
Discovery Plasma Science

Description

Discovery Plasma Science subprogram supports research that explores the fundamental properties and complex behavior of matter in the plasma state to understand the plasma universe and to learn how 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, some of them relevant to clean energy technologies, including synthesis of nanomaterials and artificial diamonds, efficient solar and fuel cells, fabrication of microelectronics and opto-electronic devices, energy-efficient lighting, low-heat chemical-free sterilization processes, tissue healing, combustion enhancement, satellite communication, laser-produced isotopes for positron emission tomography, and extreme ultraviolet lithography.

The Discovery Plasma Science subprogram is organized into four principal activities: Plasma Science and Technology, Measurement Innovation, Quantum Information Science, and Advanced Microelectronics.

<u>Plasma Science and Technology</u>

The Plasma Science and Technology (PS&T) activities involve research in largely unexplored areas of plasma science, with a combination of theory, computer modeling, and experimentation. These areas 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 PS&T portfolio includes research activities in the following areas:

- General Plasma Science (GPS): Research at the frontiers of basic and low temperature plasma science, including dynamical processes in laboratory, space, and astrophysical plasmas, such as magnetic reconnection, dynamo, shocks, turbulence cascade, structures, waves, flows and their interactions; behavior of dusty plasmas, non-neutral, single-component matter or antimatter plasmas, and ultra-cold neutral plasmas; plasma chemistry and processes in low-temperature plasma, interfacial plasma, synthesis of nanomaterials, and interaction of plasma with surfaces, materials or biomaterials.
- High Energy Density (HED) Laboratory Plasmas (HEDLP): Research directed at exploring the behavior of plasmas at extreme conditions of temperature, density, and pressure, including relativistic HED plasmas and intense beam physics, magnetized HED plasma physics, multiply ionized HED atomic physics, HED hydrodynamics, warm dense matter, nonlinear optics of plasmas and laser-plasma interactions, laboratory astrophysics, and diagnostics for HED laboratory plasmas.

The PS&T 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.

Quantum Information Science

The Quantum Information Science (QIS) activity supports basic research in QIS that can have a transformative impact on FES mission areas, including fusion and discovery plasma science, as well as research that takes advantage of unique FES-enabled capabilities to advance QIS development. The direction of the QIS efforts is informed by the findings of the 2018 Roundtable meeting[a] that was held to explore the unique role of FES in this rapidly developing high-priority crosscutting field and help FES build a community of next-generation researchers in this area. Among the areas supported by the QIS subprogram are near- and long-term quantum simulation capabilities that can solve important fusion and plasma science problems; quantum sensing approaches that can enhance diagnostic capabilities for plasma and fusion science; the use of HEDLP drivers and techniques to form novel quantum materials at ultra-high pressures; the exploration of relativistic plasma science for qubit control and quantum communication; and the refining of plasma science tools for simulation and control of quantum systems. FES also participates in the SC-wide crosscutting QIS research centers.

Advanced Microelectronics

The Advanced Microelectronics activity supports low temperature plasma research in a multi-disciplinary, co-design framework to accelerate plasma-based microelectronics fabrication and advance the development of microelectronic technologies. The direction of the Advanced Microelectronics efforts will be informed by the recent Long-Range Plan developed by FESAC and the NASEM Plasma 2020 decadal survey report.

Other FES Research

This activity supports the Fusion Energy Sciences Postdoctoral Research Program, which supports postdocs in the fusion and plasma science research areas for two years, and multiple fusion and plasma science outreach programs that work to increase fusion and plasma science literacy among the general public, K-12, undergraduate students, and graduate students. Other activities being supported include the U.S. Burning Plasma Organization; peer-reviews for FES solicitations and project activities; FESAC; and other programmatic activities.

Reaching a New Energy Sciences Workforce (RENEW)

This activity supports the RENEW initiative to provide undergraduate and graduate training opportunities for students and academic institutions not currently well represented in the U.S. S&T ecosystem and aligns with a recommendation in the FESAC Long-Range Plan.

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

Fusion Energy Sciences
Discovery Plasma Science

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Discovery Plasma Science	**$54,491**	**$65,000**	**+$10,509**
Plasma Science and Technology	$32,700	$40,000	+$7,300
Funding supports core research activities in basic and low temperature plasma science focused on supporting research on collaborative research facilities at universities and national laboratories. For HEDLP, the enacted budget supports the LaserNetUS initiative, research utilizing the MEC at SLAC, and the SC-NNSA joint program in HEDLP.		The Request will support core research at the frontiers of basic and low temperature plasma science. In the area of HEDLP, the Request will support basic and translational science, MEC and LaserNetUS operations and user support, the SC-NNSA joint program, and modest inertial fusion energy activities as recommended by the 2020 FESAC Long-Range Plan.	Funding will increase for efforts on basic and low temperature plasma and astrophysical plasma research activities in GPS and basic research activities utilizing facilities in HEDLP. Funding for advanced microelectronics moves to a new activity line in the Request.
Measurement Innovation	$3,000	$3,000	$ —
Funding supports the development of transformative and innovative diagnostics for plasma transient instabilities, plasma-material interactions, modeling validation, and basic plasma science identified in the community engagement workshops.		The Request will continue to support the development of transformative and innovative diagnostics.	Funding will continue research support for measurement innovation.
Quantum Information Science	$9,520	$10,000	+$480
Funding continues to support the third and final year of the QIS awards selected in FY 2019 and the new awards selected in FY 2020 and FY 2021. It also continues to support the FES contributions to the SC QIS Research Centers.		The Request will continue to support the research efforts initiated in FY 2020 and FY 2021 and new awards addressing priority research opportunities identified in community workshops. It will also continue to support the FES contributions to the SC QIS Research Centers.	The increase will expand the FES core QIS portfolio to address additional priority research opportunities.

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Advanced Microelectronics	$5,000	$5,000	$ —
Funding supports high priority microelectronics research as well as a joint announcement to DOE Laboratories, in partnership with ASCR, Basic Energy Sciences (BES), High Energy Physics (HEP), and Nuclear Physics (NP).		The Request will continue to support high priority multi-disciplinary research through a co-design framework to accelerate the advancement of microelectronics technologies.	Funding will maintain research support for microelectronics.
Other FES Research	$4,271	$4,000	-$271
Funding supports U.S. Burning Plasma Organization (USBPO) activities, peer reviews for solicitations, outreach programs, and FESAC.		The Request will continue to support the FES Postdoctoral Research Program, the FES Fusion and Plasma Science Outreach programs, USBPO, peer reviews for FES solicitations and project activities, FESAC, and other programmatic activities.	Efforts will focus on the highest priority activities.
Reaching a New Energy Sciences Workforce (RENEW)	$ —	$3,000	+$3,000
N/A		The Request initiates the RENEW initiative to provide undergraduate and graduate training opportunities for students and academic institutions not currently well represented in the U.S. S&T ecosystem and aligns with a recommendation in the FESAC Long-Range Plan.	Increase supports the RENEW initiative.

Note: Funding for the subprogram above, includes 3.65% of research and development (R&D) funding for the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Programs.

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.

20-SC-61, Matter in Extreme Conditions (MEC) Petawatt Upgrade, SLAC

The National Academies of Sciences, Engineering, and Medicine (NASEM) 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 will provide a collaborative user facility which utilizes the LCLS-II light source and is focused on High-Energy-Density Science that will address this NASEM recommendation as well as maintain U.S. leadership in this important field of study. The project received Critical Decision-0 (CD-0), "Approve Mission Need," on January, 4, 2019. The FY 2022 Request of $5,000,000 will support preliminary design activities. The estimated total project cost range is $60,000,000 to $300,000,000.

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

The ITER facility, currently under construction in Saint Paul-lez-Durance, France, is more than 70 percent complete towards First Plasma. ITER is designed to provide fusion power output approaching reactor levels of hundreds of megawatts, for hundreds of seconds. ITER is a necessary next step toward developing a modern carbon-free fusion energy pilot plant that will keep the U.S. competitive internationally. Construction of ITER is a collaboration among the United States, European Union, Russian Federation, Japan, India, Republic of Korea, and People's Republic of China, governed by an international agreement (the "ITER Joint Implementing Agreement"). As a co-owner of ITER, the U.S. contributes in-kind hardware components and financial contributions for the ITER Organization (IO) operations (e.g., design integration, nuclear licensing, quality control, safety, overall project management, and installation and assembly of the components provided by the U.S. and other members). The U.S. also has over 50 U.S. nationals employed by the IO and working at the site. An independent review of CD-2, "Approve Performance Baseline," for the U.S. Contributions to ITER—First Plasma subproject was completed in November 2016 and then subsequently approved by the Project Management Executive on January 13, 2017, with a total project cost of $2,500,000,000. The FY 2022 Request of $221,000,000 will support the continued design of all systems, fabrication of First Plasma hardware, and financial contributions for IO operations during construction. The estimated total project cost range is $4,700,000,000 to $6,500,000,000.

The U.S. In-kind contribution represents 9.09 percent (1/11th) of the overall ITER project, 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. The U.S. involvement in ITER will help to advance the promise of carbon-free, inherently safe, and abundant fusion energy for America.

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

Fusion Energy Sciences
Construction

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Construction	**$257,000**	**$226,000**	**-$31,000**
20-SC-61, Matter in Extreme Conditions (MEC) Petawatt Upgrade, SLAC	$15,000	$5,000	-$10,000
The Enacted budget supports design activities, preparation for developing a project baseline, and long-lead procurements for an upgrade to MEC.		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 for the MEC upgrade project.
14-SC-60, U.S. Contributions to ITER	$242,000	$221,000	-$21,000
The Enacted budget supports continued design and fabrication of In-kind hardware systems for the First Plasma subproject (SP-1).		The Request will support continued design and fabrication of In-kind hardware systems for the SP-1.	Funding will continue to focus on SP-1 activities.

Fusion Energy Sciences
Capital Summary

(dollars in thousands)

	Total	Prior Years	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Capital Operating Expenses						
Capital Equipment	N/A	N/A	21,760	27,020	27,000	-20
Minor Construction Activities						
General Plant Projects	N/A	N/A	6,350	2,000	1,500	-500
Total, Capital Operating Expenses	**N/A**	**N/A**	**28,110**	**29,020**	**28,500**	**-520**

Capital Equipment

(dollars in thousands)

	Total	Prior Years	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Capital Equipment						
Major Items of Equipment						
Burning Plasma Science: Long Pulse						
Materials Plasma Exposure eXperiment (MPEX)	108,575	11,575	21,000	21,000	25,000	+4,000
Total, MIEs	N/A	N/A	21,000	21,000	25,000	+4,000
Total, Non-MIE Capital Equipment	N/A	N/A	760	6,020	2,000	-4,020
Total, Capital Equipment	**N/A**	**N/A**	**21,760**	**27,020**	**27,000**	**-20**

Note: The Capital Equipment table includes MIEs located at a DOE facility with a Total Estimated Cost (TEC) > $5M and MIEs not located at a DOE facility with a TEC >$2M.

Fusion Energy Sciences
Minor Construction Activities

(dollars in thousands)

	Total	Prior Years	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
General Plant Projects (GPP)						
Total GPPs less than $5M	N/A	N/A	6,350	2,000	1,500	-500
Total, General Plant Projects (GPP)	**N/A**	**N/A**	**6,350**	**2,000**	**1,500**	**-500**
Total, Minor Construction Activities	**N/A**	**N/A**	**6,350**	**2,000**	**1,500**	**-500**

Note: GPP activities less than $5M include design and construction for additions and/or improvements to land, buildings, replacements or addition to roads, and general area improvements. AIP activities less than $5M include minor construction at an existing accelerator facility.

Fusion Energy Sciences
Major Items of Equipment Description(s)

Burning Plasma Science: Long Pulse MIEs:

Materials Plasma Exposure eXperiment (MPEX)

FES is developing a first-of-a-kind, world-leading experimental capability to explore solutions to the plasma-materials interactions challenge. This device, known as MPEX, will be located at ORNL and will enable dedicated studies of reactor-relevant plasma-material interactions at a scale not previously accessible to the fusion program. The overall motivation of this project 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 currently expected to be baselined in FY 2022. The proposed funding in FY 2022 will allow for the project to proceed with the highest-priority activities of baseline approval and continuation of long-lead procurements. The preliminary cost range is $86,000,000–$175,000,000.

Fusion Energy Sciences
Construction Projects Summary

(dollars in thousands)

	Total	Prior Years	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
20-SC-61, Matter in Extreme Conditions Petawatt Upgrade, SLAC						
Total Estimated Cost (TEC)	362,000	–	15,000	15,000	5,000	-10,000
Other Project Cost (OPC)	10,000	1,600	4,500	2,000	–	-2,000
Total Project Cost (TPC)	**372,000**	**1,600**	**19,500**	**17,000**	**5,000**	**-12,000**
14-SC-60, U.S. Contributions to ITER						
Total Estimated Cost (TEC)	3,587,698	1,371,617	242,000	242,000	221,000	-21,000
Other Project Cost (OPC)	70,302	70,302	–	–	–	–
Total Project Cost (TPC)	**3,658,000**	**1,441,919**	**242,000**	**242,000**	**221,000**	**-21,000**
Total, Construction						
Total Estimated Cost (TEC)	**N/A**	**N/A**	**257,000**	**257,000**	**226,000**	**-31,000**
Other Project Cost (OPC)	**N/A**	**N/A**	**4,500**	**2,000**	**–**	**-2,000**
Total Project Cost (TPC)	**N/A**	**N/A**	**261,500**	**259,000**	**226,000**	**-33,000**

Fusion Energy Sciences
Funding Summary

(dollars in thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Research	253,000	260,149	297,230	+37,081
Facility Operations	128,500	129,211	125,270	-3,941
Projects				
Line Item Construction (LIC)	261,500	259,000	226,000	-33,000
Major Items of Equipment (MIE)	21,000	21,000	25,000	+4,000
Total, Projects	**282,500**	**280,000**	**251,000**	**-29,000**
Other	7,000	2,640	1,500	-1,140
Total, Fusion Energy Sciences	**671,000**	**672,000**	**675,000**	**+3,000**

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.

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 2020 Enacted	FY 2020 Current	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Scientific User Facilities - Type A					
DIII-D National Fusion Facility	**116,500**	**114,459**	**121,000**	**120,390**	**-610**
Number of Users	718	830	830	830	–
Achieved Operating Hours	–	194	–	–	–
Planned Operating Hours	800	194	720	800	+80
Optimal Hours	960	960	960	880	-80
Percent of Optimal Hours	83.3%	20.0%	75.0%	90.0%	+15.0%
National Spherical Torus Experiment-Upgrade	**98,000**	**96,579**	**101,331**	**98,000**	**-3,331**
Number of Users	326	312	372	372	–
Total, Facilities	**214,500**	**211,038**	**222,331**	**218,390**	**-3,941**
Number of Users	1,044	1,142	1,202	1,202	–
Achieved Operating Hours	–	194	–	–	–
Planned Operating Hours	800	194	720	800	+80
Optimal Hours	960	960	960	880	-80

Note: Achieved Operating Hours and Unscheduled Downtime Hours will only be reflected in the Congressional budget cycle which provides actuals.

Fusion Energy Sciences
Scientific Employment

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Number of Permanent Ph.Ds (FTEs)	859	846	891	+45
Number of Postdoctoral Associates (FTEs)	106	104	111	+7
Number of Graduate Students (FTEs)	287	282	297	+15
Number of Other Scientific Employment (FTEs)	1,284	1,261	1,331	+70

Note: Other Scientific Employment (FTEs) includes technicians, engineers, computer professionals and other support staff.

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

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

Summary

The FY 2022 Request for the Matter in Extreme Conditions (MEC) Petawatt Upgrade project is $5,000,000. The project has a preliminary estimated Total Project Cost (TPC) range of $234,000,000 to $372,000,000. Currently, this cost range encompasses the most feasible preliminary alternatives.

The future MEC Petawatt user facility will be a premier research facility to conduct experiments in the field of High Energy Density Plasmas utilizing the Linac Coherent Light Source (LCLS) X-Ray Free-Electron Laser (XFEL) beam at SLAC to probe and characterize plasmas and extreme states of matter in pursuit of Fusion Energy as a viable unlimited, carbon-free power source.

Significant Changes

The MEC Petawatt Upgrade project was initiated in FY 2020. The project achieved Critical Decision-0 (CD-0), “Approve Mission Need,” on January 4, 2019. Other Project Costs (OPC) funding in FY 2020 supported conceptual design of the civil infrastructure and technical hardware. When the project achieves CD-1, “Approve Alternative Selection and Cost Range,” which is planned for 4Q FY 2021, the project will initiate the TEC-funded preliminary design phase.

A level-3 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	1/4/19	3Q FY 2019	1Q FY 2020	TBD	TBD	TBD	TBD	TBD
FY 2021	1/4/19	4Q FY 2020	4Q FY 2020	3Q FY 2022	4Q FY 2021	3Q FY 2023	FY 2040	1Q FY 2028
FY 2022	1/4/19	3Q FY 2021	4Q FY 2021	2Q FY 2023	2Q FY 2023	3Q FY 2023	TBD	1Q FY 2028

CD-0 – Approve Mission Need for a construction project with a conceptual scope and cost range
Conceptual Design Complete – Actual date the conceptual design was 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
FY 2022	20,000	342,000	362,000	10,000	—	10,000	372,000[a]

2. Project Scope and Justification

Scope

The scope of the MEC Petawatt Upgrade project includes the development of a user facility that couples long-pulse (1 Kilojoule or higher) and short-pulse (1 petawatt or higher) drive lasers to an X-ray source, as well as a second chamber that will accommodate laser-only fusion and material science experiments. The lasers 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 10,000 to 19,000 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 (NASEM) 2017 study titled "Opportunities in Intense Ultrafast Lasers: Reaching for the Brightest Light[b]" found that about 80 percent to 90 percent of the high-intensity laser systems are overseas, and all of the highest-power 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 high-intensity, ultrafast lasers, which have broad applications in manufacturing, medicine, and national security. The report made 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 NASEM report focuses on high-intensity, pulsed petawatt-class lasers (1 petawatt is 10^{15} watts). Such laser beams can drive nuclear reactions, heat matter to mimic conditions found in stars, and create electron-positron plasmas. In addition to discovery-driven science, petawatt-class lasers can generate particle beams with potential applications in medicine, intense neutron and gamma ray beams for homeland security applications, directed energy for defense applications, and radiation for extreme ultraviolet lithography.

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 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. The upgrade includes the

[a] This project is pre-CD-2; therefore, funding and schedule estimates are preliminary.
[b] https://www.nap.edu/catalog/24939/opportunities-in-intense-ultrafast-lasers-reaching-for-the-brightest-light

petawatt laser beam and the long pulse laser beam. The latter is required to compress matter to densities relevant to planetary science and fusion plasmas.

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

The project will be generally 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 KPPs are preliminary and may change during design phase 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 project is in the 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 Project Management Executive (PME) consideration and approval at CD-1.

Performance Measure	Threshold	Objective
Optical Laser Systems		
▪ High repetition rate short pulse laser	▪ 30 Joules of energy ▪ 300 fs pulse length 1 Hz frequency	▪ 150 Joules of energy ▪ 150 fs pulse length 10 Hz frequency
▪ High energy long pulse laser	▪ 200 Joules of energy on target ▪ 10 ns pulse length 1 shot per 60 minutes.	▪ 1000 Joules of energy on target ▪ 10 ns pulse length 1 shot per 30 minutes.
X-ray Beam Delivery		
▪ Photon energy	▪ 5-25 KeV energy delivered to target center	▪ 5-45 KeV of energy delivered to target center
Experimental Systems		
▪ Re-entrant diagnostic inserters	▪ 4 inserters	▪ 9 inserters

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
Design (TEC)			
FY 2020	15,000	–	–
FY 2021	5,000	–	–
FY 2022	–	20,000	20,000
Total, Design (TEC)	**20,000**	**20,000**	**20,000**
Construction (TEC)			
FY 2021	10,000	–	–
FY 2022	5,000	15,000	15,000
Outyears	327,000	327,000	327,000
Total, Construction (TEC)	**342,000**	**342,000**	**342,000**
Total Estimated Cost (TEC)			
FY 2020	15,000	–	–
FY 2021	15,000	–	–
FY 2022	5,000	35,000	35,000
Outyears	327,000	327,000	327,000
Total, TEC	**362,000**	**362,000**	**362,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Other Project Cost (OPC)			
FY 2019	1,600	1,600	280
FY 2020	4,500	4,500	3,808
FY 2021	2,000	2,000	2,000
FY 2022	–	–	2,012
Outyears	1,900	1,900	1,900
Total, OPC	**10,000**	**10,000**	**10,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Project Cost (TPC)			
FY 2019	1,600	1,600	280
FY 2020	19,500	4,500	3,808
FY 2021	17,000	2,000	2,000
FY 2022	5,000	35,000	37,012
Outyears	328,900	328,900	328,900
Total, TPC	**372,000**	**372,000**	**372,000**

Note: 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	17,000	17,000	**N/A**
Design - Contingency	3,000	3,000	**N/A**
Total, Design (TEC)	**20,000**	**20,000**	**N/A**
Construction	161,798	70,000	**N/A**
Equipment	115,191	60,800	**N/A**
Construction - Contingency	68,111	39,600	**N/A**
Total, Construction (TEC)	**345,100**	**170,400**	**N/A**
Total, TEC	**365,100**	**190,400**	**N/A**
Contingency, TEC	*71,111*	*42,600*	***N/A***
Other Project Cost (OPC)			
R&D	350	350	**N/A**
Conceptual Planning	850	850	**N/A**
Conceptual Design	1,900	1,900	**N/A**
Other OPC Costs	2,400	3,500	**N/A**
OPC - Contingency	1,400	3,000	**N/A**
Total, Except D&D (OPC)	**6,900**	**9,600**	**N/A**
Total, OPC	**6,900**	**9,600**	**N/A**
Contingency, OPC	*1,400*	*3,000*	***N/A***
Total, TPC	**372,000**	**200,000**	**N/A**
Total, Contingency (TEC+OPC)	***72,511***	***45,600***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Request Year	Type	Prior Years	FY 2020	FY 2021	FY 2022	Outyears	Total
FY 2020	TEC	—	1,000	—	—	TBD	TBD
	OPC	1,600	—	—	—	TBD	TBD
	TPC	1,600	1,000	—	—	TBD	TBD
FY 2021	TEC	—	15,000	5,000	—	170,400	190,400
	OPC	1,600	4,500	—	—	3,500	9,600
	TPC	1,600	19,500	5,000	—	173,900	200,000
FY 2022	TEC	—	15,000	15,000	5,000	327,000	362,000
	OPC	1,600	4,500	2,000	—	1,900	10,000
	TPC	1,600	19,500	17,000	5,000	328,900	372,000[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, Maintenance and Repair	N/A	21,200	N/A	931,000

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

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

8. Acquisition Approach

The FES is proposing that the MEC-U Project be acquired by Stanford University under the SLAC Management and Operations (M&O) Contract (DE-AC02-76-SF00515) for DOE. The acquisition of large research facilities is within the scope of the DOE contract for the management and operations of SLAC and consistent with the general expectation of the responsibilities of DOE M&O contractors.

SLAC does not currently possess all the necessary core competencies to design, procure and build the laser systems. To address this, SLAC will collaborate with Lawrence Livermore National Laboratory (LLNL) and University of Rochester Laboratory for Laser Energetics (LLE) as partners through signed Memorandum of Agreements to perform significant portions of the MEC-U laser systems scope of work. Memorandum Purchase Orders will be used to define work scopes and budgets with LLNL as funds become available. Any work accomplished through LLE will be completed using the standard DOE format university agreements. Procurements authorized by the partner institutions will utilize the approved DOE purchasing systems.

14-SC-60, U.S. Contributions to ITER
Project is for Design and Construction

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

Summary

The FY 2022 Request for the U.S. ITER project is $221,000,000. The approved Total Project Cost (TPC) for the U.S. Contributions to ITER Subproject–1 (SP-1) is $1,267,422,000. Sections of this Construction Project Data Sheet (CPDS) have been tailored accordingly to reflect the unique nature of the U.S. ITER project.

Significant Changes

The FY 2022 Request of $221,000,000 will support the continued design and fabrication of "in-kind" hardware systems and cash contributions. 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 2021, the U.S. will deliver the first CS magnet module 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 more than $1.3 billion through the end of FY 2020, of which more than 80 percent has gone to U.S. industry, universities, and DOE laboratories.

ITER was initiated in FY 2006. The ITER SP-1 achieved both Critical Decision (CD)–2, "Approve Performance Baseline," and CD-3, "Approve Start of Construction," on January 13, 2017. CD-4, "Project Completion," for SP–1 is planned for December 2028.

A 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	7/5/05	-	TBD	TBD	-	TBD	N/A	TBD
FY 2007	7/5/05	-	TBD	TBD	-	TBD	N/A	2017
FY 2008	7/5/05	-	1/25/08	4Q FY 2008	-	TBD	N/A	2017
FY 2009	7/5/05	9/30/09	1/25/08	4Q FY 2010	-	TBD	N/A	2018
FY 2010	7/5/05	7/27/10	1/25/08	4Q FY 2011	-	TBD	N/A	2019
FY 2011	7/5/05	5/30/11	1/25/08	4Q FY 2011	4/12/11	TBD	N/A	2024
FY 2012	7/5/05	7/10/12	1/25/08	3Q FY 2012	5/2/12	TBD	N/A	2028
FY 2013	7/5/05	12/11/12	1/25/08	TBD	4/10/13	TBD	N/A	2033
FY 2014	7/5/05	-	1/25/08	TBD	12/10/13	TBD	N/A	2034
FY 2015	7/5/05	-	1/25/08	TBD	-	TBD	N/A	2036
FY 2016	7/5/05	-	1/25/08	TBD	-	TBD	N/A	TBD
FY 2017	7/5/05	-	1/25/08	1/13/17	-	1/13/17	N/A	TBD
FY 2018	7/5/05	-	1/25/08	1/13/17	-	1/13/17	N/A	1Q FY 2027
FY 2019	7/5/05	-	1/25/08	1/13/17	-	1/13/17	N/A	1Q FY 2027
FY 2020	7/5/05	-	1/25/08	1/13/17	-	1/13/17	N/A	1Q FY 2027
FY 2021	7/5/05	-	1/25/08	1/13/17	-	1/13/17	N/A	1Q FY 2028
FY 2022	7/5/05	-	1/25/08	1/13/17	-	1/13/17	N/A	1Q FY 2028

CD-0 – Approve Mission Need for a construction project with a conceptual scope and cost range
Conceptual Design Complete – Actual date the conceptual design was 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	CD-1 Cost Range Update	CD-3B
FY 2018	1/13/17	1/13/17
FY 2019	1/13/17	1/13/17
FY 2021	1/13/17	1/13/17
FY 2022	1/13/17	1/13/17

Note on multiple dates in Conceptual and Final Design columns for each piece of equipment: 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); 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); Vacuum Auxiliary System (VAS) – Main Piping (12/13/2010); Diagnostics Low-Field-Side Reflectometer (LFS) (05/30/2011); Cooling Water Drain Tanks (04/12/2011); 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); Steady State Electrical Network (05/02/2012); 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); 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; RGA Divertor Sampling Tube (07/28/14); CS AT, Early Items (09/17/14); CS Modules and Structures (11/18/2013); VAS Main Piping B-2, L-1, L-2 (12/10/2013); CS AT Remaining Items (12/02/2015); 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); 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).

<u>Project Cost History</u>

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 (IO) at that time) affected the project cost and schedule. Shortly after the current Director General'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, the DOE Secretary provided a "Report on the Continued U.S. Participation in the ITER Project" to Congress, which stated that the First Plasma part of the U.S. ITER project would be baselined in FY 2017. In preparation for baselining SP-1, based on the results of the Integrated Project Review, 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 project's 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)[a]
(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D	OPC, D&D	OPC, Total	TPC
FY 2017[b]	696,025	1,723,334	2,419,359	80,641	N/A	80,641	2,500,000
FY 2018	696,025	1,723,334	2,419,359	80,641	N/A	80,641	2,500,000
FY 2019	696,025	1,723,334	2,419,359	80,641	N/A	80,641	2,500,000
FY 2020	696,025	1,733,673	2,429,698	70,302	N/A	70,302	2,500,000
FY 2021	696,025	1,733,673	2,429,698	70,302	N/A	70,302	2,500,000
FY 2022	503,262	1,926,436	2,429,698	70,302	N/A	70,302	2,500,000

2. Project Scope and Justification

ITER, currently the largest science experiment in the world, is a major fusion research facility being constructed in St. 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. ITER is co-owned and co-governed by the seven Members, including the U.S. The Energy Policy Act of 2005 (EPAct 2005), Section 972(c)(5)(C), authorized U.S. participation in ITER. The Agreement on the Establishment of the ITER International Fusion Energy Organization for the Joint Implementation of the ITER Project (Joint Implementation Agreement or JIA), signed on November 21, 2006, provides the legal framework for the four phases of the program: construction, operation, deactivation, and decommissioning. The JIA is a Congressional-Executive Hybrid Agreement that is considered “treaty-like”. The other six members entered the agreement by treaty. Through participation in the JIA, the European Union, as the Host, bears five-elevenths (45.45 percent) of the ITER facility’s construction cost, while the other six Members, including the U.S., each support one-eleventh (9.09 percent) of the ITER facility’s construction cost. The IO is an international legal entity located in France.

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). SP-1 completes all design, delivers the Steady State Electrical Network, Toroidal Field Conductor, Central Solenoid Magnet, and portions of other systems described in Table 1, SP-1 In-Kind Hardware Description. 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. These funds are used by the IO to provide design integration, nuclear licensing, regulatory engagement, assembly and installation of in-kind components, and overall project management.

<u>Scope</u>
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., and then shipped to the ITER site for IO assembly, installation, and operation. Included in this element is cash provided in-lieu of U.S. in-kind component contributions to adjust for certain reallocations of hardware contributions between the U.S. and the IO.

[a] Funding shown is for Subproject-1 and does not include cash contributions.
[b] Prior to FY2017 the TPC for U.S. ITER was reported as “TBD”; estimates reported beginning in FY 2017 represent the validated baseline values for Subproject 1 First Plasma Hardware. These values for the SP-1 baseline have not been updated to reflect impacts from FY 2017 and FY 2018 funding reductions and allocations.

- Funding to the IO to support common expenses, including ITER research and development (R&D), design and construction integration, overall project management, nuclear licensing, IO staff and infrastructure, IO-provided hardware, on-site assembly/installation/testing of all ITER components, installation, safety, quality control and operation.
- Other project costs, including R&D (other than mentioned above) and conceptual design-related activities.

The U.S. is to contribute the agreed-upon hardware to ITER, the technical components of which are split between SP-1 (FP) and SP-2 (Post-FP). The description of the component systems and the percentage to be delivered in SP-1 are indicated in the table below:

Table 1. SP-1 In-Kind Hardware Description

System/Subsystem	Threshold
Central Solenoid Magnet System	Provide seven (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. (100 percent in SP-1)
Toroidal Field Magnet Conductor	Provide 15 percent of the overall ITER requirements which includes 9 active lengths (~765m), one dummy length (~765m) for winding trials and two active lengths (~100m each) for superconducting qualification. (100 percent in SP-1)
Steady State Electrical Network	Provide 75 percent of the overall ITER requirement which includes components for a large AC power distribution system (transformers, switches, circuit breakers, etc.) at high-voltage (400kV) and medium-voltage (22kV) levels. (100 percent in SP-1)
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. (58 percent in SP-1)
Diagnostics	Provide Final Designs for four diagnostic port plugs and seven 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. (6 percent in SP-1)
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. (55 percent in SP-1)
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. (15 percent in SP-1)
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. (55 percent in SP-1)
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. (65 percent in SP-1)

Table 1. SP-1 In-Kind Hardware Description

System/Subsystem	Threshold
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. (85 percent in SP-1)
Tokamak Exhaust Processing System	Provide Final Designs for an exhaust separation system for hydrogen isotopes and non-hydrogen gases. (100 percent of design in SP-1)
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. (100 percent of design in 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 toward developing a fusion pilot 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,* to the greatest extent possible.

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 (see Table 1 on previous page for more detail).

[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)			
Design (TEC)			
FY 2006	13,754	13,754	6,169
FY 2007	33,702	33,702	21,352
FY 2008	22,371	22,371	22,992
FY 2009	45,574	45,574	26,278
FY 2010	36,218	36,218	46,052
FY 2011	39,143	39,143	67,919
FY 2012	54,151	54,151	54,151
FY 2013	49,124	49,124	49,124
FY 2014	42,811	42,811	42,811
FY 2015	55,399	55,399	55,399
FY 2016	46,996	46,996	46,996
FY 2022	43,883	43,883	43,883
Outyears	20,136	20,136	20,136
Total, Design (TEC)	**503,262**	**503,262**	**503,262**
Construction (TEC)			
FY 2007	2,886	2,886	2,886
FY 2008	1,129	1,129	1,129
FY 2009	39,827	39,827	–
FY 2010	49,048	49,048	–
FY 2011	24,732	24,732	16,402
FY 2012	37,302	37,290	45,098
FY 2013	58,511	58,545	60,950
FY 2014	123,794	123,794	111,184
FY 2015	78,644	78,644	58,730
FY 2016	68,004	68,004	59,523
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	75,338
FY 2021	182,000	182,000	182,000
FY 2022	136,117	136,117	136,117
Outyears	693,442	693,420	829,051
Total, Construction (TEC)	**1,926,436**	**1,926,436**	**1,926,436**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Cash Contributions (TEC)			
FY 2006	2,112	2,112	2,112
FY 2007	7,412	7,412	7,412
FY 2008	2,644	2,644	2,644
FY 2009	23,599	23,599	23,599
FY 2010	29,734	29,734	29,734
FY 2011	3,125	3,125	3,125
FY 2012	13,214	13,214	13,214
FY 2013	13,805	13,805	13,805
FY 2014	32,895	32,895	32,895
FY 2015	15,957	15,957	15,957
FY 2019	30,000	30,000	30,000
FY 2020	85,000	85,000	85,000
FY 2021	60,000	60,000	60,000
FY 2022	41,000	41,000	41,000
Outyears	797,503	797,503	797,503
Total, Cash Contributions (TEC)	**1,158,000**	**1,158,000**	**1,158,000**
Total Estimated Cost (TEC)			
FY 2006	15,866	15,866	8,281
FY 2007	44,000	44,000	31,650
FY 2008	26,144	26,144	26,765
FY 2009	109,000	109,000	49,877
FY 2010	115,000	115,000	75,786
FY 2011	67,000	67,000	87,446
FY 2012	104,667	104,655	112,463
FY 2013	121,440	121,474	123,879
FY 2014	199,500	199,500	186,890
FY 2015	150,000	150,000	130,086
FY 2016	115,000	115,000	106,519
FY 2017	50,000	50,000	123,117
FY 2018	122,000	122,000	98,185
FY 2019	132,000	132,000	156,726
FY 2020	242,000	242,000	160,338
FY 2021	242,000	242,000	242,000
FY 2022	221,000	221,000	221,000
Outyears	1,511,081	1,511,059	1,646,690
Total, TEC	**3,587,698**	**3,587,698**	**3,587,698**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Other Project Cost (OPC)			
FY 2006	3,449	3,449	3,449
FY 2007	16,000	16,000	16,000
FY 2008	-74	-74	-74
FY 2009	15,000	15,000	15,000
FY 2010	20,000	20,000	20,000
FY 2011	13,000	13,000	13,000
FY 2012	333	333	333
FY 2013	2,560	2,560	2,560
FY 2016	34	34	34
Total, OPC	**70,302**	**70,302**	**70,302**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Project Cost (TPC)			
FY 2006	19,315	19,315	11,730
FY 2007	60,000	60,000	47,650
FY 2008	26,070	26,070	26,691
FY 2009	124,000	124,000	64,877
FY 2010	135,000	135,000	95,786
FY 2011	80,000	80,000	100,446
FY 2012	105,000	104,988	112,796
FY 2013	124,000	124,034	126,439
FY 2014	199,500	199,500	186,890
FY 2015	150,000	150,000	130,086
FY 2016	115,034	115,034	106,553
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	160,338
FY 2021	242,000	242,000	242,000
FY 2022	221,000	221,000	221,000
Outyears	1,511,081	1,511,059	1,646,690
Total, TPC	**3,658,000**	**3,658,000**	**3,658,000**

Note:

- *TEC: Costs through FY 2020 reflect actual costs; costs for FY 2021 and the outyears are estimates.*
- *FY 2012: Prior actuals adjusted to incorporate project funds utilized at PPPL and DOE. Obligation adjusted to reflect year-end PPPL settlement funding.*

- *FY 2014: Appropriations prior to FY 2014 reflect major item of equipment funding. Starting in FY 2014, this project is funded as a Congressional control point.*
- *FY 2016 funding for taxes and tax support is included in the FY 2017 Hardware funding amount.*
- *Cash Contributions includes cash payments, secondees, taxes and tax support and are considered separate from the SP-1 TPC.*
- *Appropriations for the U.S. Contributions to ITER project include both funding for SP-1 and funding for Cash Contributions.*

4. Details of Project Cost Estimate

The overall U.S. Contributions to ITER project has an approved updated CD-1 Cost Range. 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 be done at a future point; SP-2 design work is underway. An Independent Project Review (IPR) of U.S. Contributions to ITER was conducted on November 14–17, 2016, to consider the project's readiness for CD-2 (Approve Performance Baseline) and CD-3 (Approve Start of Construction [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 ($4,000,000,000 to $6,500,000,000) 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 $4,700,000,000 to $6,500,000,000.

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design	503,262	573,660	573,660
Design - Contingency	N/A	122,365	122,365
Total, Design (TEC)	**503,262**	**696,025**	**696,025**
Construction	1,696,355	N/A	**N/A**
Equipment	N/A	1,362,521	1,362,521
Construction - Contingency	230,081	371,152	371,152
Total, Construction (TEC)	**1,926,436**	**1,733,673**	**1,733,673**
Total, TEC	**2,429,698**	**2,429,698**	**2,429,698**
Contingency, TEC	*230,081*	*493,517*	*493,517*
Other Project Cost (OPC)			
OPC, Except D&D	70,302	N/A	70,302
Other OPC Costs	N/A	70,302	**N/A**
Total, Except D&D (OPC)	**70,302**	**70,302**	**70,302**
Total, OPC	**70,302**	**70,302**	**70,302**
Contingency, OPC	***N/A***	*N/A*	***N/A***
Total, TPC	**2,500,000**	**2,500,000**	**2,500,000**
Total, Contingency (TEC+OPC)	***230,081***	***493,517***	***493,517***

Note:
- *Funding shown is for Subproject-1 and does not include cash contributions.*

5. Schedule of Appropriations Requests

(dollars in thousands)

Request Year	Type	Prior Years	FY 2020	FY 2021	FY 2022	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[a]	TEC	266,366	—	—	—	—	TBD
	OPC	38,075	—	—	—	—	TBD
	TPC	304,441	—	—	—	—	TBD
FY 2010	TEC	294,366	—	—	—	—	TBD
	OPC	70,019	—	—	—	—	TBD
	TPC	364,385	—	—	—	—	TBD
FY 2011	TEC	379,366	—	—	—	—	TBD
	OPC	65,019	—	—	—	—	TBD
	TPC	444,385	—	—	—	—	TBD
FY 2012[b]	TEC	394,366	—	—	—	—	TBD
	OPC	75,019	—	—	—	—	TBD
	TPC	469,385	—	—	—	—	TBD
FY 2013[c]	TEC	617,261	—	—	—	—	TBD
	OPC	82,124	—	—	—	—	TBD
	TPC	699,385	—	—	—	—	TBD
FY 2014[d]	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

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

(dollars in thousands)

Request Year	Type	Prior Years	FY 2020	FY 2021	FY 2022	Outyears	Total
FY 2018	TEC	1,170,244	—	—	—	—	TBD
	OPC	80,641	—	—	—	—	TBD
	TPC	1,250,885	—	—	—	—	TBD
FY 2019	TEC	1,245,244	—	—	—	—	TBD
	OPC	80,641	—	—	—	—	TBD
	TPC	1,325,885	—	—	—	—	TBD
FY 2020	TEC	1,371,617	107,000	—	—	—	TBD
	OPC	70,302	—	—	—	—	TBD
	TPC	1,441,919	107,000	—	—	—	TBD
FY 2021	TEC	1,371,617	242,000	107,000	—	—	TBD
	OPC	70,302	—	—	—	—	TBD
	TPC	1,441,919	242,000	107,000	—	—	TBD
FY 2022	TEC	1,371,617	242,000	242,000	221,000	—	TBD
	OPC	70,302	—	—	—	—	TBD
	TPC	1,441,919	242,000	242,000	221,000	—	TBD

6. Related Operations and Maintenance Funding Requirements

The U.S. Contributions to ITER operations phase is to begin with initial integrated commissioning activities and assumed to 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 phase is assumed to begin no earlier than 20 years after the start of operations. The deactivation phase is also assumed to begin no earlier than 20 years after operations begin and will continue for a period of 5 years. The U.S. is responsible for 13 percent of the total decommissioning and deactivation cost; the fund will be collected and escrowed out of research operations funding.

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 mission of the High Energy Physics (HEP) program is to understand how the universe works at its most fundamental level by discovering the elementary constituents of matter and energy, probing the interactions between them, and exploring the basic nature of space and time. HEP accomplishes its mission through excellence in scientific discovery in particle physics, and through stewardship of world-class scientific user facilities that enable cutting-edge research and development. HEP continues to deliver major construction projects on time and on budget, and provide reliable availability and support to users for operating facilities.

Our current understanding of the elementary constituents of matter and energy and the forces that govern them is described by the Standard Model of particle physics. However, experimental measurements suggest that the Standard Model is incomplete and that new physics may be discovered by future experiments. 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] was unanimously approved by the High Energy Physics Advisory Panel (HEPAP) to serve the DOE and National Science Foundation (NSF) as the ten-year strategic plan for U.S. high energy physics in the context of a 20-year global vision. The P5 report identified five intertwined science drivers of particle physics that provide compelling lines of inquiry with great promise to discover what lies beyond the Standard Model:

- 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 and supports cutting edge research and development (R&D):

- 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.
- 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.
- 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.
- Theoretical, Computational, and Interdisciplinary Physics provides the framework to explain experimental observations and gain a deeper understanding of nature.
- The Advanced Technology R&D subprogram fosters fundamental research into particle acceleration and detection techniques and instrumentation.

Innovative research methods and enabling technologies that emerge from R&D into accelerators, instrumentation, quantum information science (QIS), and artificial intelligence (AI) and machine learning (ML) will advance scientific knowledge in high energy physics and in a broad range of related fields, advancing DOE's strategic goals for science. 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.

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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

Highlights of the FY 2022 Request

The FY 2022 Request for $1,061.0 million 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.

The Accelerator Stewardship subprogram moves to the Accelerator R&D and Production (ARDAP) program in the FY 2022 Request.

Key elements in the FY 2022 Request include:

<u>Research</u>

The Request provides continued support for university and laboratory researchers carrying on critical core competencies, enabling high priority theoretical and experimental activities in pursuit of discovery science. The Request provides support to foster a diverse, highly skilled, American workforce, and to build R&D capacity and conduct world-leading R&D:

- Accelerator Science and Technology Initiative: In coordination with the ARDAP program, HEP will continue and increase support for mid- to long-term R&D to maintain a leading position in key accelerator technologies that define SC's competitive advantage.
- AI/ML: Research to tackle the challenges of managing increasingly high volumes and complexity of HEP experimental and simulated data, and to address cross-cutting challenges across the HEP program in coordination with DOE investments in exascale computing and associated AI efforts.
- Integrated Computational and Data Infrastructure for Scientific Discovery: In coordination with SC, HEP will support development of data storage capabilities to handle tens of exabytes of data from future experiments; cross-cutting efforts in AI/ML and edge computing to seek solutions for real-time and extremely high data rate environments; and investments in software development to improve the interface with SC infrastructure and ASCR-supported middleware.
- 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, including 5G, to accelerate the advancement of microelectronic technologies.
- QIS: R&D to accelerate discovery in particle physics while advancing the national effort. HEP QIS 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.
- QIS Research Centers: HEP, in partnership with other SC programs, will continue support for multi-disciplinary QIS Research Centers initiated in FY 2020 to accelerate the advancement of QIS through vertical integration between systems and theory, and hardware and software. QIS Research Center scope includes work relating to sensors, quantum computing, emulators/simulators, and enabling technologies that will pave the path to accelerate and exploit QIS-associated technologies in the longer term.
- Reaching a New Energy Sciences Workforce (RENEW): The Office of Science is fully committed to advancing a diverse, equitable, and inclusive research community. This commitment is key to providing the scientific and technical expertise for U.S. leadership in high energy physics. Toward that goal, HEP will participate in the SC-wide RENEW initiative that leverages SC's unique national laboratories, user facilities, and other research infrastructures to provide undergraduate and graduate training opportunities for students and academic institutions not currently well represented in the U.S. S&T ecosystem. This includes Minority Serving Institutions and individuals from groups historically underrepresented in STEM, but also includes students from communities with environmental justice impacts and the EPSCoR jurisdictions. The hands-on experiences gained through the RENEW initiative will open new career avenues for the participants, forming a nucleus for a future pool of talented young scientists, engineers, and technicians with the critical skills and expertise needed for the full breadth of SC research activities, including DOE national laboratory staffing.

<u>Facility Operations</u>

HEP supports two Scientific User Facilities. The Fermilab Accelerator Complex and the Facility for Advanced Accelerator Experimental Tests II (FACET-II) will continue operations at 90 percent of optimal. HEP supports laboratory-based accelerator and detector test facilities, and supports the maintenance and operations of large-scale experiments and facilities that are not based at a national laboratory, including the U.S. Large Hadron Collider (LHC) at CERN in Geneva, Switzerland; Sanford Underground Research Facility (SURF) in Lead, South Dakota; Vera C. Rubin Observatory in Chile; Dark Energy Spectroscopic Instrument (DESI) at the Mayall telescope in Arizona; Large Underground Xenon (LUX)-ZonED Proportional Scintillation in Liquid Noble gases (Zeplin) (LUX-ZEPLIN) (LZ) dark matter experiment at SURF; the Super

Cryogenic Dark Matter Search at Sudbury Neutrino Observatory Laboratory (SuperCDMS-SNOLAB) experiment in the Creighton Mine near Sudbury, Ontario, Canada; and the Belle II experiment at the High Energy Accelerator Research Organization (KEK) in Tsukuba, Japan.

Projects

The Request provides continued support for the Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment (LBNF/DUNE), Proton Improvement Plan II (PIP-II), and Muon to Electron Conversion Experiment (Mu2e) projects. The FY 2022 Request also continues four Major Item of Equipment (MIE) projects: Cosmic Microwave Background Stage 4 (CMB-S4), High-Luminosity (HL-LHC) Accelerator Upgrade Project, and the HL-LHC ATLAS and CMS Detector Upgrade Projects. The FY 2022 Request includes one new MIE start, the Accelerator Controls Operations Research Network (ACORN).

High Energy Physics
FY 2022 Research Initiatives

High Energy Physics supports the following FY 2022 Research Initiatives.

(dollars in thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Accelerator Science and Technology Initiative	–	6,411	17,432	+11,021
Artificial Intelligence and Machine Learning	15,000	33,488	35,806	+2,318
Integrated Computational & Data Infrastructure	–	–	4,146	+4,146
Microelectronics	–	5,000	7,000	+2,000
Quantum Information Science	38,500	45,072	51,566	+6,494
Reaching a New Energy Sciences Workforce (RENEW)	–	–	4,000	+4,000
Total, Research Initiatives	**53,500**	**89,971**	**119,950**	**+29,979**

High Energy Physics
Funding

(dollars in thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
High Energy Physics				
Energy Frontier, Research	71,125	68,000	71,833	+3,833
Energy Frontier, Facility Operations and Experimental Support	52,650	53,650	49,850	-3,800
Energy Frontier, Projects	100,000	72,500	40,000	-32,500
Energy Frontier, SBIR/STTR	4,663	–	–	–
Total, Energy Frontier Experimental Physics	**228,438**	**194,150**	**161,683**	**-32,467**
Intensity Frontier, Research	58,871	63,082	65,994	+2,912
Intensity Frontier, Facility Operations and Experimental Support	177,122	166,785	176,845	+10,060
Intensity Frontier, Projects	5,494	3,000	8,000	+5,000
Intensity Frontier, SBIR/STTR	8,747	–	–	–
Total, Intensity Frontier Experimental Physics	**250,234**	**232,867**	**250,839**	**+17,972**
Cosmic Frontier, Research	48,072	47,091	49,012	+1,921
Cosmic Frontier, Facility Operations and Experimental Support	41,358	44,500	42,500	-2,000
Cosmic Frontier, Projects	2,000	6,000	5,000	-1,000
Cosmic Frontier, SBIR/STTR	3,471	–	–	–
Total, Cosmic Frontier Experimental Physics	**94,901**	**97,591**	**96,512**	**-1,079**
Theoretical, Computational, and Interdisciplinary Physics, Research	111,434	136,362	157,422	+21,060
Theoretical, Computational, and Interdisciplinary Physics, SBIR/STTR	4,093	–	–	–
Total, Theoretical, Computational, and Interdisciplinary Physics	**115,527**	**136,362**	**157,422**	**+21,060**

(dollars in thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Advanced Technology R&D, Research	64,391	72,833	75,344	+2,511
Advanced Technology R&D, Facility Operations and Experimental Support	39,232	43,262	40,200	-3,062
Advanced Technology R&D, SBIR/STTR	3,783	–	–	–
Total, Advanced Technology R&D	**107,406**	**116,095**	**115,544**	**-551**
HEP Accelerator Stewardship, Research	10,788	10,835	–	-10,835
HEP Accelerator Stewardship, Facility Operations and Experimental Support	6,067	6,100	–	-6,100
HEP Accelerator Stewardship, SBIR/STTR	639	–	–	–
Total, HEP Accelerator Stewardship	**17,494**	**16,935**	**–**	**-16,935**
Subtotal, High Energy Physics	**814,000**	**794,000**	**782,000**	**-12,000**
Construction				
18-SC-42, Proton Improvement Plan II (PIP-II), FNAL	60,000	79,000	90,000	+11,000
11-SC-40, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment	171,000	171,000	176,000	+5,000
11-SC-41, Muon to Electron Conversion Experiment, FNAL	–	2,000	13,000	+11,000
Subtotal, Construction	**231,000**	**252,000**	**279,000**	**+27,000**
Total, High Energy Physics	**1,045,000**	**1,046,000**	**1,061,000**	**+15,000**

SBIR/STTR funding:

- FY 2020 Enacted: SBIR $22,265,000 and STTR $3,131,000
- FY 2021 Enacted: SBIR $22,325,000 and STTR $3,140,000
- FY 2022 Request: SBIR $22,618,000 and STTR $3,181,000

High Energy Physics
Explanation of Major Changes

	(dollars in thousands) FY 2022 Request vs FY 2021 Enacted
Energy Frontier Experimental Physics The Request will support data analysis activities during the next LHC run 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 will continue. An increase in funding to support additional U.S.-based computing infrastructure will be offset by a decrease in funding due to the completion of the installation and commissioning of U.S.-built detector components for the ATLAS and CMS detector upgrades. Support will focus on critical path items to best maintain synchronization with the international LHC and HL-LHC schedules as well as prototyping and fabrication efforts necessary to continue the HL-LHC ATLAS and CMS Detector Upgrade Projects.	**-32,467**
Intensity Frontier Experimental Physics The Request will increase research to support data collection and analysis on the Short-Baseline Neutrino (SBN) program. Support for research on lower priority small- to mid-scale neutrino experiments will ramp down. The Request will increase the Fermilab Accelerator Complex from 81 to 90 percent of optimal operations. Support for General Plant Project (GPP) funding increases to fund the Target Systems Integration Building construction. Funding will support increased excavation support costs at SURF for LBNF/DUNE construction, and increased ACORN MIE OPC for system design and other related engineering activities.	**+17,972**
Cosmic Frontier Experimental Physics The Request will increase support for research efforts for data collection and analysis on new experiments, efforts on CMB-S4, and scientific planning for future experiments, while support for completed experiments will ramp down. Support will continue for commissioning and pre-operations activities of Vera C. Rubin Observatory and the Dark Energy Science Collaboration (DESC) and the commissioning of SuperCDMS-SNOLAB will complete. The Request will prioritize design activities for CMB-S4.	**-1,079**
Theoretical, Computational, and Interdisciplinary Physics The Request will increase to support the new integrated computational and data infrastructure initiative, and the highest-impact theoretical research as determined by competitive peer review. Funding increases to support innovation and new opportunities in building algorithms that learn about complex data to solve big-data computing hardware and infrastructure challenges; embedding AI into sensors and experimental design in extreme environments; and developing operations and controls AI/ML techniques. The Request increases to support the multi-laboratory HEP Computational Center for Excellence to develop portable parallelization solutions, data transfer and storage challenges, and event generation and complex workflows. Funding increases to support quantum simulation, physics beyond the Standard Model experiments using HEP and QIS expertise and techniques, and lab research technology including quantum networks and communications testbeds. This subprogram also supports the RENEW initiative to provide undergraduate and graduate training opportunities for students and academic institutions not currently well represented in the U.S. S&T ecosystem.	**+21,060**

	(dollars in thousands) FY 2022 Request vs FY 2021 Enacted
Advanced Technology R&D The Request will capitalize on the science opportunities at the newly completed FACET-II facility and the second beamline at Berkeley Lab Laser Accelerator (BELLA); continue the Traineeship Program; increase support for the Accelerator Science and Technology Initiative; and increase support for microelectronics R&D activities. Ongoing Detector R&D will prioritize support for collaborative opportunities at universities and national laboratories that enable 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 Workshop on High Energy Physics Detector Research and Development.[a] Funding will decrease for the FACET-II operations, reducing support from 100 percent to 90 percent optimal in FY 2022.	**-551**
HEP Accelerator Stewardship Funding for the Accelerator Stewardship subprogram moves to the Accelerator R&D and Production program.	**-16,935**
Construction The Request will continue support for the completion of the design phase for PIP-II, construction of the Early Conventional Facilities subproject, and fabrication of prototypes for the linear accelerator. Approval of CD-3 in FY 2022 will allow the start of construction on the full project. The Request also will continue support for LBNF/DUNE for the excavation of detector caverns at the Far Site, and the ramp-up of design effort on the Near Site facilities and the detectors. Additional funding is also requested for Mu2e to respond to cost increases resulting from schedule delays caused by pandemic response at FNAL and at collaborating universities, and by delayed delivery of two superconducting magnets caused by poor vendor performance.	**+27,000**
Total, High Energy Physics	**+15,000**

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

Basic and Applied R&D Coordination

The HEP General Accelerator R&D (GARD) research activity within the Advanced Technology R&D subprogram provides the fundamental building blocks of accelerator technology needed for the High Energy Physics mission. The GARD activity is based on input from the community, including high-level advice on long term facility goals from HEPAP and P5, and more detailed technical advice developed through a series of Roadmap Workshops. The GARD activity is coordinated with other Offices of Science (especially Basic Energy Sciences, Fusion Energy Sciences, Nuclear Physics, and Accelerator R&D and Production programs) and other federal agencies to optimize synergy and foster strong U.S capability in this key technology area.

The HEP QIS research program has coordinated partnerships with the Department of Defense Office of Basic Research as well as the Air Force's Office of Scientific Research on synergistic research connecting foundational theory research with quantum error correction and control systems for sensors, 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 Research Center effort is a partnership across all SC 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).

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 ATLAS and CMS collaborations used the Higgs boson as a tool for discovery by searching for evidence of it decaying to pairs of muons. While this challenging decay channel is predicted by the standard model at a low rate and thereby considered rare, the analysis suggests that an observation will be possible with additional data acquired at the LHC or during the future era of the HL-LHC. A different search by the ATLAS and CMS collaborations probes the possibility for the Higgs boson to serve as a portal to dark matter particles based on the fact that the Higgs boson couples to mass, allowing potentially massive dark matter particles to interact with it. Using the full dataset acquired from the 2015-2018 run, each LHC experiment has placed stringent constraints that bound the phase space for the Higgs boson decaying to dark matter. These analyses demonstrate the potential for discovery as the LHC will resume operations in 2022.

A team of international physicists join forces in hunt for sterile neutrinos (Intensity Frontier Experimental Physics).

An international group of more than 260 scientists have produced one of the most stringent tests for the existence of sterile neutrinos to date. The close collaboration of scientists from two major international neutrino experimental groups: MINOS+, which studies the disappearance of muon neutrinos produced by the Fermilab Accelerator Complex and propagating to an underground detector in northern Minnesota 735 kilometers away; and Daya Bay, which uses eight identically designed detectors to precisely measure how electron neutrinos emitted by six nuclear reactors in China "disappear" as they morph into other types; enabled the combination of two complementary world-leading constraints on muon neutrinos and electron antineutrinos disappearing into sterile neutrinos. The combined analysis reported by Daya Bay and MINOS+ not only ruled out the specific kind of sterile neutrino oscillation that would explain the anomalous results from earlier single-detector neutrino experiments, but also looked for other sterile neutrino signatures with never-before-achieved sensitivity, yielding some of the most stringent limits on the existence of these elusive particles to date.

Double advances for Cosmic Frontier dark energy experiments (Cosmic Frontier Experimental Physics).

The extended Baryon Oscillation Spectroscopic Survey (eBOSS) completed its five-year survey, mapping of an uncharted five billion years of cosmic history. The expansion of our universe is accelerating, not slowing down under gravity, which is one of the central mysteries of physics; one explanation for this phenomenon is a new form of energy—dark energy—with "antigravity" properties. eBOSS measured both the expansion and the growth rate of large-scale structure through a spectroscopic survey of distant galaxies, quasars, and hydrogen gas. The final eBOSS results in July 2020 constrained dark energy and other cosmological parameters a total of 50 times better than the previous generation of experiments. Meanwhile, the Dark Energy Spectroscopic Instrument (DESI) is the first of the next generation, precision dark energy surveys. DESI, the world's most advanced multi-object spectrograph, successfully completed commissioning in March 2020 and had project completion approved in May 2020, fully meeting all technical design requirements. DESI operations restarted in mid-December 2020 and has collected over 1.8 million spectra of distant galaxies midway through its survey validation phase. The 5-year science survey is planned to start in May 2021.

High energy experiment undergoes successful on-orbit repair on the International Space Station (Cosmic Frontier Experimental Physics).
The Massachusetts Institute of Technology-led Alpha Magnetic Spectrometer (AMS) international collaboration, developed with National Aeronautics and Space Administration (NASA), supported a plan of action to replace the failed cooling system on the AMS experiment that resides on the International Space Station (ISS). In a series of spacewalks in the fall of 2019, NASA astronauts on the ISS installed the AMS replacement cooling system. NASA engineers regard this repair as the most complex on-orbit repair ever attempted. From early 2020, the new AMS cooling system has been performing flawlessly and AMS is once again taking data for study of cosmic rays, antimatter in space, and the cosmos.

Physicists publish worldwide consensus of muon magnetic moment calculation (Theoretical, Computational, and Interdisciplinary Physics).
The U.S. Lattice Quantum Chromodynamics (USQCD) community used Leadership Class Computing facilities and cluster hardware to calculate a precise new theoretical value of the muon’s anomalous magnetic moment, g-2, which accounts for the way muons rotate in magnetic fields. Because the quantum vacuum is composed of an almost infinite number of short-lived particle oscillations which can couple to the muon, the muon g-2 is a sensitive test for new physics beyond the Standard Model, but a precise theoretical calculation is very difficult. USQCD collaborated with the global theoretical physics community to publish a consensus Standard Model prediction for muon g-2 before the publication of the recently announced initial FNAL muon g-2 experimental result. Since the Standard Model theoretical calculation still differs from the experimental measurement with high significance, physicists may be one step closer to determining whether the muon’s magnetic interactions are hinting at particles or forces that have yet to be discovered.

FNAL has achieved breakthrough success in demonstrating unprecedented coherence times of seconds (Theoretical, Computational, and Interdisciplinary Physics).
Viable quantum computing technology relies on the development of quantum bits, or qubits, that can maintain quantum information for periods of time longer than one second. The coherence time is a function of the system’s quality (Q) factor. HEP Quantum Information Science Enabled Discovery (QuantISED) funded research at FNAL has enabled the transformation of superconducting radiofrequency (SRF) cavities to full quantum regimes of ultralow temperatures and single photon field levels. Drawing on the laboratory’s decades of world-leading expertise in superconducting technology, and exploiting existing infrastructure, FNAL scientists and engineers have designed superconducting resonators that routinely achieve a Q more than 1,000 times better than existing resonators used in quantum computing.

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. Stronger magnets reduce the collider size needed for a given particle energy or enable higher energies within the same sized machine. In 2020, scientists at FNAL announced the achievement of the highest magnetic field strength ever recorded for an accelerator magnet. The world record field strength of 14.5 Tesla was achieved with the advanced superconducting material niobium-tin at a magnet temperature of 1.9 Kelvin (minus 456 degrees Fahrenheit). Efforts are underway to push the performance of the accelerator magnet to even higher fields.

High Energy Physics
Energy Frontier Experimental Physics

Description

The Energy Frontier Experimental Physics subprogram's focus is to support the U.S. researchers participating in the Large Hadron Collider (LHC) program. 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 participating in the LHC program 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 are used to address three of the five science drivers as explained below:

- *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.

Research

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 HEP science drivers. The findings from this review[a], 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 FY 2022.

Facility Operations and Experimental Support

U.S. LHC Detector Operations supports the maintenance of U.S.-supplied detector systems for the ATLAS and CMS detectors in the LHC at CERN, and the U.S.-based computer infrastructure used by U.S. physicists to analyze LHC data, including the 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.

[a] The "HEP Portfolio Review of Operating Experiments" report can be found at: https://science.osti.gov/-/media/hep/hepap/pdf/Reports

Projects

CERN is implementing a major upgrade to the LHC machine to increase the particle collision rate by a factor of at least five 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 collisions will lead to very challenging conditions in which the ATLAS and CMS detectors must operate. As a result, the HL-LHC ATLAS and HL-LHC CMS Detector Upgrades are critical investments to enable the experiments to operate for an additional decade and collect more data by at least a factor of ten.

High Energy Physics
Energy Frontier Experimental Physics

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Energy Frontier Experimental Physics	**$194,150**	**$161,683**	**-$32,467**
Research	$68,000	$71,833	+$3,833
Funding continues to support U.S. leadership roles in all aspects of the ATLAS and CMS experimental programs, completing analysis of the large datasets collected during the previous LHC run that ended in FY 2019, and preparing for the next LHC run, which begins in FY 2022.		The Request will support U.S. scientists leading high profile analysis topics using the large datasets during the next LHC run, which will begin in FY 2022.	Funding will support data analysis activities during the next LHC run that are prioritized through a competitive peer review process and based on highest scientific merit and potential impact. Efforts associated with the HL-LHC ATLAS and HL-LHC CMS Detector upgrade activities will continue.
Facility Operations and Experimental Support	$53,650	$49,850	-$3,800
Funding supports ATLAS and CMS detector maintenance and operations at CERN, and completing the installation and commissioning of U.S.-built detector components for the initial ATLAS and CMS detector upgrades in preparation for the next LHC run.		The Request will support critical ATLAS and CMS detector maintenance activities 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 that will be acquired during the next LHC run starting in FY 2022.	An increase in funding to support additional U.S.-based computing infrastructure will be offset by a decrease in funding due to the completion of the installation and commissioning of U.S.-built detector components for the ATLAS and CMS detector upgrades.
Projects	$72,500	$40,000	-$32,500
Funding continues to support the critical path items in the production of quadrupole magnets and crab cavities for the HL-LHC Accelerator Upgrade, and continues critical path items and procurements for the Detector upgrades.		The Request will support the production of quadrupole magnets and crab cavities for the HL-LHC Accelerator Upgrade, and continue support to critical path items and procurements for the HL-LHC ATLAS and CMS Detector Upgrade Projects.	Support will focus on critical path items to best maintain synchronization with the international LHC and HL-LHC schedules as well as prototyping and fabrication efforts necessary to continue the HL-LHC ATLAS and CMS Detector Upgrade Projects.

Note: Funding for the subprogram above, includes 3.65% of research and development (R&D) funding for the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Programs.

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 are used to address three of the five science drivers as explained below:

- *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. HEP conducted an external peer review of the Intensity Frontier laboratory research groups 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[a] 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 (BRN)[b] workshop to assess the science landscape and new opportunities for dark matter particle searches and identified three priority research directions beyond the current HEP program's sensitivity. The findings from the reviews and BRN workshop, in combination with input on strategic directions from regular, open, community studies, 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 Neutrinos at the Main Injector (NuMI) beam is used by the NuMI Off-Axis ν_e Appearance (NOvA) experiment. The Booster Neutrino Beam is used by the Short-Baseline Neutrino (SBN) program, which includes a near

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[a] The "HEP Portfolio Review of Operating Experiments" report can be found at: https://science.osti.gov/hep/hepap/Reports
[b] The "Basic Research Needs for Dark Matter Small Projects New Initiatives" report can be found at: https://science.osti.gov/hep/Community-Resources/Reports

detector and a far detector 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 facility, using the world's most intense neutrino beam and large, sensitive underground detectors to make transformative discoveries.

The Research activity includes efforts at FNAL and at other international facilities, including experiments in Japan, to search for rare processes to detect physics beyond the reach of the LHC. The 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. The Mu2e experiment will search for extremely rare muon decays that, if detected, will provide clear evidence of new physics. The Tokai-to-Kamioka (T2K) long-baseline neutrino experiment in Japan is complementary to NOvA, and a combined measurement from these two experiments will offer the best available information on neutrino oscillations prior to LBNF/DUNE. At the High Energy Accelerator Research Organization (KEK) in Tsukuba, Japan, the Belle II experiment searches for new physics produced in electron-positron collisions at the SuperKEKB accelerator.

Recent theoretical studies have underscored that current dark matter particle search candidates are special cases of a broader theoretical framework that have many of the same attractive features. Along with technology advancements, this provides strong motivation for new opportunities to search for dark matter in previously unexplored areas. Two R&D efforts, aligned with the Basic Research Needs workshop priority research directions, are carrying out technology and concept studies that have the potential for future small, projects to address these new opportunities.

<u>Facility Operations and Experimental Support</u>
The Intensity Frontier Experimental Physics subprogram supports several distinct facility operations and experimental activities, the largest of which is the Fermilab Accelerator Complex User Facility. This activity includes the operations of all accelerators and beamlines at FNAL, the operation of the detectors that use those accelerators, and the 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 (SDSTA), a quasi-state agency created by the State of South Dakota for the operation of the SURF. Experiments supported by DOE, NSF, and private entities are conducted there, including the Nuclear Physics-supported Majorana Demonstrator and the HEP-supported LZ experiment. 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.

<u>Projects</u>
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.

FNAL will upgrade its dated accelerator control system with a modern system, which is maintainable, sustainable, and capable of utilizing advances in Artificial Intelligence and Machine Learning to create a high-performance accelerator for the future. The Accelerator Controls Operations Research Network (ACORN) MIE upgrade project is critical as the control system of the Fermilab Accelerator Complex initiates particle beam production; controls beam energy and intensity; steers particle beams to their ultimate destination; measures beam parameters; and monitors beam transport through the complex to ensure safe, reliable and effective operations.

High Energy Physics
Intensity Frontier Experimental Physics

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Intensity Frontier Experimental Physics	**$232,867**	**$250,839**	**+$17,972**
Research	$63,082	$65,994	+$2,912
Funding supports world-leading research efforts on short- and long-baseline neutrino experiments, muon and rare physics processes experiments, and technology studies and science planning for Mu2e and LBNF/DUNE. The SBN program will move into initial operations with the far detector installed and commissioned. The funding also supports analyses on physics data sets collected by the neutrino experiments that have completed operations.		The Request will support core research efforts in all phases of experiments. Researchers will continue data collection and analysis on NOvA, Muon g-2, T2K, and Belle II, and begin physics data taking with SBN. Researchers will support pre-operations activities for Mu2e, and continue science planning for LBNF/DUNE. HEP will sponsor modeling and design studies for ultra-efficient muon pre-conceptual modular systems in collaboration with Advanced Research Projects Agency-Energy (ARPA-E) to accelerate research for utilizing muon catalyzed fusion as a new source of carbon-free electricity generation.	Funding increase will support initial data collection and analysis on the SBN program, and a new muon-catalyzed fusion clean-energy effort with ARPA-E. Support for research on lower priority small- to mid-scale neutrino experiments, as determined by the FY 2018 HEPAP portfolio review, will ramp down.
Facility Operations and Experimental Support	$166,785	$176,845	+$10,060
Funding supports the Fermilab Accelerator Complex and the neutrino and muon experiments at 81 percent of optimal operations; modernization efforts to mitigate the risk of slowing down programs and projects; design and planning for the Target Systems Integration Building GPP; and SURF operations and investments to enhance SURF infrastructure.		The Request will support the Fermilab Accelerator Complex and the neutrino and muon experiments at 90 percent of optimal operations; construction of the Target Systems Integration Building GPP; continue modernization efforts; and SURF operations and investments to enhance SURF infrastructure.	Funding increase will support the delivery of particle beams at peak power and provide detector and computing operations for the SBN program. Overall operations of the Fermilab Accelerator Complex will increase from 81 to 90 percent of optimal. Support for GPP funding increases to fund the Target Systems Integration Building construction.

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request		Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Projects	$3,000		$8,000	+$5,000
Funding supports OPC for execution support costs including electrical power at SURF for LBNF/DUNE construction and OPC for the Fermilab Accelerator Controls Operations Research Network (ACORN) MIE to develop a work breakdown structure, hire a project team, and begin preliminary system design.		The Request will continue support of OPC execution support costs at SURF for LBNF/DUNE construction. The Fermilab Accelerator Controls Operations Research Network (ACORN) MIE will continue OPC and begin TEC and will fund system design and other related engineering activities.		Funding will support increased execution support costs at SURF for LBNF/DUNE construction, and increase support for the ACORN MIE and begin TEC funding.

Note: Funding for the subprogram above, includes 3.65% of research and development (R&D) funding for the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Programs.

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, cosmic acceleration in the forms of dark energy and inflation, neutrino properties, and other phenomena. The activities in this subprogram use diverse tools and technologies, from ground-based observatories and space-based missions, to large detectors deep underground to address four of the five science drivers as explained below:

- *Identify the new physics of dark matter*
  Experimental evidence reveals 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 the elusive 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. The cosmic microwave background (CMB), the oldest observable light in the universe, informs researchers about the era of inflation, the rapid expansion in the early universe shortly after the Big Bang. Researchers use measurements of ancient light from the early universe and light from distant galaxies to map the acceleration of the universe over time and to unravel the nature of dark energy and inflation.
- *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 scheduled for FY 2021. In FY 2018, HEPAP evaluated the currently operating portfolio of experiments in the Cosmic Frontier[a] 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 (BRN)[b] workshop to assess the science landscape and new opportunities for dark matter particle searches made possible by recent technology and theoretical advancements and identified three priority research directions beyond the current HEP program's sensitivity. The findings from the reviews and BRN workshop, in combination with input on strategic directions from regular, open community studies, inform funding decisions in subsequent years.

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[a] The "HEP Portfolio Review of Operating Experiments" report can be found at: https://science.osti.gov/-/media/hep/hepap/pdf/Reports

[b] The "Basic Research Needs for Dark Matter Small Projects New Initiatives" report can be found at: https://science.osti.gov/hep/Community-Resources/Reports

Two complementary next-generation, dark energy “Stage 4” experiments will provide increased precision in measuring the history of the expansion of the universe. The Vera C. Rubin Observatory will carry out a 10-year wide-field, ground-based optical and near-infrared imaging Legacy Survey of Space and Time (LSST) that will be used by the Dark Energy Science Collaboration (DESC). The Dark Energy Spectrographic Instrument (DESI) collaboration 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. Together the data sets will enable studies on whether acceleration of the expansion of the universe is due to an unknown force, a cosmological constant, or if Einstein’s General Theory of Relativity breaks down at large distances.

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. CMB-S4 will enable researchers to peer directly into the inflationary era in the early moments of the universe, at a time scale unreachable by other types of experiments. CMB-S4 and the dark energy experiments will also provide information on neutrino properties and searches for relic particles from the early universe.

Two complementary next-generation, dark matter particle 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 candidate, the axion. Recent theoretical studies have underscored that current dark matter particle search candidates are special cases of a broader theoretical framework that have many of the same attractive features. Along with technology advancements, this provides strong motivation for new opportunities to search for dark matter in previously unexplored areas. R&D efforts, aligned with the BRN workshop priority research directions, are conducting technology and concept studies that have the potential for future, small projects to address these new opportunities.

<u>Facility Operations and Experimental Support</u>
This activity supports the DOE share of expenses necessary to carry out the successful operating phase of Cosmic Frontier experiments, including instrumentation maintenance, data collection, and data processing and serving. These experiments are typically not sited at national laboratories, but at ground-based observatories and facilities, in space, or deep underground. Support is provided for the experiments currently operating and for pre-operations activities for the next-generation experiments in the design or fabrication phase. HEP conducts planning reviews to ensure readiness as each experiment transitions from project fabrication to science operations, and periodic reviews during the operations phase.

The DESI instrumentation is mounted and operating on the NSF’s Mayall Telescope at Kitt Peak National Observatory with both the instrumentation and telescope operations supported by DOE. The Vera C. Rubin Observatory, which includes the DOE-provided 3-billion pixel camera, is being commissioned in Chile. DOE and NSF are full partners in the Vera C. Rubin Observatory operations with planning and pre-operations activities in process. SLAC manages the Observatory’s U.S. Data Facility as part of DOE’s responsibilities during the operations phase. The DESC continues its pre-operations activities to prepare for the initiation of the 10-year LSST survey.

The LZ dark matter detector is operating underground in the Sanford Underground Research Facility (SURF) in Lead, South Dakota, and the SuperCDMS-SNOLAB dark matter detector, to be located at the Sudbury Neutrino Observatory in Sudbury, Canada, is carrying out planning and pre-operations activities. The ADMX-G2 experiment continues operations at the University of Washington to carry out its ultra-sensitive searches for axion dark matter particles.

<u>Projects</u>
The next-generation CMB-S4 experiment is a planned partnership with NSF with the distribution of scope determined in FY 2022. The project will consist of an array of small and large telescopes working in concert at two locations: the NSF Amundsen-Scott South Pole Station and the Atacama high desert in Chile. The focal planes will include 500,000 ultra-sensitive sensors and associated readout systems. Lawrence Berkeley National Laboratory (LBNL) was selected in August 2020 to lead the efforts in providing the DOE scope for the project.

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request		Explanation of Changes FY 2022 Request vs FY 2021 Enacted	
Cosmic Frontier Experimental Physics	**$97,591**		**$96,512**		**-$1,079**
Research	$47,091		$49,012		+$1,921
Funding supports core research efforts in all phases of experiments. ADMX-G2 collaboration is completing the primary data analyses on Run 1C. Researchers are participating in data collection for LZ and DESI. Researchers are participating in commissioning and pre-operations planning for SuperCDMS-SNOLAB and the Vera C. Rubin Observatory, with the associated DESC planning for the subsequent LSST. Research efforts on CMB-S4 and planning for future Dark Matter and Dark Energy opportunities are increasing.		The Request will support core research efforts in all phases of experiments. Researchers will continue data collection and analysis for ADMX-G2 Run2, LZ, and DESI, and data planning and for SuperCDMS-SNOLAB. Researchers will continue supporting commissioning and pre-operations activities of Vera C. Rubin Observatory and the DESC will continue planning for the subsequent LSST. Research efforts on CMB-S4 will support the preliminary design along with data simulations and analysis planning.		Funding increase will support data collection and analysis on new experiments, research efforts on CMB-S4 project, and scientific planning for future experiments in the Cosmic Frontier. Research on completed and lower priority experiments will ramp down.	
Facility Operations and Experimental Support	$44,500		$42,500		-$2,000
Funding supports continued science operations on DESI, LZ, and ADMX-G2 run 1C and 1D, and commissioning and pre-operations efforts on the Vera C. Rubin Observatory and SuperCDMS-SNOLAB.		The Request will support continued operations, with DESI and LZ moving into their second year of data-taking, and ADMX completing Run 1C, starting Run 1D, and preparing for Run 2A. The Vera C. Rubin Observatory and SuperCDMS-SNOLAB continue commissioning and pre-operations efforts.		The net decrease in funding includes an increase to support commissioning and pre-operations activities of Vera C. Rubin Observatory and the DESC, offset by a decrease due to the completed commissioning of SuperCDMS-SNOLAB, and the planned conclusion of operations for other Cosmic Frontier experiments.	

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request		Explanation of Changes FY 2022 Request vs FY 2021 Enacted	
Projects	$6,000		$5,000		-$1,000
CMB-S4 OPC funding supports continuing project development, R&D and conceptual design leading to planning for CD-1. TEC Funding supports a new MIE start for CMB-S4 when it moves forward with preliminary project engineering design.		The Request will support completion of the CMB-S4 conceptual design OPC activities for CD-1, as well as TEC-design activities and long lead procurements for sensors and cryostats		Support will prioritize project engineering design activities for CMB-S4.	

Note: Funding for the subprogram above, includes 3.65% of research and development (R&D) funding for the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Programs.

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 studies as well as a planned, future Basic Research Needs workshop, will inform funding decisions in subsequent years.

The HEP theory activity supports an integrated computational and data infrastructure initiative to create more seamless use of clouds, with SC computing, community software, and storage resources for experimental and observational data analysis, and enable new scientific workflows for scientific discovery. HEP's strategic focus is in the development of data storage capabilities to manage petabytes of data from future experiments; cross-cutting efforts in AI/ML and edge computing to seek solutions for real-time and ultra-high data rates towards terabits per second; and investments in software development to improve the interface with SC infrastructure and ASCR-supported middleware.

The HEP theory activity will support the Reaching a New Energy Sciences Workforce (RENEW) initiative to provide undergraduate and graduate training opportunities for students and academic institutions not currently well represented in the U.S. S&T ecosystem.

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. The multi-laboratory HEP Center for Computational Excellence (CCE) is supported to advance HEP computing by exploiting the latest architectures in current and future high performance computing platforms and exascale systems. Computational HEP partners with ASCR, including via the Scientific Discovery through Advanced Computing (SciDAC) activity, to optimize the HEP computing ecosystem for the near and long term future. The re-competition of HEP-ASCR SciDAC partnerships is planned for FY 2022.

Quantum Information Science

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 computing for foundational theory as well as for HEP experiments, development of precision quantum sensors and QIS based experiments that may yield information on fundamental physics beyond the Standard Model, and applications of HEP research to advance QIS including specialized quantum controls and communication protocols. QIS Research 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 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 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Theoretical, Computational, and Interdisciplinary Physics	**$136,362**	**$157,422**	**+$21,060**
Research	$136,362	$157,422	+$21,060
Theory	*$46,284*	*$55,050*	*+$8,766*
Funding supports 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 innovative ideas to advance the theoretical understanding of nature.		The Request will continue support for world-leading theoretical particle physics research and will support the new integrated computational and data infrastructure initiative. The Request will also support the Reaching a New Energy Sciences Workforce (RENEW) initiative to provide undergraduate and graduate training opportunities for students and academic institutions not currently well represented in the U.S. S&T ecosystem.	Funding increases to support the new integrated computational and data infrastructure initiative, the RENEW initiative and the highest-impact theoretical research as determined by competitive peer review.
Computational HEP	*$11,518*	*$15,000*	*+$3,482*
Funding supports 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 portable parallelization techniques, storage solutions, and complex workflows and optimizing use of exascale architectures.		The Request will support the multi-laboratory HEP Computational Center for Excellence (CCE) to develop portable parallelization solutions, data transfer and storage challenges, and event generation and complex workflows. The HEP-ASCR SciDAC partnerships will re-compete. The Request will support a new Traineeship Program in High Performance Scientific Computing to address critical HEP workforce needs.	Funding increase will support the HEP CCE and the new Traineeship Program.

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Quantum Information Science	*$45,072*	*$51,566*	*+$6,494*
Funding supports interdisciplinary HEP-QIS consortia and lab programs for focused research on foundational research at the intersection of HEP and QIS, including novel experiments, quantum computing, communications, sensors, and research technology. Funding also continues and enhances support for QIS Research Centers in partnership with other SC program offices.		The Request will support and enhance interdisciplinary HEP-QIS consortia and lab programs for focused research on foundational research at the intersection of HEP and QIS, including novel experiments, quantum computing, communications, sensors, and research technology. The Request will continue support for QIS Research Centers in partnership with other SC program offices.	Funding will support increases in quantum simulation, physics beyond the Standard Model experiments using HEP and QIS expertise and techniques, and lab research technology including quantum networks and communications testbeds.
Artificial Intelligence and Machine Learning	*$33,488*	*$35,806*	*+$2,318*
Funding supports 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.		The Request will continue to support AI/ML research and development to improve physics measurements and searches, and build an AI/ML community around cross-cutting challenges to fulfill the HEP mission. A new Funding Opportunity for specific AI/ML applications in HEP is planned.	Funding will support increases in innovation and new opportunities in building algorithms that learn about complex data to solve big-data computing hardware and infrastructure challenges; embedding AI into sensors and experimental design in extreme environments; and developing operations and controls AI/ML techniques.

Note: Funding for the subprogram above, includes 3.65% of research and development (R&D) funding for the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Programs.

High Energy Physics
Advanced Technology R&D

Description

The Advanced Technology Research and Development (R&D) subprogram fosters cutting-edge research in the physics of particle beams, accelerator R&D, and R&D for particle and radiation 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, which will reside in the Accelerator R&D and Production program beginning in FY 2022.

<u>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 thrust 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 studies as well as future Basic Research Needs workshops, will inform funding decisions in subsequent years. The 2016 U.S. Magnet Development Program Plan[a], a strategic plan with research roadmap for the GARD superconducting magnet and materials thrust, was refreshed in FY 2020. An HEP program review and collaboration workshop was held to assess progress in the program and to update the research roadmap[b] for this GARD thrust.

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. In coordination with the Office of Accelerator R&D and Production, the SC Accelerator Science and Technology Initiative (ASTI) 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. As a part of ASTI, ASCR, BES, FES, HEP, and NP will enhance coordination and jointly pursue accelerator R&D topics that will have a strong impact on the scientific capabilities of SC facilities.

The GARD activity supports the successful U.S. Particle Accelerator School (USPAS). HEP conducted a review of the USPAS Program in late FY 2020. The USPAS had to postpone its Summer 2020 session due to COVID-19. The Winter 2021 session was successfully accomplished via online instructions. GARD 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 and radiation 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.

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[a] https://www2.lbl.gov/LBL-Programs/atap/MagnetDevelopmentProgramPlan.pdf
[b] https://science.osti.gov/-/media/hep/pdf/Reports/2020/USMDP-2020-Plan-Update-web.pdf

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 2022. 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[a], in combination with input on strategic directions from regular, open community workshops will inform funding decisions in subsequent years.

The Detector R&D activity supports the Traineeship Program for HEP Instrumentation to address critical, targeted workforce development in fields of interest to the DOE mission. The 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 revitalize education, training, and innovation in the physics of particle detectors and next generation instrumentation for the benefit of HEP and other SC and DOE programs that rely on these enabling technologies. 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. Five SC programs—ASCR, BES, FES, HEP, and NP—will work together to advance microelectronics technologies. This activity is intentionally focused on establishing the foundational knowledge base for future microelectronics technologies for sensing, communication, and computing 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 Lawrence Berkeley National Laboratory (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 also 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.

[a] https://science.osti.gov/-/media/hep/pdf/Reports/2020/DOE_Basic_Research_Needs_Study_on_High_Energy_Physics.pdf

High Energy Physics
Advanced Technology R&D

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Advanced Technology R&D	**$116,095**	**$115,544**	**-$551**
Research	$72,833	$75,344	+$2,511
General Accelerator R&D	*$49,574*	*$51,814*	*+$2,240*
Funding supports 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. This activity is augmented by new funding for the Accelerator Science and Technology Initiative (ASTI) to support critical capabilities and maintain U.S. competitiveness. Funding also supports the Traineeship Program for Accelerator Science and Technology.		The Request will continue to support world-leading, innovative advanced accelerator R&D, provide increased support for ASTI, and continue support for the Traineeship Program for Accelerator Science and Technology.	Funding will support capitalization on the science opportunities at the newly completed FACET-II facility and the second beamline at BELLA; increases to ASTI efforts in superconducting magnet development and upgrades to SRF facilities; and co-fund a multi-SC program R&D initiative in superconducting materials.
Detector R&D	*$23,259*	*$23,530*	*+$271*
Funding supports 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 workshop on HEP Detector R&D. HEP collaborates with ASCR, BES, FES, and NP to advance microelectronics technologies. The Traineeship Program for HEP Instrumentation has been initiated.		The Request will continue to support world-leading, innovative Detector R&D, provide increased support to advance microelectronics technologies, and continue support for the Traineeship Program in HEP Instrumentation.	Funding will increase support toward the microelectronics activities, while ongoing Detector R&D support will prioritize collaborative opportunities at universities and national laboratories that enable 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 workshop.

(dollars in thousands)

FY 2021 Enacted	FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Facility Operations and Experimental Support $43,262	$40,200	-$3,062
Funding supports the operation of accelerator, test beam, and detector facilities at FNAL, LBNL, and SLAC, and improvements to superconducting radio-frequency and magnet test facilities. Funding also supports 3,720 hours (100 percent of optimal) facility operations for FACET-II.	The Request will support the operation of accelerator, test beam, and detector facilities at ANL, FNAL, LBNL, and SLAC, and improvements to superconducting radio-frequency and magnet test facilities. The Request will provide support for 2,700 hours (90 percent of optimal) of facility operations for FACET-II. Due to the COVID-19 pandemic, the FACET-II experiments will start at least six months later than planned.	Funding will support beam time for experiments but not all capability improvements to the facilities at ANL, FNAL, LBNL, and SLAC. Priority will be guided by recent comparative reviews of the laboratory programs.

Note: Funding for the subprogram above, includes 3.65% of research and development (R&D) funding for the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Programs.

High Energy Physics
HEP Accelerator Stewardship

Description

In FY 2020, the Office of Science (SC) initiated a reorganization, creating a new Office of Accelerator R&D and Production (ARDAP) that facilitates coordination of accelerator R&D needed for all Office of Science research programs and matures accelerator technologies needed for future SC facilities and by other agencies of the U.S. government. As part of this reorganization, the Accelerator Stewardship subprogram moved to ARDAP and continues to provide support in 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 deploy accelerator technology for medical, industrial, environmental cleanup, security, and defense applications; and driving a limited number of specific accelerator applications towards practical, testable prototypes in a five to seven year timeframe. The budget request and further details concerning the Accelerator Stewardship subprogram may be found in the ARDAP program budget narrative.

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request		Explanation of Changes FY 2022 Request vs FY 2021 Enacted
HEP Accelerator Stewardship	**$16,935**		**$ —**	**-$16,935**
Research	$10,835		$ —	-$10,835
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.		N/A		Funding for FY 2022 is requested in the Accelerator R&D and Production program.
Facility Operations and Experimental Support	$6,100		$ —	-$6,100
Funding supports operation of the BNL ATF at 100 percent of optimal levels.		N/A		Funding for FY 2022 is requested in the Accelerator R&D and Production program.

Note: Funding for the subprogram above, includes 3.65% of research and development (R&D) funding for the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Programs.

High Energy Physics
Construction

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

18-SC-42, Proton Improvement Plan II (PIP-II), FNAL
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 megaelectronvolt (MeV) superconducting radio-frequency (SRF) proton linear accelerator and beam transfer line. The PIP-II project also will modify the existing FNAL Booster, Recycler, and Main Injector synchrotrons downstream from the new linear accelerator to accept the increased beam intensity. Some of the new components and the cryoplant will be provided through international, in-kind contributions.

The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-3A (Approve Long-lead Procurement), approved March 16, 2021; it followed three months after CD-2 (Approve Performance Baseline), approved on December 14, 2020, with a Total Project Cost (TPC) of $978,000,000. The funding profile supports the approved TPC of $978,000,000. The CD-4 milestone date is 1Q FY 2033.

The PIP-II project is inclusive of a subproject, Early Conventional Facilities (ECF) for PIP-II, that received Critical Decision CD-2/3 (Approval of Subproject Baseline and Start of Construction) on July 17, 2020. The TPC for the ECF subproject is $36,000,000 which will be funded out of the same line-item appropriation as the PIP-II project.

11-SC-40, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment, FNAL
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 from FNAL, where they are produced in a high-energy proton beam, to a large detector in South Dakota, 800 miles away from FNAL. 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 and 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 over 1,100 scientists and engineers from over 200 institutions in over 30 countries. DOE will fund less than one-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. Scope reductions are being considered to refine the scope by FY 2022 for the baseline.

11-SC-41, Muon to Electron Conversion Experiment, FNAL
Mu2e, under construction at FNAL, will search for evidence that a muon can undergo direct (neutrinoless) conversion into an electron, a process that would violate lepton flavor conservation and probe new physics at energy scales beyond the collision energy of the Large Hadron Collider. If observed, this major discovery would signal the existence of new particles or new forces beyond the Standard Model. The Mu2e project completed its technical design phase (CD-3) on July 14, 2016 and moved into full construction at that time. Civil construction of the underground detector housing and the surface building for the experiment were completed in 2017.

The most recent approved DOE Order 413.3B Critical Decision is CD-3, Approve Start of Construction approved on July 14, 2016. The funding profile through FY 2019 supported the current TPC of $273,677,000 and the currently approved CD-4 milestone date of 1Q FY 2023.

However, it became apparent the approved baseline schedule could no longer be met as a result of the COVID-19 pandemic that resulted in unplanned work shutdowns and inefficiencies at the participating universities and laboratories in FY 2020, and because of delayed delivery of two superconducting magnets resulting from poor schedule and technical performance by the vendor. A baseline change was recommended by an Independent Project Review in February 2021; the Baseline Change Proposal (BCP) is in process but not yet submitted, reviewed, or approved. In anticipation of approval of the BCP, $2,000,000 of TEC funding was appropriated in FY 2021 and $13,000,000 of TEC funding is requested in FY 2022. None of these additional funds will be available to spend until the BCP approval and the project is re-baselined.

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted	FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Construction **$252,000**	**$279,000**	**+$27,000**
18-SC-42, Proton Improvement Plan II (PIP-II), FNAL $79,000	$90,000	+$11,000
Funding supports completion of civil engineering design for the conventional facilities, technical design and prototyping for the accelerator components, and initiation of Early Conventional Facilities (ECF) subproject construction, as well as long-lead procurement and procurement for technical systems when design is final and construction is authorized by CD-3.	The Request will support completion of procurement for the Early Conventional Facilities (ECF) subproject and initiation of civil engineering design for the rest of the linear accelerator facilities, as well as technical design and prototyping for the accelerator components and initiation of procurement and construction for technical systems when design is final and construction is authorized by CD-3.	Funding increase will support the completion of the design phase of PIP-II, the Early Conventional Facilities subproject for the cryogenic plant, and fabrication of prototypes for the linear accelerator. The construction phase will fully begin with CD-3 in FY 2022.
11-SC-40, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment, FNAL $171,000	$176,000	+$5,000
Funding supports 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. Funding also supports 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. Funding 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.	The Request will support continuation of the Far Site civil construction activities, as well as continuing design and procurement activities for Far Site cryogenics systems. The Request will also support procurement activities for the Near Site (FNAL) beamline and conventional facilities. The Request will support the continuation of construction and fabrication for technical systems, including contributions to the DUNE detectors, when design is final and construction is authorized by CD-3.	Funding will support continuation for excavation at the Far Site and the ramp-up of design effort on the Near Site facilities and the detectors.

(dollars in thousands)

FY 2021 Enacted	FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
11-SC-41, Muon to Electron Conversion Experiment, FNAL $2,000	$13,000	+$11,000
Funding will support initial mitigation of increased costs due to schedule delays caused by pandemic response at FNAL and collaborating universities. These funds were not part of the originally approved project baseline, although a BCP is in process.	The Request will support continuing mitigation of increased costs due to schedule delays caused by pandemic response at FNAL and collaborating universities, and by delayed delivery of two superconducting magnets due to vendor's poor technical and schedule performance. These funds were not part of the originally approved project baseline, although a BCP is in process.	Funding will support increased costs from COVID-19 impacts and vendor performance.

High Energy Physics
Capital Summary

	Total	Prior Years	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
	(dollars in thousands)					
Capital Operating Expenses						
Capital Equipment	N/A	N/A	105,350	91,830	52,180	-39,650
Minor Construction Activities						
General Plant Projects	N/A	N/A	10,900	1,500	14,000	+12,500
Total, Capital Operating Expenses	**N/A**	**N/A**	**116,250**	**93,330**	**66,180**	**-27,150**

Capital Equipment

	(dollars in thousands)					
	Total	Prior Years	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Capital Equipment						
Major Items of Equipment						
Energy Frontier Experimental Physics						
High Luminosity Large Hadron Collider Accelerator Upgrade Project	236,672	71,572	52,025	43,000	20,000	-23,000
High Luminosity Large Hadron Collider ATLAS Upgrade Project	136,000	27,500	24,500	16,000	10,000	-6,000
High Luminosity Large Hadron Collider CMS Upgrade Project	121,800	13,750	23,475	13,500	10,000	-3,500
Intensity Frontier Experimental Physics						
Accelerator Controls Operations Research Network	136,900	–	–	–	2,000	+2,000
Cosmic Frontier Experimental Physics						
Cosmic Microwave Background - Stage 4	375,600	–	–	1,000	2,000	+1,000
Total, MIEs	N/A	N/A	100,000	73,500	44,000	-29,500
Total, Non-MIE Capital Equipment	N/A	N/A	5,350	18,330	8,180	-10,150
Total, Capital Equipment	**N/A**	**N/A**	**105,350**	**91,830**	**52,180**	**-39,650**

Note: The Capital Equipment table includes MIEs located at a DOE facility with a Total Estimated Cost (TEC) > $5M and MIEs not located at a DOE facility with a TEC >$2M.

Minor Construction Activities

(dollars in thousands)

	Total	Prior Years	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
General Plant Projects (GPP)						
GPPs (greater than or equal to $5M and less than $20M)						
Kautz Road Sub-Station	7,500	–	7,500	–	–	–
Target Systems Integration Building	15,500	–	–	1,500	14,000	+12,500
Total GPPs (greater than or equal to $5M and less than $20M)	N/A	N/A	7,500	1,500	14,000	+12,500
Total GPPs less than $5M	N/A	N/A	3,400	–	–	–
Total, General Plant Projects (GPP)	**N/A**	**N/A**	**10,900**	**1,500**	**14,000**	**+12,500**
Total, Minor Construction Activities	**N/A**	**N/A**	**10,900**	**1,500**	**14,000**	**+12,500**

Note: GPP activities less than $5M include design and construction for additions and/or improvements to land, buildings, replacements or addition to roads, and general area improvements. 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 HL-LHC Accelerator Upgrade Project received CD-2/3b approval on February 11, 2019, with a TPC of $242,720,000. CD-3 was approved on December 21, 2020 to complete the production of the remaining accelerator components for the upgrade. Following the major upgrade, the CERN LHC machine will further increase the particle collision rate by at least a factor of five 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 radiofrequency 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 2022 Request for TEC funding of $20,000,000 will continue to 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 HL-LHC ATLAS project 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 2022. The ATLAS detector will integrate a higher amount of data per run by at least a factor of ten 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) approved support for a Major Research Equipment and Facility Construction (MREFC) project in FY 2020 to provide different scope to the HL-LHC ATLAS detector upgrade. DOE and NSF are coordinating their contributions to avoid duplication. The FY 2022 Request for TEC funding of $10,000,000 will focus support on critical path items to best maintain international schedule synchronization for the project.

High-Luminosity Large Hadron Collider CMS Detector Upgrade Project (HL-LHC CMS)

The HL-LHC CMS project received CD-1 approval on December 19, 2019, with an estimated cost range of $144,100,000 to $183,000,000, and received CD-3a approval on June 8, 2020. CD-2 is planned for FY 2022. The CMS detector will integrate a higher amount of data per run by at least a factor of ten 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 approved support for a MREFC Project in FY 2020 to provide different scope to the HL-LHC CMS detector upgrade. DOE and NSF are coordinating their contributions to avoid duplication. The FY 2022 Request for TEC funding of $10,000,000 will focus support on critical path items to best maintain international schedule synchronization for the project.

Intensity Frontier Experimental Physics MIE:

Accelerator Controls Operations Research Network (ACORN)

The ACORN project received CD-0 approval on August 28, 2020, with an estimated cost range of $100,000,000 to $142,000,000. This project will replace FNAL's dated accelerator control system with a modern system which is maintainable, sustainable, and capable of utilizing advances in Artificial Intelligence and Machine Learning to create a high-performance accelerator for the future. The control system of the Fermilab Accelerator Complex initiates particle beam production; controls beam energy and intensity; steers particle beams to their ultimate destination; measures beam parameters; and monitors beam transport through the complex to ensure safe, reliable, and effective operations. ACORN will provide FNAL with an accelerator control system that will be compatible with PIP-II. FNAL plans to collaborate with other national labs that have experience with accelerator control systems. This project is expected to receive CD-1 approval in Q4 FY 2021 and CD-2 approval in FY 2022. The FY 2022 Request for TEC funding of $2,000,000 will initiate a new start for MIE and will fund system design and other related engineering activities.

Cosmic Frontier Experimental Physics MIE:

Cosmic Microwave Background Stage 4 (CMB-S4)

The 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 2022. 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 a focal plane of 500,000 ultra-sensitive sensors with associated readout systems. LBNL was selected in August 2020 to lead the efforts in providing the DOE scope for the project. The project is expected to obtain CD-1 approval in FY 2022, along with CD-3a approval of long lead procurements at the same time. In FY 2022, 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 2022 Request for TEC funding of $2,000,000 will enable long lead procurement for sensor production and testing, as well as associated systems and infrastructure.

High Energy Physics
Minor Construction Description(s)

General Plant Projects $5 Million to less than $20 Million

Target Systems Integration Building
General Plant Project Details

Project Name:	Target Systems Integration Building
Location/Site:	Fermilab Accelerator Complex
Type:	GPP
Total Estimated Cost:	$15,500,000
Construction Design:	$1,500,000
Project Description:	The proposed building will provide facilities to produce and integrate hardware for the future activities of LBNF, and High Power Targetry R&D, as well as continuing target facilities (NuMI, BNB, g-2 Target Station, and Mu2e). Existing activities occur at the Main Injector (MI)-8 building, so the new building will expand off of MI-8. The present building has inadequate crane capacity and floor space for future activities.

High Energy Physics
Construction Projects Summary

(dollars in thousands)

	Total	Prior Years	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
18-SC-42, Proton Improvement Plan II, FNAL						
Total Estimated Cost (TEC)	891,200	21,000	60,000	79,000	90,000	+11,000
Other Project Cost (OPC)	86,800	73,100	494	–	–	–
Total Project Cost (TPC)	**978,000**	**94,100**	**60,494**	**79,000**	**90,000**	**+11,000**
11-SC-40, Long Baseline Neutrino Facility / Deep Underground Neutrino Experiment						
Total Estimated Cost (TEC)	2,390,000	336,781	171,000	171,000	176,000	+5,000
Other Project Cost (OPC)	210,000	87,625	4,000	2,000	4,000	+2,000
Total Project Cost (TPC)	**2,600,000**	**424,406**	**175,000**	**173,000**	**180,000**	**+7,000**
11-SC-41, Muon to Electron Conversion Experiment						
Total Estimated Cost (TEC)	265,000	250,000	–	2,000	13,000	+11,000
Other Project Cost (OPC)	23,677	23,677	–	–	–	–
Total Project Cost (TPC)	**288,677**	**273,677**	**–**	**2,000**	**13,000**	**+11,000**
Total, Construction						
Total Estimated Cost (TEC)	**N/A**	**N/A**	**231,000**	**252,000**	**279,000**	**+27,000**
Other Project Cost (OPC)	**N/A**	**N/A**	**4,494**	**2,000**	**4,000**	**+2,000**
Total Project Cost (TPC)	**N/A**	**N/A**	**235,494**	**254,000**	**283,000**	**+29,000**

Note for Mu2e: In anticipation of approval of the Baseline Change Proposal (BCP), $2,000,000 of TEC funding was appropriated in FY 2021 and $13,000,000 of TEC funding is requested in FY 2022. These additional funds cannot be spent until the BCP approval and the project is re-baselined.

High Energy Physics
Funding Summary

(dollars in thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Research	390,077	398,203	419,605	+21,402
Facility Operations	316,429	314,297	309,395	-4,902
Projects				
Line Item Construction (LIC)	235,494	254,000	283,000	+29,000
Major Items of Equipment (MIE)	103,000	79,500	49,000	-30,500
Total, Projects	**338,494**	**333,500**	**332,000**	**-1,500**
Total, High Energy Physics	**1,045,000**	**1,046,000**	**1,061,000**	**+15,000**

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.

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 2020 Enacted	FY 2020 Current	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Scientific User Facilities - Type A					
Fermilab Accelerator Complex	**141,520**	**142,755**	**130,900**	**143,000**	**+12,100**
Number of Users	2,450	2,014	2,050	2,340	+290
Achieved Operating Hours	–	2,604	–	–	–
Planned Operating Hours	4,900	4,340	3,640	5,180	+1,540
Optimal Hours	5,740	5,740	4,480	5,740	+1,260
Percent of Optimal Hours	85.4%	45.4%	81.3%	90.2%	+8.9%
Unscheduled Down Time Hours	–	1,736	–	–	–

(dollars in thousands)

	FY 2020 Enacted	FY 2020 Current	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Accelerator Test Facility	**6,067**	**5,310**	**6,100**	**–**	**-6,100**
Number of Users	127	106	105	–	-105
Achieved Operating Hours	–	2,341	–	–	–
Planned Operating Hours	2,500	2,500	2,250	–	-2,250
Optimal Hours	2,500	2,500	2,500	–	-2,500
Percent of Optimal Hours	100.0%	93.6%	90.0%	–	-90.0%
Unscheduled Down Time Hours	–	165	–	–	–
Facility for Advanced Accelerator Experimental Tests II (FACET II)	**6,000**	**6,000**	**16,000**	**13,000**	**-3,000**
Number of Users	200	94	250	225	-25
Planned Operating Hours	1,500	1,500	3,720	2,700	-1,020
Optimal Hours	3,000	3,000	3,720	3,000	-720
Percent of Optimal Hours	50.0%	–	100.0%	90.0%	-10.0%
Total, Facilities	**153,587**	**154,065**	**153,000**	**156,000**	**+3,000**
Number of Users	2,777	2,214	2,405	2,565	+160
Achieved Operating Hours	–	4,945	–	–	–
Planned Operating Hours	8,900	8,340	9,610	7,880	-1,730
Optimal Hours	11,240	11,240	10,700	8,740	-1,960
Unscheduled Down Time Hours	–	1,901	–	–	–

Note: Achieved Operating Hours and Unscheduled Downtime Hours will only be reflected in the Congressional budget cycle which provides actuals.
Note: Funding for the Accelerator Test Facility is funded in the Accelerator R&D and Production program in FY 2022.

High Energy Physics
Scientific Employment

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Number of Permanent Ph.Ds (FTEs)	788	780	791	+11
Number of Postdoctoral Associates (FTEs)	361	370	374	+4
Number of Graduate Students (FTEs)	486	485	486	+1
Number of Other Scientific Employment (FTEs)	1,625	1,585	1,632	+47

Note: Other Scientific Employment (FTEs) includes technicians, engineers, computer professionals and other support staff.

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

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

Summary

The FY 2022 Request for the Proton Improvement Project II (PIP-II) is $90,000,000 of Total Estimated Cost (TEC) funding. The project has an approved Total Project Cost (TPC) of $978,000,000.

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 megaelectronvolt (MeV) superconducting radio frequency (SRF) proton linear accelerator and beam transfer line. The PIP-II project also will modify the existing Fermi National Accelerator Laboratory (FNAL) Booster, Recycler, and Main Injector synchrotrons downstream from the new linear accelerator to accept the increased beam intensity. Some of the new components and the cryoplant will be provided through international, in-kind contributions.

Significant Changes

This project was initiated in FY 2018. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-3A (Approve Long-lead Procurement), approved March 16, 2021; it followed three months after CD-2 (Approve Performance Baseline), approved on December 14, 2020, with a Total Project Cost (TPC) of $978,000,000. The PIP-II project was restructured in FY 2020 with a subproject, "Early Conventional Facilities (ECF)," that received Critical Decision CD-2/3 (Approve Subproject Performance Baseline and Start of Construction) on July 17, 2020. The ECF subproject is a subsidiary subset of the PIP-II project, with TPC of $36,000,000. ECF will be funded out of the same line-item appropriation as the PIP-II project. All financial information for PIP-II is inclusive of ECF. Approve Start of Construction, CD-3, is anticipated in late FY 2021, and the preliminary date for CD-4, Project Completion, is FY 2033.

Continued design and development work in FY 2020 improved the maturity of the civil engineering and technical system designs, cost estimates, risk assessment and contingency plans, as well as the planning of technical prototypes for risk mitigation of the project. Outcomes included net reduction of the estimated cost for the civil construction and net increase of the estimated cost for the technical equipment. Assumptions were refined for the level of in-kind contributions from the international partner laboratories; and the project team now includes a new international partner, Poland's Wroclaw University of Science and Technology (WUST). Estimates were updated for indirect costs and for schedule impacts to date due to the COVID-19 pandemic.

Due to the reassessment of delivery schedules for international in-kind contributions, the planned CD-4 critical milestone date is delayed by three years to FY 2033. The planned CD-3 milestone date for starting construction has not changed because of the intentional strategy of prioritizing civil construction ahead of design completion for the accelerator's technical systems. Design of the technical components will be completed when needed for fabrication.

FY 2021 funds support initiation of construction for the cryogenic plant building and, to the extent possible, civil engineering and site work for the other PIP-II conventional facilities as well as technical design, prototyping and initiation of procurement for PIP-II technical systems when designs are final and construction is authorized by CD-3.

The FY 2022 Request will support completion of construction for the cryogenic plant building and continuation of civil engineering and site work for the other PIP-II conventional facilities as well as continue technical design, prototyping and procurement for PIP-II technical systems when designs. The Office of Science is evaluating cost and schedule impacts due to the COVID-19 pandemic.

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	CD-4
FY 2020	11/12/15	7/23/18	7/23/18	3Q FY 2020	4Q FY 2021	4Q FY 2021	1Q FY 2030
FY 2021	11/12/15	7/23/18	7/23/18	3Q FY 2020	4Q FY 2025	4Q FY 2021	1Q FY 2030
FY 2022	11/12/15	7/23/18	7/23/18	12/14/20	4Q FY 2022	4Q FY 2022	1Q 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-3A
FY 2020	2Q FY 2020	3Q FY 2020
FY 2021	2Q FY 2020	3Q FY 2020
FY 2022	12/14/20	3/16/21

CD-3A – Approve long-lead procurement of niobium for superconducting radio frequency (SRF) cavities and other long lead components for SRF cryomodules

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	184,000	617,200	801,200	86,800	N/A	86,800	888,000
FY 2022	177,000	714,200	891,200	86,800	N/A	86,800	978,000

2. Project Scope and Justification

Scope

Specific scope elements of the PIP-II project include construction of (a) the superconducting radio frequency (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 (normal-conducting) front-end injector and five types of SRF cryomodules that are continuous wave 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 one 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.[a]

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 the possibility of a future extension of the linac for beam energy up to 1 GeV. A portion of the civil construction scope comprises the ECF subproject. That subproject scope includes the cryogenics plant building and site work. ECF subproject total estimated cost is $36,000,000; $8,000,000 in FY 2020, $22,000,000 in FY 2021 and $6,000,000 in FY 2022. (See footnotes in the Financial Schedule, Section 3 below.) If the ECF subproject completes less than budget, DOE may authorize redistribution of those funds to remaining PIP-II project scope.

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, UK Science & Technology Facilities Council (STFC) Labs, and Poland Wroclaw University of Science and Technology, 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 and Distribution System
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, Poland WUST
SSR1 Cryomodule	2	325	16	U.S. DOE (FNAL), India DAE Labs	U.S. DOE (FNAL)	India DAE Labs	India DAE Labs, Poland WUST
SSR2 Cryomodule	7	325	35	France CNRS (IN2P3 Lab)	U.S. DOE (FNAL)	India DAE Labs	India DAE Labs, Poland WUST
LB-650 Cryomodule	9	650	36	Italy INFN (LASA)	France CEA (Saclay Lab)	India DAE Labs	India DAE Labs, Poland WUST
HB-650 Cryomodule	4	650	24	UK STFC Labs	UK STFC Labs, U.S. DOE (FNAL)	India DAE Labs	India DAE Labs, Poland WUST

[a] See Section 8.

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 system's 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*.

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
Linac Beam Energy	H- beam will be accelerated to 600 MeV.	H- beam will be accelerated to 700 MeV. Linac systems required for 800 MeV will be installed and tested.
Linac Beam Intensity	H- beam will be delivered to the beam absorber at the end of the linac.	H- beam with intensity of 1.3×10^{12} particles per pulse at 20 Hz pulse-repetition rate will be delivered to the Beam Transfer Line absorber.
Booster, Recycler and Main Injector Synchrotron Upgrades	Upgrades of the Booster, Recycler and Main Injector Synchrotrons, required to support delivery of 1.2 MW onto the LBNF target, will be installed and tested without beam.	Linac beam will be injected into and circulated in the Booster.

[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.

3. **Financial Schedule**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
Design (TEC)			
FY 2018	1,000	1,000	–
FY 2019	20,000	20,000	17,812
FY 2020	51,000	51,000	37,770
FY 2021	53,000	53,000	53,000
FY 2022	40,000	40,000	40,000
Outyears	12,000	12,000	28,418
Total, Design (TEC)	**177,000**	**177,000**	**177,000**
Construction (TEC)			
FY 2020	9,000	9,000	123
FY 2021	26,000	26,000	26,000
FY 2022	50,000	50,000	50,000
Outyears	629,200	629,200	638,077
Total, Construction (TEC)	**714,200**	**714,200**	**714,200**
Total Estimated Cost (TEC)			
FY 2018	1,000	1,000	–
FY 2019	20,000	20,000	17,812
FY 2020	60,000	60,000	37,893
FY 2021	79,000	79,000	79,000
FY 2022	90,000	90,000	90,000
Outyears	641,200	641,200	666,495
Total, TEC	**891,200**	**891,200**	**891,200**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Other Project Cost (OPC)			
FY 2016	18,715	18,715	12,724
FY 2017	16,285	15,220	17,494
FY 2018	23,100	24,165	22,214
FY 2019	15,000	15,000	19,112
FY 2020	494	494	1,845
FY 2021	–	–	205
Outyears	13,206	13,206	13,206
Total, OPC	**86,800**	**86,800**	**86,800**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Project Cost (TPC)			
FY 2016	18,715	18,715	12,724
FY 2017	16,285	15,220	17,494
FY 2018	24,100	25,165	22,214
FY 2019	35,000	35,000	36,924
FY 2020	60,494	60,494	39,738
FY 2021	79,000	79,000	79,205
FY 2022	90,000	90,000	90,000
Outyears	654,406	654,406	679,701
Total, TPC	**978,000**	**978,000**	**978,000**

Notes:

- *Costs through FY 2020 reflect actual costs; costs for FY 2021 and outyears are estimates.*
- *FY 2017 Budget Authority includes recategorization of pre-conceptual design activities to Other Project Costs that occurred in FY 2018.*
- *The ECF subproject, funded by TEC, is a total of $36M; with $8M in FY 2020, $22M in FY 2021 and $6M in FY 2022.*

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design	149,314	170,000	149,314
Design - Contingency	27,686	14,000	27,686
Total, Design (TEC)	**177,000**	**184,000**	**177,000**
Construction	124,009	145,000	124,009
Site Preparation	12,783	18,000	12,783
Equipment	378,705	245,000	378,705
Construction - Contingency	198,703	209,200	198,703
Total, Construction (TEC)	**714,200**	**617,200**	**714,200**
Total, TEC	**891,200**	**801,200**	**891,200**
Contingency, TEC	*226,389*	*223,200*	*226,389*
Other Project Cost (OPC)			
R&D	67,117	67,700	67,117
Conceptual Planning	8,324	9,000	8,324
Conceptual Design	2,855	4,000	2,855
OPC - Contingency	8,504	6,100	8,504
Total, Except D&D (OPC)	**86,800**	**86,800**	**86,800**
Total, OPC	**86,800**	**86,800**	**86,800**
Contingency, OPC	*8,504*	*6,100*	*8,504*
Total, TPC	**978,000**	**888,000**	**978,000**
Total, Contingency (TEC+OPC)	***234,893***	***229,300***	***234,893***

5. Schedule of Appropriations Requests

(dollars in thousands)

Request Year	Type	Prior Years	FY 2020	FY 2021	FY 2022	Outyears	Total
FY 2020	TEC	21,000	20,000	—	—	597,965	638,965
	OPC	72,035	5,000	—	—	5,000	82,035
	TPC	93,035	25,000	—	—	602,965	721,000
FY 2021	TEC	21,000	60,000	20,000	—	700,200	801,200
	OPC	72,035	494	2,000	—	12,271	86,800
	TPC	93,035	60,494	22,000	—	712,471	888,000
FY 2022	TEC	21,000	60,000	79,000	90,000	641,200	891,200
	OPC	73,100	494	—	—	13,206	86,800
	TPC	94,100	60,494	79,000	90,000	654,406	978,000

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	FY 2033
Expected Useful Life	20 years
Expected Future Start of D&D of this capital asset	FY 2053

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	127,676
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"	127,676
Total area eliminated	—

The one-for-one replacement will be met through banked space. A waiver from the one-for-one requirement to eliminate excess space at 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, long-standing collaborations in the physics programs at FNAL that PIP-II will support, 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	Fermi National Accelerator Laboratory; Lawrence Berkeley National Laboratory; Argonne National Laboratory
India	Department of Atomic Energy	Bhabha Atomic Research Centre, Mumbai; Inter University Accelerator Centre, New Delhi; Raja Ramanna Centre for Advanced Technology, Indore; Variable Energy Cyclotron Centre, Kolkata
Italy	National Institute for Nuclear Physics	Laboratory for Accelerators and Applied Superconductivity, Milan
France	Atomic Energy Commission National Center for Scientific Research	Saclay Nuclear Research Center; National Institute of Nuclear & Particle Physics, Paris
UK	Science & Technology Facilities Council	Daresbury Laboratory
Poland	Wroclaw University of Science and Technology	Wroclaw University of Science and Technology

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, FNAL
Fermi National Accelerator Laboratory
Project is for Design and Construction

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

Summary

The FY 2022 Request for Long Baseline Neutrino Facility (LBNF)/Deep Underground Neutrino Experiment (DUNE) is $176,000,000 of Total Estimated Cost (TEC) funding and $4,000,000 in Other Project Cost (OPC) funding. Currently, the project has a preliminary Total Project Cost (TPC) range of $1,260,000,000 to $1,860,000,000, which includes the full cost of the DOE contribution to the LBNF host facility and the DUNE experimental apparatus excluding foreign contributions. This cost range encompasses the most feasible preliminary alternatives at this time. The preliminary TPC estimate for DOE's share of this project is $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. An Independent Project Review conducted by DOE in January 2021 recommended the cost range be reevaluated with a planned review of new range in 1Q FY 2022. According to DOE policy, 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]

Significant Changes

This project was initiated in FY 2012. 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.

Updated planning and analysis in FY 2019-2020 increased the TPC point estimate for the LBNF/DUNE project to $2,600,000,000. The cost estimate increased for three reasons. The first is due to the cost of the excavation. The excavation Construction Manager is now on site and has identified deficiencies in the greater than 100-year-old mining 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. The third reason is due to significantly higher installation costs, determined when the detailed installation plan was developed in FY 2020. Scope reductions are being considered to refine the scope by FY 2022 for the baseline.

The Office of Science (SC) processed a reduction to the approved scope within the authorized expenditures related to work previously approved by CD-3A. This action was triggered by higher cost estimates for the scope approved by CD-3A. The change transferred some of the scope that had been approved by CD-3A to a later authorization decision. CD-3, Approve Start of Construction, is anticipated in FY 2022, and the preliminary date for CD-4, Project Completion, is early FY 2034.

In FY 2020, the project refined its plan and cost estimate for technical integration of the DUNE experimental equipment for neutrino detection, with the civil and cryogenic facility infrastructure. Prototype liquid-argon neutrino detectors and cryostats were constructed and operated by the DUNE scientific collaboration, at reduced scale, at FNAL and CERN in FY 2018-2020, reducing the project's technical risk. The refined plan and cost estimate addressed explicitly the Other Project Costs (OPC) and laboratory operating organization needed to support technical coordination. The details of the project's current total estimate now include the "Other OPC Costs" for execution support including the cost of electrical power for construction and installation, which previously had been estimated as construction costs.

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[a] Per DOE Order 413.3B, Appendix A-6, 11/29/2010.

FY 2020 funding supported the pre-excavation, the reliability projects, the design of the near site conventional facilities, the cryogenic systems, and the detectors. The project was evaluated by Independent Project Reviews in January 2020, July 2020, and January 2021. The reviews saw evidence of progress but saw the need for more work before baselining. The project plans to establish a technical, cost, and schedule baseline in FY 2022. FY 2021 funding supports the completion of the pre-excavation, which was accomplished in March 2021, and work on final design needed for CD-3.

The FY 2022 Request will support continuation of the Far Site civil construction activities for excavation of the underground equipment caverns and connecting drifts (tunnels), as well as continuing design and procurement activities for Far Site cryogenics systems. The Request will also support Near Site (FNAL) beamline and conventional facilities construction procurement activities. Near Site preparation continues in FY 2022, including relocation of utilities at FNAL and staging of beamline shielding blocks to assess their useability for the project and mitigate the need to procure new steel shielding. Shielding blocks are sourced by recovering surplus material buried on-site and by obtaining off-site recycled material. The Request will support design and prototyping of technical systems, including contributions to the DUNE detectors. When design is final and construction is authorized by CD-3, fabrication will begin. SC is evaluating cost and schedule impacts due to the COVID-19 pandemic.

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

Critical Milestone History

Fiscal Year	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	CD-4
FY 2011	1/8/10	-	1Q FY 2011	-	4Q FY 2013	-	-
FY 2012	1/8/10	-	2Q FY 2012	-	2Q FY 2015	-	-
FY 2016	1/8/10	12/10/12	12/10/12	4Q FY 2017	4Q FY 2019	4Q FY 2019	4Q FY 2027
FY 2017	1/8/10	11/5/15	11/5/15	4Q FY 2017	4Q FY 2019	4Q FY 2019	4Q FY 2030
FY 2018	1/8/10	11/5/15	11/5/15	1Q FY 2021	1Q FY 2022	1Q FY 2022	4Q FY 2030
FY 2019	1/8/10	11/5/15	11/5/15	1Q FY 2021	1Q FY 2022	1Q FY 2022	4Q FY 2030
FY 2020	1/8/10	11/5/15	11/5/15	1Q FY 2021	1Q FY 2022	1Q FY 2022	4Q FY 2030
FY 2021	1/8/10	11/5/15	11/5/15	1Q FY 2021	4Q FY 2023	4Q FY 2023	4Q FY 2033
FY 2022	1/8/10	11/5/15	11/5/15	1Q FY 2022	4Q FY 2022	4Q FY 2022	4Q FY 2034

Note:

- *No CPDS was submitted for FY 2013, FY 2014 or FY 2015 because no TEC funds were requested; however, TEC funds for design activities were provided in each year's appropriation. FY 2016 was the initial CPDS for design and construction.*

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-3C
FY 2017	1Q FY 2020	11/5/15	2Q FY 2016	3Q FY 2018	1Q FY 2020
FY 2018	1Q FY 2021	11/5/15	9/1/16	1Q FY 2021	1Q FY 2022
FY 2019	1Q FY 2021	11/5/15	9/1/16	1Q FY 2021	1Q FY 2022
FY 2020	1Q FY 2021	11/5/15	9/1/16	1Q FY 2021	1Q FY 2022
FY 2021	1Q FY 2021	11/5/15	9/1/16	1Q FY 2021	4Q FY 2023
FY 2022	1Q FY 2022	11/5/15	9/1/16	2Q FY 2022	4Q FY 2022

CD-1R – Refresh of CD-1 approval for the new Conceptual Design.
CD-3A – Approve Initial Far Site Construction: initiating excavation and construction for the LBNF Far Site conventional facilities in order to mitigate risks and minimize delays for providing a facility ready to accept detectors for installation.
CD-3B – Approve Start of Far Site Construction: procurement of the remaining Far Site scope for conventional facilities and selected long-lead procurements.
CD-3C – Approve Start of Near Site Construction: procurement of Near Site scope and any remaining LBNF/DUNE scope.

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	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	300,000	2,176,375	2,476,375	123,625	—	123,625	2,600,000
FY 2022	445,934	1,944,066	2,390,000	210,000	—	210,000	2,600,000

Note:

- *No CPDS was submitted for FY 2013, FY 2014 or FY 2015 because no TEC funds were requested; however, TEC funds for design activities were provided in each year's appropriation.*
- *The project is Pre-CD-2 and has not been baselined. All estimates are preliminary. The preliminary TPC range at CD-1 was $1,260,000,000 to $1,860,000,000. The TPC point estimate has increased to $2,600,000,000 and was reviewed by Independent Project Review (IPR) in FY 2020.*
- *No construction, other than site preparation and approved civil construction or long-lead procurement, will be performed prior to validation of the Performance Baseline and approval of CD-3.*

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 (pions 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.[a]

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.

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 1,100 scientists and engineers from over 200 institutions in over 30 countries. DOE will

[a] 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.

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 defined. FNAL continues to identify and incorporate additional design activities and prototypes into the project design.

FNAL and DOE have confirmed contributions to LBNF documented in international agreements from CERN, the UK, India, Poland, and Brazil. 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 has made significant progress and continues to advance. 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*.

Key Performance Parameters (KPPs)
The 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
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 km to 1,500 km	1,000 km to 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

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
Design (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	48,585	48,585	36,924
FY 2018	25,000	25,000	44,749
FY 2019	70,000	70,000	53,841
FY 2020	78,568	78,568	71,104
FY 2021	81,000	81,000	81,000
FY 2022	81,000	81,000	108,179
Total, Design (TEC)	**445,934**	**445,934**	**445,934**
Construction (TEC)			
FY 2017	1,415	1,415	333
FY 2018	70,000	70,000	1,427
FY 2019	60,000	60,000	25,865
FY 2020	92,432	92,432	75,605
FY 2021	90,000	90,000	90,000
FY 2022	95,000	95,000	95,000
Outyears	1,535,219	1,535,219	1,655,836
Total, Construction (TEC)	**1,944,066**	**1,944,066**	**1,944,066**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
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	146,709
FY 2021	171,000	171,000	171,000
FY 2022	176,000	176,000	203,179
Outyears	1,535,219	1,535,219	1,655,836
Total, TEC	**2,390,000**	**2,390,000**	**2,390,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Other Project Cost (OPC)			
FY 2009	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	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	4,006
FY 2021	2,000	2,000	2,000
FY 2022	4,000	4,000	4,000
Outyears	112,375	112,375	114,258
Total, OPC	**210,000**	**210,000**	**210,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Project Cost (TPC)			
FY 2009	12,486	12,486	–
FY 2010	14,178	14,178	11,032
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	150,715
FY 2021	173,000	173,000	173,000
FY 2022	180,000	180,000	207,179
Outyears	1,647,594	1,647,594	1,770,094
Total, TPC	**2,600,000**	**2,600,000**	**2,600,000**

Note:

- *Costs through FY 2020 reflect actual costs; costs for FY 2021 and outyears are estimates.*
- *In FY 2012, $1,078,000 of design funding was erroneously costed to this project, the accounting records were adjusted in early FY 2013.*
- *In FY 2012, $18,000 of FY 2011 funding was attributed towards the Other Projects Costs activities.*
- *In FY 2019, $13,000,000 of Other Project Cost for 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.*

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design	397,568	270,000	**N/A**
Design - Contingency	48,366	30,000	**N/A**
Total, Design (TEC)	**445,934**	**300,000**	**N/A**
Construction	1,134,000	1,146,000	**N/A**
Equipment	375,000	381,000	**N/A**
Construction - Contingency	435,066	649,375	**N/A**
Total, Construction (TEC)	**1,944,066**	**2,176,375**	**N/A**
Total, TEC	**2,390,000**	**2,476,375**	**N/A**
Contingency, TEC	*483,432*	*679,375*	***N/A***
Other Project Cost (OPC)			
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	100,000	38,000	**N/A**
OPC - Contingency	24,375	N/A	**N/A**
Total, Except D&D (OPC)	**210,000**	**123,625**	**N/A**
Total, OPC	**210,000**	**123,625**	**N/A**
Contingency, OPC	*24,375*	*N/A*	***N/A***
Total, TPC	**2,600,000**	**2,600,000**	**N/A**
Total, Contingency (TEC+OPC)	***507,807***	***679,375***	***N/A***

Note:

- *The validated baseline does not occur until CD-2. That column is the only place where N/As are acceptable.*
- *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.*
- *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.*
- *"Other OPC Costs" include execution support costs including electrical power for construction and equipment installation.*

5. Schedule of Appropriations Requests

(dollars in thousands)

Request Year	Type	Prior Years	FY 2020	FY 2021	FY 2022	Outyears	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	279,681	—	—	—	1,185,319	1,465,000
	OPC	86,725	—	—	—	8,275	95,000
	TPC	366,406	—	—	—	1,193,594	1,560,000
FY 2020	TEC	336,781	100,000	—	—	1,318,219	1,755,000
	OPC	87,625	4,000	—	—	3,375	95,000
	TPC	424,406	104,000	—	—	1,321,594	1,850,000
FY 2021	TEC	336,781	171,000	100,500	—	1,868,094	2,476,375
	OPC	87,625	4,000	1,000	—	31,000	123,625
	TPC	424,406	175,000	101,500	—	1,899,094	2,600,000
FY 2022	TEC	336,781	171,000	171,000	176,000	1,535,219	2,390,000
	OPC	87,625	4,000	2,000	4,000	112,375	210,000
	TPC	424,406	175,000	173,000	180,000	1,647,594	2,600,000

Note:

- *All estimates are preliminary. For the first column of Request Year, the outyears represent the time period beyond that specific requested Budget Year.*

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	FY 2034
Expected Useful Life	20 years
Expected Future Start of D&D of this capital asset	FY 2054

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	—

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 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. FNAL determined that excavation scope should be openly competed as provided by the subcontract. The cost reconciliation process provided valuable insight into understanding the scope, schedule, and various approaches to the work. An excavation proposal with a favorable schedule was received that is within the project's current budget.

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 between HEP and 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.

11-SC-41, Muon to Electron Conversion Experiment, FNAL
Fermi National Accelerator Laboratory
Project is for Design and Construction

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

Summary

The FY 2022 Request for the Muon to Electron Conversion Experiment (Mu2e) is $13,000,000 of Total Estimated Cost (TEC) funding to support the approved baseline funding profile for the construction project.

The Mu2e project provides the accelerator beam and experimental apparatus to unambiguously identify neutrinoless muon-to-electron conversion events. The conversion of a muon to an electron in the field of a nucleus would probe new physics for discovery at mass scales far beyond the reach of any existing or proposed experiment.

Significant Changes

This project was initiated in FY 2012. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-3 (Approve Start of Construction), concurrent with completion of the final design, approved on July 14, 2016. Total Project Cost was approved at $273,677,000. The approved funding profile supported this TPC. The CD-4 milestone was set at 1Q FY 2023.

Construction progressed according to plan through FY 2019, the final year of approved funding. FY 2019 funding supported continuing procurement and fabrication activities for the accelerator, beamline, superconducting magnets and particle detectors. Civil construction of the building and underground housing for the experiment was completed in April 2017. This civil facility has special capabilities required to house the primary beam target and transport systems for producing the muons and stopping them in the detector system.

The approved baseline schedule cannot be met as a result of work restrictions at most of the participating institutions in FY 2020 due to the COVID-19 pandemic and because of delayed delivery of two superconducting magnets resulting from poor schedule performance by the vendor. An Independent Project Review recommended a baseline change in February 2021. The Baseline Change Proposal (BCP) is in process, but not yet submitted, reviewed, or approved. In anticipation of approval of the BCP, $2,000,000 of TEC funding was appropriated in FY 2021 and $13,000,000 of TEC funding is requested in FY 2022. The additional funds cannot be spent until the BCP approval and the project is re-baselined.

A Federal Project Director with Certification Level 3 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	CD-4
FY 2011	11/24/09	-	4Q FY 2010	-	4Q FY 2012	-	-
FY 2012	11/24/09	-	4Q FY 2011	-	4Q FY 2013	-	-
FY 2013	11/24/09	-	4Q FY 2012	4Q FY 2013	4Q FY 2014	4Q FY 2014	4Q FY 2018
FY 2014	11/24/09	-	7/11/12	2Q FY 2014	2Q FY 2015	4Q FY 2015	2Q FY 2021
FY 2015	11/24/09	-	7/11/12	4Q FY 2014	2Q FY 2015	4Q FY 2014	2Q FY 2021
FY 2016	11/24/09	7/11/12	7/11/12	2Q FY 2015	3Q FY 2016	3Q FY 2016	1Q FY 2023
FY 2017	11/24/09	7/11/12	7/11/12	3/4/15	3Q FY 2016	3Q FY 2016	1Q FY 2023

Fiscal Year	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	CD-4
FY 2018	11/24/09	7/11/12	7/11/12	3/4/15	7/14/16	7/14/16	1Q FY 2023
FY 2019	11/24/09	7/11/12	7/11/12	3/4/15	7/14/16	7/14/16	1Q FY 2023
FY 2022	11/24/09	7/11/12	7/11/12	3/4/15	7/14/16	7/14/16	1Q FY 2023

Note:

- *Congress approved an FY 2013 reprogramming for the Mu2e construction project following the submission of the FY 2014 budget. The Critical Milestones were consistent with the FY 2014 Request.*

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	CD-3C
FY 2014	-	3Q FY 2013	-	-
FY 2015	-	3Q FY 2014	-	-
FY 2016	2Q FY 2015	7/10/14	2Q FY 2015	3Q FY 2016
FY 2017	3/4/15	7/10/14	3/4/15	3Q FY 2016
FY 2018	3/4/15	7/10/14	3/4/15	7/14/16
FY 2019	3/4/15	7/10/14	3/4/15	7/14/16
FY 2022	3/4/15	7/10/14	3/4/15	7/14/16

Note:

- *Congress approved an FY 2013 reprogramming for the Mu2e construction project following the submission of the FY 2014 budget. The Critical Milestones were consistent with the FY 2014 Request.*

CD-3A – Approve Long-Lead Procurements: advanced the procurement, prior to CD-2, for superconducting cable needed for solenoid fabrication, which reduced schedule risk and cost risk to optimize cost and schedule savings in the project baseline.
CD-3B – Approve Long-Lead Procurements: advanced the start of civil construction of the detector hall, which allowed for a shorter and more cost-effective transition from civil engineering design to construction. CD-3B also advanced procurement of superconducting magnet modules for the Transport Solenoid. Advancing these CD-3B procurements reduced the project's schedule and cost risk.
CD-3C – Approve All Construction and Fabrication (same as CD-3)

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D	OPC, D&D	OPC, Total	TPC
FY 2011	35,000	TBD	TBD	10,000	TBD	TBD	TBD
FY 2012	36,500	TBD	TBD	18,777	TBD	TBD	TBD
FY 2013	44,000	N/A	N/A	24,177	–	24,177	68,177

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D	OPC, D&D	OPC, Total	TPC
FY 2014	61,000	162,000	223,000	26,177	–	26,177	249,177
FY 2013 Reprogramming	49,000	162,000	211,000	23,677	–	23,677	234,677
FY 2015	47,000	162,900	209,900	23,677	–	23,677	233,577
FY 2016	57,000	193,000	250,000	23,677	N/A	23,677	273,677
FY 2017	57,000	193,000	250,000	23,677	N/A	23,677	273,677[a]
FY 2018	60,598[b]	189,402	250,000	23,677	N/A	23,677	273,677
FY 2019	60,598	189,402	250,000	23,677	N/A	23,677	273,677
FY 2022	60,598	204,402	265,000	23,677	N/A	23,677	288,677

Note for FY 2022:

- *In anticipation of approval of the Baseline Change Proposal (BCP), $2,000,000 of TEC funding was appropriated in FY 2021 and $13,000,000 of TEC funding is requested in FY 2022. These funds cannot be spent until the BCP approval and the project is re-baselined.*

2. Project Scope and Justification

Scope

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

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

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

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

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

Justification

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

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

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

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

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
Design (TEC)			
FY 2012	24,000	24,000	–
FY 2013	8,000	8,000	14,653
FY 2014	15,000	15,000	15,404
FY 2015	10,000	10,000	16,892
FY 2016	3,598	3,598	13,649
Total, Design (TEC)	**60,598**	**60,598**	**60,598**
Construction (TEC)			
FY 2014	20,000	20,000	–
FY 2015	15,000	15,000	9,907
FY 2016	36,502	36,502	24,300
FY 2017	43,500	43,500	26,868
FY 2018	44,400	44,400	29,364
FY 2019	30,000	30,000	28,632
FY 2020	–	–	18,360
FY 2021	2,000	2,000	18,000
FY 2022	13,000	13,000	13,000
Outyears	–	–	35,971
Total, Construction (TEC)	**204,402**	**204,402**	**204,402**
Total Estimated Cost (TEC)			
FY 2012	24,000	24,000	–
FY 2013	8,000	8,000	14,653
FY 2014	35,000	35,000	15,404
FY 2015	25,000	25,000	26,799
FY 2016	40,100	40,100	37,949
FY 2017	43,500	43,500	26,868
FY 2018	44,400	44,400	29,364
FY 2019	30,000	30,000	28,632
FY 2020	–	–	18,360
FY 2021	2,000	2,000	18,000
FY 2022	13,000	13,000	13,000
Outyears	–	–	35,971
Total, TEC	**265,000**	**265,000**	**265,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Other Project Cost (OPC)			
FY 2010	4,777	4,777	3,769
FY 2011	8,400	8,400	8,940
FY 2012	8,000	8,000	6,740
FY 2013	2,500	2,500	1,020
FY 2014	–	–	2,136
FY 2015	–	–	159
FY 2016	–	–	252
FY 2017	–	–	11
FY 2018	–	–	5
FY 2022	–	–	645
Total, OPC	**23,677**	**23,677**	**23,677**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Project Cost (TPC)			
FY 2010	4,777	4,777	3,769
FY 2011	8,400	8,400	8,940
FY 2012	32,000	32,000	6,740
FY 2013	10,500	10,500	15,673
FY 2014	35,000	35,000	17,540
FY 2015	25,000	25,000	26,958
FY 2016	40,100	40,100	38,201
FY 2017	43,500	43,500	26,879
FY 2018	44,400	44,400	29,369
FY 2019	30,000	30,000	28,632
FY 2020	–	–	18,360
FY 2021	2,000	2,000	18,000
FY 2022	13,000	13,000	13,645
Outyears	–	–	35,971
Total, TPC	**288,677**	**288,677**	**288,677**

Note:

- *Costs through FY 2020 reflect actual costs; costs for FY 2021 and outyears are estimates.*
- *In anticipation of approval of the Baseline Change Proposal (BCP), $2,000,000 of TEC funding was appropriated in FY 2021 and $13,000,000 of TEC funding is requested in FY 2022. These funds cannot be spent until the BCP approval and the project is re-baselined.*

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design	60,598	60,598	49,000
Design - Contingency	N/A	N/A	8,000
Total, Design (TEC)	**60,598**	**60,598**	**57,000**
Construction	17,336	18,477	13,000
Site Preparation	1,390	1,390	2,000
Equipment	180,346	133,535	133,000
Construction - Contingency	5,330	36,000	45,000
Total, Construction (TEC)	**204,402**	**189,402**	**193,000**
Total, TEC	**265,000**	**250,000**	**250,000**
Contingency, TEC	*5,330*	*36,000*	*53,000*
Other Project Cost (OPC)			
R&D	7,555	8,200	8,200
Conceptual Planning	2,300	2,300	2,300
Conceptual Design	13,177	13,177	13,177
OPC - Contingency	645	N/A	**N/A**
Total, Except D&D (OPC)	**23,677**	**23,677**	**23,677**
Total, OPC	**23,677**	**23,677**	**23,677**
Contingency, OPC	*645*	*N/A*	***N/A***
Total, TPC	**288,677**	**273,677**	**273,677**
Total, Contingency (TEC+OPC)	***5,975***	***36,000***	***53,000***

Note:

- *In anticipation of approval of the Baseline Change Proposal (BCP), $2,000,000 of TEC funding was appropriated in FY 2021 and $13,000,000 of TEC funding is requested in FY 2022. These funds cannot be spent until the BCP approval and the project is re-baselined.*

5. Schedule of Appropriations Requests

(dollars in thousands)

Request Year	Type	Prior Years	FY 2020	FY 2021	FY 2022	Outyears	Total
FY 2011	TEC	35,000	—	—	—	—	35,000
	OPC	10,000	—	—	—	—	10,000
	TPC	45,000	—	—	—	—	45,000
FY 2012	TEC	36,500	—	—	—	—	36,500
	OPC	18,777	—	—	—	—	18,777
	TPC	55,277	—	—	—	—	55,277
FY 2013	TEC	44,000	—	—	—	—	44,000
	OPC	24,177	—	—	—	—	24,177
	TPC	68,177	—	—	—	—	68,177
FY 2014	TEC	223,000	—	—	—	—	223,000
	OPC	26,177	—	—	—	—	26,177
	TPC	249,177	—	—	—	—	249,177
FY 2013 Reprogramming	TEC	211,000	—	—	—	—	211,000
	OPC	23,677	—	—	—	—	23,677
	TPC	234,677	—	—	—	—	234,677
FY 2015	TEC	209,900	—	—	—	—	209,900
	OPC	23,677	—	—	—	—	23,677
	TPC	233,577	—	—	—	—	233,577
FY 2016	TEC	250,000	—	—	—	—	250,000
	OPC	23,677	—	—	—	—	23,677
	TPC	273,677	—	—	—	—	273,677
FY 2017	TEC	250,000	—	—	—	—	250,000
	OPC	23,677	—	—	—	—	23,677
	TPC	273,677	—	—	—	—	273,677
FY 2018	TEC	250,000	—	—	—	—	250,000
	OPC	23,677	—	—	—	—	23,677
	TPC	273,677	—	—	—	—	273,677
FY 2019	TEC	250,000	—	—	—	—	250,000
	OPC	23,677	—	—	—	—	23,677
	TPC	273,677	—	—	—	—	273,677
FY 2022	TEC	250,000	—	2,000	13,000	—	265,000
	OPC	23,677	—	—	—	—	23,677
	TPC	273,677	—	2,000	13,000	—	288,677

Note:

- *In anticipation of approval of the Baseline Change Proposal (BCP), $2,000,000 of TEC funding was appropriated in FY 2021 and $13,000,000 of TEC funding is requested in FY 2022. These funds cannot be spent until the BCP approval and the project is re-baselined.*

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	FY 2023
Expected Useful Life	10 years
Expected Future Start of D&D of this capital asset	FY 2033

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

Related Funding Requirements
(dollars in thousands)

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

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 Fermi National Accelerator Laboratory..................	~25,000
Area of D&D in this project at FNAL..	0
Area at FNAL to be transferred, sold, and/or D&D outside the project, including area previously "banked"	0
Area of D&D in this project at other sites	0
Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked" "	~25,000
Total area eliminated	0

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

8. Acquisition Approach

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

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

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

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

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

Nuclear Physics

Overview

One of the enduring mysteries of the universe is the nature of matter—what are its basic constituents and how do they interact to form the elements and the properties we observe? The mission of the Nuclear Physics (NP) program is to solve this mystery by discovering, exploring, and understanding all forms of nuclear matter—not only the familiar forms of matter we see around us, but also exotic forms that existed in the first moments after the Big Bang and that may exist today inside neutron stars. The aim is to understand why matter takes on the specific forms observed in nature and how that knowledge can benefit society in the areas of energy, commerce, medicine, and national security.

Understanding all forms of nuclear matter requires an enormous range of capabilities: from probing quarks and gluons inside protons, to searching for the largest nuclei that can exist, such as Tennessium—one of four newly discovered super-heavy nuclei. It also encompasses discovery not only from the smallest to the largest, but through time and the evolution of the universe as well. The epoch in the cosmos when quarks and gluons first combined to form protons was millionths of a second after the Big Bang. Events in the cosmos creating heavy nuclei are still occurring today. Achieving this goal therefore requires a suite of advanced tools and support for inspired scientists and engineers to use them.

Theoretical approaches to further our understanding are based largely on calculations of the interactions of quarks and gluons described by the theory of Quantum Chromodynamics (QCD). An exciting vision is the prospect of Quantum Computing—a revolutionary new paradigm for future computers capable of solving many-body QCD problems currently intractable with today's capabilities. Experimental approaches use large accelerators at national user facilities to collide particles at nearly the speed of light, producing short-lived forms of nuclear matter for investigation. Comparison of experimental observations and theoretical predictions tests the limits of our understanding of nuclear matter and suggests new directions for experimental and theoretical research. The many forms in which nuclear matter can exist requires a suite of accelerators with complementary capabilities. NP stewards operations at four such accelerator facilities.

The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Lab (BNL) recreates new forms of matter and phenomena that occurred in the extremely hot, dense environment that existed in the infant universe. The Continuous Electron Beam Accelerator Facility (CEBAF) at Thomas Jefferson National Accelerator Facility (TJNAF) extracts information on quarks and gluons bound inside protons and neutrons that formed shortly after the universe began to cool. The Argonne Tandem Linear Accelerator System (ATLAS) "gently" accelerates nuclei to energies typical of nuclear reactions in the cosmos to further our understanding of the ongoing synthesis of heavy elements such as e.g. gold, and platinum. Stewardship of these facilities is a priority role and goal of NP, as affirmed in the Nuclear Science Advisory Committee's (NSAC) 2015 Long Range Plan for Nuclear Science, *Reaching for the Horizon*. It also underpins achieving the broader goals set for nuclear science in the 2013 National Research Council report, *Nuclear Physics: Exploring the Heart of Matter*. CEBAF, RHIC, and ATLAS operations will become ever more reliable and efficient via the deployment of data analytics for autonomous decision making, currently under development.

To maintain U.S. leadership in nuclear physics, the Facility for Rare Isotope Beams (FRIB) and the Electron-Ion Collider (EIC) are being implemented. FRIB will uniquely afford access to eighty percent of all isotopes predicted to exist in nature, including over 1,000 never produced on earth. The answers to long-standing "grand challenge" questions such as the ultimate limits of nuclear existence and the astrophysical sites and isotopic paths to heavy element production in the cosmos will be illuminated. FRIB is now an NP scientific user facility, and begins data taking for scientific research in FY 2022. The EIC will provide unprecedented ability to x-ray the proton and discover how the mass of everyday objects is dynamically generated by the interaction of quark and gluon fields inside protons and neutrons. As noted by the National Academies, the EIC will also maintain U.S. leadership in the accelerator science and technology of colliders. These facilities provide an exciting future of discovery in Nuclear Physics.

One equally exciting NP frontier does not involve accelerators, but envisions the nucleus itself as a laboratory for observing nature's fundamental symmetries. Chief among these experiments is the search, also given high priority in the 2015 NSAC Long Range Plan, for a nuclear decay predicted to happen once in 10^{28} years—and only if the elusive neutrino particle turns out to be its own anti-particle. The observation of so-called neutrino-less double beta decay would result in a disruptive change in our current understanding of the elementary constituents of nuclear matter and the forces that govern them.

Additional experiments to improve the precision of the current value of the neutron lifetime and to improve limits on a possible electric dipole moment of the neutron also have the potential to change our understanding of the physical world. NP is the primary steward of the nation's fundamental nuclear physics research portfolio providing over 90 percent of the U.S. investment in this area. It also supports the National Nuclear Data Center which collects, evaluates, curates, and disseminates nuclear physics data for basic nuclear research and applied nuclear technologies. In collaboration with other SC programs, NP continues to support development of quantum sensors and quantum control techniques, as well as efforts on data analytics for autonomous decision making which can benefit nuclear physics research and NP accelerator operations. NP also stewards strategic accelerator R&D to pursue next generation electron ion source developments and advanced approaches in superconducting radio frequency (SRF) technologies. In addition, the request supports NP participation in the following SC Initiatives: Microelectronics; Integrated Computational & Data Infrastructure for cross-cutting cloud solutions to Big Data storage challenges in Nuclear Physics; and the Reaching a New Energy Sciences Workforce (RENEW) initiative.

Highlights of the FY 2022 Request

The FY 2022 Request for $720.0 million supports high priority efforts and capabilities in fundamental nuclear physics research; operations, maintenance and upgrades of scientific user facilities; and projects identified as essential in the 2015 NSAC Long Range Plan to maintain U.S. leadership and extend well beyond current scientific capabilities. The Request enables world-class discovery science research and R&D integration to facilitate the development of state-of-the-art applications for energy, medicine, commerce, and national security.

<u>Research</u>

- *Core Research*: Support for university and laboratory researchers to nurture critical core competencies and enable high priority theoretical and experimental activities targeting compelling scientific opportunities identified by the National Academies and NSAC at the frontiers of nuclear science: the nature of matter; the limits of nuclear existence; the search via fundamental symmetries for new physics; and R&D integration of new knowledge to benefit society in the areas of energy, commerce, medicine, and national security. Primary fundamental research thrusts include:
    - The search for a Critical Point and characterization of the quark-gluon plasma at RHIC and the LHC
    - Unraveling the mechanism underlying quark confinement at CEBAF and RHIC
    - The search for new exotic particles and anomalous violations of nature's symmetries at CEBAF
    - Probing the limits of nuclear existence; site & process for heavy element production in the cosmos at FRIB and ATLAS
    - Discovery of whether the neutrino is it own anti-particle via neutrino-less double beta decay
    - Precision measurement of the neutron's properties to search for new physics
    - Research on the strong force in many-body systems via Scientific Discovery Through Advanced Computing
    - Curation of reliable, accurate Nuclear Data for basic nuclear research and nuclear technologies

- NP Research also includes support for University Centers of Excellence which provide niche capabilities and unique "hands-on" experiences in nuclear science.
- *Quantum Information Science (QIS)*: Support continues for the SC QIS Centers established in FY 2020 along with a core research portfolio to leverage discovery opportunities in sensing, simulation, and computing at the intersections of nuclear physics and QIS, as articulated in the NSAC Report, *Nuclear Physics and Quantum Information Science.*
- *Data Analytics*: As part of the Office of Science's initiative on Artificial Intelligence/Machine Learning, support for R&D to develop pilot platforms targeting automated optimization of accelerator availability, performance and operation as well as software enabling data-analytics-driven discovery.
- *Accelerator Science and Technology Initiative*: In coordination with other SC programs, support for NP's role in strengthening U.S. supply chain robustness stewarding key technologies such as next generation electron ion source developments and advanced approaches in SRF technology that underpin U.S. leadership and competitiveness in accelerator R&D.
- *Integrated Computational & Data Infrastructure*: Seed funding to explore cross-cutting cloud solutions to Big Data storage challenges in Nuclear Physics.
- *RENEW:* The Office of Science is fully committed to advancing a diverse, equitable, and inclusive research community. This commitment is key to providing the scientific and technical expertise for U.S. leadership in nuclear physics. Toward that goal, NP will participate in the SC-wide RENEW initiative that leverages SC's world-unique national laboratories,

user facilities, and other research infrastructures to provide undergraduate and graduate training opportunities for students and academic institutions not currently well represented in the U.S. S&T ecosystem. This includes Minority Serving Institutions and individuals from groups historically underrepresented in STEM, but also includes students from communities with environmental justice impacts and the EPSCoR jurisdictions. The hands-on experiences gained through the RENEW initiative will open new career avenues for the participants, forming a nucleus for a future pool of talented young scientists, engineers, and technicians with the critical skills and expertise needed for the full breadth of SC research activities, including DOE national laboratory staffing.
- *Microelectronics:* In coordination with other SC programs, support for research and development of detector materials, devices, advances in front-end electronics, and integrated sensor/processor architectures.

Facility Operations

Requested funding directs efforts to operations of the NP scientific user facilities to enable world-class science:
- RHIC operates 2,310 hours (90 percent optimal). Operating hours are capped at 2,580 hours in FY 2022 to install sPHENIX.
- CEBAF operates for 3,790 hours (90 percent of optimal), enabling highest priority 12 GeV experiments.
- ATLAS operates for 5,800 hours (93 percent of optimal) to enable the most compelling experiments in nuclear structure and astrophysics.
- FRIB operations enables transition from a construction project to commissioning of a scientific user facility, including movement of critical staff from the project to the operations budget. This transition includes 2,310 hours (100% of optimal) of operation.

Projects

The Request for Construction and Major Items of Equipment (MIEs) includes:
- Continuation of research and Project Engineering Design (PED) activities for the Electron-Ion Collider.
- Continuation of the Gamma-Ray Energy Tracking Array (GRETA) MIE, to enable provision of advanced, high resolution gamma ray detection capabilities for FRIB.
- Completion of the super Pioneering High Energy Nuclear Interaction eXperiment (sPHENIX) MIE, to further RHIC's scientific mission by studying high rate jet production.
- Continuation of the Measurement of a Lepton-Lepton Electroweak Reaction (MOLLER) MIE to measure the parity-violating asymmetry in polarized electron-electron scattering with the 12 GeV CEBAF.
- Continuation of the Ton-scale Neutrinoless Double Beta Decay MIE to determine whether the neutrino is its own antiparticle. Funding supports the management team and coordination of the collaboration.
- Continuation of the High Rigidity Spectrometer (HRS) research project at FRIB to maximize the rate of rare neutron-rich nuclei of central importance for understanding the synthesis of heavy elements in cosmic events.

Nuclear Physics
FY 2022 Research Initiatives

Nuclear Physics supports the following FY 2022 Request Research Initiatives.

	(dollars in thousands)			
	FY 2020 Enacted	**FY 2021 Enacted**	**FY 2022 Request**	**FY 2022 Request vs FY 2021 Enacted**
Accelerator Science and Technology Initiative	–	–	2,074	+2,074
Artificial Intelligence and Machine Learning	–	4,000	4,000	–
Integrated Computational & Data Infrastructure	–	–	1,073	+1,073
Microelectronics	–	–	518	+518
Quantum Information Science	10,300	13,347	10,866	-2,481
Reaching a New Energy Sciences Workforce (RENEW)	–	–	3,000	+3,000
Total, Research Initiatives	**10,300**	**17,347**	**21,531**	**+4,184**

Note: The FY 2021 Enacted funding supporting QIS included $3,500,000 of Isotope Production and Applications for Research and Applications support. In FY 2022, support for these activities can be found in the Isotope R&D and Production Program Budget Request.

Nuclear Physics
Funding

(dollars in thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Nuclear Physics				
Medium Energy, Research	65,479	41,110	54,083	+12,973
Medium Energy, Operations	122,110	117,201	142,709	+25,508
Total, Medium Energy Physics	**187,589**	**158,311**	**196,792**	**+38,481**
Heavy Ion, Research	37,661	36,313	48,059	+11,746
Heavy Ion, Operations	187,131	181,625	183,943	+2,318
Heavy Ion, Projects	19,520	30,180	10,213	-19,967
Total, Heavy Ion Physics	**244,312**	**248,118**	**242,215**	**-5,903**
Low Energy, Research	60,398	61,763	74,341	+12,578
Low Energy, Operations	55,739	79,379	107,831	+28,452
Low Energy, Projects	10,600	16,000	18,040	+2,040
Total, Low Energy Physics	**126,737**	**157,142**	**200,212**	**+43,070**
Theory, Research	51,862	61,129	60,781	-348
Total, Nuclear Theory	**51,862**	**61,129**	**60,781**	**-348**
Isotopes Operations	34,400	36,340	–	-36,340
Isotopes Research	11,500	26,660	–	-26,660
Isotopes Projects	3,600	3,000	–	-3,000
Total, Isotope Development and Production for Research and Applications	**49,500**	**66,000**	**–**	**-66,000**
Subtotal, Nuclear Physics	**660,000**	**690,700**	**700,000**	**+9,300**

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Construction				
14-SC-50, Facility for Rare Isotope Beams (FRIB), MSU	40,000	5,300	–	-5,300
20-SC-51, U.S. Stable Isotope Production and Research Center (SIPRC), ORNL	12,000	12,000	–	-12,000
20-SC-52, Electron Ion Collider (EIC), BNL	1,000	5,000	20,000	+15,000
Subtotal, Construction	**53,000**	**22,300**	**20,000**	**-2,300**
Total, Nuclear Physics	**713,000**	**713,000**	**720,000**	**+7,000**

(dollars in thousands)

SBIR/STTR funding:

- FY 2020 Enacted: SBIR $18,257,000 and STTR $2,468,000
- FY 2021 Enacted: SBIR $18,685,000 and STTR $2,625,000
- FY 2022 Request: SBIR $21,005,000 and STTR $2,955,000

Nuclear Physics
Explanation of Major Changes

	(dollars in thousands) FY 2022 Request vs FY 2021 Enacted
Medium Energy Physics The Request provides support for the CEBAF accelerator complex, including mission readiness of the four experimental halls, mission readiness of the accelerator, all power and consumables of the site, computing capabilities for data 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 3,790 operating hours (90 percent optimal), to exploit the capabilities afforded by the 12 GeV CEBAF Upgrade to address the highest priority scientific opportunities; funding is invested to improve the performance of the machine. 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 investments in maintenance activities and cryomodule refurbishment at CEBAF to improve the performance and reliability of the machine. 12 GeV researchers from national laboratories and universities will implement, commission, and operate high priority new experiments at CEBAF. Scientists play a leading role in the development of scientific instrumentation and accelerator components for the EIC. The Request includes support to participate in the Accelerator Science and Technology initiative, and the SC QIS initiative. Activities are continued in Data Analytics to develop pilot platforms targeting automated optimization of accelerator performance. Funding is also requested to initiate participation in the SC initiative on Microelectronics to support R&D for detector materials, devices, advances in front-end electronics, and integrated sensor/processor architectures, including testing and modeling to contribute to microelectronics resilience in severe high radiation environments.	**+38,481**
Heavy Ion Physics 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 2,310 hour run (at 90 percent of the capped FY 2022 maximum operations to allow for sPHENIX installation), 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 to complete the 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 includes support for the Accelerator Science and Technology initiative and the SC QIS initiative. Activities are continued in Data Analytics to develop pilot platforms targeting automated optimization of accelerator performance. 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.	**-5,903**

	(dollars in thousands)
	FY 2022 Request vs FY 2021 Enacted
Low Energy Physics	**+43,070**

The Request provides support for operations of two low energy user facilities: the ATLAS facility, which operates for 5,800 hours (93 percent optimal), and FRIB, which in its first year of operation for scientific research, provides beam time for 2,310 hours (100% of optimal) to support research, beam studies, and commissioning. FRIB research is supported with high priority as FRIB transitions from project completion to an operating Scientific User Facility. 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.

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 double beta decay 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.

The Request provides support for the Accelerator Science and Technology initiative and the SC QIS initiative. Activities are continued in Data Analytics to develop pilot platforms targeting automated optimization of accelerator performance.

Nuclear Theory	**-348**

Funding for Nuclear Theory supports 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 redistributes 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 to other relevant subprograms in NP. The Request continues support for Data Analytics that explores platforms for automated machine operations; some of these funds are distributed to other subprograms to recognize the experimental contributions to this effort. Funding is requested for participation in the Integrated Computational & Data Infrastructure initiative to explore cross-cutting cloud solutions to Big Data storage challenges in Nuclear Physics. Funding also supports the RENEW initiative to provide undergraduate and graduate training opportunities for students and academic institutions not currently well represented in the U.S. S&T ecosystem.

	(dollars in thousands) FY 2022 Request vs FY 2021 Enacted
Isotope Development and Production for Research and Applications Funding for the Isotope Development, Production, Research and Applications Subprogram is moved to the new Isotope R&D and Production Program (DOE Isotope Program) in FY 2022. In the 2020 Office of Science restructuring, the DOE IP was pulled out of the Office of Nuclear Physics into its own Program in the Office of Science.	**-66,000**
Construction The Request provides funding for the EIC to continue Project Engineering and Design.	**-2,300**
Total, Nuclear Physics	**+7,000**

Basic and Applied R&D Coordination

The NP mission supports the pursuit of unique opportunities for R&D integration and coordination with other DOE Program Offices, Federal agencies, and non-Federal entities. For example, researchers from the High Energy Physics (HEP), NP, and Advanced Scientific Computing Research (ASCR) programs coordinate and leverage forefront computing resources and/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 innovative 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, as well to meet emerging challenges such as generating new nuclear data relevant for space exploration. 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).

Program Accomplishments

A Landmark Advance on the Road to Quantum Computing.

Classical computers work by solving complex logic using electronic “bits” that can be in a logical state of 0 or 1. It is also possible to prepare a quantum mechanical two-state system or “qubit” such as e.g. an electron with its spin up or down. The difference is, for the probabilistic quantum mechanical case, it is also possible for the electron to be in a coherent superposition of both states simultaneously. That difference is key to Quantum Computing (QC)—a revolutionary new paradigm for future computers that will be capable of solving problems intractable with today’s capabilities. The viability of QC depends in part on how long such coherent superpositions can be sustained. Over the past 20 years, superconducting qubit coherence times have increased more than five orders of magnitude, from less than one nanosecond to more than 100 microseconds. Nonetheless, far longer coherence times are needed. Nuclear physicists from MIT and Pacific Northwest National Laboratory recently made a landmark discovery that ionizing radiation from environmental radioactive materials, contaminants and cosmic rays can limit superconducting qubits to coherence times in the millisecond regime—far too short for practical quantum computing. This finding has implications for the design of future QC facilities where radiation shielding may be needed to reduce the flux of ionizing radiation and increase superconducting qubit coherence times.

Mass Limit on the Elusive Neutrino is Cut in Half.

Nuclear physicists from the University of Washington, the University of North Carolina, MIT, Carnegie Mellon University, LBNL, and other international institutions recently cut the upper bound on the neutrino mass in half, demonstrating that the wispy neutrino mass is no more than the energy equivalent of one electron volt (eV)— five-hundred-thousand times less than the mass of an electron. Working on the KATRIN experiment located in Karlsruhe, Germany, the team of scientists is urgently pressing to achieve the lowest limit possible, as the existence of neutrino mass contradicts a prediction of the Standard Model of particle physics and knowing its value opens a window to discovering new physics. Over the next 5 years, KATRIN is expected to further improve its sensitivity by a factor of five.

An Exciting Future Just Around the Corner.

The Facility for Rare Isotope Beams (FRIB) recently accelerated an Argon-36 beam to 204 MeV/nucleon corresponding to 57 percent of the speed of light. With a design goal of 200 MeV/nucleon this milestone demonstrates that the FRIB superconducting linear accelerator operates as intended, with the ability to create over 80% of the isotopes predicted to possibly exist in nature—1000 of which have never been produced. Scheduled for on-time completion in FY 2022, FRIB will enable research opportunities for a worldwide community of over 1,500 scientists.

Something Good from Something Broken.

Broken symmetries in the early universe account today for the presence of stars, planets and people. For instance, the spontaneous breaking of "chiral symmetry" gives rise to pions— particles that carry the strong force between protons and neutrons, binding them into the nuclei of atoms which account for 98% of the mass of the visible universe. Recently, the PrimEx-II experiment at Thomas Jefferson National Accelerator Facility made an ultra-precise measurement of the lifetime of the pion and compared it with theoretical predictions of modern-day chiral symmetry breaking, confirming our understanding of the origin of the pion and ruling out alternative explanations of why its lifetime is so short.

Computing the Structure of Nuclei—Faster is a lot Better.
For nearly a century, nuclear physicists have sought to uncover the elusive properties of the interaction that binds protons and neutrons into atomic nuclei. Theoretical calculations on this question are very time consuming if precise, and for heavy nuclei may even be intractable using the best high-performance computers. It is therefore very exciting that nuclear physicists at Oak Ridge National Laboratory have now developed a new method that accurately emulates the quantum properties of atomic nuclei within a few milliseconds of computing. After an initial training stage using the Oak Ridge Leadership Computing Facility, millions of predictions can now be generated e.g. for the ground-state energy and charge radius of oxygen-16 in a couple of hours on a standard laptop using statistical methods. The results provide invaluable new insights into how protons and neutrons interact with each other in order to bind atomic nuclei.

Probing the Mystery of Globular Clusters: Direct Measurement of $^{30}Si(p,\gamma)^{31}P$.
NGC 2419 is a so-called globular cluster located in the outer halo of the Milky Way. It is hard to understand its nature because it consists of a group of red giant stars which have, at one and the same time, an anomalously high enrichment in potassium (K), and an unexpected depletion in magnesium (Mg). This puzzling Mg-K anticorrelation cannot be explained within the standard picture of cluster evolution, and hints at the existence of multiple stellar populations. Researchers at Triangle Universities Nuclear Laboratory's Low Energy Nuclear Astrophysics (LENA) facility have recently measured a key reaction which may shed light on this question by letting protons impinge on silicon nuclei (^{30}Si) resulting in the production of a phosphorus nuclei (^{31}P) accompanied by a gamma ray. Their results suggest the rate for this reaction, $^{30}Si(p,\gamma)^{31}P$, in the cosmos is ten time less than previously assumed. Precise knowledge of reaction rates and elemental abundances in globular clusters provides unique insights into the evolution of the early Galaxy.

Nuclear Physics
Medium Energy Physics

Description

The Medium Energy 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?

Scientists use various experimental approaches 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. In addition, 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 combinations of quarks and gluons 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. 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 addressing an outstanding grand challenge question of modern physics: 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 EIC is the facility planned to address this science and will be located at BNL; DOE approved CD-0, Approve Mission Need, in December 2019. CEBAF is partnering with BNL to develop and implement the EIC. 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 within the Accelerator Science and Technology Initiative pursue next generation ion source developments and advanced approaches in superconducting radiofrequency (SRF) technology. Accelerator scientists also pursue accelerator science aimed at improving the operations of existing facilities and developing next-generation facilities for nuclear physics. Nuclear physicists participate in activities related to quantum information science (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. Scientists develop cutting-edge techniques based on Data Analytics 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 machine learning (ML) and control and the optimization of accelerator systems operations and detector design using data analytics models. Scientists participate in the SC initiative on Microelectronics research and development.

The subprogram 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 Request also includes funding to meet other obligations, such as the Office of Science Lawrence Awards and Fermi Awards. In FY 2022, SC plans to confer up to 10 awards with honorariums of $20,000 each for the Ernest Orlando Lawrence Award.

Research

The Research activity supports 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 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 in coordination with NIH and homeland security. Scientists are engaged in experimental QIS research. TJNAF staff focus on the 12 GeV experimental program, including implementation of select experiments, acquisition of data, and data analysis at 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 from universities and laboratories advance technology and core competencies essential for improving operations of the complex NP Scientific User Facilities or developing new NP facilities. Activities in the SC Accelerator Science and Technology initiative build on the unique expertise of NP accelerator scientists to develop transformative technology for the Nation, including next-generation accelerator ion sources, innovative, efficient and cost effective cryogenic systems, high gradient SRF cavities, novel in-situ plasma processing of cryomodules, and advancements in hadron beam cooling. Researchers are also engaged in developing learning techniques focused on improving efficiencies of accelerator operations.

Operations

The Operations activity provides Accelerator Operations funding for CEBAF which boasts world unique features of continuous wave polarized beam to four experimental halls and serves over 1,600 U.S. and international users. Funding for this activity supports 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 planned operations run is initiated late in FY 2021 and extends into FY 2022, leading to two distinct running periods in FY 2022; the late operations start in FY 2021 is driven by the installation schedule of a new cryogenics system to address failing components, the cost-effectiveness of a single run that crosses a fiscal year boundary, and COVID impacts. Investments in cryomodule refurbishment, spares and critical maintenance are prioritized to address and improve machine performance and reliability. The Request supports high priority accelerator improvements aimed at providing enhanced capabilities, and high priority capital equipment for research and facility instrumentation. 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 upgrade of the 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.

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Medium Energy Physics	**$158,311**	**$196,792**	**+$38,481**
Research	$41,110	$54,083	+$12,973
Funding supports scientists, resident at TJNAF, RHIC, universities, and other 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. Funding enables continued targeted analysis of RHIC polarized proton beam data to learn more about the origin of the proton's spin. Funding supports the development of concepts for detectors to be used at the EIC and further develops the scientific program. Funding also enables researchers to pursue accelerator science pertinent to improving current operations of NP facilities including applications of artificial intelligence.		The Request will continue to support core research. Scientists, resident at TJNAF, RHIC, universities, and other national laboratories, will participate 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 and accelerator science. The Request will continue 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 detector design to be used at the EIC and further develop the scientific program. The Request will increase opportunities for researchers to pursue transformative accelerator science to improve operations of current and future NP facilities including applications of data analytics, and it will provide initial support for the SC Accelerator Science and Technology Initiative. Research on Microelectronics is initiated to study detector materials, devices, advances in front-end electronics, and integrated sensor/processor architectures. Scientists conduct research on quantum sensors to enable precision NP measurements, development of quantum sensors based on atomic-nuclear interactions.	The Request increases funding for participation in SC Initiatives, including QIS, Data Analytics, Microelectronics, and the Accelerator Science and Technology Initiative. Funding will restore core scientific workforce at universities and national laboratories conducting research related to CEBAF, RHIC, EIC and other facilities.

(dollars in thousands)

FY 2021 Enacted	FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Operations $117,201	$142,709	+$25,508
Funding for operations of the CEBAF facility supports the continuation of the high priority experiments in the 12 GeV science program. Funding initiates a long physics run late in the fiscal year which extends into FY 2022 providing 780 operational hours for research, tuning, and beam studies in FY 2021. The cryogenics systems experienced increasing rates of failure, and new critical cryogenics systems are installed in FY 2021, limiting the operations of the machine. Funding supports CEBAF operations, including mission readiness of the accelerator, all power and consumables of the site, cryogenics plant, activities to reduce Helium consumption, activities to improve accelerator performance, high priority facility and instrumentation capital equipment, high priority accelerator improvement and GPP projects, and the key computing capabilities for data taking and analysis. Funding also supports maintenance of critical core competencies and accelerator scientists, engineers, and technicians, and operations staff. Funding supports 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. Funding also supports the participation of accelerator scientists in accelerator R&D activities, including those for the EIC.	The Request for operations of the CEBAF facility will support the continuation of the high priority experiments in the 12 GeV science program. The Request will provide 3,790 operational hours (90% optimal) for research, tuning, and beam studies. The Request will support CEBAF operations, including mission readiness of the accelerator, all power and consumables of the site, cryogenics plant, activities to reduce helium consumption, activities to improve accelerator performance and reliability, 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.	The Request will increase CEBAF run time hours to approximately 90 percent of optimal operations. The Request prioritizes equipment and effort to improve CEBAF reliability and performance.

Note: Funding for the subprogram above, includes 3.65% of research and development (R&D) funding for the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Programs.

Nuclear Physics
Heavy Ion 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 quantum chromodynamics (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 (QGP) 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 demonstrating a first order 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 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. In 2018, a National Academies study gave a strong endorsement to a U.S.-based Electron-Ion Collider (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, and in January 2020, BNL was selected as the location for the EIC. Scientists and accelerator physicists from the Heavy Ion and the Medium Energy sub-programs are partnering to advance the EIC, both playing significant leadership roles in the development of the scientific agenda and implementation of the EIC.

Over the course of the implementation of the EIC, RHIC operations funding will decrease as some scientific staff, engineers and technicians move from RHIC operations to the EIC project. This is a gradual movement to balance the need for the scientific and technical experts with RHIC while ramping up the EIC project. These individuals represent the scientific and

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

technical workforce that are essential to the operations of a complex facility like RHIC and eventually, the EIC. They have critical core competencies in collider operations that cannot easily be replaced; their support is embedded in the EIC TPC funding and they represent the core facility operations force of RHIC and the EIC. Throughout the EIC project, the temporary reprioritization of funds from the collider facility operations budget to the construction budget will reduce the amount of “new funds” needed to implement the EIC, enabling a cost-effective path forward to the implementation of this world-leading facility.

Brookhaven National Laboratory was chosen to host one of the five SC QIS Research Centers in FY 2020 and will focus on building the fundamental tools necessary for the United States to create quantum computers that provide a true advantage over their classical counterparts. Scientists working in heavy ion physics leverage discovery opportunities in sensing, simulation, and computing at the intersections of nuclear physics and QIS.

The SC Accelerator Science and 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 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 Data Analytics applications in optimizing operation of complex accelerators and detectors at user facilities. This research is essential for maintaining 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.

Research

This activity supports high priority research at universities and at BNL, LBNL, LANL, and ORNL to participate in efforts at RHIC and the LHC. NP fully supports U.S. commitments to the LHC “common funds”, fees based on the level of U.S. scientist participation in the LHC program and the use of LHC computing capabilities, enabling the participation of researchers in the complementary heavy ion program at CERN. U.S. scientists work with their international peers in developing and implementing upgrades to the LHC scientific instrumentation. Heavy Ion research also supports the SC QIS Centers competitively chosen for support starting in FY 2020, in partnership with the other SC programs.

The university and national laboratory research groups support personnel and graduate students for taking data within the RHIC heavy ion program, analyzing data, publishing results, 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. Scientists participate in the development of a world-leading scientific program for the future EIC.

Transformative accelerator R&D efforts are pursued within the Accelerator Science and Technology initiative, including advancements in hadron beam cooling and SRF technology. Scientists and engineers also pursue accelerator science aimed at improving the operations of existing facilities and developing next-generation facilities for nuclear physics. Scientists develop cutting-edge techniques based on Data Analytics of relevance to nuclear science research, accelerator facility operations and automated machine operations. 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 machine learning (ML) and control and the optimization of accelerator systems operations and detector design using data analytics models.

Operations

The Heavy Ion Operations 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 2022 Request supports high priority capital equipment and accelerator improvement projects at RHIC to promote enhanced and robust operations. In FY 2022, the only detector operating at RHIC will be STAR; PHENIX operations funding is redirected to complete and install the sPHENIX MIE, in preparation for the last RHIC data taking campaign.

RHIC operations have led to advances in accelerator physics which have, in turn improved RHIC performance and enhanced 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 the EIC, 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.

In FY 2022, funding for RHIC operations will decrease as some scientific staff, and experienced accelerator collider engineers and technicians move from RHIC operations to the EIC project. This is a gradual movement, to occur throughout the EIC project, to balance the need for the scientific experts with RHIC while ramping up the EIC project. These individuals represent the scientific and technical workforce that are essential to the operations of a complex facility like RHIC and eventually, the EIC. They have critical core competencies in collider operations that cannot easily be replaced and represent a part of the core facility operations workforce of RHIC and the EIC. The temporary reprioritization of funds from the collider facility operations budget to the construction budget will prioritize funding needed to implement the EIC, enabling a cost-effective path forward to the implementation of this world-leading facility.

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 supported by NASA for the study of space radiation effects applicable to human space flight as well as electronics.

Projects

RHIC scientists and engineers focus on completing and installing sPHENIX in preparation for the last RHIC data taking campaign. 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. Other Project Costs for the EIC support scientists and accelerator physicists to advance the Conceptual Design and conduct accelerator and detector R&D. 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 technical risks and value engineering. The EIC OPC funding supports experienced scientists and engineers skilled in collider operations who were previously supported with RHIC base operations and who are essential for the operations of the current and future upgraded collider.

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted	FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Heavy Ion Physics **$248,118**	**$242,215**	**-$5,903**
Research $36,313	$48,059	+$11,746
Funding supports scientists resident at RHIC, universities and other 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 also enables scientists to continue to fabricate the sPHENIX MIE for the study of high rate particle jets. Funding also supports modest and cost effective upgrades at STAR in preparation for a polarized proton run in 2022. U.S. scientists participate in the highest priority heavy ion efforts at the international ALICE, CMS, and ATLAS LHC experiments, and the funding supports upgrades at these facilities. Funding supports targeted accelerator R&D relevant to NP programmatic needs.	The Request will support scientists resident at RHIC, universities and other national laboratories to develop, fabricate, implement and maintain scientific instrumentation; participate in experimental runs to acquire data; analyze data and publish experimental results; develop scientific plans and instrumentation for the EIC; and train students in nuclear science. 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 high priority heavy ion efforts and instrumentation upgrades at the international ALICE, CMS, and ATLAS LHC experiments. The Request will support accelerator R&D relevant to NP programmatic needs and participation in the SC Accelerator Science and Technology initiative. Research activities support the SC QIS Research Centers and data analytics aimed at applications of artificial neural networks to nuclear physics research and the optimization of accelerator performance.	Increased funding will restore the core scientific workforce at universities and national laboratories to enhance high priority research at RHIC, the LHC, and for EIC science and detector development. Heavy ion research supports the SC QIS Research Centers. Funding will support NP participation in high priority SC initiatives, including the Accelerator Science and Technology initiative and data analytics. Funding will support the LHC “common funds” to enable individual U.S. scientist participation in the LHC program and the use of LHC computing capabilities.

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Operations	$181,625	$183,943	+$2,318
Funding supports RHIC operations for 3,130 hours (100 percent optimal). Operating hours of 3,130 are lower than the typical hours RHIC can operate, however, the operating hours are capped in FY 2021 due to planned installation requirements. Funding also 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, 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 maintains critical core competencies and accelerator scientists, engineers, and technicians, for RHIC operations and EIC design. Limited operations funding is redirected to the sPHENIX MIE. Accelerator scientists participate in high priority accelerator R&D.		The Request will support RHIC operations at 2,310 hours (90 percent optimal, which in FY 2022 is capped by installation work for the sPHENIX MIE). The Request 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 provide critical core competencies and accelerator scientists, engineers, and technicians, for collider operations. Accelerator scientists conduct research aimed at improving the operations of the RHIC accelerator complex.	In FY 2022, funding for RHIC operations will allow for 2,310 hours, completion of the sPHENIX upgrade and installation, as well as the move of some scientific staff, engineers, and technicians from RHIC operations to the EIC project. This is a gradual movement to balance the need for the scientific experts with RHIC while ramping up the EIC project.

(dollars in thousands)

FY 2021 Enacted	FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Projects $30,180	$10,213	-$19,967
The FY 2021 Enacted Appropriation includes support for both the sPHENIX MIE, which will study high rate particle jets, and EIC OPC.	The sPHENIX MIE will be completed and installed in FY 2022 to enable the use of precision, high rate jet measurements to further characterize the 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. Also, the experienced scientists and engineers skilled in collider operations continue to transition from RHIC operations to support EIC activities.	RHIC scientists, engineers and technicians will be redirected to the EIC project as some RHIC activities start to ramp down. The requested funding for the sPHENIX MIE will reduce according to the budget profile. EIC OPC will decrease as effort transitions to TEC.

Note: Funding for the subprogram above, includes 3.65% of research and development (R&D) funding for the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Programs.

Nuclear Physics
Low Energy Physics

Description
The Low Energy Nuclear Physics subprogram includes two scientific activities 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 activities address 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 activities also measure 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.

ATLAS, at ANL, is an SC scientific user 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 (SRF) 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. Investments to increase ATLAS capabilities provide unique research opportunities include a new technological approach to the CARIBU ion source and a cost-effective Multi-User Upgrade (MUU) to address a backlog of compelling experiments.

FRIB, completing construction at Michigan State University (MSU) in FY 2022, will advance understanding of the atomic nucleus 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. FRIB became an SC User Facility in FY 2020 and transitions to operations for research data taking in FY 2022. 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 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, enabling the most sensitive experiments across the entire chart of nuclei with the most neutron-rich nuclei available.

In coordination with other SC programs, accelerator scientists in this activity participate in the SC Accelerator Science and Technology initiative and support NP's role in strengthening U.S. supply chain robustness stewarding key technologies such as next generation electron ion source developments and advanced approaches in SRF technology that underpin U.S. leadership and competitiveness in accelerator R&D. Scientists also participate in Data Analytics, providing support for R&D to develop pilot platforms targeting automated optimization of accelerator availability, performance and operation as well as software enabling data-analytics-driven discovery.

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 to discover Elements 119 and 120. All 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 modest 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 activities address these questions through precision studies using neutron and electron beams and decays of nuclei, including beta decay, double-beta decay, and NLDBD. 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), Karlsruhe Tritium Neutrino Experiment (KATRIN)), and in 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.

Scientists in this activity, particularly with their expertise in rare signal events, engage in QIS and quantum computing (QC), and contribute to 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.

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 design, fabricate, install and commission instrumentation at FRIB and prepare for the initiation of the scientific program. Funds transition the most critical key researchers that used to be supported by NSF at the National Superconducting Cyclotron Laboratory (NSCL) to this DOE portfolio to lead the FRIB scientific mission. The Request continues the GRETA MIE, which will be re-baselined after lower than planned FY 2021 funding; and maintains the HRS research 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. Accelerator scientists participate in transformative accelerator R&D, particularly in the development of the next generation ion source for accelerators. Scientists utilize Data Analytics that can promote automated platforms to improve machine performance and reliability.

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 is sensitive to a wide range of underlying new physics and is a test of charge-parity violation, and other experiments at the SNS FNPB continue. First-generation NLDBD experiments finalize analysis of 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. Researchers conduct NP research of relevance to QIS, with a focus on novel quantum sensors.

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 have been increased with the addition of the Electron Beam Ion Source (EBIS), the 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. Accelerator scientists continue the implementation of a neutron-generator based source for CARIBU (nuCARIBU) to improve the stability and intensity of CARIBU beams.

The ATLAS facility nurtures a core competency in accelerator science with SRF 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 MUU Accelerator Improvement Project which will significantly increase the beam hours available for experiments to the scientific community.

The Request ramps up funding to support FRIB operations in FY 2022, when commissioning of the scientific program will begin. The funds transition the most critical operations staff as accelerator components are completed on the project and effort is redirected towards 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.

Nuclear Physics
Low Energy Physics

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Low Energy Physics	**$157,142**	**$200,212**	**+$43,070**
Research	$61,763	$74,341	+$12,578
Funding supports high priority university and laboratory nuclear structure and nuclear astrophysics efforts at ATLAS and development of the FRIB scientific program including research support for FRIB scientific personnel. Scientists participate in the characterization of recently discovered elements and search for new ones. Research continues at the university-based Centers of Excellence at TUNL, CENPA, and TAMU.		The Request will support high priority university and laboratory nuclear structure and nuclear astrophysics efforts at ATLAS and installation and commissioning of instrumentation for the FRIB scientific program. The Request will target research for critical FRIB scientific personnel to lead the scientific program at FRIB. 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. Accelerator scientists will develop the next generation ion source for accelerators. Scientists utilize Data Analytics that can promote automated platforms to improve machine performance and reliability.	The Request will restore high priority research efforts and essential workforce at universities and national laboratories, with a focus on conducting experiments at ATLAS and initial physics runs at FRIB. Funding will support high priority research initiatives, including QIS, data analytics, and Accelerator Science and Technology.
High priority research in NLDBD continues with CUORE, LEGEND-200, and nEXO. Funding continues support for U.S. participation in the operations of the international KATRIN experiment.		High priority research in NLDBD will continue with CUORE, LEGEND-200, and nEXO. The Request will continue support for U.S. participation in the operations of the international KATRIN experiment.	

(dollars in thousands)

FY 2021 Enacted	FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Operations $79,379	$107,831	+$28,452
Funding supports operations of ATLAS at 5,350 hours (93 percent optimal hours; note that optimal hours were reduced due to COVID impacts), and provides 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 sustains operations of the 88-Inch Cyclotron for high priority experiments studying newly discovered elements. Funding supports high priority activities necessary to prepare for FRIB operations in FY 2022.	ATLAS operates for 5,800 hours (93 percent of optimal), an increase in hours relative to FY 2021. The Request will fund operations, 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. The Request will also support the first year of 2,310 hours of operations (100% of optimal) at FRIB to initiate the scientific program. Funding will sustain operations of the 88-Inch Cyclotron for high priority experiments studying newly discovered elements.	Requested funding will support FRIB operations, enabling initiation of the physics program and transfer of key personnel to the FRIB Operations team. Increased funding for ATLAS prioritizes increased operation hours.
Projects $16,000	$18,040	+$2,040
Funding supports the GRETA MIE, MOLLER MIE, NLDBD MIE, and HRS research project. MOLLER achieved CD-1 in FY 2021. GRETA is assessing funding impacts to the project plans.	The Request will continue support for the GRETA MIE, Moller MIE, NLDBD MIE and HRS research project. GRETA and HRS will be supported at their FY 2021 Enacted levels.	The funding increase will mainly support the Moller MIEs.

Note: Funding for the subprogram above, includes 3.65% of research and development (R&D) funding for the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Programs.

Nuclear Physics
Nuclear Theory

Description

The Nuclear Theory subprogram provides the theoretical support needed to interpret the wide range of data obtained from the experimental nuclear science subprograms and to advance new ideas and hypotheses that identify potential areas for future experimental investigations. 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 quantum chromodynamics (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 five 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 NNDC is designated as an SC Public Reusable Research (PuRe) Data Resource, a designation commensurate with high standards of data management, resource operation, and scientific impact. 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 quantum information science (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, R&D on nuclear physics techniques to enhance qubit coherence times, and development of quantum computing algorithms applied to quantum mechanical systems and NP topical problems. In partnership with the other SC programs, NP continues support in jointly stewarding SC QIS Research Centers which will focus on building the fundamental tools necessary for the United States to create quantum computers that provide a true advantage over their classical counterparts.

Scientists will develop cutting-edge techniques based on data analytics of relevance to nuclear science research, and accelerator facility operations. 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 machine learning (ML) and control and the optimization of accelerator systems operations and detector design using artificial intelligence (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 lattice quantum chromodynamics (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.

The Nuclear Theory subprogram supports the RENEW initiative to provide undergraduate and graduate training opportunities for students and academic institutions not currently well represented in the U.S. S&T ecosystem. The Request includes funding for RENEW in the theory program and it will be distributed across the other subprograms, depending on peer review results of proposals.

<u>Research</u>
This activity supports high priority research at ANL, BNL, LANL, LBNL, LLNL, ORNL, and TJNAF and universities. This research advances our fundamental understanding of nuclear physics, interpreting the results of experiments carried out under the auspices of the experimental nuclear physics program, and identifies and explores compelling new areas of research. The Request continues support of topical collaborations within available funds to bring together theorists to address specific emerging and 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 to optimize the interpretation of the experimental results.

The Request redistributes support for research related to QIS and QC to provide technological and computational advances relevant to NP and other fields to other NP subprograms, in recognition of the experimental facets of QIS; overall, the NP Request for QIS increases in FY 2022. 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 are completed in FY 2021, and a new competition will make awards for SciDAC-5 in FY 2022. In addition to addressing specific problems relevant for nuclear physics research, SciDAC projects continue to serve as a water-shed for training scientists who can address national needs.

Funding for data analytics, which has synergies with AI/ML research, continues in FY 2022. These activities help develop cutting-edge techniques based on AI of relevance to nuclear science research, accelerator facility operations, and automated machine operations. In addition, theorists explore cross-cutting cloud solutions to Big Data storage challenges in Nuclear Physics with participation in the SC Integrated Computational & Data Infrastructure Initiative; the significant volumes of data collected from RHIC, CEBAF, FRIB and the future EIC pose particular challenges to the NP community.

The Request expands support for the activities of the USNDP to collect, evaluate, and disseminate nuclear physics data for basic nuclear research and for applied nuclear technologies and their development, providing for world-leading acquisition and dissemination of high quality data for public consumption. U.S. efforts focus on improving the completeness and reliability of data already archived that is used for industry and for a variety of Federal missions, and the USNDP expands the effort to conduct experiments needed 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. NP will collaborate with other Federal Agencies that are members of the NP-led Inter-Agency Nuclear Data Working Group, to carry out experimental measurements.

[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).

Nuclear Physics
Nuclear Theory

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Nuclear Theory	**$61,129**	**$60,781**	**-$348**
Research	$61,129	$60,781	-$348
Funding supports high priority QIS efforts. LQCD computing investments continue 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 fifth and final year of SciDAC-4 grants and the final year of theory topical collaborations initiated in FY 2017. Funding targets investments in an initiative to develop cutting-edge AI techniques of relevance to nuclear science research, accelerator facility operations, and automated machine operations.		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 first year of SciDAC-5 grants and theory topical collaborations. Funding will target investments in an initiative to develop cutting-edge data analytics techniques of relevance to nuclear science research, and accelerator facility operations. Theorists participate in the Computational and Data Infrastructure Initiatives to explore solutions to Big Data storage. This activity also supports the RENEW initiative to provide undergraduate and graduate training opportunities for students and academic institutions not currently well represented in the U.S. S&T ecosystem.	Funding for QIS and data analytics are partially distributed to other NP subprograms; overall in NP, the total investment for QIS will increase and the investment in data analytics is flat. Funding will also support participation in two other SC initiatives: the Integrated Computational & Data Infrastructure Initiative and the RENEW Initiative.

(dollars in thousands)

FY 2021 Enacted	FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Funding supports 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 critical experimental measurements to address gaps in existing nuclear data.	The Request will expand USNDP efforts to collect, evaluate, and disseminate nuclear physics data for basic nuclear research and for applied nuclear technologies and their development.	Support for experimental nuclear data efforts of the USNDP will increase.

Note: Funding for the subprogram above, includes 3.65% of research and development (R&D) funding for the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Programs.

Nuclear Physics
Isotope Development and Production for Research and Applications

Description
The Isotope Development and Production for Research and Applications subprogram (DOE Isotope Program, or DOE IP) is now a separate program. Please refer to the Isotope R&D and Production Program Budget Request.

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Isotope Development and Production for Research and Applications	**$66,000**	**$ —**	**-$66,000**
Research	$26,660	$ —	-$26,660
Funding supports 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 increases 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 continues the development of full scale processing and technology for the production of alpha-emitters for cancer therapy, such as Ac-225. Funding increases for 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. Funding also increases to expand the University 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 continue. Research to develop enrichment capability for new isotopes of importance increase.		Beginning in the FY 2022 Request, the Isotope Development and Production for Research and Applications subprogram is now a separate program. Funds are requested under the new Isotope R&D and Production Program within the Office of Science.	Beginning in the FY 2022 Request, the Isotope Development and Production for Research and Applications subprogram is now a separate program. Funds are requested under the new Isotope R&D and Production Program within the Office of Science.

(dollars in thousands)

FY 2021 Enacted	FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Operations $36,340	$ —	-$36,340
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. 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 are maintained. Funding continues 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. Funding supports 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.	Beginning in the FY 2022 Request, the Isotope Development and Production for Research and Applications subprogram is now a separate program. Funds are requested under the new Isotope R&D and Production Program within the Office of Science.	Beginning in the FY 2022 Request, the Isotope Development and Production for Research and Applications subprogram is now a separate program. Funds are requested under the new Isotope R&D and Production Program within the Office of Science.
Projects $3,000	$ —	-$3,000
Funding supports research and development and conceptual design OPC activities of the U.S. SIPRC construction project	Beginning in the FY 2022 Request, the Isotope Development and Production for Research and Applications subprogram is now a separate program. Funds are requested under the new Isotope R&D and Production Program within the Office of Science.	Beginning in the FY 2022 Request, the Isotope Development and Production for Research and Applications subprogram is now a separate program. Funds are requested under the new Isotope R&D and Production Program within the Office of Science.

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. The FY 2022 Request continues the construction effort for the Electron-Ion Collider (EIC). The estimated Total Project Cost (TPC) range for the EIC project, which is to be located at Brookhaven National Laboratory (BNL), is $1.7 billion to $2.8 billion. BNL has teamed with Thomas Jefferson National Accelerator Facility (TJNAF) to lead the development and implementation of the EIC. The EIC scope, cost, and schedule include an electron injector chain, an electron storage ring, modifications to one of the two Relativistic Heavy Ion Collider (RHIC) ion accelerators, and one interaction region with a colliding beam detector. The plan also allows for a second interaction region and its detector, although they are not part of the project scope. The project is expected to attract international collaboration and contribution.

Over the course of the implementation of the EIC, the activities of experienced RHIC scientists, engineers and technicians will be redirected to the EIC TPC as RHIC activities start to ramp down. These individuals represent the scientific and technical workforce that are essential to the operations of a complex facility like RHIC and eventually, the EIC. They have critical core competencies in collider operations that cannot easily be replaced and represent a part of the core facility operations workforce of RHIC and the EIC. The temporary reprioritization of funds from the collider facility operations budget to the construction budget will prioritize funding needed to implement the EIC, enabling a cost-effective path forward to the implementation of this world-leading facility.

Since the 2002 Long Range Plan (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 quantum chromodynamics, the theory of the strong force, which explains all strongly interacting matter in terms of points like quarks interacting via the exchange of gluons, acts in detail to generate the "macroscopic" properties of protons and neutrons. The 2015 LRP for Nuclear Science concluded, "…a high energy, polarized electron ion collider is the highest priority for new facility construction..." 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.

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request		Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Construction	**$22,300**		**$20,000**	**-$2,300**
20-SC-51, U.S. Stable Isotope Production and Research Center (SIPRC), ORNL	$12,000		$ —	-$12,000
Funding supports 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.		Funds will be requested under the new Isotope R&D and Production Program within the Office of Science.		Funds will be requested under the new Isotope R&D and Production Program within the Office of Science.
20-SC-52, Electron Ion Collider (EIC), BNL	$5,000		$20,000	+$15,000
Funding continues TEC 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. RHIC operations includes a “reprioritization” of expert workforce from the RHIC facilities operations budget to support the EIC OPC and TEC request.		Funding will support ongoing engineering and design efforts.
14-SC-50, Facility for Rare Isotope Beams (FRIB), MSU	$5,300		$ —	-$5,300
Funding supports the completion of cryomodule installation, experimental systems installation, and testing. Funding also continues commissioning efforts associated with technical components as they are completed. This is the final year of funding. Project completion is planned in FY 2022.		No funding planned in FY 2022.		The FY 2021 Enacted reflects the final year of funding for FRIB.

Nuclear Physics
Capital Summary

(dollars in thousands)

	Total	Prior Years	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Capital Operating Expenses						
Capital Equipment	N/A	N/A	30,291	34,243	30,411	-3,832
Minor Construction Activities						
General Plant Projects	N/A	N/A	9,616	1,579	1,626	+47
Accelerator Improvement Projects	N/A	N/A	7,268	8,456	5,159	-3,297
Total, Capital Operating Expenses	**N/A**	**N/A**	**47,175**	**44,278**	**37,196**	**-7,082**

Capital Equipment

	(dollars in thousands)					
	Total	**Prior Years**	**FY 2020 Enacted**	**FY 2021 Enacted**	**FY 2022 Request**	**FY 2022 Request vs FY 2021 Enacted**
Capital Equipment						
Major Items of Equipment						
Heavy Ion Physics						
Super Pioneering High Energy Nuclear Interaction Experiment (sPHENIX)	20,573	5,310	9,520	5,530	213	-5,317
Low Energy Physics						
Gamma-Ray Energy Tracking Array (GRETA), LBNL	58,400	12,300	6,600	6,600	6,600	–
High Rigidity Spectrometer	97,940	240	1,000	3,000	3,000	–
MOLLER	46,050	–	2,000	5,000	7,000	+2,000
Ton-Scale Neutrinoless Double Beta Decay (NLDBD) MIE	234,540	–	1,000	1,400	1,440	+40
Isotope Development and Production for Research and Applications						
Stable Isotope Production Facility (SIPF), ORNL	25,500	24,000	1,500	–	–	–
Total, MIEs	N/A	N/A	21,620	21,530	18,253	-3,277
Total, Non-MIE Capital Equipment	N/A	N/A	8,671	12,713	12,158	-555
Total, Capital Equipment	**N/A**	**N/A**	**30,291**	**34,243**	**30,411**	**-3,832**

Note:

- *The High Ridgity Spectrometer (HRS) is not an MIE, but a research project supported on a cooperative agreement with Michigan State University.*
- *The Capital Equipment table includes MIEs located at a DOE facility with a Total Estimated Cost (TEC) > $5M and MIEs not located at a DOE facility with a TEC >$2M.*

Minor Construction Activities

(dollars in thousands)

	Total	Prior Years	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
General Plant Projects (GPP)						
GPPs (greater than or equal to $5M and less than $20M)						
End Station Refrigerator	9,500	–	9,500	–	–	–
Total GPPs (greater than or equal to $5M and less than $20M)	N/A	N/A	9,500	–	–	–
Total GPPs less than $5M	N/A	N/A	116	1,579	1,626	+47
Total, General Plant Projects (GPP)	**N/A**	**N/A**	**9,616**	**1,579**	**1,626**	**+47**
Accelerator Improvement Projects (AIP)						
AIPs (greater than or equal to $5M and less than $20M)						
FRIB Isotope Harvesting	5,500	–	2,000	3,500	–	-3,500
Total AIPs (greater than or equal to $5M and less than $20M)	N/A	N/A	2,000	3,500	–	-3,500
Total AIPs less than $5M	N/A	N/A	5,268	4,956	5,159	+203
Total, Accelerator Improvement Projects (AIP)	**N/A**	**N/A**	**7,268**	**8,456**	**5,159**	**-3,297**
Total, Minor Construction Activities	**N/A**	**N/A**	**16,884**	**10,035**	**6,785**	**-3,250**

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 on 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 have been 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 2022 Request for sPHENIX of $213,000 is the final year of TEC funding. SC is assessing the impact of COVID on project performance.

Low Energy Nuclear Physics: Nuclear Structure and Nuclear Astrophysics MIEs and Research Project:

Gamma-Ray Energy Tracking Array (GRETA) MIE

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. CD-2/3 was obtained October 7, 2020 with a TPC of $58,300,000. The FY 2022 Request for GRETA is below the CD-2/3 baseline at $6,600,000 of TEC funding. SC is assessing the impact of constrained funding in FY 2021. SC is assessing the impact of COVID on project performance.

High Rigidity Spectrometer (HRS) Research Project

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 is being funded through a cooperative agreement with MSU and is not a capital asset (MIE). CD-0 was approved November 2018. CD-1 was approved in September 2020, with a TPC range of $85,000,000 to $111,400,000. The FY 2022 Request for the HRS of $3,000,000 will support the management team, coordination of collaboration activities and allow preliminary engineering and design work towards future critical decision points.

Low Energy Nuclear Physics: Fundamental Symmetries MIEs:

Ton-Scale Neutrino-less Double Beta Decay (NLDBD) Experiment MIE

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, several demonstrator efforts using smaller volumes of isotopes and various technologies (bolometry in tellurium dioxide (TeO2) crystals, light collection in liquid xenon, 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 10^{25} years. The goal of a next generation ton-scale experiment is to reach a lifetime limit of 10^{28} years. For reference, the "lifetime limit" discussed is the time one might have to wait to observe neutrino-less double beta decay if observing a single nucleus only. Fortunately, in the ton of isotope planned for the ton-scale neutrino-less double beta decay experiment there are many trillions of nuclei. Thus, such decays, if they exist, should be observable on a much more reasonable timescale (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 to $250,000,000. The FY 2022 Request of $1,440,000 will support the management team and collaboration activities. SC is assessing the impact of COVID on project performance.

Measurement of a Lepton-Lepton Electroweak Reaction (MOLLER) MIE

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. CD-1 was approved in December 2021 with a TPC range of $42,000,000 to $60,100,000. The 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 FY 2022 Request for MOLLER of $7,000,000 is the third year of TEC funding.

Nuclear Physics
Construction Projects Summary

	(dollars in thousands)					
	Total	**Prior Years**	**FY 2020 Enacted**	**FY 2021 Enacted**	**FY 2022 Request**	**FY 2022 Request vs FY 2021 Enacted**
20-SC-51, U.S. Stable Isotope Production and Research Center, ORNL						
Total Estimated Cost (TEC)	24,000	–	12,000	12,000	–	-12,000
Other Project Cost (OPC)	5,600	500	2,100	3,000	–	-3,000
Total Project Cost (TPC)	**29,600**	**500**	**14,100**	**15,000**	**–**	**-15,000**
20-SC-52, Electron Ion Collider						
Total Estimated Cost (TEC)	2,061,000	–	1,000	5,000	20,000	+15,000
Other Project Cost (OPC)	187,650	–	10,000	24,650	10,000	-14,650
Total Project Cost (TPC)	**2,248,650**	**–**	**11,000**	**29,650**	**30,000**	**+350**
14-SC-50, Facility for Rare Isotope Beams (FRIB), Michigan State University						
Total Estimated Cost (TEC)	635,500	590,200	40,000	5,300	–	-5,300
Total Project Cost (TPC)	**635,500**	**590,200**	**40,000**	**5,300**	**–**	**-5,300**
Total, Construction						
Total Estimated Cost (TEC)	**N/A**	**N/A**	**53,000**	**22,300**	**20,000**	**-2,300**
Other Project Cost (OPC)	**N/A**	**N/A**	**12,100**	**27,650**	**10,000**	**-17,650**
Total Project Cost (TPC)	**N/A**	**N/A**	**65,100**	**49,950**	**30,000**	**-19,950**

Notes:

- *The total for the U.S. Stable Isotope Production and Research Center (SIPRC) of $29,600,000 does not include $220,400,000 included in the Isotopes R&D and Production program beginning in FY 2022. All future requests for SIPRC will be through the Isotope R&D and Production Program.*
- *The total for FRIB 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.*

Nuclear Physics
Funding Summary

(dollars in thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Research	223,300	225,191	233,455	+8,264
Facility Operations	399,380	414,545	434,483	+19,938
Projects				
Line Item Construction (LIC)	65,100	49,950	30,000	-19,950
Major Items of Equipment (MIE)	21,620	21,530	18,253	-3,277
Total, Projects	**86,720**	**71,480**	**48,253**	**-23,227**
Other	3,600	1,784	3,809	+2,025
Total, Nuclear Physics	**713,000**	**713,000**	**720,000**	**+7,000**

Nuclear Physics
Scientific User Facility Operations

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

Definitions 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.

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 2020 Enacted	FY 2020 Current	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Scientific User Facilities - Type A					
Relativistic Heavy Ion Collider	**193,678**	**192,799**	**187,527**	**191,519**	**+3,992**
Number of Users	990	1,007	1,010	1,010	–
Achieved Operating Hours	–	4,041	–	–	–
Planned Operating Hours	3,260	3,700	3,130	2,310	-820
Optimal Hours	3,700	–	3,130	2,580	-550
Percent of Optimal Hours	88.1%	88.1%	100.0%	90.0%	-10.0%
Continuous Electron Beam Accelerator Facility	**127,173**	**130,593**	**122,315**	**153,794**	**+31,479**
Number of Users	1,690	1,623	1,560	1,620	+60
Achieved Operating Hours	–	2,587	–	–	–
Planned Operating Hours	2,560	2,820	780	3,790	+3,010
Optimal Hours	2,560	–	1,890	4,220	+2,330
Percent of Optimal Hours	100.0%	100.0%	41.3%	90.0%	+48.7%
Facility for Rare Isotope Beams	**28,500**	**28,500**	**51,825**	**82,106**	**+30,281**
Number of Users	–	–	–	605	+605
Planned Operating Hours	–	–	–	2,310	+2,310
Optimal Hours	–	–	–	2,310	+2,310
Percent of Optimal Hours	–	–	–	100.0%	+100.0%

	(dollars in thousands)				
	FY 2020 Enacted	**FY 2020 Current**	**FY 2021 Enacted**	**FY 2022 Request**	**FY 2022 Request vs FY 2021 Enacted**
Argonne Tandem Linac Accelerator System	**25,846**	**27,657**	**24,539**	**26,708**	**+2,169**
Number of Users	340	304	305	305	–
Achieved Operating Hours	–	4,529	–	–	–
Planned Operating Hours	5,950	5,950	5,350	5,800	+450
Optimal Hours	6,400	–	5,780	6,250	+470
Percent of Optimal Hours	93.0%	93.0%	92.6%	92.8%	+0.2%
Total, Facilities	**375,197**	**379,549**	**386,206**	**454,127**	**+67,921**
Number of Users	3,020	2,934	2,875	3,540	+665
Achieved Operating Hours	–	11,157	–	–	–
Planned Operating Hours	11,770	12,470	9,260	14,210	+4,950
Optimal Hours	12,660	–	10,800	15,360	+4,560

Note:

- *Achieved Operating Hours and Unscheduled Downtime Hours will only be reflected in the Congressional budget cycle which provides actuals.*
- *In FY 2022, the MOLLER MIE (CEBAF) and sPHENIX MIE (BNL) are not included in the funding amounts above.*
- *The FY 2022 Request level for CEBAF funding includes Theory Research funds which are not included in the FY 2020 Enacted ($3,789,000), FY 2020 Current ($3,789,000), and FY 2021 Enacted ($4,222,000) columns.*
- *For FY 2021, FRIB planned operating hours and optimal hours include 800 hours of operations (commissioning) that are supported from FRIB construction funding that are part of the project TPC. FY 2021 is the first year of operations after project completion.*

Nuclear Physics
Scientific Employment

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Number of Permanent Ph.Ds (FTEs)	839	819	880	+61
Number of Postdoctoral Associates (FTEs)	326	328	381	+53
Number of Graduate Students (FTEs)	530	532	546	+14
Number of Other Scientific Employment (FTEs)	1,030	1,029	1,003	-26

Note: Number of Other Scientific Employment (FTEs) include technicians, engineers, computer professionals and other support staff.

20-SC-52, Electron Ion Collider (EIC), BNL
Brookhaven National Laboratory
Project is for Design

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

Summary
The FY 2022 Request for the Electron-Ion Collider (EIC) is $20,000,000 of Total Estimated Cost (TEC) funding and $10,000,000 of Other Project Cost (OPC) funding. The current Total Project Cost (TPC) estimate is $1,700,000,000 to $2,800,000,000.

Significant Changes
The EIC was initiated in FY 2020. The most recent DOE Order 413.3B approval, Critical Decision (CD)-0, Approve Mission Need, was received on December 19, 2019. In this Project Data Sheet (PDS), the estimated completion date of the EIC has been changed to FY 2033, reflecting the level of FY 2021 Enacted funding and additional schedule contingency as recommended by peer review. In addition, the preliminary TPC has been decreased in this PDS to reflect the preliminary point estimate as opposed to the upper value of the TPC range presented in the FY 2021 PDS.

In FY 2020, the Analysis of Alternatives was completed by the project team and peer reviewed by an independent panel. The EIC has completed conceptual design on January 12, 2021 and is preparing for CD-1, Approve Alternative Selection and Cost Range, planned in the 3Q FY 2021. In FY 2022, the EIC team will focus on preliminary design of the collider machine and detector instrumentation. Of the $30,000,000 TPC funding requested in FY 2022, $20,000,000 in TEC funding will support the development and completion of the preliminary design. $10,000,000 will be needed for research and development (OPC) to validate technical assumptions and to reduce project risk prior to start of construction.

A Federal Project Director (FPD) has been assigned to this project and has approved this project data sheet. The FPD completed Level 3 certification in FY 2021, 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	CD-4
FY 2021	12/19/19	4Q FY 2020	4Q FY 2020	4Q FY 2022	TBD	4Q FY 2023	4Q FY 2030
FY 2022	12/19/19	01/12/21	3Q FY 2021	2Q FY 2023	3Q FY 2024	3Q FY 2024	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

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	340,000	2,010,000	2,350,000	250,000	N/A	250,000	2,600,000
FY 2022[a]	413,000	1,648,000	2,061,000	187,650	N/A	187,650	2,248,650

2. Project Scope and Justification

Scope

The scope of this project is to design and build the EIC at Brookhaven National Laboratory (BNL) that will fulfill the scientific gap as identified in the 2015 Nuclear Science Advisory Committee (NSAC) Long Range Plan (LRP). BNL is partnering with Thomas Jefferson National Accelerator Facility (TJNAF) in the implementation of the EIC. The EIC will have performance parameters that include a high beam polarization of >70 percent from both electrons and light ions, and the capability to accommodate ion beams from deuterons to the heaviest stable nuclei. The EIC will also have variable center of mass energies from 20 to 100 GeV and upgradable to 140 GeV, high collision luminosity from 10^{33} -10^{34} $cm^{-2}s^{-1}$, one detector and one interaction region at project completion, and the capability for a second interaction region and second detector.

The scope also includes a new electron injection system and storage ring while taking full advantage of the existing infrastructure by modifying the existing hadron facility of the Relativistic Heavy Ion Collider (RHIC) infrastructure at BNL.

The electron system will include a highly polarized room temperature photo-electron gun and a 400 MeV linac to be installed in an existing available straight section of the RHIC tunnel. It will include a transfer line that brings the electrons into the storage ring at the energy of 5 -18 GeV that will be installed in the existing 2.4 mile circular RHIC tunnel.

Modifications to the existing hadron system include the injection, transfer line and storage ring to increase beam energy to 275 GeV. It will include a strong-hadron-cooling system to reduce and maintain the hadron beam emittance to the level needed to operate with the anticipated luminosity of 10^{33} -10^{34} $cm^{-2}s^{-1}$.

The interaction region will have superconducting final focusing magnets, crab-cavities and spin rotators to provide longitudinally polarized beams for collisions, where the outgoing particles will be collected by one detector.

An enhanced 2 K liquid helium cryogenic plant is provided for the superconducting radiofrequency cavities, with enhanced water cooling capacity and cooling towers and chillers to stabilize the environment in the existing tunnel. Civil construction will also include electrical systems, service buildings, and access roads.

It is anticipated that non-DOE funding sources such as international collaborations, the National Science Foundation, and the State of New York, will contribute to the EIC Project. The timeframe for commitments by non-DOE contributors will vary throughout the life of the project and become more certain as the project progresses. All non-DOE funding sources will be closely coordinated with the Office of Nuclear Physics and will be incorporated into the project through the change control process once baselined.

Justification

The last three Nuclear Science Advisory Committee (NSAC) Long Range Plan (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

[a] The project is pre-CD-2; the estimated cost and schedule shown are preliminary.

highest priority for new facility construction following the completion of the Facility for Rare Isotope Beams. Consistent with that vision, in 2016 NP commissioned a National Academies of Sciences, Engineering, and Medicine 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 Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets.*

Key Performance Parameters (KPPs)
The 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 project performance stretch goal. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

Performance Measure	Threshold	Objective
Conventional facilities	BOD for at least 90,000 gross square feet of new construction.	BOD for at least 90,000 gross square feet of new construction.
Center-of-Mass	Center-of-mass energy measured in the range of 20 GeV- 100 GeV.	Center-of-mass energy measured in the range of 20 GeV- 140 GeV.
Beam Species	Accelerator capable of delivering beams of protons and a heavy nucleus such as Au.	Ability to deliver a versatile choice of beams from protons and light ions to heavy ions such as Au.
Detector system	Detector installed and ready for beam operations.	Inelastic scattering events in the e-p and e-A collisions measured in Detector.
Beam Polarization	Hadron beam polarization of > 50% and electron beam polarization of > 40% measured at E_{cm} = 100 GeV.	Hadron beam polarization of > 60% measured at E_{cm} = 100 GeV and electron beam polarization of > 50% measured at E_{cm} = 100 GeV.
Luminosity	Luminosity for e-p collisions measured up to 1.0×10^{32} cm^{-2} s^{-1}.	Luminosity greater than 1.0×10^{33} cm^{-2} s^{-1}.

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
Design (TEC)			
FY 2020	1,000	1,000	–
FY 2021	5,000	5,000	5,750
FY 2022	20,000	20,000	19,750
Outyears	387,000	387,000	387,500
Total, Design (TEC)	**413,000**	**413,000**	**413,000**
Construction (TEC)			
Outyears	1,648,000	1,648,000	1,648,000
Total, Construction (TEC)	**1,648,000**	**1,648,000**	**1,648,000**
Total Estimated Cost (TEC)			
FY 2020	1,000	1,000	–
FY 2021	5,000	5,000	5,750
FY 2022	20,000	20,000	19,750
Outyears	2,035,000	2,035,000	2,035,500
Total, TEC	**2,061,000**	**2,061,000**	**2,061,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Other Project Cost (OPC)			
FY 2020	10,000	10,000	6,120
FY 2021	24,650	24,650	24,150
FY 2022	10,000	10,000	12,000
Outyears	143,000	143,000	145,380
Total, OPC	**187,650**	**187,650**	**187,650**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Project Cost (TPC)			
FY 2020	11,000	11,000	6,120
FY 2021	29,650	29,650	29,900
FY 2022	30,000	30,000	31,750
Outyears	2,178,000	2,178,000	2,180,880
Total, TPC	**2,248,650**	**2,248,650**	**2,248,650**

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design	298,000	250,000	**N/A**
Design - Contingency	115,000	90,000	**N/A**
Total, Design (TEC)	**413,000**	**340,000**	**N/A**
Construction	1,177,000	1,490,000	**N/A**
Construction - Contingency	471,000	520,000	**N/A**
Total, Construction (TEC)	**1,648,000**	**2,010,000**	**N/A**
Total, TEC	**2,061,000**	**2,350,000**	**N/A**
Contingency, TEC	*586,000*	*610,000*	***N/A***
Other Project Cost (OPC)			
R&D	46,650	30,000	**N/A**
Conceptual Design	11,000	40,000	**N/A**
Other OPC Costs	93,000	115,000	**N/A**
OPC - Contingency	37,000	65,000	**N/A**
Total, Except D&D (OPC)	**187,650**	**250,000**	**N/A**
Total, OPC	**187,650**	**250,000**	**N/A**
Contingency, OPC	*37,000*	*65,000*	***N/A***
Total, TPC	**2,248,650**	**2,600,000**	**N/A**
Total, Contingency (TEC+OPC)	***623,000***	***675,000***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Request Year	Type	Prior Years	FY 2020	FY 2021	FY 2022	Outyears	Total
FY 2021	TEC	—	1,000	1,000	—	—	—
	OPC	—	10,000	1,500	—	—	—
	TPC	—	11,000	2,500	—	—	—
FY 2022	TEC	—	1,000	5,000	20,000	2,035,000	2,061,000
	OPC	—	10,000	24,650	10,000	143,000	187,650
	TPC	—	11,000	29,650	30,000	2,178,000	2,248,650

6. Related Operations and Maintenance Funding Requirements

Over the course of the implementation of the EIC, NP will redirect experienced RHIC scientists, engineers, and technicians from RHIC operations to the EIC project. This is a gradual movement to balance the need for the scientific experts with RHIC while ramping up EIC project. These individuals represent the scientific and technical workforce that are essential to the operations of a complex facility like RHIC and eventually, the EIC. They have critical core competencies in collider operations that cannot easily be replaced, and they represent the core facility operations force of RHIC and the EIC. In the FY 2022 Request, RHIC Operations includes a “reprioritization” of expert workforce from the RHIC facility operations budget to support the EIC OPC and TEC request. The temporary reprioritization of funds from the facility operations budget to the construction budget will reduce the amount of “new funds” needed to implement the EIC, enabling a cost-effective path forward to the implementation of this world-leading facility. As the EIC nears CD-4 when the machine will be restarted, the scientists, engineers and technicians that are needed to operate the EIC will be transferred back to the facility operations budget.

Start of Operation or Beneficial Occupancy	4Q FY 2031
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, Maintenance and Repair	TBD	TBD	TBD	TBD

7. D&D Information

As part of the upgrade and renovation of the existing accelerator facilities, up to 200,000 square feet of industrial space will be built as service buildings to house mechanical and electrical equipment.

	Square Feet
New area being constructed by this project at BNL	200,000
Area of D&D in this project at BNL	0
Area at BNL to be transferred, sold, and/or D&D outside the project, including area previously "banked"	N/A
Area of D&D in this project at other sites	N/A
Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked"	N/A
Total area eliminated	0

8. Acquisition Approach

SC selected Brookhaven National Laboratory (BNL) as the site for the EIC on January 9, 2020. NP will approve the Acquisition Strategy in conjunction with CD-1. DOE will utilize the expertise of the Managing and Operating contractors at BNL and TJNAF to manage the project including the design, fabrication, monitoring cost and schedule, and delivering the technical performance specified in the KPPs. A certified Earned Value Management System already exists at both Laboratories and will be implemented to evaluate project progress and to ensure consistence with DOE O 413.3B, Program and Project Management for the Acquisition of Capital Assets.

Isotope R&D and Production

Overview

The DOE Isotope Program (DOE IP), which includes both the appropriated funding requested in the Isotope R&D and Production (IRP) program, as well as collections in the revolving fund, produces critical radioactive and stable isotopes in short supply for the Nation that no domestic entity has the infrastructure or core competency to produce; the Program is typically the only, or one of few, global or domestic producers for these novel isotopes. Isotopes are high-priority commodities of strategic importance for the Nation and are essential in medical diagnosis and treatment, discovery science, national security and preparedness, industrial processes and advanced manufacturing, space exploration and communications, biology, archaeology, quantum science, clean energy, environmental science, and other fields. Isotopes can directly enable emerging technology, and contribute to the economic, technical and scientific strength of the United States. The mission of the DOE IP is to:

- Produce and/or distribute radioactive and enriched stable isotopes that are in short supply or not produced in the U.S., including valuable by-products and related isotope services.
- Ensure National preparedness for critical isotope production and distribution by maintaining mission readiness of relevant national infrastructure and core competencies, to ensure functionality even during times of national crisis.
- Conduct advanced R&D to develop innovative technology, advanced radiochemical separations and purifications, and unique and diverse core competencies to create or improve entirely novel isotope production and radiochemistry processing capability.
- Mitigate U.S. dependence on foreign supplies of isotopes and ensure robust domestic supply chains.

The DOE IP utilizes particle accelerators, nuclear research reactors, enrichment technologies, and radiochemical processing capabilities throughout the national laboratory complex and at universities that it stewards, or leverages capabilities stewarded by other federal programs or academic institutions to most cost effectively utilize national capabilities to meet the requirements of the Nation in isotope demand. During the COVID-19 pandemic, the DOE IP continued operating as a department “Mission Essential Function” to ensure stability in critical supply chains and intervened multiple times to fill gaps in international disruptions in supply chains of critical isotopes for medical applications. The DOE IP works closely with U.S. industry to ensure availability of adequate, high quality isotopic supply for continued stability and planned growth, and facilitates commercialization of isotope production to the domestic private sector. The DOE IP supports world-leading research and development associated with creating innovative and more efficient isotope production and processing techniques. The R&D activities provide collateral benefits for training, workforce development, and promotion of a future U.S.-based expertise relevant to nuclear energy, accelerator science, nuclear engineering, nuclear physics, isotope enrichment, and nuclear chemistry and radiochemistry. These disciplines are foundational, not only to isotope production and processing, but underpin many critical aspects of basic and applied nuclear and radiochemical science.

The DOE IP manages federal inventories of key isotopes, such as helium-3 for cryogenics and other applications, and the national repository for all stable isotopes that were created by calutrons (electro-magnetic ion separation) developed as part of the Manhattan Project; the calutrons ceased operations in 1998. The U.S. inventory of stable isotopes is limited or has even been depleted in some cases, causing the U.S. to be dependent on foreign supply chains for certain stable isotopes. The DOE IP has developed and implemented modern stable isotope enrichment capabilities to replenish supplies and promote U.S. independence from foreign supply. The DOE IP also considers DOE-owned legacy waste or inventories and extracts isotopes of interest to re-purpose unwanted or excess materials and reduce waste disposal.

The National Isotope Development Center (NIDC) is located at the Oak Ridge National Laboratory (ORNL) and is responsible for the day-to-day business operations of the programs, including sales, contract negotiation, marketing assessment, public outreach, quality control, packaging and transportation. The NIDC interfaces regularly with industry, research, and medical communities to gauge future needs since new isotopes can take years of research and development to bring to market.

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 this appropriation for the Isotope R&D and Production Office, along with collections from customers for the sale of isotopes and services. The funds in this Budget Request are used to ensure mission readiness of the staff, facilities, and capabilities; to support R&D activities related to the production and processing of isotopes; and to strengthen and develop new capabilities to meet the growing demand of the Nation for isotopes. The customer collections pay for the activities associated with the actual production, distribution, and related services of the isotope. Isotopes sold to commercial customers are priced to recover the full cost of production, or if a market actually exists, 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.

Highlights of the FY 2022 Request

In FY 2022, the DOE IP anticipates continued growth in novel isotope demand, especially for medicine, nuclear batteries, space applications, clean energy, national security, biology, discovery research and quantum computing. In medicine, there is interest in alpha and beta emitters for revolutionary cancer and infectious disease therapy and diagnostics. The DOE IP has established itself as the world leader in this arena, typically being the sole global source for many of these isotopes of interest or leading the way in transformative research to make them available. Interests in isotopes for biological imaging and as biological tracers continue to rise. There is a current global shortage for isotopes needed for nuclear batteries and the DOE IP is positioning itself to enter a market in which there is only one other foreign producer. Interests in isotopes for space applications are also on the rise, and the DOE IP anticipates working with an increasing number of industrial entities in testing isotopes for nuclear batteries used in space applications and producing novel isotopes for atomic clocks used in satellite communications.

In FY 2022, mission readiness of both radio- and stable isotope production facilities modestly increases over levels in the FY 2021 Enacted Appropriation. The DOE IP is not able to keep pace with incoming requests for stable isotopes and is developing additional stable isotope enrichment capabilities as quickly as it can. The only other global producers/exporters of enriched stable isotopes are Russia, followed by the Netherlands. The implementation of the Stable Isotope Production Facility (SIPF) Major Item of Equipment (MIE) is continued, and funds in FY 2022 are requested for pre-operations funding to start commissioning SIPF gas centrifuges (GC) to produce enriched Xenon-129. Xenon-129 is the newest isotope to show its effectiveness in polarized lung imaging; there is no U.S. production capability. This isotope has also garnered the interest of the medical community in monitoring lung function and damage from infectious disease such as COVID-19. The FY 2022 Request includes $3.2 million in Other Project Cost (OPC) and $12.0 million in Total Estimated Cost (TEC) funding to continue the U.S. Stable Isotope Production and Research Center (SIPRC) at ORNL, which will significantly enhance stable isotope production capacity for the Nation. SIPRC will build upon the expertise in centrifuge and electromagnetic isotope separation (EMIS) technology nurtured by SIPF and the Enriched Stable Isotope Prototype Plant (ESIPP) to enable multiple production campaigns of critical stable isotopes simultaneously.

Funding in research strengthens or initiates participation in several high priority Office of Science initiatives. The DOE IP joins the SC Fundamental Science to Transform Advanced Manufacturing Initiative and pursues transformative approaches to target advanced manufacturing, such as ink jet printing of thin film targets for isotope production, and modular automated systems for radioisotope purification and processing. In cooperation with the NIH, the DOE IP focuses on research facilitating the translation of novel radioisotopes and targeted delivery agents from the laboratory to use in clinical trials for both diagnosis and treatment of disease, supporting a known “valley of death” that lies at the intersection of these two federal programs. As part of the Biopreparedness Research Virtual Environment (BRaVE) Initiative, the DOE IP will tackle what has become a significant obstacle and single point failure in the program, processing of irradiated nuclear reactor targets. This is actively limiting the ability of the Program to make available certain new isotopes and provide assurance of the Nation’s readiness to respond to disruptions in global isotope supply chains. Funding will develop short-term reactor target processing capabilities at the University of Missouri Research Reactor (MURR) and further develop the conceptual design of a new long-term facility at ORNL, the ORNL Radioisotope Processing Facility (RPF). Increased investment in the ongoing SC Quantum Information Sciences (QIS) Initiative will advance development of cutting-edge technology for the production of isotopes of interest to QIS. Funding continues the Isotope Program Traineeship to promote innovative and transformative approaches to isotope production and processing, such as advanced manufacturing, artificial intelligence and machine learning, and robotics; the Traineeship emphasizes participation of minority serving institutions and increasing the diversity of the program.

The portfolio of production capabilities in the DOE IP continues to grow to meet the rapidly changing needs of U.S. Federal Agencies, the medical community, industry and academia. The FY 2022 Request continues the Facility for Rare Isotope

Beams (FRIB) Isotope Harvesting at Michigan State University effort, which adds the capabilities to extract and process significant quantities of isotopes from the beam dump of the FRIB, cost effectively repurposing unwanted product. FRIB is a Nuclear Physics DOE Scientific User Facility dedicated to the study of nuclear structure and astrophysics research. Funding supports newcomers to the DOE IP, an inherited radioisotope separation system at Idaho National Laboratory (INL) that can make small quantities of highly enriched and pure isotopes for the nuclear forensics community; and a modest increase for the new group at Argonne National Laboratory (ANL) that brought to the Program an electron accelerator for novel isotope production. The FY 2022 Request also continues increased funding to prepare ORNL facilities for the receipt, storage, and processing of the heavy curium product stream (for use in californium-252 and actinide production) coming from 65 Mark 18-A targets from the National Nuclear Security Administration (NNSA) recovery project at the Savannah River Site (SRS).

<u>Research</u>
The DOE IP supports core research groups at ANL, Brookhaven National Laboratory (BNL), INL, Los Alamos National Laboratory (LANL), ORNL, and Pacific Northwest National Laboratory (PNNL) to conduct transformative research for novel or advanced production and separation techniques for high priority isotopes in short supply. A high priority of the DOE IP remains the dedicated research effort to develop large scale production capabilities of the alpha-emitter 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 of Ac-225 derived from thorium-229 (Th-229) have limited clinical trials and applications. The DOE IP leads the world in the provision of Ac-225 and development of novel production routes. DOE IP now routinely produces accelerator-produced Ac-225 and is continuing research to develop efficient full-scale production and processing capabilities to enable sufficient supply of the isotope for cancer treatment.

The lack of processing capabilities for processing irradiated reactor targets is significantly limiting the DOE IP in making available new isotopes and represents a single point failure in national preparedness to respond to disruptions in global isotope supply chains. As part of the SC Biopreparedness Research Virtual Environment (BRaVE) Initiative, research enables a scientific and technical workforce and capability to process reactor targets at MURR in order to introduce domestic supplies of critical isotopes to the Nation, such as iridium-192 for industrial radiography and lutetium-177 for prostate cancer. In parallel, scientists and engineers are developing options and the conceptual design of the Radioisotope Processing Facility for new long-term capabilities at ORNL.

Competitive research funds to universities and national laboratories support activities in a myriad of 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. Research topics include production of highly enriched lithium-7 for molten salt reactors, new sources of helium-3 for cryogenics, advanced manufacturing approaches to isotope production, critical nuclear data measurements, novel radioisotope enrichment technology, next generation targetry, modular automated systems, the application of machine learning and artificial intelligence to isotope production, and production of neptunium-236 for nuclear forensics. Scientists conduct translational research aimed at facilitating promising isotopes for use in clinical trials for the diagnosis and treatment of infectious disease and cancer; activities focus on basic chemistry (chelates, labeling, stability), biodistribution, toxicity, and dosimetry research that is necessary to develop sufficient data to be able to apply for an NIH grant for drug development.

Scientists perform simulations and conduct cutting-edge research to develop stable isotope enrichment capabilities. Every stable isotope enriched requires an intense and independent research campaign. Current efforts include ytterbium (Yb)-176 as feedstock for isotopes that treat prostate cancer, Yb-171 for quantum memory, xenon (Xe)-129 for polarized lung imaging, and molybdenum (Mo)-100 as feedstock for Mo-99 production. Dedicated machines are designed and optimized for isotopes of interest for quantum computing. In addition, as this technology is 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 and other enrichment technologies are investigated. Research to promote clean energy considers isotopically tailored low activation materials for fusion and fast fission nuclear reactors, and transformative technology development to enrich isotopes that can yield fuel cycle cost savings and reduced nuclear waste.

The DOE IP supports universities with unique capabilities, such as the multi-particle cyclotron at the University of Washington where full-scale production of astatine-211 was developed to support research into the use of the isotope in cancer therapy; and the University of Missouri Research Reactor which the DOE IP uses for the production of lutetium (Lu)-177 for cancer therapy research, and selenium-75 for biomedical research. Funding also supports implementation of isotope production capabilities at additional facilities at Texas A&M University, the University of Alabama-Birmingham, University of Pennsylvania, and the University of Wisconsin. The coordinated university 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.

Emphasis is placed on providing training opportunities to students and post-docs to help assure a vibrant diverse workforce essential to the technologies associated with isotope production. In addition to the recently initiated DOE IP Traineeship Program which supports undergraduate and graduate students, the DOE IP also sponsors workshops at professional society meetings to promote communication of advances in isotope availability and 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 Basic Energy Sciences (BES) and Nuclear Physics (NP) programs, 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.

Facility Operations

The DOE IP is the steward of several facilities for isotope production and processing, and in addition, leverages facilities and capabilities across the United States government complex that are owned by other federal entities. The DOE IP stewards the Isotope Production Facility (IPF) at LANL, the Brookhaven Linac Isotope Producer (BLIP) facility at BNL, the ESIPP at ORNL, and hot cell facilities for processing and handling irradiated materials and purified products at ORNL, BNL, and LANL. In addition, the DOE IP utilizes the capabilities of the Low Energy Accelerator Facility (LEAF) at ANL, the High Flux Isotope Reactor (HFIR) at ORNL, the INL Advanced Test Reactor (ATR), Pacific Northwest National Laboratory (PNNL) for processing and packaging strontium-90, the Y-12 National Security Complex for processing and packaging lithium-6 and lithium-7, the LANL Plutonium Facility for extracting americium-241 from NNSA plutonium processes, the Savannah River Site (SRS) for the extraction and distribution of helium-3, and the radioisotope separator at INL for nuclear forensic isotopes.

The DOE IP ensures National Preparedness or mission readiness for the production and processing of isotopes at this growing portfolio of production sites to provide domestic supply chains of critical isotopes not available commercially or domestically; the isotope production costs are paid by the customer. Operating and capital investments enable critical and compelling enhancements to production or processing capability, including recovery of valuable isotopes from legacy reactor targets (Mark 18-A); development of enrichment capabilities for heavier stable isotopes; the fabrication and assembly of enrichment technology. Scientists and engineers support the implementation of Food and Drug Administration (FDA) regulatory requirements for production of isotopes such as actinium-225 to enable their use in future or approved radiopharmaceuticals.

DOE IP operations of ESIPP at ORNL produce research quantities of enriched stable isotopes through the use of electromagnetic separation and centrifuge technology. The first campaign at ESIPP produced ruthenium-96 to provide the otherwise unavailable world-wide target material to the Relativistic Heavy Ion Collider (RHIC) for its planned physics program. ESIPP is now focused on production of ytterbium-176, currently only produced in Russia, needed for the production of no-carrier added (NCA) lutetium-177, which is used in a drug to treat prostate cancer. The DOE IP is expanding enriched stable isotope production capabilities with the implementation of the SIPF MIE and SIPRC line item construction project.

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-254, 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;
- silicon-32 for oceanography and climate modeling;
- ytterbium-171 for quantum memory;
- nickel-63 for explosives detection, and lithium-6 and helium-3 for neutron detectors for homeland security applications;
- promethium-147 for nuclear batteries; and
- arsenic-73, iron-52, and zinc-65 as tracers in metabolic studies.

It can take decades for an economically and technically viable commercial market to be formed for any novel isotope. The DOE IP works closely with industry to commercialize technology and promote domestic independent producers in a smooth transition that does not disrupt supply and or prohibit research; at that point, the DOE IP stops production so as to not compete with the domestic industry. Recent examples include strontium-82 for cardiac heart imaging and germanium-68 for medical diagnostics in which domestic commercial production now exists.

<u>Projects</u>
The prototype capabilities of the ESIPP, developed through DOE IP-supported research, demonstrated the feasibility of new EMIS and GC technology and re-established a general enriched stable isotope production capability in the U.S. The SIPF MIE at ORNL received baseline approval in July 2020 and modestly increases GC production capability. The U.S. SIPRC line item construction project 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 $250,000,000 with an updated preliminary TPC range of $187,000,000 to $338,000,000. Demand drivers include enriched stables isotopes for medical, national security and fundamental research projects. With support from the DOE IP, ORNL is advancing production capabilities for these stable isotopes, primarily EMIS and GC technologies. Electromagnetic isotope separators can separate isotopes for many elements to very high purity but at lower production rates, while gas centrifuge production cascades can produce much larger quantities of isotopes but are limited to those isotopes that have compatible feedstock chemicals.

Isotope R&D and Production
FY 2022 Research Initiatives

Isotope R&D and Production supports the following FY 2022 Research Initiatives.

(dollars in thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Biopreparedness Research Virtual Environment (BRaVE)	–	–	2,073	+2,073
Fundamental Science to Transform Advanced Manufacturing	–	–	1,000	+1,000
Quantum Information Science	–	–	4,300	+4,300
Reaching a New Energy Sciences Workforce (RENEW)	–	–	2,000	+2,000
Total, Research Initiatives	**–**	**–**	**9,373**	**+9,373**

Isotope R&D and Production
Funding

(dollars in thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Isotope R&D and Production				
Isotopes, Research	–	–	36,776	+36,776
Isotopes, Operations	–	–	41,224	+41,224
Subtotal, Isotope R&D and Production	**–**	**–**	**78,000**	**+78,000**
Construction				
20-SC-51, U.S. Stable Isotope Production and Research Center (SIPRC), ORNL	–	–	12,000	+12,000
Subtotal, Construction	**–**	**–**	**12,000**	**+12,000**
Total, Isotope R&D and Production	**–**	**–**	**90,000**	**+90,000**

Basic and Applied R&D Coordination

R&D coordination and integration are deeply rooted in all activities of the DOE IP as a goal of the Program is to ensure that critical isotopes needed to achieve federal missions, are in fact, available. Stable and radioactive isotopes are vital to the missions of many federal agencies, including the National Institutes of Health (NIH), National Aeronautics and Space Administration (NASA), Department of Defense (DoD), Office of the Director of National Intelligence (ODNI), National Institute of Standards and Technology (NIST), Federal Bureau of Investigations (FBI), Department of Agriculture, Department of Homeland Security (DHS), NNSA, National Science Foundation (NSF), and other SC programs. The DOE IP conducts biennial Workshops on Federal isotope Supply and Demand to collect 5-year projections from all federal agencies across the USG complex to ensure adequate supply. 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 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. 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.

While the DOE IP is not responsible for the production of molybdenum-99, the most widely used isotope in diagnostic medical imaging in the Nation, it works closely with NNSA, the lead entity responsible for domestic molybdenum-99 production, offering technical and management support. Additionally, DOE IP participates in the international High-Level Group on the Security of Supply of Medical Isotopes lead by the Organization for Economic Co-operation and Development.

Program Accomplishments

Completion of Drug Master File Enables Advanced Clinical Trials for Cancer and Infectious Disease Therapy

Actinium-225 (Ac-225) has shown great promise as a highly effective radioisotope in pharmaceuticals being developed for the treatment of various cancers and infectious diseases such as COVID-19. For an isotope to be used in advanced clinical trials necessary for Food and Drug Administration (FDA) approval of these pharmaceuticals, production of actinium-225 must be compliant with stringent guidelines and regulatory requirements. In FY 2020, a Drug Master File (DMF) for the DOE Isotope Program's accelerator-produced actinium-225, which was submitted to the FDA, enabling its use by drug developers in advanced clinical trials and ultimately in approved drugs. In early FY 2021, a DMF was also submitted to the FDA for the actinium-225 derived from thorium-229. As required to assure the quality of the actinium-225, current Good Manufacturing Practices production was implemented for both routes; this was a substantial undertaking involving the establishment of dedicated infrastructure, the training of all personnel involved in the production process, and the development of dozens of procedures and quality control documents.

New Gas Centrifuge Cascade Completes First Production Campaign

The DOE IP team at ORNL has successfully re-established U.S. stable isotope enrichment with gas centrifuge technology by completing its first gas centrifuge campaign for molybdenum-100. Molybdenum-100 and -98 stable isotopes are alternative feedstocks for production of the radioisotope technicium-99m, a medical radiotracer diagnostic that is in short supply due to its extensive use in medical procedures around the world. ORNL operated the prototype gas centrifuge cascade in its ESIPP for many months to collect crucial mechanical reliability data and followed that with four months of gas operations that produced the enriched material.

DOE Isotope Program makes available new isotope for diagnosis and treatment of cancer and infectious disease

Routine production of the copper-67 radioisotope has been established at the ANL LEAF. The routine availability of clinically relevant quantities of copper-67 is enabling medical research and clinical trials to investigate the potential of copper-67 to treat cancers through targeted radiotherapy. Copper-67 falls in a unique category of isotope known as theranostics, or isotopes which allow for simultaneous therapeutic disease treatment and diagnostic imaging of a patient. A recent collaboration between researchers at ANL and the University of Iowa demonstrated the theranostic potential of copper-67 could be realized using existing clinical infrastructure, and without modification of the costly computer programs which interpret scans and provide diagnostic information (e.g. tumor location and size). The studies were conducted using clinical grade models of a human torso and demonstrate the cost-effective role isotopes play in personalized medicine.

New chemical separation system for rare-earth radio-isotope production

Rare earth elements (REE) are critical materials since their unique optical, electric and magnetic properties render them indispensable components in modern electronic and electrical devices. Techniques to foster independence from foreign suppliers include recycling of REE from spent electronic parts or other materials, which in turn require novel preparative and analytical separation systems. LANL prepared and evaluated a new chromatographic system based on solvent impregnated resins that enables the efficient and selective separation of REE from other chemical elements and from each other. This system can enable efficient and cost-effective production of rare earth radioisotopes such as lutetium-177 for cancer therapy and promethium-147 for radioisotope power sources for national security, space exploration, and industrial application.

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Isotope R&D and Production	**$ —**	**$90,000**	**+$90,000**
Isotopes, Research	$ —	$36,776	+$36,776
Isotopes Research was under the Nuclear Physics program in the FY 2021 Enacted Appropriation with a funding level of $26,660,000. As part of the SC reorganization in FY 2020, a separate Office of Isotope R&D and Production was established.		The Request supports high impact R&D activities at universities and national laboratories leading to advanced, innovative, and novel isotope production and processing technologies, to increase the availability of isotopes in short supply and promote U.S. independence. A priority of the research program will be to continue R&D on the development of full-scale processing and technology capabilities for the production of alpha-and beta-emitters for cancer therapy, of which the DOE IP is a global leader, and to promote their translation to medical applications. The Request maintains the University Isotope Network to perform the R&D necessary to enable routine production. Research to develop enrichment capability for new stable isotopes of importance, including isotopes for clean energy and quantum computing is a priority. Research to ensure National Preparedness in isotope production and availability support research efforts in partnership with the University of Missouri to address a single point failure in reactor isotope processing; simultaneously, conceptual design for the RPF is pursued to develop longer-term solutions to this challenge at ORNL. Research to advance isotope harvesting capabilities and expertise at FRIB are roughly maintained. The Request continues OPC for the SIPRC project.	Core research groups are initiated at ANL and INL, both of whom bring unique capabilities to the portfolio. The research group at ANL brings new core competence in isotope production using accelerator electron beams and the group at INL brings experience in the production of highly pure enriched radioisotopes for the nuclear forensics community using electromagnetic separation. Research activities aimed at the development of production approaches for isotopes of interest to next-generation QIS systems increase, as does support for National Preparedness to address a lack of reactor isotope processing expertise and capabilities, and for research to promote the translation of isotopes to medical applications, in coordination with NIH. Support for the DOE IP Traineeship Program with a goal to increase the diversity of the workforce continues in FY 2022.

(dollars in thousands)

FY 2021 Enacted	FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Isotopes, Operations $ —	$41,224	+$41,224
Isotopes Operations was under the Nuclear Physics program in the FY 2021 Enacted Appropriation with a funding level of $36,640,000.	The Request supports mission readiness of the growing portfolio of isotope production and processing sites and nurtures critical core competencies in isotope production and development, ensuring robust domestic supply chains so that isotope orders for cancer therapy and other commitments are reliably met. Support maintains NIDC activities to interface with the growing stakeholder community and rapidly expanding isotope portfolio. Funding will continue support of electromagnetic separation technology optimized to heavy elements, enriched radioisotope separation technology, extraction of valuable isotopes from legacy Mark 18-A targets, infrastructure for assembly and fabrication of stable enrichment components.	Increased support for stable isotope operations enable additional production campaigns on gas centrifuges and EMIS machines, and SIPF commissioning preparation. Increased support for accelerator reactor production and processing captures growth in production portfolios, particularly at LANL with increased efforts for alpha-emitting isotope production and ANL, that continues to ramp up copper-67 for clinical trials. Support increases for the new radio-isotope separations capabilities at INL for nuclear forensics. Activities related to QIS isotopes and FRIB Isotope Harvesting are moved to the Research subprogram.
Construction $ —	$12,000	+$12,000
The U.S. Stable Isotope Production and Research Center (SIPRC) was under the Nuclear Physics program in the FY 2021 Enacted Appropriation with a funding level of $12,000,000.	The Request will support the continuation of engineering design of the U.S. SIPRC and long lead procurements.	Progress continues in design of the U.S. SIPRC and long lead procurements to mitigate dependence on foreign supply of isotopes.

Isotope R&D and Production
Construction Projects Summary

	(dollars in thousands)					
	Total	**Prior Years**	**FY 2020 Enacted**	**FY 2021 Enacted**	**FY 2022 Request**	**FY 2022 Request vs FY 2021 Enacted**
20-SC-51, U.S. Stable Isotope Production and Research Center, ORNL						
Total Estimated Cost (TEC)	215,200	–	–	–	12,000	+12,000
Other Project Cost (OPC)	5,200	–	–	–	3,200	+3,200
Total Project Cost (TPC)	**220,400**	**–**	**–**	**–**	**15,200**	**+15,200**
Total, Construction						
Total Estimated Cost (TEC)	**N/A**	**N/A**	**–**	**–**	**12,000**	**+12,000**
Other Project Cost (OPC)	**N/A**	**N/A**	**–**	**–**	**3,200**	**+3,200**
Total Project Cost (TPC)	**N/A**	**N/A**	**–**	**–**	**15,200**	**+15,200**

Note: The total for the U.S. Stable Isotope Production and Research Center (SIPRC) of $220,400,000 does not include $29,600,000 included in the Nuclear Physics program for prior years. The full preliminary total for SIPRC, combining the Nuclear Physics and Isotope R&D and Production, is $250,000,000. This project is not baselined.

Isotope R&D and Production
Funding Summary

	(dollars in thousands)			
	FY 2020 Enacted	**FY 2021 Enacted**	**FY 2022 Request**	**FY 2022 Request vs FY 2021 Enacted**
Research	–	–	30,576	+30,576
Facility Operations	–	–	41,224	+41,224
Projects				
Line Item Construction (LIC)	–	–	18,200	+18,200
Total, Projects	**–**	**–**	**18,200**	**+18,200**
Total, Isotope R&D and Production	**–**	**–**	**90,000**	**+90,000**

Isotope R&D and Production
Scientific Employment

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Number of Permanent Ph.Ds (FTEs)	–	–	37	+37
Number of Postdoctoral Associates (FTEs)	–	–	31	+31
Number of Graduate Students (FTEs)	–	–	26	+26
Number of Other Scientific Employment (FTEs)	–	–	91	+91

Note: Other Scientific Employment (FTEs) includes technicians, engineers, computer professionals and other support staff.

20-SC-51, U.S. Stable Isotope Production and Research Center (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 2022 Request for the U.S. Stable Isotope Production and Research Center (SIPRC) is $12,000,000 of TEC funding and $3,200,000 of OPC funding. The current Total Project Cost (TPC) point estimate is $250,000,000 with an updated preliminary TPC range of $187,000,000 to $338,000,000 in preparation for CD-1 consideration.

Significant Changes

This project data sheet (PDS) is an update of the FY 2021 PDS; the project is not a new start in FY 2022. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-0, Approve Mission Need, which was approved on January 4, 2019. The project is working to achieve CD-1/3A, Approve Alternative Selection and Cost Range/Long Lead Procurement, planned for the fourth quarter FY 2021. The TPC point estimate and range are a result of advancing project maturity with the completion of conceptual design in preparation for CD-1/3A. In addition, the project advanced the overall project structure by adding one additional subproject (SP) for a total of three. SIPRC's three subprojects are as follows: 1) new facility and Electromagnetic Isotope Separator (EMIS) production capability; 2) centrifuge production capability for Molybdenum 100; and 3) centrifuge infrastructure in preparation for Silicon 28 production capability. FY 2022 funding will continue support for project engineering and design activities and planned long lead procurements, such as 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	CD-4
FY 2020	1/4/19	4Q FY 2020	4Q FY 2020	3Q FY 2022	2Q FY 2022	3Q FY 2022	4Q FY 2027
FY 2021	1/4/19	4Q FY 2020	4Q FY 2020	3Q FY 2022	2Q FY 2022	3Q FY 2022	4Q FY 2027
FY 2022	1/4/19	4Q FY 2021	4Q FY 2021	4Q FY 2025	4Q FY 2025	4Q FY 2025	1Q FY 2031

Note: CD-2, CD-3, and CD-4 dates are for the overall project and correspond to the latest subproject date for a given CD.

Critical Decision dates for SP-1, SP-2 and SP-3 are broken out below:

FY 2022[a]						
Subproject (SP)	CD-0	Conceptual Design Complete	CD-1	CD-3A	CD-2/3	CD-4
SP-1	1/4/19	4Q FY 2021	4Q FY 2021	4Q FY 2021	4Q FY 2023	4Q FY 2029
SP-2	1/4/19	4Q FY 2021	4Q FY 2021	3Q FY 2025	4Q FY 2025	1Q FY 2031
SP-3	1/4/19	4Q FY 2021	4Q FY 2021	1Q FY 2025	4Q FY 2025	2Q FY 2030

[a] The project is pre-CD-1. The estimated cost and schedule shown are preliminary.

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	3Q FY 2022	4Q FY 2020	-
FY 2021	3Q FY 2022	4Q FY 2020	-
FY 2022	4Q FY 2023	4Q FY 2021	1Q FY 2023

CD-3A for Sub-Project 1 – Approve Long-Lead Procurements, (EMIS components)
CD-3B for Sub-Project 1 – Approve Long-Lead Procurements for Facility (Site preparations)

Project Cost History
This project is at CD-0 with an updated preliminary point estimate of $250,000,000 and Total Project Cost (TPC) range of $187,000,000 to $338,000,000. The point estimate has been refined as the previous rough order of magnitude estimate was matured in preparation for CD-1 approval. 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	14,000	274,000	288,000	10,000	N/A	10,000	298,000
FY 2022	36,000	203,200	239,200	10,800	N/A	10,800	250,000

2. Project Scope and Justification

Scope
The scope of this project includes design and construction of a building and associated instrumentation and equipment 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 systems development and will be a purely technical facility (i.e., minimal office and staff amenities), and located on the Oak Ridge National Laboratory (ORNL) main campus. Gas centrifuges and electromagnetic separators are leveraged by existing designs developed from prior projects and R&D supported by the DOE Isotope Program (DOE IP). The laboratory is considering the optimal number of production systems for each type of technology as part of the alternatives analysis for Critical Decision-1 (CD-1).

Justification
SIPRC is critical to the Nation and to the DOE IP within SC's Office of Isotope R&D and Production. The facility will expand the U.S. stable isotope production capability to address multiple production capabilities of enriched stable isotopes to provide domestic supply chains of critical isotopes and mitigating U.S. dependencies on foreign suppliers. 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. The SIPRC project will provide an adequately sized building to address our Nation's isotope needs in a more economical and operationally efficient manner.

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*, and all appropriate project management requirements will be met.

Key Performance Parameters (KPPs)
Preliminary Key Performance Parameters (KPPs) are defined at CD-1 and may change as each subproject continues towards CD-2, Approve Performance Baseline. CD-1 approval is expected later in 2021. 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
Design/construct building	TBD	TBD
Instrumentation design/development	TBD	TBD

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
Design (TEC)			
FY 2020	12,000	12,000	–
FY 2022	9,000	9,000	11,500
Outyears	15,000	15,000	24,500
Total, Design (TEC)	**36,000**	**36,000**	**36,000**
Construction (TEC)			
FY 2021	12,000	12,000	–
FY 2022	3,000	3,000	13,600
Outyears	188,200	188,200	189,600
Total, Construction (TEC)	**203,200**	**203,200**	**203,200**
Total Estimated Cost (TEC)			
FY 2020	12,000	12,000	–
FY 2021	12,000	12,000	–
FY 2022	12,000	12,000	25,100
Outyears	203,200	203,200	214,100
Total, TEC	**239,200**	**239,200**	**239,200**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Other Project Cost (OPC)			
FY 2019	500	500	171
FY 2020	2,100	2,100	2,429
FY 2021	3,000	3,000	3,000
FY 2022	3,200	3,200	3,200
Outyears	2,000	2,000	2,000
Total, OPC	**10,800**	**10,800**	**10,800**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Project Cost (TPC)			
FY 2019	500	500	171
FY 2020	14,100	14,100	2,429
FY 2021	15,000	15,000	3,000
FY 2022	15,200	15,200	28,300
Outyears	205,200	205,200	216,100
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	27,000	12,000	**N/A**
Design - Contingency	9,000	2,000	**N/A**
Total, Design (TEC)	**36,000**	**14,000**	**N/A**
Construction	150,000	210,000	**N/A**
Construction - Contingency	53,200	64,000	**N/A**
Total, Construction (TEC)	**203,200**	**274,000**	**N/A**
Total, TEC	**239,200**	**288,000**	**N/A**
Contingency, TEC	*62,200*	*66,000*	***N/A***
Other Project Cost (OPC)			
R&D	2,600	N/A	**N/A**
Conceptual Design	4,000	2,600	**N/A**
Start-up	1,500	5,000	**N/A**
OPC - Contingency	2,700	2,400	**N/A**
Total, Except D&D (OPC)	**10,800**	**10,000**	**N/A**
Total, OPC	**10,800**	**10,000**	**N/A**
Contingency, OPC	*2,700*	*2,400*	***N/A***
Total, TPC	**250,000**	**298,000**	**N/A**
Total, Contingency (TEC+OPC)	***64,900***	***68,400***	***N/A***

5. Schedule of Appropriations Requests[a]

(dollars in thousands)

Request Year	Type	Prior Years	FY 2020	FY 2021	FY 2022	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
FY 2022	TEC	—	12,000	12,000	12,000	203,200	239,200
	OPC	500	2,100	3,000	3,200	2,000	10,800
	TPC	500	14,100	15,000	15,200	205,200	250,000

[a] The project does not have CD-1 or CD-2 approval; FY 2022 schedules and costs are estimates consistent with the updated preliminary point estimate.

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	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
New area being constructed by this project at ORNL	54,000
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.

8. Acquisition Approach

The ORNL Management and Operating (M&O) contractor, UT Battelle, will perform the acquisition for this project, overseen by the DOE Oak Ridge National Laboratory 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.

Isotope Production and Distribution Program Fund

Overview
The Department of Energy's (DOE) Isotope Production and Distribution Program Fund, more commonly called the DOE Isotope Program (DOE IP), provides critical isotopes in short supply to the Nation to ensure robust domestic supply chains to meet federal missions, facilitate emerging technology, reduce U.S. dependence on foreign supply, and promote the Nation's economic prosperity and technical strength. The DOE IP produces and sells radioactive and stable isotopes, byproducts, surplus materials, and related isotope services worldwide, and is often the single source for these critical assets. Isotopes are used for hundreds of essential applications that benefit society every day, such as revolutionary new cancer therapy, diagnostic medical imaging, environmental studies, smoke detectors, explosives detection, quantum computing, advanced manufacturing, nuclear batteries, space exploration, clean energy and biological tracers. For example, radioisotopes are used in the diagnosis or treatment of about one-third of all patients admitted to hospitals.[a] Substantial national and international research, medicine, industry, and national security relies upon the use of isotopes and is strongly dependent on the Department's products and services.

A priority of the Program is to mitigate the Nation's dependency on foreign supply chains of isotopes, particularly those from sensitive countries, that are essential for facilitating emerging technology. DOE IP continuously assesses isotope needs to inform program direction, including biennial federal workshops to evaluate U.S. federal demand, in order to optimize the utilization of resources and assure the greatest availability of isotopes for the advancement of federal missions and emerging technology.

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. 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. The Program 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 this revolving fund is provided by the combination of annual appropriations from the Science appropriation account (from the new Office of Isotope R&D and Production Program (IRP)) beginning in FY 2022; prior to FY 2022 appropriations were included in the Nuclear Physics program), and collections from isotope sales; both are needed to maintain the Isotope Program's viability. The 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 IRP fund a payment into the revolving fund to maintain mission-readiness of facilities, including the support of core scientists and engineers needed to produce and process isotopes, and the maintenance and enhancement of isotope facilities and capabilities to assure reliable production and provide novel isotopes in high demand and short supply. In addition, appropriated funds provide support for R&D activities associated with development of new production and processing techniques for isotopes and workforce development in isotope production and chemical processing. 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 revenue, manufacturing equipment, capability and infrastructure upgrades, and capital equipment such as assay equipment, glove boxes, and shipping containers needed to ensure on-time deliveries.

The DOE IP produces radioisotopes by irradiating targets in accelerators and reactors at national laboratories and universities, and from extraction of materials and legacy waste. Accelerator facilities include the Brookhaven Linac Isotope Producer at Brookhaven National Laboratory, the Isotope Production Facility at Los Alamos National Laboratory, the Low Energy Accelerator Facility at Argonne National Laboratory, and the University of Washington cyclotron. Reactor facilities

[a] https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/med-use-radioactive-materials.html

include the Advanced Test Reactor at Idaho National Laboratory, the High Flux Isotope Reactor at Oak Ridge National Laboratory (ORNL), and the University of Missouri Research Reactor. Irradiated targets are processed in associated hot cells and gloveboxes at these facilities. Isotopes are extracted and purified at the Y-12 National Security Complex near ORNL, processing facilities at the Pacific Northwest National Laboratory, and the Savannah River Site. Enriched stable isotopes are produced at the Enriched Stable Isotope Prototype Plant at ORNL.

In FY 2020, a total of $117.2 million was deposited into the revolving fund. This consists of the FY 2020 appropriation of $62.3 million paid into the revolving fund from the Nuclear Physics (NP) program, plus collections of $54.9 million to recover costs related to isotope production and isotope services. In FY 2020, the DOE IP sold over 120 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, about ten are high-volume isotopes often with commercial applications and the remaining are low-volume, mostly research isotopes, which are more expensive to produce and thus not readily available.

Collections in FY 2020 included, for example, sales of actinium-225, actinium-227, strontium-89, californium-252, helium-3, nickel-63, and selenium-75. The DOE IP is the global leader in the development and provision of alpha-emitters for novel cancer-fighting therapies, enabling and accelerating the conduct of clinical trials. Actinium-225 is used in pharmaceuticals under development to treat cancer and other diseases more effectively. Actinium-227 provides radium-223 for Xofigo®, which is the first alpha particle-emitting radioisotopic drug approved by the Federal Drug Administration; Xofigo® extends patient survival as well as alleviates the excruciating pain associated with cancer that has metastasized to bone. Californium-252 has a variety of industrial applications, including oil and gas well-logging and fission start-up sources in nuclear reactors. Helium-3 is used in neutron detectors for national security and cryogenics. Nickel-63 enhances national security through its use in detectors for explosives and illicit material, and also enhances performance of nuclear batteries. Selenium-75 is used as a radiography source.

Highlights of the FY 2022 Request

For FY 2022, the Department foresees continued strong growth in isotope demand, including alpha and beta emitters for novel cancer therapy and medical diagnostics; stable isotopes to enable high-discovery science, emerging technologies in medicine and national security; isotopes for quantum information science; isotopes to promote clean energy; and isotopes for batteries and power supplies. The FY 2022 Request of the IRP Budget is $90.0 million. Revolving fund resources will be used to address the following priorities in the program:

- Maintain and enhance critical infrastructure and core competencies for isotope production to address unanticipated gaps and lack of capabilities in international supply chains for high priority and new isotopes
- Through cutting-edge research and advanced manufacturing, introduce novel isotopes to the Nation to facilitate emerging technology and applications (medicine, quantum computing, clean energy, nuclear batteries…), promoting U.S. economic prosperity and technical strengths
- Mitigate U.S. dependence on foreign supply chains and promote domestic production capabilities with technology transfer
- Enhance isotope processing capabilities to address a lack of infrastructure limiting the availability of new isotopes and mitigating single point failures to increase the Nation's preparedness for reacting to global supply chain disruptions
- Advance and expand stable isotope enrichment capabilities

The FY 2022 Request in the IRP Budget includes $3.2 million to continue the Isotope Harvesting research effort at the Facility for Rare Isotope Beams (FRIB) to add the capabilities to extract and process significant quantities of high-value isotopes from the FRIB beamdump. FRIB, funded in the Nuclear Physics program, is a DOE Scientific User Facility dedicated to the study of nuclear structure and astrophysics research. The FY 2022 Request in the IRP also includes $12.0 million to continue the U.S. Stable Isotope Production and Research Center (SIPRC) at ORNL, to significantly enhance stable isotope production capacity for the Nation. This Line Item Construction Project will build upon the expertise in centrifuge and electromagnetic isotope separation technology nurtured by the Stable Isotope Production Facility (SIPF) Major Item of

Equipment, funded through NP and IRP, which receives pre-operations support in FY 2022. The IRP Request supports and participates in a number of high priority initiatives for the Department and Administration, including Advanced Manufacturing, National Preparedness in the Biopreparedness Research Virtual Environment (BRaVE) initiative, Quantum Information Science, Artificial Intelligence and Machine Learning, Climate/Clean Energy, and the Reaching a New Energy Sciences Workforce (RENEW) initiative.

Program Accomplishments

DOE Isotope Program Maintains Operations During COVID-19 Pandemic

As a Mission Essential Function in the DOE, the DOE IP continued isotope production operations throughout the COVID-19 pandemic in FY 2020 which ensured supply chain robustness in critical isotopes. The production sites across the national laboratory complex quickly and successfully established safe protocols for continued operations to ensure critical isotope supply, and overcame extraordinary global transportation hurdles. Not only did the Program meet commitments to its stakeholders during the pandemic, but the Program monitored international supply chains and stepped in to fill shortages when international suppliers could either not produce or transport their product during the pandemic. In FY 2020, DOE IP made 359 shipments of isotopes during the pandemic.

DOE IP Provided Californium-252 for a Startup Source to First New Nuclear Reactor in U.S. in 30 Years

Californium-252 produced at the ORNL High Flux Isotope Reactor has been produced and specially formed into wires for use as sources to start operations of two new nuclear reactors in Georgia—Plant Vogtle Units 3 and 4, creating the largest nuclear power station in the U.S. These will be the first new nuclear units built in the U.S. in the last three decades. Californium-252 is only produced in the U.S. and Russia, and is required to startup such nuclear reactors enabling a stable supply of electrical energy to U.S. society.

Establishment of Domestic Enrichment of Ytterbium-176 for Use in Radiopharmaceutical Production

There is a global shortage of ytterbium-176, which is highly sought after as feedstock for lutetium-177 production, used worldwide in radiopharmaceuticals for the targeted treatment of gastrointestinal tumors and metastatic prostate cancer. Production of highly enriched ytterbium-176, which until now has only been produced in Russia, was demonstrated at ORNL in the Enriched Stable Isotope Prototype Plant. R&D activities in ion source technology, ion beam optics, and collection systems at ORNL culminated in the production of several batches of highly enriched ytterbium-176. Efforts are underway to expand production capabilities.

Accelerator R&D and Production

Overview

Formed in FY 2020, the Office of Accelerator R&D and Production's (ARDAP's) mission is to help coordinate Office of Science (SC) accelerator R&D, foster public-private partnerships to develop and deploy accelerator technology, support workforce development and improve its diversity, and provide resources for accelerator design and engineering. The overarching goal is to ensure a robust pipeline of innovative accelerator technology, train an expert workforce, and reduce significant supply chain risks by re-shoring critical accelerator technology.

Building on the successful High Energy Physics (HEP) Accelerator Stewardship subprogram, ARDAP will continue innovative accelerator science & technology (AS&T) R&D activities of broad benefit to SC programs, other federal agencies, and U.S. industry. The new program will develop a strategy and plans to invest in public-private production partnerships in key accelerator technology areas; operate scientific user facilities to support cross-cutting accelerator R&D; use a center-based approach to pursue focused, basic R&D on specific technologies; provide support to address workforce shortages and improve its diversity; and curate material databases, accelerator simulation software, and engineering knowledge for use by the accelerator community.

As the lead Office in the Accelerator Science and Technology Initiative, ARDAP will help coordinate accelerator R&D across SC and initiate new public-private partnerships to move technologies from basic R&D into use at U.S. science facilities and into commercial products that benefit all Americans.

The ARDAP program is organized into two subprograms: Accelerator Stewardship and Accelerator Production.

<u>Accelerator Stewardship</u>

The Accelerator Stewardship subprogram supports cross-cutting basic R&D; facilitates access to unique state-of-the-art SC accelerator R&D infrastructure for the private sector and other users, including operating a dedicated user facility for accelerator R&D; and drives a limited number of specific accelerator applications towards practical, testable prototypes in a five to seven year timeframe. The Accelerator Stewardship subprogram also will support database curation services.

<u>Accelerator Production</u>

The Accelerator Production subprogram supports public-private partnerships to advance new accelerator technologies to sufficient technical maturity for use in scientific facilities, commercial products, or both. Increasing the capabilities of domestic accelerator technology suppliers to both innovate and produce components will strengthen the SC mission to conduct world-leading scientific research.

Highlights of the FY 2022 Request

The FY 2022 Request for $24.0 million focuses resources on fundamental research, operation and maintenance of a scientific user facility, and production of accelerator technologies in industry. The FY 2022 Request supports innovative R&D and deployment of accelerator technology, the strategy and development of the first center-based approach to accelerator R&D, and workforce development. The FY 2022 Request supports operation of the Brookhaven National Laboratory (BNL) Accelerator Test Facility (ATF) for 2,500 hours (100 percent of optimal). Accelerator Production activities support public-private partnerships to develop advanced superconducting wire and cable, superconducting accelerators, and advanced radiofrequency power sources for accelerators.

Accelerator R&D and Production
FY 2022 Research Initiatives

Accelerator R&D and Production supports the following FY 2022 Research Initiatives.

(dollars in thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Accelerator Science and Technology Initiative	–	–	5,183	+5,183
Total, Research Initiatives	**–**	**–**	**5,183**	**+5,183**

Accelerator R&D and Production
Funding

(dollars in thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Accelerator R&D and Production				
Accelerator Stewardship, Research	–	–	15,457	+15,457
Accelerator Stewardship, Facility Operations and Experimental Support	–	–	6,797	+6,797
Total, Accelerator Stewardship	**–**	**–**	**22,254**	**+22,254**
Accelerator Production, Research	–	–	1,746	+1,746
Total, Accelerator Production	**–**	**–**	**1,746**	**+1,746**
Total, Accelerator R&D and Production	**–**	**–**	**24,000**	**+24,000**

SBIR/STTR funding:
- FY 2020 Enacted: SBIR $ — and STTR $ —
- FY 2021 Enacted: SBIR $ — and STTR $ —
- FY 2022 Request: SBIR $768,000 and STTR $108,000

Accelerator R&D and Production

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Accelerator R&D and Production	**$ —**	**$24,000**	**+$24,000**
Accelerator Stewardship	$ —	$22,254	+$22,254
Research	*$ —*	*$15,457*	*+$15,457*
The Accelerator Stewardship program is part of the High Energy Physics program in FY 2021 with a funding level of $10,835,000.		The Request will support new research activities at laboratories, universities, and in the private sector on cross-cutting accelerator technologies such as superconducting magnets and accelerators, beam physics, data analytics-based accelerator controls, new particle sources, advanced laser technology R&D, and transformative R&D.	Funding will support the start of the Accelerator Science and Technology Initiative to advance basic R&D on accelerator technologies that define the U.S. competitive advantage in physical sciences research. R&D will initiate cross-cutting accelerator technology areas identified to provide new facility capabilities and/or posing significant supply chain risk to Office of Science programs.
Facility Operations and Experimental Support	*$ —*	*$6,797*	*+$6,797*
BNL-ATF User Facility operations is part of the High Energy Physics program in FY 2021 with a funding level of $6,100,000.		The Request will support the BNL-ATF operations at 100 percent of optimal levels.	BNL-ATF User Facility will continue operations at optimal levels.
Accelerator Production	$ —	$1,746	+$1,746
Research	*$ —*	*$1,746*	*+$1,746*
Accelerator Production is a new subprogram created when the Office of Science was reorganized, creating ARDAP.		The Request will support public-private partnerships to develop advanced superconducting wire and cable, superconducting RF cavities, and high efficiency radiofrequency power sources for accelerators.	Public-private partnerships will initiate to mature accelerator technology and ensure adequate domestic sources of critical accelerator components.

Note: Funding for the subprogram above, includes 3.65% of research and development (R&D) funding for the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Programs.

Basic and Applied R&D Coordination
Accelerator R&D and Production 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). The Accelerator R&D and Production program was developed 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 supply chain gaps where investments would have sizable impacts beyond the SC research mission. This program is closely coordinated with BES, FES, HEP, and 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.

Discussions with the NCI, DOD, and National Nuclear Security Administration (NNSA) on mission needs and R&D coordination in medical accelerators, laser technology, radioactive source replacement, and particle detector technologies 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. This workshop was co-sponsored by NNSA, DOD, DHS, and NIH, and has inspired follow-on funding opportunities at those agencies in addition to informing use-inspired basic R&D investments by the Accelerator Stewardship program. These R&D and facility investments are guided through the participation of applied agencies in merit and facility operations reviews. In addition, to ensure R&D is aimed at a commercially viable product, accelerator 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, L3Harris, and General Atomics), advanced laser technology development (with IPG Photonics 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 resulted in 19 patents, more than 600 publications, and the training of 45 PhDs, and have drawn an average of 20 percent of voluntary cost sharing over the initial years of the subprogram, providing evidence of the potential impact.

[a] https://science.osti.gov/-/media/hep/pdf/Reports/2020/CASM_WorkshopReport.pdf

Accelerator R&D and Production
Funding Summary

(dollars in thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Research	–	–	17,203	+17,203
Facility Operations	–	–	6,797	+6,797
Total, Accelerator R&D and Production	**–**	**–**	**24,000**	**+24,000**

Accelerator R&D and Production
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.

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 2020 Enacted	FY 2020 Current	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Scientific User Facilities - Type A					
Accelerator Test Facility	**–**	**–**	**–**	**6,797**	**+6,797**
Number of Users	–	–	–	116	+116
Planned Operating Hours	–	–	–	2,500	+2,500
Optimal Hours	–	–	–	2,500	+2,500
Percent of Optimal Hours	–	–	–	100.0%	+100.0%
Total, Facilities	**–**	**–**	**–**	**6,797**	**+6,797**
Number of Users	–	–	–	116	+116
Planned Operating Hours	–	–	–	2,500	+2,500
Optimal Hours	–	–	–	2,500	+2,500

Note: Achieved Operating Hours and Unscheduled Downtime Hours will only be reflected in the Congressional budget cycle which provides actuals.

Accelerator R&D and Production
Scientific Employment

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Number of Permanent Ph.Ds (FTEs)	–	–	12	+12
Number of Postdoctoral Associates (FTEs)	–	–	4	+4
Number of Graduate Students (FTEs)	–	–	20	+20
Number of Other Scientific Employment (FTEs)	–	–	19	+19

Note: Other Scientific Employment (FTEs) includes technicians, engineers, computer professionals and other support staff.

Workforce Development for Teachers and Scientists

Overview

The Workforce Development for Teachers and Scientists (WDTS) program mission is to 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 2022 Request

The FY 2022 Request for $35.0 million prioritizes funding for programs that place highly qualified applicants in STEM learning, training, and research experiences at DOE laboratories and expands training opportunities to underrepresented, underserved groups. The Request initiates a new activity, Reaching a New Energy Sciences Workforce (RENEW), which will significantly increase outreach and provide workforce training opportunities to underrepresented and underserved groups, described further below. The Request continues strong support for the undergraduate internships, graduate thesis research, and visiting faculty program to help sustain a skilled workforce pipeline. The Request maintains support for the technology infrastructure development and evaluation activity, which is critically important for sustaining the workforce training programs at DOE laboratories. 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 and preparing students to pursue STEM careers, these programs address the DOE's STEM mission critical workforce pipeline needs required to advance science innovation and energy, environment, and national security.

The Office of Science (SC) is fully committed to advancing a diverse, equitable, and inclusive research community. This commitment is key to providing the scientific and technical expertise for U.S. leadership in SC mission areas. Toward that goal, WDTS will participate in the SC-wide RENEW initiative that leverages SC's world-unique national laboratories, user facilities, and other research infrastructures to provide undergraduate and graduate training opportunities for students and academic institutions not currently well represented in the U.S. S&T ecosystem. This includes Minority Serving Institutions (MSIs), and individuals from groups historically underrepresented in STEM, but also includes students from communities with environmental justice impacts and the EPSCoR jurisdictions. The hands-on experiences gained through the RENEW initiative will open new career avenues for the participants, forming a nucleus for a future pool of talented young scientists, engineers, and technicians with the critical skills and expertise needed for the full breadth of SC research activities, including DOE national laboratory staffing.

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 Visiting Faculty Program (VFP), the Office of Science Graduate Student Research (SCGSR) program, and RENEW. 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 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 a diverse and skilled U.S. 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 ten 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 ten weeks during the summer, fall, and spring terms.

The VFP goal is to increase the research competitiveness of faculty members and students at U.S. institutions of higher education historically underrepresented in the research community, including Minority Serving Institutions (MSIs). 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 underrepresented within the DOE enterprise. Appointments are in the summer term for ten weeks, and faculty may participate in the program for up to three 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.

WDTS will participate in the SC-wide RENEW initiative. As a partner of the SC workforce development ecosystem, WDTS will coordinate with SC research programs and DOE national laboratories to develop SC mission research focused training opportunities for undergraduate and graduate students from population groups and academic institutions not currently well represented in the U.S. S&T ecosystem. WDTS will have a unique role to play by significantly expanding SC outreach to students and educators from underrepresented and underserved groups and enabling additional pathways to help them advance along the STEM workforce development pipeline. Initial activities include a proactive, comprehensive effort to understand the barriers that prevent underrepresented and underserved groups from participating in SC workforce development programs. Based on this understanding, strategies and mechanisms will be developed to remove barriers and facilitate participation by underrepresented and underserved groups, including experimenting with new training models or elements to enable participation. Funding will also support DOE national laboratory-based research or technical training experiences for preparing future scientists, technicians, and professionals to support DOE mission needs.

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 Program for the Federal government. DOE and other Federal agencies support these Fellows. SC sponsors placement opportunities in WDTS and in Congressional offices. Other Federal agencies sponsor placement opportunities in their own offices. Participating agencies include the National Aeronautics and Space Administration, the Library of Congress, the Department of Defense (DOD), the Smithsonian, and the U.S. Geological Survey. 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 315,000 students have participated in the National Science Bowl® throughout its 30-year history, and it is one of the nation's largest science competitions. SC 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 2020, more than 4,950 middle school students (from 613 schools) and 8,660 high school students (from 1,100 schools) participated in 106 regional competitions, with 43 middle school teams (206 students) and 63 high school teams (302 students) advancing to the National Finals that were scheduled to be in Washington, D.C. April 29–May 4, 2020. All 50 U.S. States, the District of Columbia, and Puerto Rico were represented at regionals. More than 5,000 volunteers also participated in the local and national competitions.

The National Science Bowl® Championship Finals are usually held at the Lisner Auditorium, located on the campus of The George Washington University, and feature a live web-streaming broadcast of the event; however, due to the COVID-19 pandemic, the National Finals, including the Championship Finals, were held virtually in early June 2020.

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

The Evaluation 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. WDTS is also tracking and reporting how its programs, and activities at DOE labs and SC scientific user facilities, fulfill program goals and objectives.

The Evaluation activity is aligned with the Government Performance and Results Act 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.

In support of the RENEW initiative, the knowledge, infrastructure, and capabilities built through the Evaluation activity for the current WDTS programs will be leveraged to help set the goals and craft strategies for assessing the new activities, in coordination with SC research programs and offices.

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. WDTS utilizes SC's social media resources to advertise program opportunities to a broad distribution of stakeholders, including SC research grantees, scientific professional societies, and HBCUs and Other MSIs, with a focus on under-represented and under-served groups. 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 MSIs. Eligible DOE 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 eligible students and faculty.

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.

Workforce Development for Teachers and Scientists
Funding

(dollars in thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Workforce Development for Teachers and Scientists				
Science Undergraduate Laboratory Internship (SULI)	13,600	13,800	14,000	+200
Community College Internship Program (CCI)	1,700	1,900	2,000	+100
Visiting Faculty Program (VFP)	2,000	1,800	2,100	+300
Office of Science Graduate Student Research (SCGSR) Program	4,500	4,600	5,000	+400
Reaching a New Energy Sciences Workforce (RENEW)	–	–	5,000	+5,000
Internships and Visiting Faculty Activities at DOE Labs	**21,800**	**22,100**	**28,100**	**+6,000**
Albert Einstein Distinguished Educator Fellowship	**1,200**	**1,200**	**1,200**	**–**
National Science Bowl	**2,900**	**2,900**	**2,900**	**–**
Technology Development and On-Line Application	**700**	**700**	**700**	**–**
Evaluation	**600**	**600**	**600**	**–**
Outreach	**800**	**1,500**	**1,500**	**–**
Total, Workforce Development for Teachers and Scientists	**28,000**	**29,000**	**35,000**	**+6,000**

Program Accomplishments

Science Undergraduate Laboratory Internship (SULI) — In FY 2020, approximately 742 placements were supported, of which 0.5 percent were from HBCUs, 13.2 percent from all other MSIs, and approximately 33 percent were women. Among the participants, more than 98 percent reported positive impacts to their educational and career goals, and 99.5 percent 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 their undergraduate 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 Committee of Visitors review.

Community College Internship Program (CCI) — In FY 2020, 76 placements were supported, with 1.3 percent from Predominantly Black Institution (PBI) and over 40 percent of the participants from all other MSIs. Among the participants, 100 percent would recommend CCI to their peers and nearly 95 percent reported positive impacts to their educational and career goals. All participants reported that they would consider a job or career at their host DOE laboratory or facility.

Visiting Faculty Program (VFP) — In FY 2020, 36 faculty and 17 student placements were supported, and of these participants, at least 15 were women and 27 were from MSIs. Twenty-five percent of faculty and 23.5 percent of students were from HBCUs. All VFP Faculty participants reported a positive impact on their careers, and all expressed interest in continuing their research collaboration. All would recommend VFP to their peers. VFP-Student participants reported receiving a high quality internship experience (96 percent), with 97 percent reporting impacts to their educational and career goals, and 98 percent reporting they would recommend VFP to their peers.

Office of Science Graduate Student Research (SCGSR) Program — In FY 2019, SCGSR added new research areas in disciplines that are not well represented in academic curricula; in high demand, nationally and/or internationally, resulting in difficulties in recruitment and retention at U.S. universities and at DOE laboratories; for which the DOE laboratories may play a role in providing needed workforce development; and needed for the SC workforce. Additionally, the program developed new convergence research areas (e.g. data science, microelectronics, and accelerator science) to address workforce needs for 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 21st century economy. Based on the feedback received in FY 2019, the new convergence research areas were adjusted for the two application cycles in FY 2020. Since 2014, there have been over 700 SCGSR awardees from 150 institutions across the U.S.

Response to the COVID-19 Pandemic — All WDTS laboratory-based workforce training programs have been continuously offered and supported throughout the COVID-19 pandemic via alternative arrangements. The Spring, Summer, and Fall 2020 Terms of the SULI, CCI, and VFP programs were significantly impacted by restricted access and minimum operations status at DOE national laboratories due to the pandemic. WDTS, in collaboration with DOE national laboratories, delivered virtual summer internships. About 70% of all the internships accepted before the pandemic were successfully executed remotely; the remainder were offered the option of deferring to a later term. During the pandemic, the SCGSR program gave graduate awardees three options: delaying their start dates within a 12-month window of flexibility (normally 4-month window), conducting the research project via a hybrid mode, or modifying the project due to unique circumstances (such as proximity to graduation and family needs). The participants in these WDTS programs, their DOE national laboratory scientist mentors, and the host DOE national laboratories were very positive about the virtual internships and hybrid training experiences.

Reaching a New Energy Sciences Workforce (RENEW) — As part of the preliminary planning for the RENEW initiative, WDTS has started discussions with DOE national laboratories on understanding barriers that prevent underrepresented and underserved groups from participating in WDTS workforce development programs. The effort adopted an evidence-based approach using application data from multiple terms and included a holistic examination of existing practice for recruitment and selection. The group effort is ongoing and the associated findings will be incorporated into the further development and implementation of the RENEW initiative, including the development of metrics for evaluation.

Albert Einstein Distinguished Educator Fellowship (AEF) — In FY 2020, one of the six WDTS sponsored AEF participants held a WDTS office appointment. As part of the efforts to expand federal agency participation, the 2019-2020 cohort included a placement at the DOD's Naval Surface Warfare Center, and WDTS established partnerships with other agencies that have expressed interest. During the pandemic, the AEF participants of the 2019-2020 cohort engaged with their host federal agencies or Congressional offices remotely and actively participated in the program's professional development activities.

National Science Bowl® — The National Finals of the 30th DOE National Science Bowl® originally scheduled for April 29 – May 4, 2020, in Washington, DC, was changed to a virtual event due to the impact of COVID-19 pandemic. SC provided a virtual competition to support the hundreds of students who had been preparing for the event for many months. The 63 high school and 43 middle school teams who won their Regional Science Bowl events were invited to participate in the DOE SC National Science Bowl® Virtual National Finals. Between May 11 and May 27, each team competed in a Preliminary Round by answering one round of questions. The 32 middle schools and the 32 high schools with the highest scores advanced to the Elimination Tournament. On Saturday, June 4, 2020, the 32 middle school teams that advanced from the Preliminary Round competed for the national championship. On Sunday, June 5, 2020, the 32 high school teams that advanced from the Preliminary Round competed for the National Championship.

Technology Development and On-Line Application — In FY 2020, the technical development performed by the Oak Ridge Institute for Science and Education (ORISE) for a National Science Bowl® alumni website was continued, with support for the National Science Bowl® Travel Portal. Additionally, the technical requirements and information architecture for a virtual National Science Bowl® training site on SC's website started and are under development. 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 central portal for DOE lab points-of-contact enabling facile data collection, management, and archiving in a manner that minimizes burdens of specialized unscheduled data calls to the DOE laboratories.

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. In FY 2020, WDTS started the planning for a pilot longitudinal study with ORISE. The study is planned for longitudinal evaluation of the impacts of WDTS-sponsored undergraduate internship programs at DOE national laboratories.

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 laboratories in a week-long immersion experience is proving successful and being adopted by increasing numbers of host labs. In FY 2020, Brookhaven National Laboratory, Oak Ridge National Laboratory, and the National Renewable Energy Laboratory hosted students during their “Mini-Semesters.” A complex-wide virtual career fair was also held during which laboratories 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 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 with the implementation of recipient reporting.

Workforce Development for Teachers and Scientists

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Workforce Development for Teachers and Scientists	**$29,000**	**$35,000**	**+$6,000**
Activities at the DOE Laboratories	$22,100	$28,100	+$6,000
Science Undergraduate Laboratory Internship (SULI)	*$13,800*	*$14,000*	*+$200*
Funding for SULI supports approximately 1,186 students.		The Request for SULI will support approximately 1,203 students.	Funding will support 17 more students.
Community College Internship Program (CCI)	*$1,900*	*$2,000*	*+$100*
Funding for CCI supports approximately 167 students.		The Request for CCI will support approximately 176 students.	Funding will support 9 more students.
Visiting Faculty Program (VFP)	*$1,800*	*$2,100*	*+$300*
Funding for the VFP supports approximately 62 faculty and 44 students.		The Request for the VFP will support approximately 72 faculty and 52 students.	Funding will support 10 more faculty and 8 more students.
Office of Science Graduate Student Research (SCGSR) Program	*$4,600*	*$5,000*	*+$400*
Funding for the SCGSR program supports approximately 180 graduate students. Targeted priority research areas are informed by SC's workforce training needs studies.		The Request for the SCGSR program will support approximately 190 graduate students. Targeted priority research areas will be informed by SC's workforce training needs studies.	Funding will support 10 more graduate students.

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Reaching a New Energy Sciences Workforce (RENEW)	*$ —*	*$5,000*	*+$5,000*
No funding in FY 2021.		The Request supports the RENEW initiative to provide undergraduate and graduate training opportunities for students and academic institutions not currently well represented in the U.S. S&T ecosystem.	Increase supports the RENEW initiative.
Albert Einstein Distinguished Educator Fellowship	$1,200	$1,200	$ —
Funding supports 6 Fellows.		The Request will support 6 Fellows.	No Change.
National Science Bowl®	$2,900	$2,900	$ —
Funding provides support to sponsor the virtual finals competition and provides central management of 116 virtual 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 virtual finals competition and provide central management of 116 virtual 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	$700	$700	$ —
Funding continues development and operation of the on-line systems.		The Request will continue development and operation of the on-line systems, and support new development to meet the evolving needs of the programs.	Funding will support new development to meet the evolving needs of the WDTS programs, based on the experiences in response to new circumstances, such as COVID-19 pandemic and supporting remote research participation.
Evaluation	$600	$600	$ —
Funding continues support for evaluation activities, including data archiving, curation, and analyses.		The Request will continue support for evaluation activities and studies, including data archiving, curation, and analyses.	The pilot study on longitudinal evaluation will continue and is expected to transition from planning to implementation phase.

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Outreach	$1,500	$1,500	$ —
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 activity proposal solicitations from DOE host labs and facilities. WDTS will maintain support of activities such as those that promote inclusion and diversity; and/or prioritize recruitment of STEM students to DOE research and development workforce mission-relevant fields of study, and particularly to fields related to SC research programs. Support continues for the LEDP program.	Funding will focus on outreach activity proposals from DOE National Laboratories and facilities that hosted WDTS participants in SULI, CCI, VFP, and SCGSR.

Workforce Development for Teachers and Scientists
Funding Summary

(dollars in thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Other	28,000	29,000	35,000	+6,000
Total, Workforce Development for Teachers and Scientists	**28,000**	**29,000**	**35,000**	**+6,000**

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 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. SC provides significant stewardship of research facilities, the renovation and replacement of general-purpose infrastructure, including buildings and support infrastructure, however approximately half of the buildings are rated substandard or inadequate to meet mission needs. In addition, nearly two-thirds of support infrastructure, including utility systems, is rated as substandard or inadequate, resulting in unplanned outages, costly repairs, elevated safety risks and inefficiencies. In collaboration with SC programs and the laboratories, the SLI program works to address identified deficiencies to reduce the impacts on the mission.

SC laboratories conduct rigorous and consistent analyses of the condition, utilization, mission readiness, and resilience 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 over $650 million in maintenance, repair, and upgrades in FY 2020. 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 2022 Request

The SLI program Request continues to focus on improving infrastructure across the SC national laboratory complex. The FY 2022 Request includes funding for two new construction starts: the Critical Infrastructure Modernization Project at ORNL and the Thomas Jefferson Infrastructure Improvements project at Thomas Jefferson National Accelerator Facility (TJNAF).

The Request also supports sixteen ongoing construction projects: the Princeton Plasma Innovation Center at Princeton Plasma Physics Laboratory (PPPL), the Critical Infrastructure Recovery & Renewal project at PPPL, the Ames Infrastructure Modernization project at Ames Laboratory, 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 TJNAF, the Large Scale Collaboration Center at SLAC National Accelerator Laboratory (SLAC), the Tritium System Demolition and Disposal project at PPPL, 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 ORNL, the Biological and Environmental Program Integration Center (BioEPIC) at LBNL, and provides final funding for the Integrated Engineering Research Center at FNAL. These ongoing projects, along with the newly proposed projects, will upgrade and improve utility systems and facilities and provide new laboratory space with the necessary performance capabilities to enhance SC's mission.

The FY 2022 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 evaluated annually by SLI. Projects considered are evaluated on mission readiness, cost savings including energy and water, environment safety and health issues, sustainability including net zero initiatives, resilience, and reliability.

Science Laboratories Infrastructure
Funding

(dollars in thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Science Laboratories Infrastructure				
Payment In Lieu of Taxes (PILT)	4,540	4,650	4,820	+170
OR Landlord	5,610	5,860	6,430	+570
Facilities and Infrastructure	56,850	29,790	17,200	-12,590
Oak Ridge Nuclear Operations	26,000	26,000	20,000	-6,000
Subtotal, Science Laboratories Infrastructure	**93,000**	**66,300**	**48,450**	**-17,850**
Construction				
22-SC-71, Critical Infrastructure Modernization Project (CIMP), ORNL	–	–	1,000	+1,000
22-SC-72, Thomas Jefferson Infrastructure Improvements (TJII), TJNAF	–	–	1,000	+1,000
21-SC-71, Princeton Plasma Innovation Center (PPIC), PPPL	–	150	7,750	+7,600
21-SC-72, Critical Infrastructure Recovery & Renewal (CIRR), PPPL	–	150	2,000	+1,850
21-SC-73, Ames Infrastructure Modernization (AIM)	–	150	2,000	+1,850
20-SC-71, Critical Utilities Rehabilitation Project (CURP), BNL	20,000	20,000	26,000	+6,000
20-SC-72, Seismic and Safety Modernization (SSM), LBNL	10,000	5,000	27,500	+22,500
20-SC-73, CEBAF Renovation and Expansion (CEBAF), TJNAF	2,000	2,000	10,000	+8,000

	(dollars in thousands)			
	FY 2020 Enacted	**FY 2021 Enacted**	**FY 2022 Request**	**FY 2022 Request vs FY 2021 Enacted**
20-SC-74, Craft Resources Support Facility (CRSF), ORNL	15,000	25,000	–	-25,000
20-SC-75, Large Scale Collaboration Center (LSCC), SLAC	11,000	11,000	12,000	+1,000
20-SC-76, Tritium System Demolition and Disposal (TSDD), PPPL	13,000	13,000	6,400	-6,600
20-SC-77, Argonne Utilities Upgrade (AU2), ANL	500	500	10,000	+9,500
20-SC-78, Linear Assets Modernization Project (LAMP), LBNL	500	500	12,850	+12,350
20-SC-79, Critical Utilities Infrastructure Revitalization (CUIR), SLAC	500	500	10,000	+9,500
20-SC-80, Utilities Infrastructure Project (UIP), FNAL	500	500	13,300	+12,800
19-SC-71, Science User Support Center (SUSC), BNL	20,000	20,000	38,000	+18,000
19-SC-72 - Electrical Capacity and Distribution Capability, ANL	30,000	–	–	–
19-SC-73, Translational Research Capability (TRC), ORNL	25,000	22,000	21,500	-500
19-SC-74, BioEPIC, LBNL	15,000	20,000	35,000	+15,000
18-SC-71, Energy Sciences Capability (ESC), PNNL	23,000	23,000	–	-23,000
17-SC-71, Integrated Engineering Research Center (IERC), FNAL	22,000	10,250	10,250	–
Subtotal, Construction	**208,000**	**173,700**	**246,550**	**+72,850**
Total, Science Laboratories Infrastructure	**301,000**	**240,000**	**295,000**	**+55,000**

Science Laboratories Infrastructure
Explanation of Major Changes

	(dollars in thousands) FY 2022 Request vs FY 2021 Enacted
Infrastructure Support The Request continues funding to support Payment in Lieu of Taxes (PILT), nuclear facilities at ORNL, and landlord responsibilities at the Oak Ridge Reservation. Funding for critical core infrastructure across the SC complex decreases in FY 2022.	**-17,850**
Construction Funding supports sixteen ongoing line-item projects at Ames, FNAL, LBNL, ANL, ORNL, BNL, SLAC, PPPL, and TJNAF. The increase also supports the initiation of two new line-item projects at ORNL and TJNAF.	**+72,850**
Total, Science Laboratories Infrastructure	**+55,000**

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 16 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 1,200,000 gsf of new space and modernized more than 450,000 gsf of existing space. As a result, an estimated 2,900 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 $184,000,000 in laboratory core infrastructure improvements including $133,000,000 in electrical and utility improvements, $34,000,000 in building renovations, and $17,000,000 in safety and environmental projects. Examples of recent SLI investments in core infrastructure include building HVAC upgrades at BNL and access control upgrades at Ames and Fermi. SLI also funded electrical substation and building HVAC system improvements at LBNL, upgrades to the cryogenics facility at TJNAF and facility improvement including fire protection at OSTI.

Building 350 Legacy Project at Argonne National Laboratory (ANL).

As of the end of FY 2020, this SLI-funded project removed all 20,253 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.

Science Laboratories Infrastructure
Infrastructure Support

Description

This subprogram supports 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. This investment enables SC laboratories to keep up with needed upgrades and repairs. The funded activities include core infrastructure upgrades at various laboratories, general infrastructure support, and support for nuclear operations 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.

Facilities and Infrastructure

This activity supports 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. Projects considered are evaluated on mission readiness, cost savings including energy and water, environment safety and health issues, sustainability including net zero initiatives, resilience, and reliability. Priorities are evaluated continuously, and the highest priority projects are selected for funding upon entry into the corresponding execution year.

Oak Ridge Nuclear Operations

To support critical DOE nuclear operations, this Request includes funding to operate ORNL's non-reactor nuclear facilities (i.e., Buildings 7920, 7930, 3525, 3047, and 3025E). These facilities support a variety of users including SC Programs, the National Nuclear Security Administration, the Office of Nuclear Energy, and other agencies. This funding supports maintenance and repair of hot cells and supporting systems and ensuring compliance with safety standards and procedures.

OR Landlord

This funding supports landlord responsibilities, including infrastructure for the 24,000-acre Oak Ridge Reservation and DOE facilities in the city of Oak Ridge, Tennessee. Activities include maintenance of roads, grounds, and other infrastructure; and support and improvement of environmental protection, safety, and health.

Payment In Lieu of Taxes (PILT)

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 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Infrastructure Support	**$66,300**	**$48,450**	**-$17,850**
Facilities and Infrastructure	$29,790	$17,200	-$12,590
Funding supports the highest priority core infrastructure needs across the SC complex.		The Request will continue to support the highest priority core infrastructure needs across the SC complex.	Funding will support critical core infrastructure needs.
Oak Ridge Nuclear Operations	$26,000	$20,000	-$6,000
Funding supports critical nuclear operations and will provide 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 will continue to support the most critical nuclear operations and facilities at ORNL.
OR Landlord	$5,860	$6,430	+$570
Funding continues 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.		The Request will continue to 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 will support OR landlord requirements.
Payment In Lieu of Taxes (PILT)	$4,650	$4,820	+$170
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 will increase to support anticipated PILT requirements.

Science Laboratories Infrastructure
Construction

Description

The SLI Construction program funds line-item projects to maintain and enhance the general purpose infrastructure at SC laboratories. SLI's infrastructure modernization construction projects are focused on the accomplishment of long-term science goals and strategies at each SC laboratory. The main objectives of the SLI program are improvement of SC's physical assets and funding of new cutting-edge facilities to enable emerging science opportunities as well as funding to replace the 50 plus year old basic infrastructure supporting the SC national laboratories to ensure the new infrastructure provides for the critical needs of the future science initiatives and world class user facilities.

The FY 2022 Request includes funding for:

Two new line-item construction projects:

- Critical Infrastructure Modernization Project at ORNL; and
- Thomas Jefferson Infrastructure Improvements at TJNAF.

Sixteen ongoing line-item construction projects:

- Princeton Plasma Innovation Center at PPPL;
- Critical Infrastructure Recovery & Renewal at PPPL;
- Ames Infrastructure Modernization at Ames;
- Critical Utilities Rehabilitation Project at BNL;
- Seismic and Safety Modernization at LBNL;
- CEBAF Renovation and Expansion at TJNAF;
- 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 at LBNL; and
- Integrated Engineering Research Center at FNAL.

<u>22-SC-71, Critical Infrastructure Modernization Project, ORNL</u>

The Critical Infrastructure and Modernization Project (CIMP) is proposed to upgrade critical infrastructure systems which may include upgrades/replacement to the following systems: potable water, sanitary sewer/wastewater treatment, storm water, chilled water, steam, electrical, natural gas, compressed air, telecommunications, etc.

DOE Order 413.3B Critical Decision (CD)-0, Approve Mission Need, was achieved on October 26, 2020. The preliminary estimate for CD-1, Approve Alternative Selection and Cost Range, is anticipated in the 4th quarter of FY 2022. 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 $221,000,000 to $415,000,000. The preliminary Total Project Cost (TPC) range for this project is $225,000,000 to $419,000,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The preliminary TPC estimate for this project is $419,000,000.

<u>22-SC-72, Thomas Jefferson Infrastructure Improvements, TJNAF</u>

The Thomas Jefferson National Accelerator Facility (TJNAF) requires additional laboratory space and modern utility systems that are safer and more operationally efficient for employees and visitors of TJNAF. This project is proposed to address the lack of efficient high-bay laboratory space, growing repair needs and deferred maintenance, and safety and security risks currently posed by intermingling of operations, projects, and users. It would renovate/modernize 54,000 square feet and construct 65,000-80,000 square feet of new space to facilitate renovation/modernization efforts and support projected workload. Additionally, there will be improvements to the water, sanitary and communication utilities, roads, sidewalks and parking infrastructure.

DOE Order 413.3B Critical Decision (CD)-0, Approve Mission Need, was achieved on December 8, 2020. The preliminary estimate for CD-1, Approve Alternative Selection and Cost Range, is anticipated in the second quarter of FY 2022. This project is pre-CD-2; therefore, schedule estimates are preliminary and subject to change. The preliminary TEC range for this project is $76,000,000 to $98,000,000. The preliminary TPC range for this project is $77,000,000 to $99,000,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The preliminary TPC estimate for this project is $99,000,000.

21-SC-71, Princeton Plasma Innovation Center, PPPL

The Princeton Plasma Innovation Center (PPIC) will provide a multi-purpose facility to PPPL, with space for offices, medium bay research labs for diagnostics and fabrication, remote participation and collaboration, and research support to meet the SC 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-1, Approve Alternative Selection and Cost Range, approved on January 22, 2021. The preliminary estimate for CD-2 Approve Performance Baseline, is anticipated in the fourth quarter of FY 2023. This project is pre-CD-2; therefore, schedule estimates are preliminary and subject to change. The preliminary TEC range for this project is $78,300,000 to $96,300,000. The preliminary TPC range for this project is $80,500,000 to $98,500,000. These cost ranges encompass the most feasible preliminary alternative at this time. The preliminary TPC estimate for this project is $98,500,000.

21-SC-72, Critical Infrastructure Recovery & Renewal, PPPL

The Critical Infrastructure Recovery & Renewal (CIRR) project at PPPL will revitalize critical infrastructure that supports the PPPL campus. Upgrades considered as part of the CIRR 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-1, Approve Alternative Selection and Cost Range, approved on February 23, 2021. The preliminary estimate for CD-2, Approve Performance Baseline, is anticipated in the third quarter of FY 2024. This project is pre-CD-2; therefore, schedule estimates are preliminary and subject to change. The preliminary TEC range for this project is $78,000,000 to $94,100,000. The preliminary TPC range for this project is $79,900,000 to $96,000,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The preliminary TPC estimate for this project is $89,000,000.

21-SC-73, Ames Infrastructure Modernization

The Ames Infrastructure Modernization (AIM) project will support the SC mission by providing a more operationally efficient campus and safer environment 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 first quarter of FY 2022. This project is pre-CD-2; therefore, schedule estimates are preliminary and subject to change. The preliminary TEC range for this project is $22,000,000 to $89,000,000. The preliminary 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. The preliminary TPC estimate for this project is $31,000,000.

20-SC-71, 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 SC facilities supporting Nuclear Physics (NP), BES, High Energy Physics (HEP), Biological and Environmental Research (BER), and ASCR program missions.

The most recent DOE Order 413.3B Critical Decision (CD) is CD-1/3A, Approve Alternative Selection and Cost Range and Approve Long-Lead Procurements and Start of Early Construction Activities, was approved on February 6, 2020. The preliminary estimate for CD-2/3, Approve Performance Baseline and approve Start of Construction, is anticipated in the second quarter of FY 2022. 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 $71,000,000 to $93,000,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The preliminary TPC estimate for this project is $93,000,000.

20-SC-72, 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 first quarter of FY 2022. This project is pre-CD-2; therefore, schedule estimates are preliminary and subject to change. The preliminary TEC range for this project is $76,300,000 to $95,400,000. The preliminary TPC range for this project is $78,500,000 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.

20-SC-73, CEBAF Renovation and Expansion, TJNAF

The CEBAF Renovation and Expansion project will renovate existing space and provide new research, administrative, and support service space enabling TJNAF to better support SC missions. The CEBAF center at TJNAF is currently overcrowded and has compromised 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-1, Approve Alternative Selection and Cost Range which was approved on March 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. The preliminary TEC range for this project is $47,000,000 to $96,000,000. The preliminary TPC range for this project is $50,000,000 to $99,000,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The preliminary TPC estimate for this project is $90,000,000.

20-SC-75, Large Scale Collaboration Center, SLAC

The Large Scale Collaboration Center project will construct a multi-office building of approximately 38,000 to 45,000 gsf to consolidate and provide space for 100-150 occupants in a common building, provide synergies among all major SC-sponsored programs at SLAC, and provide a centralized office and collaboration space for cross-functional teams with the necessary performance capabilities to grow the science research programs. With the growth in SC mission activities at SLAC – from the Linac Coherent Light Source (LCLS), LCLS-II, LCLS-II-HE projects to Facility for Advanced Accelerator Experimental

Tests (FACET)-II and the Matter in Extreme Conditions project – the lab currently lacks office spaces for scientists and staff as current spaces 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, was approved on November 18, 2019. The preliminary estimate for CD-2, Approve Performance Baseline, is anticipated in the third quarter of FY 2022. This project is pre-CD-2; therefore, schedule estimates are preliminary and subject to change. The preliminary TEC range for this project is $56,000,000 to $90,400,000. The preliminary TPC range for this project is $58,000,000 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.

<u>20-SC-76, Tritium System Demolition and Disposal, PPPL</u>
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 expenditures on a legacy system.

The most recent DOE Order 413.3B Critical Decision (CD) CD-0, Approve Mission Need, was approved on September 16, 2019. The preliminary estimate for approval of combined CD-1, Approve Alternative Selection and Cost Range, CD-2, Approve Performance Baseline, and CD-3, Approve Start of Construction, 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 preliminary TEC range for this project is $19,500,000 to $32,400,000. The preliminary 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.

<u>20-SC-77, Argonne Utilities Upgrade, ANL</u>
The Argonne Utilities Upgrade project at ANL will revitalize and selectively upgrade ANL's existing major utility systems to increase the reliability, capability, and safety of ANL's infrastructure to meet the DOE's mission. The project will focus on systems such as 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 third quarter of FY 2021. This project is pre-CD-2; therefore, schedule estimates are preliminary and subject to change. The preliminary TEC range for this project is $72,000,000 to $215,000,000. The preliminary 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. The preliminary TPC estimate for this project is $216,000,000.

<u>20-SC-78, Linear Assets Modernization Project, LBNL</u>
The Linear Assets Modernization Project at LBNL will 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 first quarter of FY 2022. This project is pre-CD-2, therefore schedule estimates are preliminary and subject to change. The preliminary TEC range for this project is $142,000,000 to $236,000,000. The preliminary 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. The preliminary TPC estimate for this project is $240,000,000.

20-SC-79, Critical Utilities Infrastructure Revitalization, SLAC

The primary objective of Critical Utilities Infrastructure Revitalization (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 2021. This project is pre-CD-2; therefore, schedule estimates are preliminary and subject to change. The preliminary TEC range for this project is $80,000,000 to $186,000,000. The preliminary 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.

20-SC-80, 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 2022. This project is pre-CD-2; therefore, schedule estimates are preliminary and subject to change. The preliminary TEC range for this project is $146,000,000 to $310,000,000. The preliminary TPC range for this project is $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.

19-SC-71, 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 first quarter of FY 2022. This project is pre-CD-2; therefore, schedule estimates are preliminary and subject to change. The preliminary TEC range for this project is $70,800,000 to $94,800,000. The preliminary 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 TPC estimate for this project is $86,200,000.

19-SC-73, Translational Research Capability, ORNL

The Translational Research Capability project will 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-2/3, Approve Performance Baseline and Approve Start of Construction/Execution approved on April 3, 2020. This project has a TEC of $93,500,000 and a TPC of $95,000,000.

19-SC-74, 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. The new building will consolidate much of the widely dispersed biological sciences program at LBNL and off-site and will facilitate 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. The preliminary TEC range for this project is $110,000,000 to $190,000,000. The preliminary 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 this project is $142,200,000.

17-SC-71, 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. 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-2/3 Approve Project Baseline and Approve Start of Construction Activities, which was approved on September 30, 2020. This project has a TEC of $85,000,000 and a TPC of $86,000,000.

Science Laboratories Infrastructure
Construction

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Construction	**$173,700**	**$246,550**	**+$72,850**
22-SC-71, Critical Infrastructure Modernization Project, ORNL	$ —	$1,000	+$1,000
No funding requested.		The Request will initiate Project Engineering and Design (PED) activities.	Funding will support the initiation of PED activities for this new project.
22-SC-72, Thomas Jefferson Infrastructure Improvements, TJNAF	$ —	$1,000	+$1,000
No funding requested.		The Request will initiate PED activities.	Funding will support the initiation of PED activities for this new project.
21-SC-71, Princeton Plasma Innovation Center, PPPL	$150	$7,750	+$7,600
Funding initiates PED activities.		The Request will support ongoing PED activities.	Funding will support the continuation of PED activities for this project.
21-SC-72, Critical Infrastructure Recovery & Renewal, PPPL	$150	$2,000	+$1,850
Funding initiates PED activities.		The Request will support ongoing PED activities.	Funding will support the continuation of PED activities for this project.
21-SC-73, Ames Infrastructure Modernization	$150	$2,000	+$1,850
Funding initiates PED activities.		The Request will support ongoing PED activities.	Funding will support the continuation of PED activities for this project.

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
20-SC-71, Critical Utilities Rehabilitation Project, BNL	$20,000	$26,000	+$6,000
Funding supports construction activities.		The Request will support ongoing construction activities.	Funding will support ongoing construction activities for this project.
20-SC-72, Seismic and Safety Modernization, LBNL	$5,000	$27,500	+$22,500
Funding initiates construction activities.		The Request will support construction and associated activities.	Funding will support ongoing construction and associated activities for this project.
20-SC-73, CEBAF Renovation and Expansion, TJNAF	$2,000	$10,000	+$8,000
Funding supports ongoing PED activities.		The Request will support ongoing PED activities and initiate construction activities.	Funding will support ongoing PED activities and the initiation of construction activities for this project.
20-SC-74, Craft Resources Support Facility, ORNL	$25,000	$ —	-$25,000
Funding supports the completion of construction activities.		Final funding for this project was received in FY 2021.	FY 2021 provided final funding for this project.
20-SC-75, Large Scale Collaboration Center, SLAC	$11,000	$12,000	+$1,000
Funding supports ongoing construction activities.		The Request will support ongoing construction activities.	Funding will support ongoing construction for this project.
20-SC-76, Tritium System Demolition and Disposal, PPPL	$13,000	$6,400	-$6,600
Funding supports ongoing construction activities.		The Request will support final construction activities.	Final funding for this project is requested in FY 2022.

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
20-SC-77, Argonne Utilities Upgrade, ANL	$500	$10,000	+$9,500
Funding supports ongoing PED activities.		The Request will support ongoing PED activities.	Funding will support ongoing PED activities for this project.
20-SC-78, Linear Assets Modernization Project, LBNL	$500	$12,850	+$12,350
Funding supports ongoing PED activities.		The Request will support ongoing PED activities and initiate early construction activities.	Funding will support ongoing PED activities and the initiation of early construction activities for this project.
20-SC-79, Critical Utilities Infrastructure Revitalization, SLAC	$500	$10,000	+$9,500
Funding supports ongoing PED activities.		The Request will support ongoing PED activities and initiate early construction activities.	Funding will support ongoing PED activities and the initiation of early construction activities for this project.
20-SC-80, Utilities Infrastructure Project, FNAL	$500	$13,300	+$12,800
Funding supports ongoing PED activities.		The Request will support ongoing PED activities and initiate early construction activities.	Funding will support ongoing PED activities and the initiation of early construction activities for this project.
19-SC-71, Science User Support Center, BNL	$20,000	$38,000	+$18,000
Funding supports construction activities.		The Request will support construction activities.	Funding will support ongoing construction activities for this project.
19-SC-73, Translational Research Capability, ORNL	$22,000	$21,500	-$500
Funding supports construction activities.		The Request will support construction activities.	Funding will support ongoing construction activities for this project.

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
19-SC-74, BioEPIC, LBNL	$20,000	$35,000	+$15,000
Funding supports construction activities.		The Request will support ongoing construction activities.	Funding will support ongoing construction activities for this project.
18-SC-71, Energy Sciences Capability, PNNL	$23,000	$ —	-$23,000
Funding supports the completion of construction activities.		Final funding for this project was received in FY 2021.	FY 2021 provided final funding for this project.
17-SC-71, Integrated Engineering Research Center, FNAL	$10,250	$10,250	$ —
Funding supports construction activities.		The Request will support final construction activities.	Final funding for this project is requested in FY 2022.

Science Laboratories Infrastructure
Capital Summary

(dollars in thousands)

	Total	Prior Years	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Capital Operating Expenses						
Capital Equipment	N/A	N/A	–	–	–	–
Minor Construction Activities						
General Plant Projects	N/A	N/A	38,578	29,590	17,000	-12,590
Total, Capital Operating Expenses	**N/A**	**N/A**	**38,578**	**29,590**	**17,000**	**-12,590**

Science Laboratories Infrastructure
Minor Construction Activities

(dollars in thousands)

	Total	Prior Years	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
General Plant Projects (GPP)						
GPPs (greater than or equal to $5M and less than $20M)						
Advanced PFAS Characterization and Remediation at BNL	10,900	–	10,900	–	–	–
Grizzly Substation Yard Expansion at LBNL	15,000	–	15,000	–	–	–
Village Sanitary Improvements/Lift Station at FNAL	6,000	–	6,000	–	–	–
Cryogenics Test Facility (CTF) Upgrade at TJNAF	5,200	–	5,200	–	–	–
Welcome and Access Center at FNAL	12,500	–	–	1,000	11,500	+10,500
Mission Critical Buildings Upgrade HVAC Systems at BNL	8,700	–	–	8,700	–	-8,700
Site-wide HVAC System Improvements at LBNL	15,000	–	–	15,000	–	-15,000
Steam to Hydronics Conversion Project at PNNL	7,000	–	–	–	1,600	+1,600
Total GPPs (greater than or equal to $5M and less than $20M)	N/A	N/A	37,100	24,700	13,100	-11,600
Total GPPs less than $5M	N/A	N/A	1,478	4,890	3,900	-990
Total, General Plant Projects (GPP)	**N/A**	**N/A**	**38,578**	**29,590**	**17,000**	**-12,590**
Total, Minor Construction Activities	**N/A**	**N/A**	**38,578**	**29,590**	**17,000**	**-12,590**

Note: GPP activities less than $5M include design and construction for additions and/or improvements to land, buildings, replacements or addition to roads, and general area improvements. AIP activities less than $5M include minor construction at an existing accelerator facility.

	(dollars in thousands)				
	Total	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Institutional General Plant Projects (IGPP)					
IGPPs (greater than or equal to $5M and less than $20M)					
Chilled Water Capacity Upgrades at ANL	5,320	5,320	—	—	—
Site Security Upgrades - North/West Gates at ANL	7,200	7,200	—	—	—
B77 Enclosure at LBNL	6,970	6,970	—	—	—
Transit Hub and Site Utilities at LBNL	14,865	14,865	—	—	—
B73 Seismic Upgrade at LBNL	12,060	12,060	—	—	—
B77 Metrology Lab at LBNL	6,800	6,800	—	—	—
Secondary Sewage Treatment at ORNL	19,500	19,500	—	—	—
Multi-Program Office Building #1 at ORNL	9,563	9,563	—	—	—
Mission Support Facility at ORNL	19,140	19,140	—	—	—
Quantum Lab Renovations at ANL	6,000	—	6,000	—	-6,000
Bldg. 222 Lab Renovations at ANL	6,000	—	6,000	—	-6,000
Electrical Modernization Program at ANL	8,500	—	8,500	—	-8,500
Sitewide Fixed Generator installations and upgrades at LBNL	10,000	—	10,000	—	-10,000
Grizzly Substation Transformers Installation at LBNL	17,500	—	17,500	—	-17,500
Consolidate Power Operations at ORNL	5,000	—	5,000	—	-5,000
ESH Lab and Training Space at ORNL	10,100	—	10,100	—	-10,100
4501 Ventilation Safety Improvements at ORNL	5,000	—	5,000	—	-5,000
6007/6008 Shop and Change house mods at ORNL	8,000	—	8,000	—	-8,000
4500N Modifications at ORNL	9,600	—	9,600	—	-9,600
Remodel Life Sciences Laboratory 2 (LSL2) Labs 404-424 at PNNL	6,200	—	6,200	—	-6,200

(dollars in thousands)

	Total	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Institutional General Plant Projects (IGPP)					
IGPPs (greater than or equal to $5M and less than $20M)					
Electric Switch station (SW-A3) Replacement at LBNL	12,600	—	—	12,600	+12,600
TRU Waste Certification and Loading Support Building at ORNL	18,000	—	—	18,000	+18,000
High Bandwidth Network at ORNL	9,600	—	—	9,600	+9,600
EGCR Campus Utilities at ORNL	7,000	—	—	7,000	+7,000
Utilities Modernization at ORNL	10,100	—	—	10,100	+10,100
7667 LLW Site Improvements at ORNL	7,000	—	—	7,000	+7,000
Campus Parking Areas at ORNL	5,000	—	—	5,000	+5,000
Richland North Office Building at PNNL	13,000	—	—	13,000	+13,000
Total IGPPs (greater than or equal to $5M and less than $20M)	275,618	101,418	91,900	82,300	-9,600
Total IGPPs less than $5M	80,026	19,596	37,780	22,650	-15,130
Total, Institutional General Plant Projects (IGPP)	**355,644**	**121,014**	**129,680**	**104,950**	**-24,730**
Total, Minor Construction Activities	**440,812**	**159,592**	**159,270**	**121,950**	**-37,320**

Note: 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 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
22-SC-71, Critical Infrastructure Modernization Project, ORNL						
Total Estimated Cost (TEC)	415,000	–	–	–	1,000	+1,000
Other Project Cost (OPC)	4,000	–	500	750	750	–
Total Project Cost (TPC)	**419,000**	**–**	**500**	**750**	**1,750**	**+1,000**
22-SC-72, Thomas Jefferson Infrastructure Improvements, TJNAF						
Total Estimated Cost (TEC)	98,000	–	–	–	1,000	+1,000
Other Project Cost (OPC)	1,000	–	–	1,000	–	-1,000
Total Project Cost (TPC)	**99,000**	**–**	**–**	**1,000**	**1,000**	**–**
21-SC-71, Princeton Plasma Innovation Center, PPPL						
Total Estimated Cost (TEC)	96,300	–	–	150	7,750	+7,600
Other Project Cost (OPC)	2,200	10	1,400	90	–	-90
Total Project Cost (TPC)	**98,500**	**10**	**1,400**	**240**	**7,750**	**+7,510**
21-SC-72, Critical Infrastructure Recovery & Renewal, PPPL						
Total Estimated Cost (TEC)	87,100	–	–	150	2,000	+1,850
Other Project Cost (OPC)	1,900	6	1,046	300	–	-300
Total Project Cost (TPC)	**89,000**	**6**	**1,046**	**450**	**2,000**	**+1,550**
21-SC-73, Ames Infrastructure Modernization						
Total Estimated Cost (TEC)	30,000	–	–	150	2,000	+1,850
Other Project Cost (OPC)	1,000	25	50	200	225	+25
Total Project Cost (TPC)	**31,000**	**25**	**50**	**350**	**2,225**	**+1,875**

(dollars in thousands)

	Total	Prior Years	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
20-SC-71, Critical Utilities Rehabilitation Project, BNL						
Total Estimated Cost (TEC)	92,000	–	20,000	20,000	26,000	+6,000
Other Project Cost (OPC)	1,000	–	410	590	–	-590
Total Project Cost (TPC)	**93,000**	**–**	**20,410**	**20,590**	**26,000**	**+5,410**
20-SC-72, Seismic and Safety Modernization, LBNL						
Total Estimated Cost (TEC)	95,400	–	10,000	5,000	27,500	+22,500
Other Project Cost (OPC)	2,200	1,050	20	–	–	–
Total Project Cost (TPC)	**97,600**	**1,050**	**10,020**	**5,000**	**27,500**	**+22,500**
20-SC-73, CEBAF Renovation and Expansion, TJNAF						
Total Estimated Cost (TEC)	87,000	–	2,000	2,000	10,000	+8,000
Other Project Cost (OPC)	3,000	1,000	467	–	–	–
Total Project Cost (TPC)	**90,000**	**1,000**	**2,467**	**2,000**	**10,000**	**+8,000**
20-SC-74, Craft Resources Support Facility, ORNL						
Total Estimated Cost (TEC)	40,000	–	15,000	25,000	–	-25,000
Other Project Cost (OPC)	1,000	590	260	–	–	–
Total Project Cost (TPC)	**41,000**	**590**	**15,260**	**25,000**	**–**	**-25,000**
20-SC-75, Large Scale Collaboration Center, SLAC						
Total Estimated Cost (TEC)	64,000	–	11,000	11,000	12,000	+1,000
Other Project Cost (OPC)	2,000	500	4	–	–	–
Total Project Cost (TPC)	**66,000**	**500**	**11,004**	**11,000**	**12,000**	**+1,000**

(dollars in thousands)

	Total	Prior Years	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
20-SC-76, Tritium System Demolition and Disposal, PPPL						
Total Estimated Cost (TEC)	32,400	–	13,000	13,000	6,400	-6,600
Other Project Cost (OPC)	1,000	100	800	100	–	-100
Total Project Cost (TPC)	**33,400**	**100**	**13,800**	**13,100**	**6,400**	**-6,700**
20-SC-77, Argonne Utilities Upgrade, ANL						
Total Estimated Cost (TEC)	215,000	–	500	500	10,000	+9,500
Other Project Cost (OPC)	1,000	100	600	300	–	-300
Total Project Cost (TPC)	**216,000**	**100**	**1,100**	**800**	**10,000**	**+9,200**
20-SC-78, Linear Assets Modernization Project, LBNL						
Total Estimated Cost (TEC)	236,000	–	500	500	12,850	+12,350
Other Project Cost (OPC)	4,000	172	398	1,230	500	-730
Total Project Cost (TPC)	**240,000**	**172**	**898**	**1,730**	**13,350**	**+11,620**
20-SC-79, Critical Utilities Infrastructure Revitalization, SLAC						
Total Estimated Cost (TEC)	186,000	–	500	500	10,000	+9,500
Other Project Cost (OPC)	3,000	–	323	1,000	–	-1,000
Total Project Cost (TPC)	**189,000**	**–**	**823**	**1,500**	**10,000**	**+8,500**
20-SC-80, Utilities Infrastructure Project, FNAL						
Total Estimated Cost (TEC)	310,000	–	500	500	13,300	+12,800
Other Project Cost (OPC)	4,000	–	–	1,530	500	-1,030
Total Project Cost (TPC)	**314,000**	**–**	**500**	**2,030**	**13,800**	**+11,770**
19-SC-71, Science User Support Center, BNL						
Total Estimated Cost (TEC)	85,000	7,000	20,000	20,000	38,000	+18,000
Other Project Cost (OPC)	1,200	1,200	–	–	–	–
Total Project Cost (TPC)	**86,200**	**8,200**	**20,000**	**20,000**	**38,000**	**+18,000**

(dollars in thousands)

	Total	Prior Years	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
19-SC-72, Electrical Capacity and Distribution Capability, ANL						
Total Estimated Cost (TEC)	60,000	30,000	30,000	–	–	–
Other Project Cost (OPC)	1,000	1,000	–	–	–	–
Total Project Cost (TPC)	**61,000**	**31,000**	**30,000**	**–**	**–**	**–**
19-SC-73, Translational Research Capability, ORNL						
Total Estimated Cost (TEC)	93,500	25,000	25,000	22,000	21,500	-500
Other Project Cost (OPC)	1,500	1,400	–	–	–	–
Total Project Cost (TPC)	**95,000**	**26,400**	**25,000**	**22,000**	**21,500**	**-500**
19-SC-74, BioEPIC						
Total Estimated Cost (TEC)	140,000	5,000	15,000	20,000	35,000	+15,000
Other Project Cost (OPC)	2,200	1,500	21	–	–	–
Total Project Cost (TPC)	**142,200**	**6,500**	**15,021**	**20,000**	**35,000**	**+15,000**
18-SC-71, Energy Sciences Capability, PNNL						
Total Estimated Cost (TEC)	90,000	44,000	23,000	23,000	–	-23,000
Other Project Cost (OPC)	3,000	1,236	126	–	1,638	+1,638
Total Project Cost (TPC)	**93,000**	**45,236**	**23,126**	**23,000**	**1,638**	**-21,362**
17-SC-71, Integrated Engineering Research Center, FNAL						
Total Estimated Cost (TEC)	85,000	42,500	22,000	10,250	10,250	–
Other Project Cost (OPC)	1,000	950	–	–	50	+50
Total Project Cost (TPC)	**86,000**	**43,450**	**22,000**	**10,250**	**10,300**	**+50**
Total, Construction						
Total Estimated Cost (TEC)	**N/A**	**N/A**	**208,000**	**173,700**	**246,550**	**+72,850**
Other Project Cost (OPC)	**N/A**	**N/A**	**6,425**	**7,090**	**3,663**	**-3,427**
Total Project Cost (TPC)	**N/A**	**N/A**	**214,425**	**180,790**	**250,213**	**+69,423**

Science Laboratories Infrastructure
Funding Summary

(dollars in thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Projects				
Line Item Construction (LIC)	208,000	173,700	246,550	+72,850
Total, Projects	**208,000**	**173,700**	**246,550**	**+72,850**
Other	93,000	66,300	48,450	-17,850
Total, Science Laboratories Infrastructure	**301,000**	**240,000**	**295,000**	**+55,000**

22-SC-71, Critical Infrastructure Modernization Project, ORNL
Oak Ridge National Laboratory
Project is for Design and Construction

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

Summary

The FY 2022 Request for the Critical Infrastructure Modernization Project is $1,000,000. The preliminary Total Estimated Cost (TEC) range for this project is $221,000,000 to $415,000,000. The preliminary Total Project Cost (TPC) range for this project is $225,000,000 to $419,000,000. Currently, these cost ranges encompass the most feasible preliminary alternatives. The preliminary TPC estimate for this project is $419,000,000.

Oak Ridge National Laboratory (ORNL) requires utilities infrastructure improvements that provide reliable, available, safe, compliant, maintainable, redundant, energy and cost efficient, and flexible and expandable operations to address current and emerging research needs. Modernization, renewal, and expansion of existing degraded and/or at designed capacity site utility infrastructure is required to operate and maintain modern, world-class facilities for scientific discovery at ORNL in support of the SC mission. Investment in utility infrastructure to meet future utility needs in support of new SC missions and/or growth of SC missions at ORNL is also needed.

Significant Changes

This project is a new start in FY 2022. DOE Order 413.3B Critical Decision (CD)-0, Approve Mission Need, was achieved on October 26, 2020. FY 2022 funds will support the initiation of Project Engineering and Design (PED) activities.

A Federal Project Director with the appropriate certification 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 2022	10/26/20	4Q FY 2022	4Q FY 2022	4Q FY 2024	2Q FY 2024	4Q FY 2026	N/A	4Q FY 2035

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 2022	4Q FY 2024	4Q FY 2024

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

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D[a]	OPC, D&D	OPC, Total	TPC
FY 2022	50,000	365,000	415,000[b]	4,000	N/A	4,000	419,000[b]

2. Project Scope and Justification

Scope

The scope of the Critical Infrastructure Modernization Project (CIMP) at ORNL will address critical utility infrastructure capability gaps due to deterioration, non-redundancy, lack of availability, and or capacity limitations in infrastructure systems such as electrical distribution, potable water distribution, chilled water and steam generation and distribution, sanitary wastewater collection and treatment, natural gas distribution, compressed air distribution, storm water collection, etc.

Prioritized scope will be finalized as the project matures and will focus on system capability gaps associated with the greatest risk probability/impact of a system failure, impacts to science operations, and meeting the demand required to support future scientific endeavors.

Justification

Advancing the SC mission requires modern, reliable, and operationally efficient infrastructure. At ORNL, the site utility infrastructure supporting all core capabilities and all SC programs is degraded and needs to be modernized. To continue to deliver scientific and technical breakthroughs needed to realize solutions in energy and national security and provide economic benefit to the nation, ORNL requires utilities infrastructure improvements that provide reliable, available, safe, compliant, maintainable, redundant, energy and cost efficient, and flexible and expandable operations to address current and emerging research needs.

Many of ORNL's utilities were installed prior to the 1950's as part of the Manhattan Project. The systems are beyond useful life, suffer from parts obsolescence, and were not designed to support the experimental parameters needed for scientific research today and the future. With deteriorating infrastructure that has an average age greater than 50 years old, ORNL is experiencing increasing failure rates and costs for emergency repairs. The failure of critical utility systems disrupts science research, production, operations, and support activities in offices, laboratories, industrial areas, and major user facilities.

CIMP will deliver a significantly more modern and resilient general-purpose infrastructure. The combination of data collection and artificial intelligent monitoring systems will be able to adjust to trends, predict failures, and react to extreme weather events, such as automatically transfer power to minimize impacts to mission critical scientific operations. Additionally, modern utility systems will be more efficient and sustainable. Every element of this project will be designed to consider best available/most efficient technology resulting in energy savings. Additionally, the utilities will be designed to be maintainable and monitored using artificial intelligence to enable predictive maintenance.

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

Key Performance Parameters (KPPs)

The 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.
[b] This project is pre-CD-2; therefore, funding estimate are preliminary.

Performance Measure	Threshold	Objective
Rehabilitate, expand, and/or upgrade ORNL's major utility systems	Renovate and modernize highest priority utilities including generation and/or distribution systems and components for systems which, at this preconceptual stage, may include: ▪ Electrical ▪ Natural Gas ▪ Potable water supply, Sanitary Storm water ▪ Steam ▪ chilled water, and/or ▪ Compressed Air ▪ Establish system redundancy for critical systems	Establish, expand, and/or renovate additional utility systems

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
Design (TEC)			
FY 2022	1,000	1,000	500
Outyears	49,000	49,000	49,500
Total, Design (TEC)	**50,000**	**50,000**	**50,000**
Construction (TEC)			
Outyears	365,000	365,000	365,000
Total, Construction (TEC)	**365,000**	**365,000**	**365,000**
Total Estimated Cost (TEC)			
FY 2022	1,000	1,000	500
Outyears	414,000	414,000	414,500
Total, TEC	**415,000**	**415,000**	**415,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Other Project Cost (OPC)			
FY 2020	500	500	500
FY 2021	750	750	750
FY 2022	750	750	750
Outyears	2,000	2,000	2,000
Total, OPC	**4,000**	**4,000**	**4,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Project Cost (TPC)			
FY 2020	500	500	500
FY 2021	750	750	750
FY 2022	1,750	1,750	1,250
Outyears	416,000	416,000	416,500
Total, TPC	**419,000**	**419,000**	**419,000**

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design	42,500	N/A	**N/A**
Design - Contingency	7,500	N/A	**N/A**
Total, Design (TEC)	**50,000**	**N/A**	**N/A**
Construction	275,000	N/A	**N/A**
Construction - Contingency	90,000	N/A	**N/A**
Total, Construction (TEC)	**365,000**	**N/A**	**N/A**
Total, TEC	**415,000**	**N/A**	**N/A**
Contingency, TEC	*97,500*	***N/A***	***N/A***
Other Project Cost (OPC)			
Conceptual Design	2,100	N/A	**N/A**
Start-up	1,100	N/A	**N/A**
OPC - Contingency	800	N/A	**N/A**
Total, Except D&D (OPC)	**4,000**	**N/A**	**N/A**
Total, OPC	**4,000**	**N/A**	**N/A**
Contingency, OPC	*800*	*N/A*	***N/A***
Total, TPC	**419,000**	**N/A**	**N/A**
Total, Contingency (TEC+OPC)	***98,300***	***N/A***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Request Year	Type	FY 2020	FY 2021	FY 2022	Outyears	Total
FY 2022	TEC	—	—	1,000	414,000	415,000[a]
	OPC[b]	500	750	750	2,000	4,000
	TPC	500	750	1,750	416,000	419,000[a]

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	Varies by System
Expected Useful Life	Varies by System
Expected Future Start of D&D of this capital asset	Varies by System

[a] This project is pre-CD-2; therefore, funding estimate 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	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

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 Oak Ridge National Laboratory	N/A
Area of D&D in this project at Oak Ridge National Laboratory	N/A
Area at Oak Ridge National Laboratory to be transferred, sold, and/or D&D outside the project, including area previously "banked"	N/A
Area of D&D in this project at other sites	N/A
Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked"	N/A
Total area eliminated	N/A

8. Acquisition Approach

The Oak Ridge National Laboratory 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 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.

22-SC-72, Thomas Jefferson Infrastructure Improvements, TJNAF
Thomas Jefferson National Accelerator Facility
Project is for Design and Construction

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

Summary

The FY 2022 Request for the Thomas Jefferson Infrastructure Improvements project is $1,000,000. The preliminary Total Estimated Cost (TEC) range for this project is $76,000,000 to $98,000,000. The preliminary Total Project Cost (TPC) range for this project is $77,000,000 to $99,000,000. Currently, these cost ranges encompass the most feasible preliminary alternatives. The preliminary TPC estimate for this project is $99,000,000.

Thomas Jefferson National Accelerator Facility (TJNAF) needs additional laboratory space and modern utility systems that are safer and more operationally efficient for employees and visitors of TJNAF. This project will address the lack of efficient high-bay laboratory space, growing repair needs and deferred maintenance, and safety and security risks currently posed by intermingling of operations, projects, and users. It will renovate/modernize 54,000 square feet and construct 65,000-80,000 square feet of new space to facilitate renovation/modernization efforts and support projected workload.

Additionally, there will be improvements to the water, sanitary and communications utilities, and roads, sidewalks, and parking infrastructure.

Significant Changes

This project is a new start in FY 2022. DOE Order 413.3B Critical Decision (CD)-0, Approve Mission Need, was achieved on December 8, 2020. FY 2022 funds will support the initiation 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) 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 2022	12/8/20	4Q FY 2021	2Q FY 2022	4Q FY 2023	3Q FY 2025	4Q FY 2024	N/A	4Q FY 2030

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

Fiscal Year	Performance Baseline Validation
FY 2022	4Q FY 2023

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D[a]	OPC, D&D	OPC, Total	TPC
FY 2022	10,000	88,000	98,000[b]	1,000	N/A	1,000	99,000[b]

2. Project Scope and Justification

Scope

The scope of the Thomas Jefferson Infrastructure Improvements project will include renovating 54,000 gross square feet (gsf) of existing space and providing 65,000 to 80,000 gsf of additional office and laboratory space. The renovation will include reconfiguration to provide more functional, flexible, and efficient spaces that meet current code standards. The project will upgrade the mechanical systems in the existing Experimental Equipment Lab (EEL), Technology and Engineering Development (TED) building, and Test Lab Center, which have exceeded their service life. The renovated building will be energy sustainable and will meet high performance building standards, including energy conservation, green building principles, and sustainable design.

Additional infrastructure improvements include the consolidation of facilities for technical shops and logistics staff, improvements to the water, sanitary and communication utilities, as well as improvements to roads, sidewalks and parking infrastructure. Utilities require improvement to correct deficiencies and provide added capability to align with the current and projected mission need. Road, sidewalk, and parking improvements support and align with general site needs to support new construction and renovation projects.

Justification

At TJNAF, superconducting radio frequency (SRF) cryomodule production, cryogenics fabrication, and the development, assembly, and staging of experiments prior to installation in the experimental halls primarily occur in high bay space in the EEL building, TED building, and Test Lab. Growing SRF cryomodule production work, forecasted high-volume experiment assembly, and ongoing cryogenics fabrication exceed high bay and associated staging and storage capacity in these buildings. This work supports large-scale and complex experiment assembly (Measurement of a Lepton-Lepton Electroweak Reaction (MOLLER), Solenoidal Large Intensity Device (SoLID for the Nuclear Physics (NP) program and major line-item projects Linac Coherent Light Source-II High Energy (LCLS-II HE), Spallation Neutron Source (SNS) for the Basic Energy Sciences (BES) Program. The aforementioned intermingling of operations, projects, and users is inefficient, creates many safety and security challenges (e.g., frequent overhead crane work and high-dollar-value items in areas open to multiple groups), and forces a dependence on supplemental off-site leased space as a stop-gap measure.

In addition to space over-utilization issues, the EEL building is in substandard condition—with repair needs and deferred maintenance quickly escalating, as major building systems approach and exceed their service life. Additionally, meeting this mission need will mitigate intermingling of operations, projects, and users which poses an increased safety risk to staff and visiting scientists. This risk is growing and will continue with the forecasted workload and scheduled near-term projects.

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 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

[a] Other Project Costs (OPC) are funded through laboratory overhead.
[b] This project is pre-CD-2; therefore, funding estimates are preliminary.

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
EEL, TED, Test Lab Renovation	54,000 gsf	N/A
New Construction	65,000 gsf	80,000 gsf
Water, Sanitary, Communications	5000 lf	20,000 lf
Roadway Improvements	0.25 mi	2.0 mi

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
Design (TEC)			
FY 2022	1,000	1,000	500
Outyears	9,000	9,000	9,500
Total, Design (TEC)	**10,000**	**10,000**	**10,000**
Construction (TEC)			
Outyears	88,000	88,000	88,000
Total, Construction (TEC)	**88,000**	**88,000**	**88,000**
Total Estimated Cost (TEC)			
FY 2022	1,000	1,000	500
Outyears	97,000	97,000	97,500
Total, TEC	**98,000**	**98,000**	**98,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Other Project Cost (OPC)			
FY 2021	1,000	1,000	1,000
Total, OPC	**1,000**	**1,000**	**1,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Project Cost (TPC)			
FY 2021	1,000	1,000	1,000
FY 2022	1,000	1,000	500
Outyears	97,000	97,000	97,500
Total, TPC	**99,000**	**99,000**	**99,000**

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design	8,000	N/A	**N/A**
Design - Contingency	2,000	N/A	**N/A**
Total, Design (TEC)	**10,000**	**N/A**	**N/A**
Construction	72,000	N/A	**N/A**
Construction - Contingency	16,000	N/A	**N/A**
Total, Construction (TEC)	**88,000**	**N/A**	**N/A**
Total, TEC	**98,000**	**N/A**	**N/A**
Contingency, TEC	*18,000*	***N/A***	***N/A***
Other Project Cost (OPC)			
Conceptual Planning	600	N/A	**N/A**
Conceptual Design	300	N/A	**N/A**
OPC - Contingency	100	N/A	**N/A**
Total, Except D&D (OPC)	**1,000**	**N/A**	**N/A**
Total, OPC	**1,000**	**N/A**	**N/A**
Contingency, OPC	*100*	*N/A*	***N/A***
Total, TPC	**99,000**	**N/A**	**N/A**
Total, Contingency (TEC+OPC)	***18,100***	***N/A***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Request Year	Type	Prior Years	FY 2020	FY 2021	FY 2022	Outyears	Total
FY 2022	TEC	—	—	—	1,000	97,000	98,000[a]
	OPC[b]	—	—	1,000	—	—	1,000
	TPC	—	—	1,000	1,000	97,000	99,000[a]

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	4Q FY 2028
Expected Useful Life	50 years
Expected Future Start of D&D of this capital asset	4Q FY 2078

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	63	N/A	3,160
Utilities	N/A	213	N/A	10,666
Maintenance and Repair	N/A	642	N/A	32,087
Total, Operations and Maintenance	N/A	918	N/A	45,913

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.......	65,000-116,000
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 is pre CD-2; 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.

21-SC-71, Princeton Plasma Innovation Center, PPPL
Princeton Plasma Physics Laboratory
Project is for Design and Construction

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

Summary

The FY 2022 Request for the Princeton Plasma Innovation Center (PPIC) project is $7,750,000. The preliminary Total Estimated Cost (TEC) range for this project is $78,300,000 to $96,300,000. The preliminary Total Project Cost (TPC) range for this project is $80,500,000 to $98,500,000. Currently, these cost ranges encompass the most feasible preliminary alternatives. The preliminary TPC estimate for this project is $98,500,000.

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 was initiated in FY 2021. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range, which was approved on January 22, 2021. FY 2022 funds will support Project Engineering and Design (PED) activities.

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

Critical Milestone History

Fiscal Year	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2021	9/9/19	N/A	4Q FY 2020	2Q FY 2022	N/A	2Q FY 2023	N/A	4Q FY 2029
FY 2022	9/9/19	8/25/20	1/22/21	4Q FY 2023	1Q FY 2024	2Q FY 2024	N/A	4Q 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

Fiscal Year	Performance Baseline Validation	CD-3A
FY 2021	N/A	2Q FY 2022
FY 2022	4Q FY 2023	4Q FY 2023

CD-3A – Approve Long-Lead Procurements and Start of Early Construction Activities

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D[a]	OPC, D&D	OPC, Total	TPC
FY 2021	9,000	100,000[b]	109,000	2,500	N/A	2,500	111,500[b]
FY 2022	8,900	87,400[b]	96,300	2,200	N/A	2,200	98,500[b]

2. Project Scope and Justification

Scope

The Princeton Plasma Innovation Center (PPIC) is envisioned as a 77,000 to 107,000 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 experiment 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 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 adequately support current or planned scientific efforts. In particular, the lack of adequate laboratory infrastructure, modern collaboration space, and modern office infrastructure are not optimal to support PPPL research. 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 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	77,000 gsf	107,000 gsf

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
Design (TEC)			
FY 2021	150	150	150
FY 2022	7,750	7,750	6,000
Outyears	1,000	1,000	2,750
Total, Design (TEC)	**8,900**	**8,900**	**8,900**
Construction (TEC)			
Outyears	87,400	87,400	87,400
Total, Construction (TEC)	**87,400**	**87,400**	**87,400**
Total Estimated Cost (TEC)			
FY 2021	150	150	150
FY 2022	7,750	7,750	6,000
Outyears	88,400	88,400	90,150
Total, TEC	**96,300**	**96,300**	**96,300**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Other Project Cost (OPC)			
FY 2019	10	10	10
FY 2020	1,400	1,400	1,400
FY 2021	90	90	90
Outyears	700	700	700
Total, OPC	**2,200**	**2,200**	**2,200**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Project Cost (TPC)			
FY 2019	10	10	10
FY 2020	1,400	1,400	1,400
FY 2021	240	240	240
FY 2022	7,750	7,750	6,000
Outyears	89,100	89,100	90,850
Total, TPC	**98,500**	**98,500**	**98,500**

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design	7,900	7,500	**N/A**
Design - Contingency	1,000	1,500	**N/A**
Total, Design (TEC)	**8,900**	**9,000**	**N/A**
Construction	72,000	83,300	**N/A**
Construction - Contingency	15,400	16,700	**N/A**
Total, Construction (TEC)	**87,400**	**100,000**	**N/A**
Total, TEC	**96,300**	**109,000**	**N/A**
Contingency, TEC	*16,400*	*18,200*	***N/A***
Other Project Cost (OPC)			
Conceptual Planning	300	300	**N/A**
Conceptual Design	1,700	2,000	**N/A**
OPC - Contingency	200	200	**N/A**
Total, Except D&D (OPC)	**2,200**	**2,500**	**N/A**
Total, OPC	**2,200**	**2,500**	**N/A**
Contingency, OPC	*200*	*200*	***N/A***
Total, TPC	**98,500**	**111,500**	**N/A**
Total, Contingency (TEC+OPC)	***16,600***	***18,400***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Request Year	Type	Prior Years	FY 2020	FY 2021	FY 2022	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]
FY 2022	TEC	—	—	150	7,750	88,400	96,300[a]
	OPC[b]	10	1,400	90	—	700	2,200
	TPC	10	1,400	240	7,750	89,100	98,500[a]

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	4Q FY 2028
Expected Useful Life	50 years
Expected Future Start of D&D of this capital asset	4Q FY 2078

Related Funding Requirements
(dollars in thousands)

	Annual Costs		Life Cycle Costs[c]	
	Previous Total Estimate	Current Total Estimate	Previous Total Estimate	Current Total Estimate
Operations	N/A	1,336	N/A	46,774
Utilities	N/A	198	N/A	6,936
Maintenance and Repair	N/A	1,518	N/A	53,154
Total, Operations and Maintenance	N/A	3,052	N/A	106,864

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	77,000-107,000
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[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	13,400

[a] This project has not received CD-2 approval; therefore, funding estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.
[c] Life-Cycle costs will be performed as part of CD-1.
[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 decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

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.

21-SC-72, Critical Infrastructure Recovery & Renewal, PPPL
Princeton Plasma Physics Laboratory
Project is for Design and Construction

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

Summary

The FY 2022 Request for the Critical Infrastructure Recovery & Renewal (CIRR) project is $2,000,000. The preliminary Total Estimated Cost (TEC) range for this project is $78,000,000 to $94,100,000. The preliminary Total Project Cost (TPC) range for this project is $79,900,000 to $96,000,000. Currently, these cost ranges encompass the most feasible preliminary alternatives. The preliminary TPC estimate for this project is $89,000,000.

Princeton Plasma Physics Laboratory's (PPPL's) deteriorating utility infrastructure is non-redundant and increasingly unreliable, which negatively impacts laboratory operations. Scientific productivity is dependent on a capable, available, flexible, maintainable, reliable, and resilient support infrastructure. This project will provide critical infrastructure needed to operate the laboratory missions safely and efficiently. These systems will be modern and energy efficient, reducing the operating cost and improving the resilience of the facilities.

Significant Changes

This project was initiated in FY 2021. The most recent DOE Order 413.3B Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range, which was approved on February 23, 2021. FY 2022 funds will continue Project Engineering and Design (PED) activities.

A Federal Project Director with the appropriate certification level will be assigned to this project prior to CD-1 approval.

Critical Milestone History

Fiscal Year	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2021	9/16/19	N/A	2Q FY 2020	4Q FY 2022	4Q FY 2023	4Q FY 2023	N/A	4Q FY 2029
FY 2022	9/16/19	12/31/20	2/23/21	3Q FY 2024	1Q FY 2024	3Q FY 2024	N/A	4Q 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
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	1Q FY 2023
FY 2022	3Q FY 2024	3Q FY 2023

CD-3A – Approve Long-Lead Procurements and Start of Early Construction Activities

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D[a]	OPC, D&D	OPC, Total	TPC
FY 2021	8,000	72,400[b]	80,400	1,500	N/A	1,500	81,900[b]
FY 2022	9,800	77,300[b]	87,100	1,900	N/A	1,900	89,000[b]

2. Project Scope and Justification

Scope

The CIRR project at PPPL will revitalize critical infrastructure that supports the PPPL campus to ensure reliability and resilience. Upgrades that may be completed as part of the CIRR 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 scientific activities that require reliable and resilient utilities include: NSTX-U; LTX-β; and FLARE.

Justification

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. To maintain current missions and enable future ones, the infrastructure must be upgraded with modern, efficient, and reliable systems.

CIRR will deliver a significantly more modern and resilient general-purpose infrastructure. The combination of data collection and artificial intelligent monitoring systems will be able to adjust to trends, predict failures, and react to extreme weather events, such as automatically transfer power to minimize impacts to mission critical scientific operations. Additionally, modern utility systems will be more efficient and sustainable. For example, replacing the obsolete hot deck/cold deck HVAC system will not only result in repair savings, but significant energy savings as well. Every element of this project will be designed to consider the best available and most efficient 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 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.
[b] This project has not received CD-2 approval; therefore, funding estimates are preliminary.

Performance Measure	Threshold	Objective
▪ Rehabilitate and selectively upgrade PPPL's existing major utility systems.	▪ Improve configuration and efficiency of the Central Chilled Water Plant to ensure distribution of 1,200 tons of cooling capacity to the site. ▪ Improve data infrastructure cabling and components by replacing existing copper cable with 2,000 linear feet of cat 6 cable. ▪ Provide 2,500 linear feet of 48 strand network fiber cable connected to the Princeton University Computer Center. ▪ Provide 15,000 linear feet of 24 strand fiber optic cable to support site wide communication. ▪ Create redundancy and improve mission readiness of the primary electrical distribution system in the 138 kV yard. ▪ Provide site-wide capacity of standby generation at 3,500 KW. ▪ Upgrade 8 Substations for priority buildings and facilities. ▪ Upgrade 8 HVAC system equipment for priority buildings on C-Site and D-Site. ▪ Replace all failed critical underground piping, valves, and components for campus utilities. ▪ Replace 1,700 linear feet of electrical feeders (26kv) for improved reliability. ▪ Upgrade 9,500 sqft of Storm Retention Basin liner.	▪ Threshold plus upgrade additional communication system components to improve security, reliability, and flexibility. ▪ Increase site-wide capacity of standby generation up to 4,350 KW. ▪ Upgrade up to 10 substations for additional buildings/facilities to improve flexibility for maintenance and operations. ▪ Upgrade up to 14 HVAC system equipment for additional buildings to meet sustainability goals and improve maintenance and operations. ▪ Threshold plus upgrade additional underground system components to improve maintenance and reliability.

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
Design (TEC)			
FY 2021	150	150	150
FY 2022	2,000	2,000	1,750
Outyears	7,650	7,650	7,900
Total, Design (TEC)	**9,800**	**9,800**	**9,800**
Construction (TEC)			
Outyears	77,300	77,300	77,300
Total, Construction (TEC)	**77,300**	**77,300**	**77,300**
Total Estimated Cost (TEC)			
FY 2021	150	150	150
FY 2022	2,000	2,000	1,750
Outyears	84,950	84,950	85,200
Total, TEC	**87,100**	**87,100**	**87,100**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Other Project Cost (OPC)			
FY 2019	6	6	6
FY 2020	1,046	1,046	1,046
FY 2021	300	300	300
Outyears	548	548	548
Total, OPC	**1,900**	**1,900**	**1,900**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Project Cost (TPC)			
FY 2019	6	6	6
FY 2020	1,046	1,046	1,046
FY 2021	450	450	450
FY 2022	2,000	2,000	1,750
Outyears	85,498	85,498	85,748
Total, TPC	**89,000**	**89,000**	**89,000**

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design	7,600	6,700	**N/A**
Design - Contingency	2,200	1,300	**N/A**
Total, Design (TEC)	**9,800**	**8,000**	**N/A**
Construction	59,400	60,300	**N/A**
Construction - Contingency	17,900	12,100	**N/A**
Total, Construction (TEC)	**77,300**	**72,400**	**N/A**
Total, TEC	**87,100**	**80,400**	**N/A**
Contingency, TEC	*20,100*	*13,400*	***N/A***
Other Project Cost (OPC)			
Conceptual Planning	200	100	**N/A**
Conceptual Design	1,500	1,200	**N/A**
OPC - Contingency	200	200	**N/A**
Total, Except D&D (OPC)	**1,900**	**1,500**	**N/A**
Total, OPC	**1,900**	**1,500**	**N/A**
Contingency, OPC	*200*	*200*	***N/A***
Total, TPC	**89,000**	**81,900**	**N/A**
Total, Contingency (TEC+OPC)	***20,300***	***13,600***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Request Year	Type	Prior Years	FY 2020	FY 2021	FY 2022	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]
FY 2022	TEC	—	—	150	2,000	84,950	87,100[a]
	OPC[b]	6	1,046	300	—	548	1,900
	TPC	6	1,046	450	2,000	85,498	89,000[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 2029
Expected Useful Life	50 years
Expected Future Start of D&D of this capital asset	N/A

Related Funding Requirements
(dollars in thousands)

	Annual Costs		Life Cycle Costs[a]	
	Previous Total Estimate	Current Total Estimate	Previous Total Estimate	Current Total Estimate
Operations	1,100	1,100	55,000	55,000
Utilities	N/A	N/A	N/A	N/A
Maintenance and Repair	1,000	1,000	50,000	50,000
Total, Operations and Maintenance	2,100	2,100	105,000	105,000

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 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 2022 Request for the Ames Infrastructure Modernization (AIM) project is $2,000,000. The preliminary Total Estimated Cost (TEC) range for this project is $22,000,000 to $89,000,000. The preliminary Total Project Cost (TPC) range for this project is $23,000,000 to $90,000,000. Currently, these cost ranges encompass the most feasible preliminary alternatives. 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 was initiated 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 2022 funds will support Project Engineering and Design (PED) activities and initiate long lead procurement and early construction activities upon the appropriate CD approvals.

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	3Q FY 2022	1Q FY 2023	2Q FY 2023	N/A	4Q FY 2026
FY 2022	9/16/19	3Q FY 2021	1Q FY 2022	2Q FY 2023	2Q FY 2023	3Q FY 2023	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 FY 2022	3Q FY 2022
FY 2022	2Q FY 2023	2Q FY 2023

CD-3A – Approve Long-Lead Procurements and Start of Early Construction Activities

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D[a]	OPC, D&D	OPC, Total	TPC
FY 2021	3,000	27,000[b]	30,000	1,000	N/A	1,000	31,000[b]
FY 2022	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 distribution 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 delivering critical materials for the Nation. 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) deteriorating 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 workspaces.

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 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 existing building systems	▪ Replace and upgrade plumbing systems in mission critical buildings. Replace 2,700 linear feet of domestic supply piping and 5,000 linear feet of sanitary sewer piping. ▪ Upgrade building envelopes for mission critical buildings. Upgrade 30,000 square feet of past end-of-life built up roofs. ▪ Improve emergency/backup power systems. Replace two existing backup generators. ▪ Improve telecommunications systems. Establish two new telecom rooms and install 200,000 linear feet of new CAT6A cabling. ▪ Modernize existing laboratory spaces in mission critical buildings. Renovate 10,000 square feet of wet labs, dry labs, and office space.	▪ Replace 4,000 linear feet of domestic supply piping and 7,500 linear feet of sanitary sewer piping. ▪ Upgrade 68,450 square feet of past end-of-life built up roofs. ▪ Replace three existing backup generators. ▪ Establish three new telecom rooms and install 300,000 linear feet of new CAT6A cabling. ▪ Renovate 15,000 square feet of wet labs, dry labs, and office space.

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
Design (TEC)			
FY 2021	150	150	–
FY 2022	2,000	2,000	2,150
Outyears	850	850	850
Total, Design (TEC)	**3,000**	**3,000**	**3,000**
Construction (TEC)			
Outyears	27,000	27,000	27,000
Total, Construction (TEC)	**27,000**	**27,000**	**27,000**
Total Estimated Cost (TEC)			
FY 2021	150	150	–
FY 2022	2,000	2,000	2,150
Outyears	27,850	27,850	27,850
Total, TEC	**30,000**	**30,000**	**30,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Other Project Cost (OPC)			
FY 2019	25	25	25
FY 2020	50	50	50
FY 2021	200	200	200
FY 2022	225	225	225
Outyears	500	500	500
Total, OPC	**1,000**	**1,000**	**1,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Project Cost (TPC)			
FY 2019	25	25	25
FY 2020	50	50	50
FY 2021	350	350	200
FY 2022	2,225	2,225	2,375
Outyears	28,350	28,350	28,350
Total, TPC	**31,000**	**31,000**	**31,000**

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design	2,500	2,500	**N/A**
Design - Contingency	500	500	**N/A**
Total, Design (TEC)	**3,000**	**3,000**	**N/A**
Construction	22,500	22,500	**N/A**
Construction - Contingency	4,500	4,500	**N/A**
Total, Construction (TEC)	**27,000**	**27,000**	**N/A**
Total, TEC	**30,000**	**30,000**	**N/A**
Contingency, TEC	*5,000*	*5,000*	***N/A***
Other Project Cost (OPC)			
Conceptual Planning	250	250	**N/A**
Conceptual Design	250	250	**N/A**
OPC - Contingency	500	500	**N/A**
Total, Except D&D (OPC)	**1,000**	**1,000**	**N/A**
Total, OPC	**1,000**	**1,000**	**N/A**
Contingency, OPC	*500*	*500*	***N/A***
Total, TPC	**31,000**	**31,000**	**N/A**
Total, Contingency (TEC+OPC)	***5,500***	***5,500***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Request Year	Type	Prior Years	FY 2020	FY 2021	FY 2022	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]
FY 2022	TEC	—	—	150	2,000	27,850	30,000[a]
	OPC[b]	25	50	200	225	500	1,000
	TPC	25	50	350	2,225	28,350	31,000[a]

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	4Q FY 2027
Expected Useful Life	25 years
Expected Future Start of D&D of this capital asset	4Q FY 2052

Related Funding Requirements
(dollars in thousands)

	Annual Costs		Life Cycle Costs[c]	
	Previous Total Estimate	Current Total Estimate	Previous Total Estimate	Current Total Estimate
Operations	N/A	335	N/A	8,375
Utilities	N/A	1,024	N/A	25,600
Maintenance and Repair	N/A	1,685	N/A	42,125
Total, Operations and Maintenance	N/A	3,044	N/A	76,100

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[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] Life-Cycle costs will be performed as part of CD-1.
[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 decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

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.

20-SC-71, Critical Utilities Rehabilitation Project, BNL
Brookhaven National Laboratory
Project is for Design and Construction

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

Summary

The FY 2022 Request for the Critical Utilities Rehabilitation Project (CURP) is $26,000,000. The 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 $71,000,000 to $93,000,000. Currently, these cost ranges encompass the most feasible preliminary alternatives. The preliminary TPC estimate for this project is $93,000,000.

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-1/3A, Approve Alternate Selection and Cost Range/Approve Long Lead Procurements, which was approved on February 6, 2020. The project has initiated long lead procurements in accordance with the approve CD-3A scope. FY 2022 funds will support 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) was assigned to this project at CD-1.

Critical Milestone History

Fiscal Year	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2020	7/20/18	4Q FY 2019	4Q FY 2019	4Q FY 2020	4Q FY 2021	4Q FY 2021	N/A	4Q FY 2026
FY 2021	7/20/18	4Q FY 2019	2Q FY 2020	2Q FY 2021	3Q FY 2021	4Q FY 2021	N/A	4Q FY 2024
FY 2022	7/20/18	8/16/19	2/6/20	2Q FY 2022	4Q FY 2023	2Q FY 2022	N/A	4Q FY 2025

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	N/A
FY 2021	4Q FY 2020	2Q FY 2020
FY 2022	2Q FY 2022	2/6/20

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

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D[a]	OPC, D&D	OPC, Total	TPC
FY 2020	8,500	76,500	85,000[b]	800	N/A	800	85,800[b]
FY 2021	7,100	84,900	92,000[b]	800	N/A	800	92,800[b]
FY 2022	6,700	85,300	92,000[b]	1,000	N/A	1,000	93,000[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.*

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[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 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	**Chilled Water**	
	▪ Replace one 1250 ton Centrifugal Chiller, refrigerant alarm, and chemical injection system at the Central Chilled Water Facility (CCWF)	▪ Install new Reduced Pressure Zone's and chemical injection systems on various cooling towers
		▪ Replace additional Chillers
	Steam	
	▪ Replace 1 Manhole	▪ Replace manholes, steam and condensate piping, valves and equipment within 18 manholes
	▪ Replace 3,000 LF steam/condensate	▪ Replace up to approximately 10 miles steam and/or condensate piping site wide
	▪ Replace obsolete control systems, install economizer on boiler and build 200SF extension on B610	▪ Upgrade B610 Building Envelope
		▪ Replace generators and associated switchgear.
		▪ Replace Boiler 1A & stack in B610
	Potable Water	
	▪ Rebuild Wellhouse # 12 & Granular Activated Carbon System (CD-3A)	▪ Replace up to approximately 35 miles of water mains, valves, hydrants and service lines site wide
	▪ Replace and demolish 300,000-gallon water tank (CD-3A)	▪ Repair/revitalize 1 Million Gallon water tank
	▪ Replace/add 5 isolation valves	▪ Replace/add up to 40 isolation valves
	Electrical	
	▪ Install new 13.8KV feeder B603 to B600 to serve as an alternate to B600 & NSLS II	▪ Replace 69KV Oil Circuit Breaker
	▪ Refurbish 30 magnablast breakers in substation 603	▪ Install new 13.8KV feeder from substation 603 to Renaissance Road
		▪ Install new 13.SKV feeder from Renaissance to Technology Drive
	Sanitary Sewer	
	▪ Replace 4 lift stations site wide	▪ Replace up to 40 lift stations site wide
	▪ Re-line 200LF of sewer lines & refurbish 1 manhole	▪ Re-line up to approximately 35 miles of sewer lines & replace 40 manholes
		▪ Install storage facility chemical dosing system at B575
		▪ Recoat aeration and aerobic digester tanks
		▪ Demolish primary clarifier tank

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
Design (TEC)			
FY 2020	10,000	10,000	–
FY 2021	400	400	740
FY 2022	–	–	7,190
Outyears	–	–	2,470
Total, Design (TEC)	**10,400**	**10,400**	**10,400**
Construction (TEC)			
FY 2020	10,000	10,000	89
FY 2021	19,600	19,600	200
FY 2022	26,000	26,000	26,000
Outyears	26,000	26,000	55,311
Total, Construction (TEC)	**81,600**	**81,600**	**81,600**
Total Estimated Cost (TEC)			
FY 2020	20,000	20,000	89
FY 2021	20,000	20,000	940
FY 2022	26,000	26,000	33,190
Outyears	26,000	26,000	57,781
Total, TEC	**92,000**	**92,000**	**92,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Other Project Cost (OPC)			
FY 2020	410	410	410
FY 2021	590	590	590
Total, OPC	**1,000**	**1,000**	**1,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Project Cost (TPC)			
FY 2020	20,410	20,410	499
FY 2021	20,590	20,590	1,530
FY 2022	26,000	26,000	33,190
Outyears	26,000	26,000	57,781
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	8,320	5,680	**N/A**
Design - Contingency	2,080	1,420	**N/A**
Total, Design (TEC)	**10,400**	**7,100**	**N/A**
Construction	65,280	70,320	**N/A**
Construction - Contingency	16,320	14,580	**N/A**
Total, Construction (TEC)	**81,600**	**84,900**	**N/A**
Total, TEC	**92,000**	**92,000**	**N/A**
Contingency, TEC	*18,400*	*16,000*	***N/A***
Other Project Cost (OPC)			
Conceptual Design	1,000	N/A	**N/A**
Other OPC Costs	N/A	800	**N/A**
Total, Except D&D (OPC)	**1,000**	**800**	**N/A**
Total, OPC	**1,000**	**800**	**N/A**
Contingency, OPC	***N/A***	*N/A*	***N/A***
Total, TPC	**93,000**	**92,800**	**N/A**
Total, Contingency (TEC+OPC)	***18,400***	***16,000***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Request Year	Type	Prior Years	FY 2020	FY 2021	FY 2022	Outyears	Total
FY 2020	TEC	—	12,000	—	—	73,000	85,000[a]
	OPC[b]	800	—	—	—	—	800
	TPC	800	12,000	—	—	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]
FY 2022	TEC	—	20,000	20,000	26,000	26,000	92,000[a]
	OPC[b]	—	410	590	—	—	1,000
	TPC	—	20,410	20,590	26,000	26,000	93,000[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-2. Potential acquisition and project delivery methods include, but are not limited to, firm-fixed-price contracts for design-bid-build, construction manager/general contractor methods, 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. 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, LBNL
Lawrence Berkeley National Laboratory
Project is for Design and Construction

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

Summary

The FY 2022 Request for the Seismic and Safety Modernization (SSM) project is $27,500,000. The preliminary Total Estimated Cost (TEC) range for this project is $76,300,000 to $95,400,000. The preliminary Total Project Cost (TPC) range for this project is $78,500,000 to $97,600,000. Currently, these cost ranges encompass the most feasible preliminary alternatives. 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 2022 funds will support long-lead procurement, early construction activities, and 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	9/6/18	4Q FY 2019	4Q FY 2019	4Q FY 2021	4Q FY 2022	4Q FY 2022	N/A	4Q FY 2027
FY 2021	9/6/18	6/17/19	9/4/19	3Q FY 2021	1Q FY 2022	2Q FY 2022	N/A	2Q FY 2027
FY 2022	9/6/18	6/17/19	9/4/19	1Q FY 2022	1Q FY 2022	1Q FY 2023	N/A	4Q FY 2026

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

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
FY 2022	1Q FY 2022	1Q FY 2022	N/A

CD-3A – Approve Long-Lead Procurement and Site Preparation Activities
CD-3B – Approve Remaining Construction Activities

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D[a]	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]
FY 2022	9,000	86,400	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 III 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

Lawrence Berkeley National Laboratory (LBNL) 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 (ASCR), Biological and Environment Research (BER), Basic Energy Sciences (BES), and High Energy Physics (HEP) programs. LBNL is located on a 202-acre site in the hills above the University of California, Berkeley campus employs approximately 3,400 full time employees; and is home to five SC national user facilities: the Advanced Light Source, the Energy Sciences Network, the Joint Genome Institute, the Molecular Foundry, and the National Energy Research Scientific Computing Center. In FY 2016, over 11,000 researchers used these facilities, representing roughly one third of the total for all SC user facilities. In pursuing the SC mission, LBNL leverages collaborative science to bring together teams of individuals with different fields of expertise to work together on common solutions to the SC mission. However, these research activities must be executed with a unique caution since LBNL is located less than one mile from the Hayward Fault and less than 25 miles from the San Andreas Fault, which would both pose a life safety risk to employees, visitors, and guests during a significant seismic event.

The U.S. Geological Survey's newest earthquake forecast, the third Uniform California Earthquake Rupture Forecast, 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 sleeping quarters. Demolition of the cafeteria is anticipated to allow for construction of a new, more sustainable, and operationally resilient 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 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) ▪ Meet requirements of Risk Category III of the CBC	▪ 60,000 gsf ▪ 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 (TEC)			
FY 2020	9,000	9,000	3,000
FY 2021	–	–	5,000
FY 2022	–	–	1,000
Total, Design (TEC)	**9,000**	**9,000**	**9,000**
Construction (TEC)			
FY 2020	1,000	1,000	–
FY 2021	5,000	5,000	–
FY 2022	27,500	27,500	6,000
Outyears	52,900	52,900	80,400
Total, Construction (TEC)	**86,400**	**86,400**	**86,400**
Total Estimated Cost (TEC)			
FY 2020	10,000	10,000	3,000
FY 2021	5,000	5,000	5,000
FY 2022	27,500	27,500	7,000
Outyears	52,900	52,900	80,400
Total, TEC	**95,400**	**95,400**	**95,400**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Other Project Cost (OPC)			
FY 2019	1,050	1,050	1,050
FY 2020	20	20	20
Outyears	1,130	1,130	1,130
Total, OPC	**2,200**	**2,200**	**2,200**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Project Cost (TPC)			
FY 2019	1,050	1,050	1,050
FY 2020	10,020	10,020	3,020
FY 2021	5,000	5,000	5,000
FY 2022	27,500	27,500	7,000
Outyears	54,030	54,030	81,530
Total, TPC	**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	8,300	8,300	**N/A**
Design - Contingency	700	1,700	**N/A**
Total, Design (TEC)	**9,000**	**10,000**	**N/A**
Construction	71,400	70,400	**N/A**
Construction - Contingency	15,000	15,000	**N/A**
Total, Construction (TEC)	**86,400**	**85,400**	**N/A**
Total, TEC	**95,400**	**95,400**	**N/A**
Contingency, TEC	*15,700*	*16,700*	***N/A***
Other Project Cost (OPC)			
OPC, Except D&D	N/A	2,000	**N/A**
Conceptual Planning	200	N/A	**N/A**
Conceptual Design	1,800	N/A	**N/A**
OPC - Contingency	200	200	**N/A**
Total, Except D&D (OPC)	**2,200**	**2,200**	**N/A**
Total, OPC	**2,200**	**2,200**	**N/A**
Contingency, OPC	*200*	*200*	***N/A***
Total, TPC	**97,600**	**97,600**	**N/A**
Total, Contingency (TEC+OPC)	***15,900***	***16,900***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Request Year	Type	Prior Years	FY 2020	FY 2021	FY 2022	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]
FY 2022	TEC	—	10,000	5,000	27,500	52,900	95,400[a]
	OPC[b]	1,050	20	—	—	1,130	2,200
	TPC	1,050	10,020	5,000	27,500	54,030	97,600[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	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	N/A	N/A	N/A	N/A
Utilities	53	53	2,658	2,658
Maintenance and Repair	318	318	15,882	15,882
Total, Operations and Maintenance	371	371	18,540	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[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	15,000 - 60,000

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.

[a] With the implementation of OMB's Reduce the Footprint initiative, DOE no longer maintains the space bank. Footprint is managed using the Facility Information Management System, with decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

20-SC-73, CEBAF Renovation and Expansion, TJNAF
Thomas Jefferson National Accelerator Facility
Project is for Design and Construction

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

Summary

The FY 2022 Request for the Continuous Electron Beam Accelerator Facility (CEBAF) Renovation and Expansion (CRE) project is $10,000,000. 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 $50,000,000 to $99,000,000. Currently, these cost ranges encompass the most feasible preliminary alternatives. The preliminary TPC estimate for this project is $90,000,000.

The CEBAF center at Thomas Jefferson National Accelerator Facility (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-1, Approve Alternative Selection and Cost Range, which was approved on March 18, 2019. FY 2022 funds will support Project Engineering and Design (PED) activities and initiate 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	7/20/18	4Q FY 2019	4Q FY 2019	4Q FY 2020	3Q FY 2021	4Q FY 2021	N/A	4Q FY 2026
FY 2021	7/20/18	4Q FY 2019	2Q FY 2020	4Q FY 2020	3Q FY 2021	4Q FY 2021	N/A	4Q FY 2026
FY 2022	7/20/18	10/16/19	3/18/19	1Q FY 2022	3Q FY 2022	4Q FY 2022	N/A	4Q 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
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	N/A	N/A
FY 2021	4Q FY 2020	4Q FY 2020	4Q FY 2021
FY 2022	1Q FY 2022	1Q FY 2022	N/A

CD-3A – Approve Long-Lead Procurements and Start of Early Construction Activities
CD-3B – Approve Start of Remaining Construction Activities

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D[a]	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]
FY 2022	8,000	79,000	87,000[b]	3,000	N/A	3,000	90,000[b]

2. Project Scope and Justification

Scope

The scope of the CRE 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. CRE 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. Also, 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 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 Laboratory. 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 several large inter-entity transfer projects such as the cryomodules and cryogenics plants for Linac Coherent Light Source ((LCLS)-I, LCLS-II-High Energy, Facility for Rare Isotope Beams (FRIB), and the Utilities Upgrade Project (UUP) that 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. Additionally, there is a potential increase in anticipated usage in the near future.

[a] Other Project Costs (OPC) are funded through laboratory overhead.
[b] This project is pre-CD-2; therefore, funding estimates are preliminary.

TJNAF also continues to advance a strategic campus plan designed to deliver more attractive, mission-focused, and functional workspaces by consolidating the Laboratory 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 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. This project will upgrade mechanical systems and provide 82,000 to 150,000 gsf of additional space for visitors, users, research, education, and support especially for projects such as 12 GeV and the newly planned EIC at BNL. The CRE project infrastructure and buildings will support climate resilience by being designed to account for projected changes in temperature and precipitation through building energy efficiency, precipitation retention, buried electrical distribution and enhanced monitoring of assets to reduce the risk of failure as climate conditions change.

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 (MIEs), several large inter-entity transfer projects for other national laboratories, and a pivotal technical role in a proposed Electron Ion Collider.

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 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 (TEC)			
FY 2020	2,000	2,000	39
FY 2021	1,000	1,000	2,000
Outyears	5,000	5,000	5,961
Total, Design (TEC)	**8,000**	**8,000**	**8,000**
Construction (TEC)			
FY 2021	1,000	1,000	–
FY 2022	10,000	10,000	6,000
Outyears	68,000	68,000	73,000
Total, Construction (TEC)	**79,000**	**79,000**	**79,000**
Total Estimated Cost (TEC)			
FY 2020	2,000	2,000	39
FY 2021	2,000	2,000	2,000
FY 2022	10,000	10,000	6,000
Outyears	73,000	73,000	78,961
Total, TEC	**87,000**	**87,000**	**87,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Other Project Cost (OPC)			
FY 2019	1,000	1,000	1,000
FY 2020	467	467	467
Outyears	1,533	1,533	1,533
Total, OPC	**3,000**	**3,000**	**3,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Project Cost (TPC)			
FY 2019	1,000	1,000	1,000
FY 2020	2,467	2,467	506
FY 2021	2,000	2,000	2,000
FY 2022	10,000	10,000	6,000
Outyears	74,533	74,533	80,494
Total, TPC	**90,000**	**90,000**	**90,000**

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design	6,500	4,200	**N/A**
Design - Contingency	1,500	800	**N/A**
Total, Design (TEC)	**8,000**	**5,000**	**N/A**
Construction	62,000	68,300	**N/A**
Construction - Contingency	17,000	13,700	**N/A**
Total, Construction (TEC)	**79,000**	**82,000**	**N/A**
Total, TEC	**87,000**	**87,000**	**N/A**
Contingency, TEC	*18,500*	*14,500*	***N/A***
Other Project Cost (OPC)			
OPC, Except D&D	N/A	2,300	**N/A**
Conceptual Planning	2,400	N/A	**N/A**
Conceptual Design	400	N/A	**N/A**
OPC - Contingency	200	N/A	**N/A**
Total, Except D&D (OPC)	**3,000**	**2,300**	**N/A**
Total, OPC	**3,000**	**2,300**	**N/A**
Contingency, OPC	*200*	*N/A*	***N/A***
Total, TPC	**90,000**	**89,300**	**N/A**
Total, Contingency (TEC+OPC)	***18,700***	***14,500***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Request Year	Type	Prior Years	FY 2020	FY 2021	FY 2022	Outyears	Total
FY 2020	TEC	—	2,000	—	—	64,000	66,000[a]
	OPC[b]	1,485	—	—	—	415	1,900
	TPC	1,485	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]
FY 2022	TEC	—	2,000	2,000	10,000	73,000	87,000[a]
	OPC[b]	1,000	467	—	—	1,533	3,000
	TPC	1,000	2,467	2,000	10,000	74,533	90,000[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

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-75, Large Scale Collaboration Center, SLAC
SLAC National Accelerator Laboratory
Project is for Design and Construction

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

Summary

The FY 2022 Request for the Large Scale Collaboration Center (LSCC) is $12,000,000. The preliminary Total Estimated Cost (TEC) range for this project is $56,000,000 to $90,400,000. The preliminary Total Project Cost (TPC) range for this project is $58,000,000 to $92,400,000. Currently, these cost ranges encompass the most feasible preliminary alternatives. 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 and determined the preferred alternative is to construct a new building, which the SLI program approved. FY 2022 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	4Q FY 2020	4Q FY 2020	4Q FY 2020	N/A	4Q FY 2026
FY 2021	7/20/18	4Q FY 2019	11/18/19	1Q FY 2022	1Q FY 2023	1Q FY 2023	3Q FY 2023	4Q FY 2027
FY 2022	7/20/18	8/15/19	11/18/19	3Q FY 2022	1Q FY 2024	3Q FY 2022	3Q FY 2023	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	CD-3B
FY 2020	TBD	N/A	N/A
FY 2021	TBD	1Q FY 2020	1Q FY 2023
FY 2022	3Q FY 2022	N/A	N/A

CD-3A – Approve Long-Lead Procurements and Start of Early Construction
CD-3B – Approve Remaining Construction Activities

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D[a]	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]
FY 2022	7,000	57,000[b]	64,000[b]	2,000	N/A	2,000	66,000[b]

2. Project Scope and Justification

Scope

The LSCC project will construct a multi-office building of approximately 34,000 to 45,000 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-

[a] Other Project Costs (OPC) are funded through laboratory overhead.
[b] This project is pre-CD-2; therefore, funding estimates are preliminary.

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, artificial intelligence/machine learning (AI/ML), exascale computing, data management, data acquisition, simulation, imaging, visualization, and modeling are also not currently available.

To address these capability gaps, SLAC proposes to construct a new 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.

LSCC is a modern, energy efficient, sustainable, and collaborative facility for data analytics which supports scientific research and development for energy savings, battery energy storage, charging infrastructure, electrical power grids, and artificial photo-catalysts to convert sunlight to fuel. LSCC will also use AI/ML in the building management system to provide energy savings in utility usage. LSCC is being analyzed to be SLAC's first campus net-zero and carbon-zero building. LSCC will also provide collaborative work, research, and meeting space for Energy@Stanford & SLAC conference, held annually at Stanford and SLAC.

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 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 (TEC)			
FY 2020	11,000	11,000	314
FY 2021	–	–	1,931
FY 2022	–	–	8,755
Total, Design (TEC)	**11,000**	**11,000**	**11,000**
Construction (TEC)			
FY 2021	11,000	11,000	–
FY 2022	12,000	12,000	13,000
Outyears	30,000	30,000	40,000
Total, Construction (TEC)	**53,000**	**53,000**	**53,000**
Total Estimated Cost (TEC)			
FY 2020	11,000	11,000	314
FY 2021	11,000	11,000	1,931
FY 2022	12,000	12,000	21,755
Outyears	30,000	30,000	40,000
Total, TEC	**64,000**	**64,000**	**64,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Other Project Cost (OPC)			
FY 2019	500	500	500
FY 2020	4	4	4
Outyears	1,496	1,496	1,496
Total, OPC	**2,000**	**2,000**	**2,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Project Cost (TPC)			
FY 2019	500	500	500
FY 2020	11,004	11,004	318
FY 2021	11,000	11,000	1,931
FY 2022	12,000	12,000	21,755
Outyears	31,496	31,496	41,496
Total, TPC	**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	8,800	7,200	**N/A**
Design - Contingency	2,200	1,800	**N/A**
Total, Design (TEC)	**11,000**	**9,000**	**N/A**
Construction	42,400	45,000	**N/A**
Construction - Contingency	10,600	10,000	**N/A**
Total, Construction (TEC)	**53,000**	**55,000**	**N/A**
Total, TEC	**64,000**	**64,000**	**N/A**
Contingency, TEC	*12,800*	*11,800*	***N/A***
Other Project Cost (OPC)			
Conceptual Design	2,000	N/A	**N/A**
Other OPC Costs	N/A	1,600	**N/A**
OPC - Contingency	N/A	400	**N/A**
Total, Except D&D (OPC)	**2,000**	**2,000**	**N/A**
Total, OPC	**2,000**	**2,000**	**N/A**
Contingency, OPC	***N/A***	*400*	***N/A***
Total, TPC	**66,000**	**66,000**	**N/A**
Total, Contingency (TEC+OPC)	***12,800***	***12,200***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Request Year	Type	Prior Years	FY 2020	FY 2021	FY 2022	Outyears	Total
FY 2020	TEC	—	3,000	—	—	57,000	60,000[a]
	OPC[b]	700	—	—	—	300	1,000
	TPC	700	3,000	—	—	57,300	61,000[a]
FY 2021	TEC	—	11,000	8,000	—	45,000	64,000[a]
	OPC[b]	500	200	1,300	—	—	2,000
	TPC	500	11,200	9,300	—	45,000	66,000[a]
FY 2022	TEC	—	11,000	11,000	12,000	30,000	64,000[a]
	OPC[b]	500	4	—	—	1,496	2,000
	TPC	500	11,004	11,000	12,000	31,496	66,000[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	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

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[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 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.

20-SC-76, Tritium System Demolition and Disposal, PPPL
Princeton Plasma Physics Laboratory
Project is for Design and Construction

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

Summary

The FY 2022 Request for the Tritium System Demolition and Disposal (TSDD) project is $6,400,000. The 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. Currently, these cost ranges encompass the most feasible preliminary alternatives. The preliminary TPC estimate for this project is $33,400,000.

This project will remove tritium contaminated legacy systems at the Princeton Plasma Physics Laboratory (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 2022 funds will support 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	4Q FY 2020	4Q FY 2021	4Q FY 2021	4Q FY 2021	N/A	2Q FY 2025
FY 2022	9/16/19	3/6/20	3Q FY 2021	3Q FY 2021	9/18/20	3Q FY 2021	N/A	2Q FY 2025

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
FY 2022	3Q FY 2021

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D[a]	OPC, D&D	OPC, Total	TPC
FY 2021	4,000	28,400[b]	32,400[b]	1,000	N/A	1,000	33,400[b]
FY 2022	4,000	28,400[b]	32,400[b]	1,000	N/A	1,000	33,400[b]

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 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, and
- 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 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 the tritium contaminated process equipment, contaminated ductwork, and waste from PPPL Tritium Areas ▪ Eliminate or reduce surface contamination in contaminated areas	N/A

[a] Other Project Costs (OPC) are funded through laboratory overhead.
[b] This project is pre-CD-2; therefore, funding estimates are preliminary.

Performance Measure	Threshold	Objective
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 ▪ Remove all Tritium contaminated ductwork ▪ Decontaminate or encapsulate floors and walls	N/A

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
Design (TEC)			
FY 2020	4,000	4,000	4,000
Total, Design (TEC)	**4,000**	**4,000**	**4,000**
Construction (TEC)			
FY 2020	9,000	9,000	–
FY 2021	13,000	13,000	20,000
FY 2022	6,400	6,400	8,400
Total, Construction (TEC)	**28,400**	**28,400**	**28,400**
Total Estimated Cost (TEC)			
FY 2020	13,000	13,000	4,000
FY 2021	13,000	13,000	20,000
FY 2022	6,400	6,400	8,400
Total, TEC	**32,400**	**32,400**	**32,400**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Other Project Cost (OPC)			
FY 2019	100	100	100
FY 2020	800	800	800
FY 2021	100	100	100
Total, OPC	**1,000**	**1,000**	**1,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Project Cost (TPC)			
FY 2019	100	100	100
FY 2020	13,800	13,800	4,800
FY 2021	13,100	13,100	20,100
FY 2022	6,400	6,400	8,400
Total, TPC	**33,400**	**33,400**	**33,400**

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design	3,200	3,200	**N/A**
Design - Contingency	800	800	**N/A**
Total, Design (TEC)	**4,000**	**4,000**	**N/A**
Construction	23,400	23,400	**N/A**
Construction - Contingency	5,000	5,000	**N/A**
Total, Construction (TEC)	**28,400**	**28,400**	**N/A**
Total, TEC	**32,400**	**32,400**	**N/A**
Contingency, TEC	*5,800*	*5,800*	***N/A***
Other Project Cost (OPC)			
Conceptual Planning	200	200	**N/A**
Conceptual Design	800	800	**N/A**
Total, Except D&D (OPC)	**1,000**	**1,000**	**N/A**
Total, OPC	**1,000**	**1,000**	**N/A**
Contingency, OPC	***N/A***	*N/A*	***N/A***
Total, TPC	**33,400**	**33,400**	**N/A**
Total, Contingency (TEC+OPC)	***5,800***	***5,800***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Request Year	Type	Prior Years	FY 2020	FY 2021	FY 2022	Outyears	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]
FY 2022	TEC	—	13,000	13,000	6,400	—	32,400[a]
	OPC[b]	100	800	100	—	—	1,000
	TPC	100	13,800	13,100	6,400	—	33,400[a]

6. Related Operations and Maintenance Funding Requirements

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[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

8. Acquisition Approach

The PPPL (M&O) contractor, Princeton University, will perform the acquisition for this project, overseen by the Princeton 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] This project is pre-CD-2; 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.

20-SC-77, Argonne Utilities Upgrade, ANL
Argonne National Laboratory
Project is for Design and Construction

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

Summary

The FY 2022 Request for the Argonne Utilities Upgrade (AU2) project is $10,000,000. 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. Currently, these cost ranges encompass the most feasible preliminary alternatives. The preliminary TPC estimate for this project is $216,000,000.

AU2 is proposed to revitalize and selectively upgrade Argonne National Laboratory's (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 2022 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	4Q FY 2021	4Q FY 2021	4Q FY 2022	N/A	4Q FY 2026
FY 2022	5/17/19	11/20/20	3Q FY 2021	4Q FY 2023	2Q FY 2024	4Q FY 2024	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-3A	CD-3B
FY 2021	4Q FY 2021	1Q FY 2021	N/A
FY 2022	2Q FY 2024	N/A	N/A

CD-3A – Approve Long-Lead Procurements and Start of Early Construction
CD-3B – Approve Remaining Construction Activities

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D[a]	OPC, D&D	OPC, Total	TPC
FY 2021	37,500	177,500	215,000[b]	1,000	N/A	1,000	216,000[b]
FY 2022	37,500	177,500	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. For example, steam is a critical infrastructure for Argonne facilities; a failure of this plant during the winter season would result in catastrophic freezing damage to buildings, utilities, and major pieces of scientific equipment. Additionally, the Advanced Photon Source (APS) is dependent on the steam utility for holding extremely tight temperature and humidity ranges required for beam line operations and stability requirements.

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 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
▪ Utility Plants (Chilled Water, Steam & Condensate)	▪ Construct new combined 6,300-ton chilled water plant with N+1 reliability and boiler house with peak demand of 250,000 lbs./hour of 200 psi saturated steam with N+1 reliability	▪ Equipment & controls upgrades at the 371, 450, and 528 chilled water plants ▪ Repair five domestic water tanks ▪ Potential capacity upgrades, new equipment, equipment replacements, and various other utility system reliability projects to increase reliability of laboratory internal utilities

[a] Other Project Costs (OPC) are funded through laboratory overhead.
[b] This project is pre-CD-2; therefore, funding estimates are preliminary.

Performance Measure	Threshold	Objective
▪ Utility Piping (Chilled Water, Steam & Condensate, Sewer, Domestic, Lab, & Canal Water)	▪ Repair, replace or construct new distribution piping for 7,500 linear feet of utility piping and support structures (e.g., vaults, pipe supports, valves, culverts, etc.)	▪ Repair, replace or construct new distribution piping for up to 15,000 linear feet of utility piping and support structures (e.g. vaults, pipe supports, valves, culverts, etc.) ▪ Install between 50 and 250 new smart meters

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
Design (TEC)			
FY 2020	500	500	–
FY 2021	500	500	500
FY 2022	10,000	10,000	10,500
Outyears	26,500	26,500	26,500
Total, Design (TEC)	**37,500**	**37,500**	**37,500**
Construction (TEC)			
Outyears	177,500	177,500	177,500
Total, Construction (TEC)	**177,500**	**177,500**	**177,500**
Total Estimated Cost (TEC)			
FY 2020	500	500	–
FY 2021	500	500	500
FY 2022	10,000	10,000	10,500
Outyears	204,000	204,000	204,000
Total, TEC	**215,000**	**215,000**	**215,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Other Project Cost (OPC)			
FY 2019	100	100	100
FY 2020	600	600	600
FY 2021	300	300	300
Total, OPC	**1,000**	**1,000**	**1,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Project Cost (TPC)			
FY 2019	100	100	100
FY 2020	1,100	1,100	600
FY 2021	800	800	800
FY 2022	10,000	10,000	10,500
Outyears	204,000	204,000	204,000
Total, TPC	**216,000**	**216,000**	**216,000**

4. **Details of Project Cost Estimate**

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design	30,000	30,000	**N/A**
Design - Contingency	7,500	7,500	**N/A**
Total, Design (TEC)	**37,500**	**37,500**	**N/A**
Construction	142,000	142,000	**N/A**
Construction - Contingency	35,500	35,500	**N/A**
Total, Construction (TEC)	**177,500**	**177,500**	**N/A**
Total, TEC	**215,000**	**215,000**	**N/A**
Contingency, TEC	*43,000*	*43,000*	***N/A***
Other Project Cost (OPC)			
Conceptual Planning	1,000	N/A	**N/A**
Other OPC Costs	N/A	1,000	**N/A**
Total, Except D&D (OPC)	**1,000**	**1,000**	**N/A**
Total, OPC	**1,000**	**1,000**	**N/A**
Contingency, OPC	***N/A***	*N/A*	***N/A***
Total, TPC	**216,000**	**216,000**	**N/A**
Total, Contingency (TEC+OPC)	***43,000***	***43,000***	***N/A***

5. **Schedule of Appropriations Requests**

(dollars in thousands)

Request Year	Type	Prior Years	FY 2020	FY 2021	FY 2022	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]
FY 2022	TEC	—	500	500	10,000	204,000	215,000[a]
	OPC[b]	100	600	300	—	—	1,000
	TPC	100	1,100	800	10,000	204,000	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 the decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

20-SC-78, Linear Assets Modernization Project, LBNL
Lawrence Berkeley National Laboratory
Project is for Design and Construction

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

Summary

The FY 2022 Request for the Linear Assets Modernization Project (LAMP) at Lawrence Berkeley National Laboratory (LBNL) is $12,850,000. 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. Currently, these cost ranges encompass the most feasible preliminary alternatives. The preliminary TPC estimate for this project is $240,000,000.

LAMP will 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 in the 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 2022 funds will support Project Engineering and Design (PED) activities and will initiate long-lead procurements and early construction activities after the appropriate CD approvals.

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	4Q FY 2021	3Q FY 2022	4Q FY 2022	N/A	4Q FY 2032
FY 2022	5/17/19	1Q FY 2022	1Q FY 2022	1Q FY 2023	4Q FY 2022	1Q 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-3A
FY 2021	4Q FY 2021	1Q FY 2021
FY 2022	1Q FY 2023	3Q FY 2022

CD-3A – Approve Long-Lead Procurements and Start of Early Construction

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D[a]	OPC, D&D	OPC, Total	TPC
FY 2021	48,000[b]	188,000[b]	236,000[b]	4,000	N/A	4,000	240,000[b]
FY 2022	23,500[b]	212,500[b]	236,000[b]	4,000	N/A	4,000	240,000[b]

2. Project Scope and Justification

Scope

LAMP will upgrade the highest priority utility systems to increase the reliability, capability, and safety of LBNL's infrastructure to meet the DOE's mission. The utility systems include, but are not limited to, domestic water, natural gas, storm drain, sanitary sewer, electrical, and communication.

The project will first address higher priority/higher risk areas and will aim to resolve the most critical systems while focusing infrastructure investment considering operational risk and efficiencies, redundancy, utility bundling, and preparation for strategic growth including expanding the primary switching substation at Grizzly Peak. LAMP will implement a multi-system-based, common geographical approach in the repair and improvement of LBNL's utility assets, considering potential synergies with nearby sustainment and improvement projects such as 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, many of which support all dimensions of climate research initiatives. 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 utility infrastructure while significantly reducing deferred maintenance. Utility infrastructure represents almost half of LBNL's large 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, increase resiliency, 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.

Although LBNL has begun measures to strengthen the laboratory's resilience to unplanned outages due to natural hazards such as earthquake, wildfire and extreme weather, the mission need of this project remains, which is to support the SC mission and multiple scientific programs by modernizing distributed utilities to increase reliability, resilience, and capacity to meet growing demands. The first phase of the LAMP project will enable the National Energy Research Scientific Computing Center (NERSC)-10 upgrade which will play a central role in discovery breakthrough science in the climate arena.

LAMP will deliver a significantly more modern and resilient general-purpose infrastructure. The combination of data collection and artificial intelligent monitoring systems will be able to adjust to trends, predict failures, and react to extreme weather events, such as automatically transfer power to minimize impacts to mission critical scientific operations. Additionally, modern utility systems will be more efficient and sustainable. For example, the underground utility corridors will not only be upgraded to the best available technology, but will be designed to be maintainable and monitored using artificial intelligence to enable predictive maintenance.

[a] Other Project Costs (OPC) are funded through laboratory overhead.
[b] This project has not received CD-2 approval; therefore, funding estimates are preliminary.

The 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 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 LBNL's existing major utility systems	▪ Renovate and modernize highest priority utility systems including distribution systems and components for: • Electrical • Natural Gas • Domestic water supply/Sanitary/ storm water; and/or • Data and communication ▪ Establish critical loops for redundancy	▪ Establish and renovate additional utility corridors

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
Design (TEC)			
FY 2020	500	500	–
FY 2021	500	500	–
FY 2022	9,000	9,000	6,000
Outyears	13,500	13,500	17,500
Total, Design (TEC)	**23,500**	**23,500**	**23,500**
Construction (TEC)			
FY 2022	3,850	3,850	–
Outyears	208,650	208,650	212,500
Total, Construction (TEC)	**212,500**	**212,500**	**212,500**
Total Estimated Cost (TEC)			
FY 2020	500	500	–
FY 2021	500	500	–
FY 2022	12,850	12,850	6,000
Outyears	222,150	222,150	230,000
Total, TEC	**236,000**	**236,000**	**236,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Other Project Cost (OPC)			
FY 2019	172	172	172
FY 2020	398	398	398
FY 2021	1,230	1,230	1,230
FY 2022	500	500	500
Outyears	1,700	1,700	1,700
Total, OPC	**4,000**	**4,000**	**4,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Project Cost (TPC)			
FY 2019	172	172	172
FY 2020	898	898	398
FY 2021	1,730	1,730	1,230
FY 2022	13,350	13,350	6,500
Outyears	223,850	223,850	231,700
Total, TPC	**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	19,500	38,000	**N/A**
Design - Contingency	4,000	10,000	**N/A**
Total, Design (TEC)	**23,500**	**48,000**	**N/A**
Construction	162,500	150,000	**N/A**
Construction - Contingency	50,000	38,000	**N/A**
Total, Construction (TEC)	**212,500**	**188,000**	**N/A**
Total, TEC	**236,000**	**236,000**	**N/A**
Contingency, TEC	*54,000*	*48,000*	***N/A***
Other Project Cost (OPC)			
Conceptual Design	2,200	1,700	**N/A**
Start-up	1,000	1,600	**N/A**
OPC - Contingency	800	700	**N/A**
Total, Except D&D (OPC)	**4,000**	**4,000**	**N/A**
Total, OPC	**4,000**	**4,000**	**N/A**
Contingency, OPC	*800*	*700*	***N/A***
Total, TPC	**240,000**	**240,000**	**N/A**
Total, Contingency (TEC+OPC)	***54,800***	***48,700***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Request Year	Type	Prior Years	FY 2020	FY 2021	FY 2022	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]
FY 2022	TEC	—	500	500	12,850	222,150	236,000[a]
	OPC[b]	172	398	1,230	500	1,700	4,000
	TPC	172	898	1,730	13,350	223,850	240,000[a]

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	2033
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	
	Previous Total Estimate	**Current Total Estimate**	**Previous Total Estimate**	**Current Total Estimate**
Operations	1,500	1,500	75,000	75,000
Utilities	12	12	600	600
Maintenance and Repair	4,200	4,200	210,000	210,000
Total, Operations and Maintenance	5,712	5,712	285,600	285,600

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[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 is responsible for awarding and managing all subcontracts related to this project. Various acquisition approaches and project delivery methods will be considered prior to achieving CD-1. Potential methods for project acquisition and completion methods include, but are not limited to, firm fixed price contracts for design-bid-build and design-build. The benefits of using a single or multiple contracts to procure materials, equipment, construction, commissioning, and other project scope elements will be evaluated by the M&O Contractor. Project performance metrics will be performed by in-house management and Project Controls.

[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 the decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

20-SC-79, Critical Utilities Infrastructure Revitalization, SLAC
SLAC National Accelerator Laboratory
Project is for Design and Construction

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

Summary

The FY 2022 Request for the Critical Utilities Infrastructure Revitalization (CUIR) project is $10,000,000. 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. Currently, these cost ranges encompass the most feasible preliminary alternatives. The preliminary TPC estimate for this project is $189,000,000.

The primary objective of this project is to close utilities infrastructure gaps, such as utility piping breaks, power fluctuations, faults, and cooling water interruptions 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 2022 funds will support Project Engineering and Design (PED) activities and initiate long-lead procurement and early construction activities after the appropriate CD approvals.

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	4Q FY 2021	3Q FY 2022	4Q FY 2022	N/A	4Q FY 2032
FY 2022	FY 2022	5/17/19	4Q FY 2021	1Q FY 2024	4Q FY 2026	1Q 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
FY 2021	4Q FY 2021	1Q FY 2021
FY 2022	1Q FY 2024	4Q FY 2021

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

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D[a]	OPC, D&D	OPC, Total	TPC
FY 2021	20,000	166,000[b]	186,000	3,000	N/A	3,000	189,000[b]
FY 2022	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 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 science research and the greater SLAC population. Workarounds and administrative controls placed on existing equipment and systems, which are underrated, 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 the current and future success of SLAC's science programs. SC will evaluate alternatives during acquisition strategy development prior to CD-1.

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 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.

[a] Other Project Costs (OPC) are funded through laboratory overhead.
[b] This project has not received CD-2 approval; therefore, funding estimates are preliminary.

The 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 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 ▪ Repair/Replace 9,000 LF of domestic water/fire protection piping ▪ 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 ▪ Repair/Replace 28,000 LF of domestic water/fire protection piping ▪ 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 ▪ Increase the existing underground cooling tower header pipe capacity to 18 inches	▪ Provides two new 5 MW cooling towers at Linac ▪ Increase the existing underground cooling tower header pipe capacity to 20 inches. ▪ Install new non-radioactive Low Conductivity Water systems for cooling at sectors 4-10 ▪ 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 ▪ Replace five electrical switchgear in substations in Linac ▪ Install two new 12 kilovolt (kV) electrical feeder and switching equipment for Linac ▪ Provide integration trial project for supervisory control and data acquisition (SCADA) for the SLAC power system in master substation and Linac	▪ Replace twelve Motor Control Centers on Linac ▪ Replace sixteen electrical switchgear in substations in Linac ▪ Replace six 12kV electrical feeders across site ▪ Provide complete SCADA for 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 (TEC)			
FY 2020	500	500	–
FY 2021	500	500	500
FY 2022	2,000	2,000	1,000
Outyears	17,000	17,000	18,500
Total, Design (TEC)	**20,000**	**20,000**	**20,000**
Construction (TEC)			
FY 2022	8,000	8,000	–
Outyears	158,000	158,000	166,000
Total, Construction (TEC)	**166,000**	**166,000**	**166,000**
Total Estimated Cost (TEC)			
FY 2020	500	500	–
FY 2021	500	500	500
FY 2022	10,000	10,000	1,000
Outyears	175,000	175,000	184,500
Total, TEC	**186,000**	**186,000**	**186,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Other Project Cost (OPC)			
FY 2020	323	323	323
FY 2021	1,000	1,000	1,000
Outyears	1,677	1,677	1,677
Total, OPC	**3,000**	**3,000**	**3,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Project Cost (TPC)			
FY 2020	823	823	323
FY 2021	1,500	1,500	1,500
FY 2022	10,000	10,000	1,000
Outyears	176,677	176,677	186,177
Total, TPC	**189,000**	**189,000**	**189,000**

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design	16,000	16,000	**N/A**
Design - Contingency	4,000	4,000	**N/A**
Total, Design (TEC)	**20,000**	**20,000**	**N/A**
Construction	132,000	132,000	**N/A**
Construction - Contingency	34,000	34,000	**N/A**
Total, Construction (TEC)	**166,000**	**166,000**	**N/A**
Total, TEC	**186,000**	**186,000**	**N/A**
Contingency, TEC	*38,000*	*38,000*	***N/A***
Other Project Cost (OPC)			
OPC, Except D&D	N/A	3,000	**N/A**
Conceptual Planning	2,200	N/A	**N/A**
Conceptual Design	800	N/A	**N/A**
Total, Except D&D (OPC)	**3,000**	**3,000**	**N/A**
Total, OPC	**3,000**	**3,000**	**N/A**
Contingency, OPC	***N/A***	*N/A*	***N/A***
Total, TPC	**189,000**	**189,000**	**N/A**
Total, Contingency (TEC+OPC)	***38,000***	***38,000***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Request Year	Type	FY 2020	FY 2021	FY 2022	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]
FY 2022	TEC	500	500	10,000	175,000	186,000[a]
	OPC[b]	323	1,000	—	1,677	3,000
	TPC	823	1,500	10,000	176,677	189,000[a]

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	4Q FY 2032
Expected Useful Life	50 years
Expected Future Start of D&D of this capital asset	4Q FY 2082

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[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 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 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.

20-SC-80, Utilities Infrastructure Project, FNAL
Fermi National Accelerator Laboratory
Project is for Design and Construction

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

Summary

The FY 2022 Request for the Utilities Infrastructure Project (UIP) is $13,300,000. The preliminary Total Estimated Cost (TEC) range for this project is $146,000,000 to $310,000,000. The preliminary Total Project Cost (TPC) range for this project is $150,000,000 to $314,000,000. Currently, these cost ranges encompass the most feasible preliminary alternatives. The preliminary TPC estimate for this project is $314,000,000.

This project will modernize 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 2022 funds will support Project Engineering and Design (PED), long lead procurement, and early construction activities after the appropriate CD approvals.

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	4Q FY 2021	3Q FY 2022	4Q FY 2022	N/A	4Q FY 2034
FY 2022	5/17/19	4Q FY 2021	1Q FY 2022	4Q FY 2024	2Q FY 2025	2Q FY 2025	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
FY 2021	4Q FY 2021	4Q FY 2020
FY 2022	4Q FY 2024	2Q FY 2023

CD-3A – Approve Long-Lead Procurements and Start of Early Construction Activities

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D[a]	OPC, D&D	OPC, Total	TPC
FY 2021	73,000	237,000[b]	310,000	4,000	N/A	4,000	314,000[b]
FY 2022	28,300	281,700[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, Kautz Road Substation, 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 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 UIP will deliver a significantly more modern and resilient general-purpose infrastructure. The combination of data collection and artificial intelligent monitoring systems will be able to adjust to trends, predict failures, and react to extreme weather events, such as automatically transferring power to minimize impacts to mission critical scientific operations. Additionally, modern utility systems will be more efficient and sustainable. For example, replacing inefficient boilers and improving electrical metering to identify future energy savings projects.

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 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.
[b] This project has not received CD-2 approval, therefore, funding estimates are preliminary.

Performance Measure	Threshold	Objective
▪ Rehabilitate and selectively upgrade FNAL's existing major utility systems	▪ Revitalize 5 miles of the Industrial Cooling Water (ICW) system extending from backbone ▪ Replace 10 miles of the Domestic Water System (DWS) identified as inadequate or sub-standard ▪ Replace 10 miles of the Sanitary Sewer & Storm Collection systems identified as inadequate or sub-standard ▪ Replace 2 miles of underground Natural Gas lines ▪ Construct a new building for chilled water production and renovate the existing Central Utility Building to ensure viability for current and near future (PIP-II, IERC, LBNF-Dune) projects ▪ Replace/Upgrade to Kautz Road Substation to improve safety and reliability	▪ Revitalize 16 miles of the ICW system extending from backbone ▪ Replace 20 miles of the DWS identified as inadequate or sub-standard ▪ Replace 27 miles of the Sanitary Sewer & Storm Collection systems identified as inadequate or sub-standard ▪ Replace 22 miles of underground Natural Gas lines ▪ Provide Safety / Reliability upgrades to Master Substation

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
Design (TEC)			
FY 2020	500	500	–
FY 2021	500	500	–
FY 2022	11,300	11,300	11,000
Outyears	16,000	16,000	17,300
Total, Design (TEC)	**28,300**	**28,300**	**28,300**
Construction (TEC)			
FY 2022	2,000	2,000	–
Outyears	279,700	279,700	281,700
Total, Construction (TEC)	**281,700**	**281,700**	**281,700**
Total Estimated Cost (TEC)			
FY 2020	500	500	–
FY 2021	500	500	–
FY 2022	13,300	13,300	11,000
Outyears	295,700	295,700	299,000
Total, TEC	**310,000**	**310,000**	**310,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Other Project Cost (OPC)			
FY 2021	1,530	1,530	1,530
FY 2022	500	500	500
Outyears	1,970	1,970	1,970
Total, OPC	**4,000**	**4,000**	**4,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Project Cost (TPC)			
FY 2020	500	500	–
FY 2021	2,030	2,030	1,530
FY 2022	13,800	13,800	11,500
Outyears	297,670	297,670	300,970
Total, TPC	**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	24,000	60,800	**N/A**
Design - Contingency	4,300	12,200	**N/A**
Total, Design (TEC)	**28,300**	**73,000**	**N/A**
Construction	220,000	197,500	**N/A**
Construction - Contingency	61,700	39,500	**N/A**
Total, Construction (TEC)	**281,700**	**237,000**	**N/A**
Total, TEC	**310,000**	**310,000**	**N/A**
Contingency, TEC	*66,000*	*51,700*	***N/A***
Other Project Cost (OPC)			
OPC, Except D&D	N/A	3,300	**N/A**
Conceptual Planning	2,300	N/A	**N/A**
Conceptual Design	700	N/A	**N/A**
OPC - Contingency	1,000	700	**N/A**
Total, Except D&D (OPC)	**4,000**	**4,000**	**N/A**
Total, OPC	**4,000**	**4,000**	**N/A**
Contingency, OPC	*1,000*	*700*	***N/A***
Total, TPC	**314,000**	**314,000**	**N/A**
Total, Contingency (TEC+OPC)	***67,000***	***52,400***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Request Year	Type	Prior Years	FY 2020	FY 2021	FY 2022	Outyears	Total
FY 2021	TEC	—	500	2,000	—	307,500	310,000[a]
	OPC[b]	100	1,900	—	—	2,000	4,000
	TPC	100	2,400	2,000	—	309,500	314,000[a]
FY 2022	TEC	—	500	500	13,300	295,700	310,000[a]
	OPC[b]	—	1,530	—	500	1,970	4,000
	TPC	—	2,030	500	13,800	297,670	314,000[a]

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	4Q FY 2032
Expected Useful Life	50 years
Expected Future Start of D&D of this capital asset	TBD[c]

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	TBD	N/A	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

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[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	TBD

[a] This project has not received CD-2 approval, therefore, funding estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.
[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 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.

19-SC-71, Science User Support Center, BNL
Brookhaven National Laboratory
Project is for Design and Construction

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

Summary

The FY 2022 Request for the Science User Support Center (SUSC) is $38,000,000. The preliminary Total Estimated Cost (TEC) range for this project is $70,800,000 to $94,800,000. The preliminary Total Project Cost (TPC) range for this project is $72,000,000 to $96,000,000. Currently, these cost ranges encompass the most feasible preliminary alternatives. 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 2022 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	4Q FY 2020	3Q FY 2021	4Q FY 2021	N/A	4Q FY 2025
FY 2020	12/12/16	9/7/18	12/18/18	4Q FY 2020	3Q FY 2021	4Q FY 2021	N/A	4Q FY 2025
FY 2021	12/12/16	9/7/18	12/18/18	4Q FY 2020	3Q FY 2021	3Q FY 2021	N/A	4Q FY 2026
FY 2022	12/12/16	9/7/18	12/18/18	1Q FY 2022	1Q FY 2022	1Q FY 2022	N/A	4Q FY 2025

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	4Q FY 2020
FY 2022	1Q FY 2022	N/A

CD-3A – Approve Long Lead Procurements and Site Preparation

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D[a]	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]
FY 2022	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 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 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*.

[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 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

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
Design (TEC)			
FY 2019	7,000	7,000	400
FY 2020	2,400	2,400	5,200
FY 2021	–	–	2,200
FY 2022	–	–	1,600
Total, Design (TEC)	**9,400**	**9,400**	**9,400**
Construction (TEC)			
FY 2020	17,600	17,600	–
FY 2021	20,000	20,000	–
FY 2022	38,000	38,000	34,000
Outyears	–	–	41,600
Total, Construction (TEC)	**75,600**	**75,600**	**75,600**
Total Estimated Cost (TEC)			
FY 2019	7,000	7,000	400
FY 2020	20,000	20,000	5,200
FY 2021	20,000	20,000	2,200
FY 2022	38,000	38,000	35,600
Outyears	–	–	41,600
Total, TEC	**85,000**	**85,000**	**85,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Other Project Cost (OPC)			
FY 2017	700	700	700
FY 2018	300	300	300
FY 2019	200	200	200
Total, OPC	**1,200**	**1,200**	**1,200**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Project Cost (TPC)			
FY 2017	700	700	700
FY 2018	300	300	300
FY 2019	7,200	7,200	600
FY 2020	20,000	20,000	5,200
FY 2021	20,000	20,000	2,200
FY 2022	38,000	38,000	35,600
Outyears	–	–	41,600
Total, TPC	**86,200**	**86,200**	**86,200**

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design	8,200	7,800	**N/A**
Design - Contingency	1,200	1,600	**N/A**
Total, Design (TEC)	**9,400**	**9,400**	**N/A**
Construction	64,000	63,000	**N/A**
Construction - Contingency	11,600	12,600	**N/A**
Total, Construction (TEC)	**75,600**	**75,600**	**N/A**
Total, TEC	**85,000**	**85,000**	**N/A**
Contingency, TEC	*12,800*	*14,200*	***N/A***
Other Project Cost (OPC)			
Conceptual Planning	700	500	**N/A**
Conceptual Design	500	500	**N/A**
OPC - Contingency	N/A	200	**N/A**
Total, Except D&D (OPC)	**1,200**	**1,200**	**N/A**
Total, OPC	**1,200**	**1,200**	**N/A**
Contingency, OPC	***N/A***	*200*	***N/A***
Total, TPC	**86,200**	**86,200**	**N/A**
Total, Contingency (TEC+OPC)	***12,800***	***14,400***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Request Year	Type	Prior Years	FY 2020	FY 2021	FY 2022	Outyears	Total
FY 2019	TEC	2,000	7,400	—	—	75,600	85,000[a]
	OPC[b]	1,000	—	—	—	—	1,000
	TPC	3,000	7,400	—	—	75,600	86,000[a]
FY 2020	TEC	7,000	6,400	—	—	71,600	85,000[a]
	OPC[b]	1,200	—	—	—	—	1,200
	TPC	8,200	6,400	—	—	71,600	86,200[a]
FY 2021	TEC	7,000	20,000	7,000	—	51,000	85,000[a]
	OPC[b]	1,200	—	—	—	—	1,200
	TPC	8,200	20,000	7,000	—	51,000	86,200[a]
FY 2022	TEC	7,000	20,000	20,000	38,000	—	85,000[a]
	OPC[b]	1,200	—	—	—	—	1,200
	TPC	8,200	20,000	20,000	38,000	—	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	None

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, ORNL
Oak Ridge National Laboratory
Project is for Design and Construction

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

Summary

The FY 2022 Request for the Translational Research Capability (TRC) project is $21,500,000. The Total Estimated Cost (TEC) for this project $93,500,000. The Total Project Cost (TPC) for this project is $95,000,000.

This project will provide low-vibration, wet, and dry laboratory space; high bay space; office space; and collaboration space to support advancement in high-performance computing and materials science in support of multidisciplinary research. In particular, SC's Basic Energy Sciences (BES) program research on energy storage and design will be improved and consolidated allowing for state-of-the-art, cross-cutting theory, synthesis, and characterization capabilities, and enhanced control over the synthesis of atomic architectures could transform our basic scientific understanding of materials and pave the way for new classes of devices for quantum computing, and spin sensing. Also, SC's Advanced Scientific Computing Research (ASCR) program will further strengthen its exascale initiative by leveraging Beyond Moore's Law technologies developed and advanced in technical spaces that support translational computing technologies such as quantum computing and neuromorphic computing.

Significant Changes

This project was initiated in FY 2019. The most recent DOE Order 413.3B Critical Decision (CD) is CD-2/3, Approve Performance Baseline and Construction Start, which was approved on April 3, 2020. FY 2022 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	11/2/18	1Q FY 2020	4Q FY 2019	1Q FY 2020	N/A	4Q FY 2025
FY 2021	10/26/17	7/20/18	11/2/18	3Q FY 2020	4Q FY 2019	3Q FY 2020	N/A	4Q FY 2025
FY 2022	10/26/17	7/20/18	11/2/18	4/3/20	3Q FY 2021	4/3/20	N/A	1Q FY 2025

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	N/A	2Q FY 2019	N/A
FY 2021	N/A	2/5/19	N/A
FY 2022	4/3/20	2/5/19	N/A

CD-2/3 – Approve Performance Baseline and Start of Construction Activities
CD-3A – Approve Long-Lead Procurements
CD-3B – Approve Remaining Construction Activities

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D[a]	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]
FY 2022	9,250	84,250	93,500	1,500	N/A	1,500	95,000

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. Currently, it is envisioned that the project will construct a 97,050 gsf facility. 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 10 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*.

[a] Other Project Costs (OPC) are funded through laboratory overhead.
[b] This project has not yet received CD-2 approval; therefore, funding estimates are preliminary.

Key Performance Parameters (KPPs)
The KPPs have been established/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

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
Design (TEC)			
FY 2019	9,250	9,250	680
FY 2020	–	–	4,400
FY 2021	–	–	4,170
Total, Design (TEC)	**9,250**	**9,250**	**9,250**
Construction (TEC)			
FY 2019	15,750	15,750	1,700
FY 2020	25,000	25,000	1,700
FY 2021	22,000	22,000	15,000
FY 2022	21,500	21,500	53,000
Outyears	–	–	12,850
Total, Construction (TEC)	**84,250**	**84,250**	**84,250**
Total Estimated Cost (TEC)			
FY 2019	25,000	25,000	2,380
FY 2020	25,000	25,000	6,100
FY 2021	22,000	22,000	19,170
FY 2022	21,500	21,500	53,000
Outyears	–	–	12,850
Total, TEC	**93,500**	**93,500**	**93,500**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Other Project Cost (OPC)			
FY 2017	190	190	190
FY 2018	1,000	1,000	1,000
FY 2019	210	210	210
Outyears	100	100	100
Total, OPC	**1,500**	**1,500**	**1,500**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Project Cost (TPC)			
FY 2017	190	190	190
FY 2018	1,000	1,000	1,000
FY 2019	25,210	25,210	2,590
FY 2020	25,000	25,000	6,100
FY 2021	22,000	22,000	19,170
FY 2022	21,500	21,500	53,000
Outyears	100	100	12,950
Total, TPC	**95,000**	**95,000**	**95,000**

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design	8,250	6,400	8,250
Design - Contingency	1,000	1,000	1,000
Total, Design (TEC)	**9,250**	**7,400**	**9,250**
Construction	72,000	70,100	72,080
Construction - Contingency	12,250	16,000	12,170
Total, Construction (TEC)	**84,250**	**86,100**	**84,250**
Total, TEC	**93,500**	**93,500**	**93,500**
Contingency, TEC	*13,250*	*17,000*	*13,170*
Other Project Cost (OPC)			
Conceptual Planning	500	500	500
Conceptual Design	800	800	800
OPC - Contingency	200	200	200
Total, Except D&D (OPC)	**1,500**	**1,500**	**1,500**
Total, OPC	**1,500**	**1,500**	**1,500**
Contingency, OPC	*200*	*200*	*200*
Total, TPC	**95,000**	**95,000**	**95,000**
Total, Contingency (TEC+OPC)	***13,450***	***17,200***	***13,370***

5. Schedule of Appropriations Requests

(dollars in thousands)

Request Year	Type	Prior Years	FY 2020	FY 2021	FY 2022	Outyears	Total
FY 2020	TEC	25,000	15,000	—	—	53,500	93,500[a]
	OPC[b]	1,190	—	—	—	310	1,500
	TPC	26,190	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	—	—	—	100	1,500
	TPC	26,190	25,000	10,000	—	33,600	95,000[a]
FY 2022	TEC	25,000	25,000	22,000	21,500	—	93,500
	OPC[b]	1,400	—	—	—	100	1,500
	TPC	26,400	25,000	22,000	21,500	100	95,000

[a] This project has not yet 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	1Q FY 2025
Expected Useful Life	50 years
Expected Future Start of D&D of this capital asset	1Q 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	742	26,823	26,823
Utilities	258	258	9,030	9,030
Maintenance and Repair	720	720	25,201	25,201
Total, Operations and Maintenance	1,720	1,720	61,054	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 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, BioEPIC, LBNL
Lawrence Berkeley National Laboratory
Project is for Design and Construction

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

Summary

The FY 2022 Request for the Biological and Environmental Program Integration Center (BioEPIC) project is $35,000,000. 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. Currently, these cost ranges encompass the most feasible preliminary alternatives. 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 2022 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	2Q FY 2022	4Q FY 2021	N/A	4Q FY 2027
FY 2021	3/13/18	5/9/19	5/9/19	4Q FY 2021	2Q FY 2021	4Q FY 2021	N/A	4Q FY 2027
FY 2022	3/13/18	5/9/19	5/9/19	4Q FY 2021	2Q FY 2021	4Q FY 2021	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
FY 2020	4Q FY 2020
FY 2021	4Q FY 2021
FY 2022	4Q FY 2021

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D[a]	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]
FY 2022	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 BioEPIC building will bring together important Office of Science (BER) programs and unique capabilities that are currently housed in leased space and buildings both on and off the LBNL campus that are not well-suited to BioEPIC programs, are near 'end-of-life', are not energy efficient and are prone to prolonged outages in the face of regular wildfire risks that trigger power shutdowns by the LBNL's local power authority. The experiments hosted within this new facility will be able to run through power shutdown events because of the modern systems built into BioEPIC. The BioEPIC building is designed to directly address these issues through pursuit of LEED gold certification, optimization of natural lighting, and provision of adequate emergency power. BioEPIC will not use natural gas for space and water heating but rather will have energy saving all-electric mechanical and plumbing systems. BioEPIC will bring together the LBNL's four BER 'science focus area' programs to focus on how soil-plant-microbe interactions impact growth of alternative energy feedstocks, agricultural productivity, water resources, and terrestrial carbon storage. Understanding and predicting responses to climate change is a central theme of all four 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.*

[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
Biosciences and other research space	55,000 gsf	90,000 gsf

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
Design (TEC)			
FY 2019	5,000	5,000	5,000
FY 2020	8,000	8,000	6,919
FY 2021	–	–	1,081
Total, Design (TEC)	**13,000**	**13,000**	**13,000**
Construction (TEC)			
FY 2020	7,000	7,000	–
FY 2021	20,000	20,000	2,000
FY 2022	35,000	35,000	30,000
Outyears	65,000	65,000	95,000
Total, Construction (TEC)	**127,000**	**127,000**	**127,000**
Total Estimated Cost (TEC)			
FY 2019	5,000	5,000	5,000
FY 2020	15,000	15,000	6,919
FY 2021	20,000	20,000	3,081
FY 2022	35,000	35,000	30,000
Outyears	65,000	65,000	95,000
Total, TEC	**140,000**	**140,000**	**140,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Other Project Cost (OPC)			
FY 2019	1,500	1,500	1,500
FY 2020	21	21	21
Outyears	679	679	679
Total, OPC	**2,200**	**2,200**	**2,200**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Project Cost (TPC)			
FY 2019	6,500	6,500	6,500
FY 2020	15,021	15,021	6,940
FY 2021	20,000	20,000	3,081
FY 2022	35,000	35,000	30,000
Outyears	65,679	65,679	95,679
Total, TPC	**142,200**	**142,200**	**142,200**

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design	10,600	10,600	**N/A**
Design - Contingency	2,400	2,400	**N/A**
Total, Design (TEC)	**13,000**	**13,000**	**N/A**
Construction	105,000	105,000	**N/A**
Construction - Contingency	22,000	22,000	**N/A**
Total, Construction (TEC)	**127,000**	**127,000**	**N/A**
Total, TEC	**140,000**	**140,000**	**N/A**
Contingency, TEC	*24,400*	*24,400*	***N/A***
Other Project Cost (OPC)			
Conceptual Planning	1,500	N/A	**N/A**
Conceptual Design	600	1,500	**N/A**
Start-up	N/A	600	**N/A**
OPC - Contingency	100	100	**N/A**
Total, Except D&D (OPC)	**2,200**	**2,200**	**N/A**
Total, OPC	**2,200**	**2,200**	**N/A**
Contingency, OPC	*100*	*100*	***N/A***
Total, TPC	**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	Prior Years	FY 2020	FY 2021	FY 2022	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]
FY 2022	TEC	5,000	15,000	20,000	35,000	65,000	140,000[a]
	OPC[b]	1,500	21	—	—	679	2,200
	TPC	6,500	15,021	20,000	35,000	65,679	142,200[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	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[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 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.

17-SC-71, Integrated Engineering Research Center, FNAL
Fermi National Accelerator Laboratory
Project is for Design and Construction

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

Summary

The FY 2022 Request for the Integrated Engineering Research Center (IERC) project is $10,250,000. The Total Estimated Cost (TEC) for this project is $85,000,000. The Total Project Cost (TPC) 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 support the establishment of an international neutrino campus, which was 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-2/3, Approve Performance Baseline and Approve Start of Construction which was approved on September 30, 2020. FY 2022 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	N/A	3Q FY 2019	N/A	4Q FY 2023
FY 2018	7/17/15	N/A	4/18/17	3Q FY 2019	N/A	3Q FY 2020	N/A	4Q FY 2024
FY 2019	7/17/15	3Q FY 2018	4/18/17	3Q FY 2019	3Q FY 2019	3Q FY 2020	N/A	4Q FY 2024
FY 2020	7/17/15	4/18/17	4/18/17	3Q FY 2019	3Q FY 2019	3Q FY 2019	N/A	2Q FY 2024
FY 2021	7/17/15	4/18/17	4/18/17	4Q FY 2020	2Q FY 2020	4Q FY 2020	N/A	3Q FY 2024
FY 2022	7/17/15	4/18/17	4/18/17	9/30/20	3/11/20	9/30/20	N/A	1Q 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-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 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
FY 2022	9/30/20	7/16/19

CD-3A – Approve Long-Lead Procurements

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D[a]	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]
FY 2022	8,547	76,453	85,000	1,000	N/A	1,000	86,000

2. Project Scope and Justification

Scope

The IERC project will construct an approximately 79,200 gross square feet (gsf) building 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.

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.

[a] Other project costs (OPC) are funded through laboratory overhead.
[b] This project has not received CD-2 approval; therefore, funding estimates are preliminary.

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 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 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
Total Estimated Cost (TEC)			
Design (TEC)			
FY 2017	2,500	2,500	38
FY 2018	6,047	6,047	804
FY 2019	–	–	4,844
FY 2020	–	–	2,794
FY 2021	–	–	67
Total, Design (TEC)	**8,547**	**8,547**	**8,547**
Construction (TEC)			
FY 2018	13,953	13,953	–
FY 2019	20,000	20,000	2,296
FY 2020	22,000	22,000	7,701
FY 2021	10,250	10,250	31,735
FY 2022	10,250	10,250	28,000
Outyears	–	–	6,721
Total, Construction (TEC)	**76,453**	**76,453**	**76,453**
Total Estimated Cost (TEC)			
FY 2017	2,500	2,500	38
FY 2018	20,000	20,000	804
FY 2019	20,000	20,000	7,140
FY 2020	22,000	22,000	10,495
FY 2021	10,250	10,250	31,802
FY 2022	10,250	10,250	28,000
Outyears	–	–	6,721
Total, TEC	**85,000**	**85,000**	**85,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Other Project Cost (OPC)			
FY 2015	120	120	120
FY 2016	530	530	530
FY 2017	300	300	300
FY 2022	50	50	50
Total, OPC	**1,000**	**1,000**	**1,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Project Cost (TPC)			
FY 2015	120	120	120
FY 2016	530	530	530
FY 2017	2,800	2,800	338
FY 2018	20,000	20,000	804
FY 2019	20,000	20,000	7,140
FY 2020	22,000	22,000	10,495
FY 2021	10,250	10,250	31,802
FY 2022	10,300	10,300	28,050
Outyears	–	–	6,721
Total, TPC	**86,000**	**86,000**	**86,000**

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design	8,547	6,000	8,547
Design - Contingency	N/A	1,000	**N/A**
Total, Design (TEC)	**8,547**	**7,000**	**8,547**
Construction	61,000	63,000	61,000
Construction - Contingency	15,453	15,000	15,453
Total, Construction (TEC)	**76,453**	**78,000**	**76,453**
Total, TEC	**85,000**	**85,000**	**85,000**
Contingency, TEC	*15,453*	*16,000*	*15,453*
Other Project Cost (OPC)			
Conceptual Planning	120	250	120
Conceptual Design	830	530	830
Other OPC Costs	N/A	150	**N/A**
OPC - Contingency	50	70	50
Total, Except D&D (OPC)	**1,000**	**1,000**	**1,000**
Total, OPC	**1,000**	**1,000**	**1,000**
Contingency, OPC	*50*	*70*	*50*
Total, TPC	**86,000**	**86,000**	**86,000**
Total, Contingency (TEC+OPC)	***15,503***	***16,070***	***15,503***

5. Schedule of Appropriations Requests

(dollars in thousands)

Request Year	Type	Prior Years	FY 2020	FY 2021	FY 2022	Outyears	Total
FY 2017	TEC	2,500	TBD	—	—	TBD	85,000[a]
	OPC[b]	500	TBD	—	—	TBD	2,000
	TPC	5,000	TBD	—	—	TBD	87,000[a]
FY 2018	TEC	4,000	TBD	—	—	TBD	85,000[a]
	OPC[b]	1,000	—	—	—	—	1,000
	TPC	5,000	TBD	—	—	TBD	86,000[a]
FY 2019	TEC	9,000	20,000	28,096	—	27,904	85,000[a]
	OPC[b]	930	—	—	—	70	1,000
	TPC	9,930	20,000	28,096	—	27,974	86,000[a]
FY 2020	TEC	42,500	10,000	—	—	32,500	85,000[a]
	OPC[b]	930	—	—	—	70	1,000
	TPC	43,430	10,000	—	—	32,570	86,000[a]
FY 2021	TEC	42,500	22,000	12,000	—	8,500	85,000
	OPC[b]	930	—	—	—	70	1,000
	TPC	43,430	22,000	12,000	—	8,570	86,000
FY 2022	TEC	42,500	22,000	10,250	10,250	—	85,000
	OPC[b]	950	—	—	50	—	1,000
	TPC	43,450	22,000	10,250	10,300	—	86,000

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

[a] This project has not received CD-2 approval; therefore, funding estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

7. D&D Information

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

	Square Feet
New area being constructed by this project at Fermi National Accelerator Laboratory...................	79,200
Area of D&D in this project at Fermi National Accelerator Laboratory..	None
Area at Fermi National Accelerator Laboratory to be transferred, sold, and/or D&D outside the project, including area previously "banked"	55,200
Area of D&D in this project at other sites	None
Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked"	None[a]
Total area eliminated	55,200

8. Acquisition Approach

The FNAL Management and Operating (M&O) contractor, Fermi Research Alliance, LLC performed 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.

[a] With the implementation of OMB's Reduce the Footprint initiative, DOE no longer maintains the space bank. Footprint is managed using the Facility Information Management System, with decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

Safeguards and Security

Overview
The Department of Energy's (DOE) Office of Science (SC) Safeguards and Security (S&S) program is designed to ensure appropriate security measures are in place to support the SC mission requirements of open scientific research and to protect critical assets within SC laboratories. Accomplishing this mission depends on providing physical controls that will mitigate possible risks to the laboratories' employees, nuclear and special materials, classified and sensitive information, and facilities. The SC S&S program also provides funding for cybersecurity for the laboratories' information technology systems to protect computers, networks, and data from unauthorized access.

Highlights of the FY 2022 Request
The FY 2022 Request for S&S is $170.0 million. The FY 2022 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 Request also includes an additional $43.74 million in Cyber Security to address long standing gaps in infrastructure, operations, and compliance to ensure adequate detection, mitigation, and recovery from cyber intrusions and attacks against DOE laboratories.

The FY 2022 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 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.

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.

Security Systems

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

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 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Safeguards and Security				
Protective Forces	43,545	44,200	46,710	+2,510
Security Systems	16,960	20,180	22,490	+2,310
Information Security	4,356	4,420	4,490	+70
Cyber Security	33,346	37,520	81,260	+43,740
Personnel Security	5,444	5,500	5,750	+250
Material Control and Accountability	2,431	2,465	2,500	+35
Program Management	6,618	6,715	6,800	+85
Total, Safeguards and Security	**112,700**	**121,000**	**170,000**	**+49,000**

Safeguards and Security
Explanation of Major Changes

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Safeguards and Security	**$121,000**	**$170,000**	**+$49,000**
Protective Forces	$44,200	$46,710	+$2,510
Funding maintains support for 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 increases will support sustained levels of operations at increased overhead, inflationary, and contractually obligated rates for the Protective Forces activity.
Security Systems	$20,180	$22,490	+$2,310
Funding maintains 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.		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 will continue implementation of DBT and S&T Policy mandated physical security modifications at SC laboratories. To address both new initiatives, automated access controls are the program's priority to protect the workforce and intellectual property and mitigate active shooter and workplace violence threats.
Information Security	$4,420	$4,490	+$70
Funding continues support for the 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 increases will support sustained levels for Information Security activities at increased overhead and inflationary rates.

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Cyber Security	$37,520	$81,260	+$43,740
Funding continues support for the protection of laboratory computers, networks, and data from unauthorized access.		The Request will support investments in cyber infrastructure and cyber capability including new cyber tools, incident response enhancements, cyber workforce development, data protections, and protections for unique SC facilities and capabilities that cannot be protected with commercial tools. Additionally, the Request will implement requirements at both federal and M&O sites to build out Controlled Unclassified Information (CUI) protections, participate in the DHS Continuous Diagnostics and Monitoring (CDM) program, build out Industrial Control Systems (ICS) protections, and protect Government Furnished Equipment (GFE) on foreign travel.	Funding increases will support increased investments in cyber infrastructure and capabilities at all SC sites. The increase will also begin implementation of heightened requirements to further protect SC computers, networks, and data from unauthorized access.
Personnel Security	$5,500	$5,750	+$250
Funding continues support for Personnel Security efforts at SC laboratories as well as SC Headquarters security investigations.		The Request will continue support for Personnel Security efforts at SC laboratories as well as SC Headquarters security investigations.	Funding will provide sustained support for Personnel Security activities in support of the Protection of Science and Technology and to address increased overhead and inflationary rates.
Material Control and Accountability	$2,465	$2,500	+$35
Funding maintains support for 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 will provide sustained support for MC&A activities at increased overhead and inflationary rates.
Program Management	$6,715	$6,800	+$85
Funding maintains support for 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 will provide sustained support for Program Management activities at increased overhead and inflationary rates.

Safeguards and Security
Funding Summary

(dollars in thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Other	112,700	121,000	170,000	+49,000
Total, Safeguards and Security	**112,700**	**121,000**	**170,000**	**+49,000**

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 nearly 28,000 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 36,000 users per year. SC also oversees ten of DOE's 17 national laboratories.

Headquarters

The SC Headquarters (HQ) includes the eight SC research program offices (Advanced Scientific Computing Research, Basic Energy Sciences, Biological and Environmental Research, Fusion Energy Sciences, High Energy Physics, Nuclear Physics, Isotope R&D and Production, and Accelerator R&D and Production), 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 over 5,000 ongoing laboratory, university, non-profit, and private industry research awards and conducts over 31,000 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.

Consolidated Service Center

The Consolidated Service Center (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.

Office of Scientific and Technical Information
Office of Scientific and Technical Information (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.

Highlights of the FY 2022 Request
The FY 2022 Request is $202.0 million and will support a total level of approximately 810 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 2022 Request supports:
- Three-hundred and nine (309) SC HQ federal staff, spread among the eight 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 to support the Office of the Under Secretary for Science and Energy.
- Twenty-five (25) FTEs in the Office of the Chief Human Capital Officer operating the Shared Service Center (SSC) and supporting HR Advisory Offices.
- Thirty-seven (37) FTEs in the DOE Office of the Chief Council. This activity is realigned from Field Offices to Headquarters.
- Two (2) FTEs supporting the President's Council of Advisors on Science and Technology (PCAST).[b]
- Three-hundred and ninety-three (393) Consolidated Service Center (CSC) and site office federal staff.
- Forty-two (42) OSTI federal staff to manage SC's public access program.

[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 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Program Direction				
Salaries and Benefits	135,611	142,245	146,387	+4,142
Travel	4,300	1,500	4,600	+3,100
Support Services	24,626	27,341	28,876	+1,535
Other Related Expenses	13,188	12,687	13,812	+1,125
Working Capital Fund	8,575	8,227	8,325	+98
Total, Program Direction	**186,300**	**192,000**	**202,000**	**+10,000**
Federal FTE	785	778	810	+32

Program Direction

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 Enacted
Program Direction	**$192,000**	**$202,000**	**+$10,000**
Salaries and Benefits	$142,245	$146,387	+$4,142
Funding supports 778 FTEs to perform scientific oversight, program and project management, essential operations support associated with science program portfolio management, and support for the Office of the Chief Human Capital Officer operating the SSC and supporting HR Advisory Offices. Funding supports costs associated with Federal employee benefits, including health insurance costs and retirement allocations in FERS.		The Request will support 810 FTEs to perform scientific oversight, program and project management, essential operations support associated with science program portfolio management, and support for the Office of the Chief Human Capital Officer operating the SSC and supporting HR Advisory Offices. The Request will support costs associated with Federal employee benefits, including health insurance costs and retirement allocations in FERS.	The increase will support a 2.7% pay raise and the projected salary and benefit requirements for the requested FTE levels.
Travel	$1,500	$4,600	+$3,100
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. Increase travel is expected as people return to work in office and travel is safe again. 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 2022. Ongoing analysis of travel may determine the shift of funding for improved communications.

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 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. Funding supports the PCAST advisory committee travel.		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. The Request will continue to support the PCAST advisory committee travel.	
Support Services	$27,341	$28,876	+$1,535
Funding supports select administrative and professional services including: support for the Small Business Innovation Research/Small Business Technology Transfer program; grants and contract processing and close-out activities; accessibility to DOE's corporate multi-billion dollar 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. 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 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 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 support service contract requirements for FY 2022.

(dollars in thousands)

FY 2021 Enacted		FY 2022 Request	Explanation of Changes FY 2022 Request vs FY 2021 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	$12,687	$13,812	+$1,125
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 increase will support the projected fixed requirements for FY 2022.
Working Capital Fund	$8,227	$8,325	+$98
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.	The increase will support the projected WCF charges.

Program Direction
Funding

(dollars in thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Program Direction				
HQ Salaries and Benefits	63,672	70,993	74,268	+3,275
HQ Travel	2,432	1,068	2,965	+1,897
HQ Support Services	17,884	20,529	22,068	+1,539
HQ Other Related Expenses	5,339	5,015	6,137	+1,122
HQ Working Capital Fund	8,575	8,227	8,325	+98
Total, Headquarters	**97,902**	**105,832**	**113,763**	**+7,931**
Field Offices Salaries and Benefits	65,723	64,611	65,525	+914
Field Offices Travel	1,795	417	1,535	+1,118
Field Offices Support Services	4,661	4,037	3,950	-87
Field Offices Other Related Expenses	6,822	6,626	6,608	-18
Total, Field Offices	**79,001**	**75,691**	**77,618**	**+1,927**
OSTI Salaries and Benefits	6,216	6,641	6,594	-47
OSTI Travel	73	15	100	+85
OSTI Support Services	2,081	2,775	2,858	+83
OSTI Other Related Expenses	1,027	1,046	1,067	+21
Total, Office of Scientific and Technical Information	**9,397**	**10,477**	**10,619**	**+142**
Total, Program Direction	**186,300**	**192,000**	**202,000**	**+10,000**
Program Direction Summary				
Salaries and Benefits	135,611	142,245	146,387	+4,142
Travel	4,300	1,500	4,600	+3,100
Support Services	24,626	27,341	28,876	+1,535
Other Related Expenses	13,188	12,687	13,812	+1,125
Working Capital Fund	8,575	8,227	8,325	+98
Total, Program Direction	**186,300**	**192,000**	**202,000**	**+10,000**
Federal FTE	785	778	810	+32

Program Direction
Funding Detail

(dollars in thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Technical Support				
System review and reliability analyses	2,051	1,373	1,414	+41
Management Support				
Automated data processing	10,500	10,850	11,414	+564
Training and education	954	577	737	+160
Reports and analyses, management, and general administrative services	11,121	14,541	15,311	+770
Total, Management Support	**22,575**	**25,968**	**27,462**	**+1,494**
Total, Support Services	**24,626**	**27,341**	**28,876**	**+1,535**
Other Related Expenses				
Rent to GSA	637	775	850	+75
Rent to others	1,412	2,162	2,234	+72
Communications, utilities, and miscellaneous	3,234	2,622	3,598	+976
Other services	1,978	551	855	+304
Operation and maintenance of equipment	—	—	—	—
Operation and maintenance of facilities	1,515	1,340	1,391	+51
Supplies and materials	426	491	583	+92
Equipment	3,986	4,746	4,301	-445
Total, Other Related Expenses	**13,188**	**12,687**	**13,812**	**+1,125**
Working Capital Fund	**8,575**	**8,227**	**8,325**	**+98**

Program Direction
Funding Summary

(dollars in thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Other	186,300	192,000	202,000	+10,000
Total, Program Direction	**186,300**	**192,000**	**202,000**	**+10,000**

Public Access[a]

The Department of Energy fulfills Legislative and Executive requirements to provide increased 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 through the Office of Scientific and Technical Information (OSTI). The DOE Public Access Plan, required by a 2013 OSTP policy memorandum, added peer-reviewed, final accepted manuscripts to the types of unclassified scientific and technical information already made publicly accessible as required by 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 ensuring 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), developed and hosted by OSTI. Since implementation of the DOE policy, DOE is among the top agencies in implementing public access, with DOE PAGES providing free access to over 130,000 scholarly publications resulting from DOE research funding. More recently, the concept of "public access" has broadened to "open science," where DOE has taken a leadership role in the federal government in assigning persistent identifiers to related research objects, such as the datasets and software underlying findings described in publications. Persistent identifiers (PIDs) are an essential element in promoting research integrity, reproducibility, and discoverability, and DOE provides an "identifier service" to its national labs and, through interagency agreements, to several federal agencies.

[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 2020 Planned Cost	**FY 2020 Actual Cost**	**FY 2021 Planned Cost**	**FY 2022 Planned Cost**
Brookhaven National Laboratory	4,821	5,495	4,917	5,578
Lawrence Berkeley National Laboratory	8,612	6,335	3,900	19,089
Notre Dame Radiation Laboratory	124	167	125	127
Oak Ridge National Laboratory	18,994	27,774	19,564	28,886
Oak Ridge Office	6,479	2,832	6,673	6,410
Office of Scientific and Technical Information	382	392	421	397
SLAC National Accelerator Laboratory	3,276	3,663	3,407	3,934
Thomas Jefferson National Accelerator Facility	195	98	198	133
Total, Direct-Funded Maintenance and Repair	**42,883**	**46,756**	**39,205**	**64,554**

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 2020 Planned Cost	**FY 2020 Actual Cost**	**FY 2021 Planned Cost**	**FY 2022 Planned Cost**
Ames Laboratory	2,700	2,200	2,400	2,400
Argonne National Laboratory	45,823	45,370	46,768	51,237
Brookhaven National Laboratory	29,619	31,183	30,211	33,352
Fermi National Accelerator Laboratory	20,994	15,682	21,704	23,183
Lawrence Berkeley National Laboratory	28,778	31,220	29,749	31,051
Oak Ridge Institute for Science and Education	468	622	480	656
Oak Ridge National Laboratory and Y-12	71,680	59,868	73,830	55,925
Oak Ridge Office	1,492	1,976	1,537	2,236
Pacific Northwest National Laboratory	10,591	6,199	10,322	11,270
Princeton Plasma Physics Laboratory	6,644	6,029	6,843	6,280
SLAC National Accelerator Laboratory	13,649	16,847	14,195	14,089
Thomas Jefferson National Accelerator Facility	9,988	6,652	10,188	7,634
Total, Indirect-Funded Maintenance and Repair	**242,426**	**223,848**	**248,227**	**239,313**

Report on FY 2020 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 2020 to the amount planned for FY 2020, including Congressionally directed changes.

Science
Total Costs for Maintenance and Repair

	(dollars in thousands)	
	FY 2020 Planned Costs	**FY 2020 Actual Costs**
Ames Laboratory	2,700	2,200
Argonne National Laboratory	45,823	45,370
Brookhaven National Laboratory	34,440	36,678
Fermi National Accelerator Laboratory	20,994	15,682
Lawrence Berkeley National Laboratory	37,390	37,555
Oak Ridge Institute for Science and Education	468	622
Notre Dame Radiation Laboratory	124	167
Oak Ridge National Laboratory and Y-12	90,674	87,642
Oak Ridge Office	7,971	4,808
Office of Scientific and Technical Information	382	392
Pacific Northwest National Laboratory	10,591	6,199
Princeton Plasma Physics Laboratory	6,644	6,029
SLAC National Accelerator Laboratory	16,925	20,510
Thomas Jefferson National Accelerator Facility	10,183	6,750
Total, Maintenance and Repair	**285,309**	**270,604**

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 2020 Planned Cost	FY 2020 Actual Cost	FY 2021 Planned Cost	FY 2022 Planned Cost
Argonne National Laboratory	400	400	400	400
Brookhaven National Laboratory	958	595	978	619
Fermi National Accelerator Laboratory	20	20	20	20
Lawrence Berkeley National Laboratory	16	1	16	2
Oak Ridge National Laboratory	500	250	500	250
SLAC National Accelerator Laboratory	54	—	56	—
Total, Indirect-Funded Excess Facilities	**1,948**	**1,266**	**1,970**	**1,291**

Science
Research and Development

(dollars in thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Basic	5,325,327	5,335,339	5,765,254	+429,915
Applied	—	—	—	—
Development	—	—	—	—
Subtotal, R&D	5,325,327	5,335,339	5,765,254	+429,915
Equipment	217,526	239,552	208,391	-31,161
Construction	1,380,147	1,343,109	1,298,355	-44,754
Total, R&D	**6,923,000**	**6,918,000**	**7,272,000**	**+354,000**

Science
Small Business Innovative Research/Small Business Technology Transfer (SBIR/STTR)

(dollars in thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 Request vs FY 2021 Enacted
Office of Science				
Advanced Scientific Computing Research				
SBIR	25,160	25,736	28,354	+2,618
STTR	3,538	3,620	3,989	+369
Basic Energy Sciences				
SBIR	57,423	56,592	59,865	+3,273
STTR	8,075	7,963	8,432	+469
Biological and Environmental Research				
SBIR	23,687	23,851	25,504	+1,653
STTR	3,330	3,352	3,589	+237
Fusion Energy Sciences				
SBIR	12,348	12,352	13,360	+1,008
STTR	1,737	1,740	1,885	+145
High Energy Physics				
SBIR	22,265	22,325	22,618	+293
STTR	3,131	3,140	3,181	+41
Nuclear Physics				
SBIR	18,257	18,685	21,005	+2,320
STTR	2,468	2,625	2,955	+330
Accelerator R&D and Production				
SBIR	—	—	768	+768
STTR	—	—	108	+108
Total, Office of Science SBIR[a]	**159,140**	**159,541**	**171,474**	**+11,933**
Total, Office of Science STTR	**22,279**	**22,440**	**24,139**	**+1,699**

[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 2020 Enacted	**FY 2021 Enacted**	**FY 2022 Request**	**FY 2022 Request vs FY 2021 Enacted**
Safeguards and Security				
Protective Forces	43,545	44,200	46,710	+2,510
Security Systems	16,960	20,180	22,490	+2,310
Information Security	4,356	4,420	4,490	+70
Cyber Security	33,346	37,520	81,260	+43,740
Personnel Security	5,444	5,500	5,750	+250
Material Control and Accountability	2,431	2,465	2,500	+35
Program Management	6,618	6,715	6,800	+85
Total, Safeguards and Security	**112,700**	**121,000**	**170,000**	**+49,000**

The FY 2022 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, while also addressing the program's highest priority of providing adequate security for the special nuclear material housed in Building 3019 at the Oak Ridge National Laboratory (ORNL).

The Request also includes an additional $43.74 million in Cyber Security to address long standing gaps in infrastructure, operations, and compliance to ensure adequate detection, mitigation, and recovery from cyber intrusions and attacks against DOE laboratories.

DEPARTMENT OF ENERGY
Funding by Site
Science BY 2022
(Dollars in Thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request Detail
Ames Laboratory			
Research - Basic Energy Sciences	17,578	16,782	16,782
Basic Energy Sciences	17,578	16,782	16,782
Research - Biological & Environmental Research	1,250	1,250	0
Biological and Environmental Research	1,250	1,250	0
Research - Fusion Energy Sciences	0	275	225
Fusion Energy Sciences	0	275	225
Research - High Energy Physics	0	1,618	1,600
High Energy Physics	0	1,618	1,600
Workforce Development for Teachers & Scientists	709	0	0
21-SC-73, Ames Infrastructure Modernization	0	150	2,000
Construction - Science Laboratories Infrastructure	0	150	2,000
Science Laboratories Infrastructure	0	150	2,000
Safeguards and Security - SC	1,231	1,231	2,474
Total Ames Laboratory	**20,768**	**21,306**	**23,081**
Ames Site Office			
Program Direction - SC	678	664	713
Total Ames Site Office	**678**	**664**	**713**
Argonne National Laboratory			
Research - Advanced Scientific Computing Research	160,042	161,432	161,104
Advanced Scientific Computing Research	160,042	161,432	161,104
Research - Basic Energy Sciences	239,274	223,706	230,598
18-SC-10, Advanced Photon Source Upgrade (APS-U), ANL	170,000	160,000	101,000
Construction - Basic Energy Sciences	170,000	160,000	101,000
Basic Energy Sciences	409,274	383,706	331,598
Research - Biological & Environmental Research	42,832	33,868	33,920
Biological and Environmental Research	42,832	33,868	33,920
Research - Fusion Energy Sciences	181	389	200
Fusion Energy Sciences	181	389	200
Research - High Energy Physics	13,913	16,795	13,918
High Energy Physics	13,913	16,795	13,918
Operations and Maintenance - Nuclear Physics	33,680	30,552	33,766
Nuclear Physics	33,680	30,552	33,766
Workforce Development for Teachers & Scientists	2,340	0	0
Facilities and Infrastructure (SLI)	10,800	0	0
20-SC-77, Argonne Utilities Upgrade, ANL (20-SC-79)	500	500	10,000
19-SC-72, Electrical Capacity and Distribution Capability, ANL	30,000	0	0
Construction - Science Laboratories Infrastructure	30,500	500	10,000
Science Laboratories Infrastructure	41,300	500	10,000
Safeguards and Security - SC	10,019	10,469	17,625
Total Argonne National Laboratory	**713,581**	**637,711**	**602,131**
Argonne Site Office			
Program Direction - SC	4,424	3,997	4,485
Total Argonne Site Office	**4,424**	**3,997**	**4,485**
Bay Area Site Office			
Program Direction - SC	5,834	6,027	5,983
Total Bay Area Site Office	**5,834**	**6,027**	**5,983**
Brookhaven National Laboratory			

DEPARTMENT OF ENERGY
Funding by Site
Science BY 2022
(Dollars in Thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request Detail
Research - Advanced Scientific Computing Research	1,228	2,313	1,580
Advanced Scientific Computing Research	1,228	2,313	1,580
Research - Basic Energy Sciences	182,858	167,542	181,501
Basic Energy Sciences	182,858	167,542	181,501
Research - Biological & Environmental Research	20,462	17,353	16,188
Biological and Environmental Research	20,462	17,353	16,188
Research - Fusion Energy Sciences	0	2,409	2,409
Fusion Energy Sciences	0	2,409	2,409
Research - High Energy Physics	80,167	75,692	58,873
11-SC-40, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment	2,942	3,516	6,000
Construction - High Energy Physics	2,942	3,516	6,000
High Energy Physics	83,109	79,208	64,873
Operations and Maintenance - Nuclear Physics	225,544	220,175	205,853
20-SC-52, Electron Ion Collider, BNL	1,000	5,000	20,000
Construction - Nuclear Physics	1,000	5,000	20,000
Nuclear Physics	226,544	225,175	225,853
Research - Accelerator R&D and Production	0	0	5,367
Accelerator R&D and Production	0	0	5,367
Workforce Development for Teachers & Scientists	2,852	0	0
20-SC-71, Critical Utilities Rehabilitation Project, BNL	20,000	20,000	26,000
19-SC-71, Science User Support Center, BNL	20,000	20,000	38,000
Construction - Science Laboratories Infrastructure	40,000	40,000	64,000
Science Laboratories Infrastructure	40,000	40,000	64,000
Safeguards and Security - SC	14,013	14,233	20,202
Total Brookhaven National Laboratory	**571,066**	**548,233**	**581,973**
Brookhaven Site Office			
Program Direction - SC	4,575	4,444	4,932
Total Brookhaven Site Office	**4,575**	**4,444**	**4,932**
Chicago Operations Office			
Research - Basic Energy Sciences	226,976	217,479	221,734
Basic Energy Sciences	226,976	217,479	221,734
Research - Biological & Environmental Research	2	23,772	0
Biological and Environmental Research	2	23,772	0
Research - Fusion Energy Sciences	7,799	41,878	50,287
Fusion Energy Sciences	7,799	41,878	50,287
Operations and Maintenance - Nuclear Physics	48,711	140,954	175,238
Nuclear Physics	48,711	140,954	175,238
PILT	1,650	1,650	0
Science Laboratories Infrastructure	1,650	1,650	0
Safeguards and Security - SC	50	0	0
Total Chicago Operations Office	**285,188**	**425,733**	**447,259**
Consolidated Service Center - Illinois			
PILT	0	1,500	2,410
Science Laboratories Infrastructure	0	1,500	2,410
Safeguards and Security - SC	0	2,199	2,556
Program Direction - SC	22,621	21,740	20,913
Total Consolidated Service Center - Illinois	**22,621**	**25,439**	**25,879**
Consolidated Service Center - Tennessee			
PILT	0	1,500	2,410
Oak Ridge Landlord	0	5,860	6,430

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request Detail
Science Laboratories Infrastructure	0	7,360	8,840
Safeguards and Security - SC	0	2,198	2,556
Program Direction - SC	22,621	21,741	20,914
Total Consolidated Service Center - Tennessee	**22,621**	**31,299**	**32,310**
Fermi National Accelerator Laboratory			
Research - Advanced Scientific Computing Research	874	874	700
Advanced Scientific Computing Research	874	874	700
Research - Basic Energy Sciences	135	0	0
Basic Energy Sciences	135	0	0
Research - High Energy Physics	323,994	326,113	307,892
18-SC-42, Proton Improvement Plan II (PIP-II), FNAL	60,000	79,000	90,000
11-SC-40, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment	168,058	167,484	170,000
11-SC-41, Muon to Electron Conversion Experiment, FNAL	0	2,000	13,000
Construction - High Energy Physics	228,058	248,484	273,000
High Energy Physics	552,052	574,597	580,892
Operations and Maintenance - Nuclear Physics	500	0	0
Nuclear Physics	500	0	0
Workforce Development for Teachers & Scientists	463	0	0
Facilities and Infrastructure (SLI)	0	0	11,500
20-SC-80, Utilities Infrastructure Project, FNAL (20-SC-82)	500	500	13,300
17-SC-71, Integrated Engineering Research Center, FNAL	22,000	10,250	10,250
Construction - Science Laboratories Infrastructure	22,500	10,750	23,550
Science Laboratories Infrastructure	22,500	10,750	35,050
Safeguards and Security - SC	7,877	8,480	13,411
Total Fermi National Accelerator Laboratory	**584,401**	**594,701**	**630,053**
Fermi Site Office			
Program Direction - SC	3,070	3,452	3,408
Total Fermi Site Office	**3,070**	**3,452**	**3,408**
Idaho National Laboratory			
Research - Advanced Scientific Computing Research	70	70	0
Advanced Scientific Computing Research	70	70	0
Research - Basic Energy Sciences	3,723	570	570
Basic Energy Sciences	3,723	570	570
Research - Fusion Energy Sciences	2,500	1,646	3,550
Fusion Energy Sciences	2,500	1,646	3,550
Workforce Development for Teachers & Scientists	522	0	0
Total Idaho National Laboratory	**6,815**	**2,286**	**4,120**
Idaho Operations Office			
Research - Basic Energy Sciences	369	369	369
Basic Energy Sciences	369	369	369
Total Idaho Operations Office	**369**	**369**	**369**
Lawrence Berkeley National Laboratory			
Research - Advanced Scientific Computing Research	215,822	238,816	220,112
Advanced Scientific Computing Research	215,822	238,816	220,112
Research - Basic Energy Sciences	170,004	147,285	153,500
18-SC-12, Advanced Light Source Upgrade (ALS-U), LBNL	60,000	62,000	75,100
Construction - Basic Energy Sciences	60,000	62,000	75,100
Basic Energy Sciences	230,004	209,285	228,600
Research - Biological & Environmental Research	171,201	166,693	170,232

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request Detail
Biological and Environmental Research	171,201	166,693	170,232
Research - Fusion Energy Sciences	1,525	1,200	1,352
Fusion Energy Sciences	1,525	1,200	1,352
Research - High Energy Physics	68,664	71,772	63,326
High Energy Physics	68,664	71,772	63,326
Operations and Maintenance - Nuclear Physics	22,228	23,069	26,048
Nuclear Physics	22,228	23,069	26,048
Research - Accelerator R&D and Production	0	0	1,282
Accelerator R&D and Production	0	0	1,282
Workforce Development for Teachers & Scientists	1,586	0	0
20-SC-72, Seismic and Safety Modernization, LBNL	10,000	5,000	27,500
20-SC-78, Linear Assets Modernization Project, LBNL (20-SC-80)	500	500	12,850
19-SC-74, Biological & Environmental Program Integration Center (BioEPIC), LBNL	15,000	20,000	35,000
Construction - Science Laboratories Infrastructure	25,500	25,500	75,350
Science Laboratories Infrastructure	25,500	25,500	75,350
Safeguards and Security - SC	7,175	7,675	12,590
Total Lawrence Berkeley National Laboratory	**743,705**	**744,010**	**798,892**
Lawrence Livermore National Laboratory			
Research - Advanced Scientific Computing Research	2,472	5,254	3,490
Advanced Scientific Computing Research	2,472	5,254	3,490
Research - Basic Energy Sciences	2,948	2,091	2,091
Basic Energy Sciences	2,948	2,091	2,091
Research - Biological & Environmental Research	33,625	28,095	27,297
Biological and Environmental Research	33,625	28,095	27,297
Research - Fusion Energy Sciences	8,062	9,765	8,410
Fusion Energy Sciences	8,062	9,765	8,410
Research - High Energy Physics	3,750	3,665	2,271
High Energy Physics	3,750	3,665	2,271
Operations and Maintenance - Nuclear Physics	1,470	1,607	1,809
Nuclear Physics	1,470	1,607	1,809
Research - Accelerator R&D and Production	0	0	258
Accelerator R&D and Production	0	0	258
Workforce Development for Teachers & Scientists	431	0	0
Total Lawrence Livermore National Laboratory	**52,758**	**50,477**	**45,626**
Los Alamos National Laboratory			
Research - Advanced Scientific Computing Research	2,930	4,096	1,469
Advanced Scientific Computing Research	2,930	4,096	1,469
Research - Basic Energy Sciences	27,422	20,646	21,470
Basic Energy Sciences	27,422	20,646	21,470
Research - Biological & Environmental Research	36,735	32,230	32,247
Biological and Environmental Research	36,735	32,230	32,247
Research - Fusion Energy Sciences	3,910	1,700	650
Fusion Energy Sciences	3,910	1,700	650
Research - High Energy Physics	2,040	3,177	1,650
High Energy Physics	2,040	3,177	1,650
Operations and Maintenance - Nuclear Physics	12,972	8,259	10,178
Nuclear Physics	12,972	8,259	10,178
Research - Accelerator R&D and Production	0	0	50
Accelerator R&D and Production	0	0	50
Workforce Development for Teachers & Scientists	669	0	0
Safeguards and Security - SC	0	248	0
Total Los Alamos National Laboratory	**86,678**	**70,356**	**67,714**

DEPARTMENT OF ENERGY
Funding by Site
Science BY 2022
(Dollars in Thousands)

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request Detail
National Renewable Energy Laboratory			
Research - Basic Energy Sciences	12,109	5,742	5,742
Basic Energy Sciences	12,109	5,742	5,742
Research - Biological & Environmental Research	3,848	3,877	3,500
Biological and Environmental Research	3,848	3,877	3,500
Workforce Development for Teachers & Scientists	2,095	0	0
Total National Renewable Energy Laboratory	**18,052**	**9,619**	**9,242**
Oak Ridge Institute for Science & Education			
Research - Advanced Scientific Computing Research	0	500	0
Advanced Scientific Computing Research	0	500	0
Research - Basic Energy Sciences	0	28	0
Basic Energy Sciences	0	28	0
Research - Biological & Environmental Research	3,549	778	1,838
Biological and Environmental Research	3,549	778	1,838
Research - High Energy Physics	0	170	0
High Energy Physics	0	170	0
Operations and Maintenance - Nuclear Physics	697	0	239
Nuclear Physics	697	0	239
Workforce Development for Teachers & Scientists	12,653	0	0
Safeguards and Security - SC	1,894	2,425	3,861
Total Oak Ridge Institute for Science & Education	**18,793**	**3,901**	**5,938**
Oak Ridge National Laboratory			
Research - Advanced Scientific Computing Research	235,031	251,854	247,946
17-SC-20, SC Exascale Computing Project (ECP)	188,735	168,945	129,000
Advanced Scientific Computing Research	423,766	420,799	376,946
Research - Basic Energy Sciences	374,486	350,012	337,923
19-SC-14, Second Target Station (STS), ORNL	0	29,000	32,000
18-SC-11, Spallation Neutron Source Proton Power Upgrade (PPU), ORNL	80,000	52,000	17,000
Construction - Basic Energy Sciences	80,000	81,000	49,000
Basic Energy Sciences	454,486	431,012	386,923
Research - Biological & Environmental Research	92,633	86,641	85,557
Biological and Environmental Research	92,633	86,641	85,557
Research - Fusion Energy Sciences	31,362	27,947	35,682
14-SC-60, U.S. Contributions to ITER (U.S. ITER)	242,000	242,000	221,000
Construction - Fusion Energy Sciences	242,000	242,000	221,000
Fusion Energy Sciences	273,362	269,947	256,682
Research - High Energy Physics	697	1,253	990
High Energy Physics	697	1,253	990
Operations and Maintenance - Nuclear Physics	13,605	15,436	17,757
Nuclear Physics	13,605	15,436	17,757
20-SC-51, U.S. Stable Isotope Production and Research Center, ORNL	12,000	12,000	0
Construction - Isotope R&D and Production	12,000	12,000	0
Isotope R&D and Production	12,000	12,000	0
Research - Accelerator R&D and Production	0	0	57
Accelerator R&D and Production	0	0	57
Oak Ridge Nuclear Operations	26,000	26,000	20,000
22-SC-71, Critical Infrastructure Modernization Project (CIMP), ORNL	0	0	1,000
20-SC-74, Craft Resources Support Facility, ORNL (19-SC-74)	15,000	25,000	0
19-SC-73, Translational Research Capability, ORNL	25,000	22,000	21,500
Construction - Science Laboratories Infrastructure	40,000	47,000	22,500
Science Laboratories Infrastructure	66,000	73,000	42,500
Safeguards and Security - SC	29,973	30,166	35,947
Total Oak Ridge National Laboratory	**1,366,522**	**1,340,254**	**1,203,359**

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request Detail
Oak Ridge National Laboratory Site Office			
Program Direction - SC	5,934	4,757	6,382
Total Oak Ridge National Laboratory Site Office	**5,934**	**4,757**	**6,382**
Oak Ridge Office			
PILT	2,890	0	0
Oak Ridge Landlord	5,610	0	0
Facilities and Infrastructure (SLI)	7,272	0	0
Science Laboratories Infrastructure	15,772	0	0
Safeguards and Security - SC	4,558	0	0
Total Oak Ridge Office	**20,330**	**0**	**0**
Office of Scientific & Technical Information			
Research - Advanced Scientific Computing Research	157	0	0
Advanced Scientific Computing Research	157	0	0
Research - Basic Energy Sciences	0	161	0
Basic Energy Sciences	0	161	0
Research - Biological & Environmental Research	185	285	159
Biological and Environmental Research	185	285	159
Research - High Energy Physics	189	0	0
High Energy Physics	189	0	0
Operations and Maintenance - Nuclear Physics	285	0	455
Nuclear Physics	285	0	455
Facilities and Infrastructure (SLI)	200	200	200
Science Laboratories Infrastructure	200	200	200
Safeguards and Security - SC	759	759	2,045
Program Direction - SC	9,397	10,477	10,619
Total Office of Scientific & Technical Information	**11,172**	**11,882**	**13,478**
Pacific Northwest National Laboratory			
Research - Advanced Scientific Computing Research	4,360	4,635	600
Advanced Scientific Computing Research	4,360	4,635	600
Research - Basic Energy Sciences	33,838	23,694	23,694
Basic Energy Sciences	33,838	23,694	23,694
Research - Biological & Environmental Research	132,882	113,325	138,894
Biological and Environmental Research	132,882	113,325	138,894
Research - Fusion Energy Sciences	650	723	1,678
Fusion Energy Sciences	650	723	1,678
Research - High Energy Physics	1,855	1,995	1,300
High Energy Physics	1,855	1,995	1,300
Operations and Maintenance - Nuclear Physics	830	0	0
Nuclear Physics	830	0	0
Workforce Development for Teachers & Scientists	1,589	0	0
Facilities and Infrastructure (SLI)	0	0	1,600
18-SC-71, Energy Sciences Capability, PNNL	23,000	23,000	0
Construction - Science Laboratories Infrastructure	23,000	23,000	0
Science Laboratories Infrastructure	23,000	23,000	1,600
Safeguards and Security - SC	12,759	13,512	19,093
Total Pacific Northwest National Laboratory	**211,763**	**180,884**	**186,859**
Pacific Northwest Site Office			
Program Direction - SC	5,186	5,066	5,599
Total Pacific Northwest Site Office	**5,186**	**5,066**	**5,599**
Princeton Plasma Physics Laboratory			
Research - Advanced Scientific Computing Research	335	400	0

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request Detail
Advanced Scientific Computing Research	335	400	0
Research - Fusion Energy Sciences	83,350	65,015	76,006
Fusion Energy Sciences	83,350	65,015	76,006
Workforce Development for Teachers & Scientists	729	0	0
21-SC-71, Princeton Plasma Innovation Center, PPPL	0	150	7,750
21-SC-72, Critical Infrastructure Recovery & Renewal, PPPL	0	150	2,000
20-SC-76, Tritium System Demolition and Disposal, PPPL (20-SC-78)	13,000	13,000	6,400
Construction - Science Laboratories Infrastructure	13,000	13,300	16,150
Science Laboratories Infrastructure	13,000	13,300	16,150
Safeguards and Security - SC	3,358	3,358	5,586
Total Princeton Plasma Physics Laboratory	**100,772**	**82,073**	**97,742**
Princeton Site Office			
Program Direction - SC	1,910	1,991	2,036
Total Princeton Site Office	**1,910**	**1,991**	**2,036**
Sandia National Laboratories			
Research - Advanced Scientific Computing Research	14,920	18,509	14,862
Advanced Scientific Computing Research	14,920	18,509	14,862
Research - Basic Energy Sciences	26,900	24,264	24,390
Basic Energy Sciences	26,900	24,264	24,390
Research - Biological & Environmental Research	12,350	15,928	16,535
Biological and Environmental Research	12,350	15,928	16,535
Research - Fusion Energy Sciences	0	2,100	3,100
Fusion Energy Sciences	0	2,100	3,100
Research - High Energy Physics	0	50	500
High Energy Physics	0	50	500
Workforce Development for Teachers & Scientists	235	0	0
Total Sandia National Laboratories	**54,405**	**60,851**	**59,387**
Savannah River National Laboratory			
Research - Basic Energy Sciences	410	0	0
Basic Energy Sciences	410	0	0
Research - Biological & Environmental Research	115	150	0
Biological and Environmental Research	115	150	0
Research - Fusion Energy Sciences	400	75	150
Fusion Energy Sciences	400	75	150
Workforce Development for Teachers & Scientists	73	0	0
Total Savannah River National Laboratory	**998**	**225**	**150**
SLAC National Accelerator Laboratory			
Research - Advanced Scientific Computing Research	1,170	670	450
Advanced Scientific Computing Research	1,170	670	450
Research - Basic Energy Sciences	231,945	215,455	225,178
21-SC-10, Cryomodule Repair and Maintenance Facilty, SLAC	0	1,000	1,000
18-SC-13, Linac Coherent Light Source-II-High Energy (LCLS-II-HE), SLAC	50,000	52,000	50,000
13-SC-10, Linac Coherent Light Source-II (LCLS-II), SLAC	0	33,000	28,100
Construction - Basic Energy Sciences	50,000	86,000	79,100
Basic Energy Sciences	281,945	301,455	304,278
Research - Biological & Environmental Research	5,270	4,100	3,100
Biological and Environmental Research	5,270	4,100	3,100
Research - Fusion Energy Sciences	6,800	5,495	5,945
20-SC-61, Matter in Extreme Conditions (MEC) Petawatt Upgrade, SLAC	15,000	15,000	5,000
Construction - Fusion Energy Sciences	15,000	15,000	5,000
Fusion Energy Sciences	21,800	20,495	10,945

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request Detail
Research - High Energy Physics	66,589	81,678	75,715
High Energy Physics	66,589	81,678	75,715
Operations and Maintenance - Nuclear Physics	1,336	1,166	1,341
Nuclear Physics	1,336	1,166	1,341
Research - Accelerator R&D and Production	0	0	1,320
Accelerator R&D and Production	0	0	1,320
Workforce Development for Teachers & Scientists	817	0	0
20-SC-75, Large Scale Collaboration Center, SLAC (19-SC-75)	11,000	11,000	12,000
20-SC-79, Critical Utilities Infrastructure Revitalization, SLAC (20-SC-81)	500	500	10,000
Construction - Science Laboratories Infrastructure	11,500	11,500	22,000
Science Laboratories Infrastructure	11,500	11,500	22,000
Safeguards and Security - SC	4,328	3,914	8,359
Total SLAC National Accelerator Laboratory	**394,755**	**424,978**	**427,508**
Thomas Jefferson National Accelerator Facility			
Research - Advanced Scientific Computing Research	382	360	0
Advanced Scientific Computing Research	382	360	0
Research - Biological & Environmental Research	242	0	0
Biological and Environmental Research	242	0	0
Research - High Energy Physics	750	420	0
High Energy Physics	750	420	0
Operations and Maintenance - Nuclear Physics	133,267	129,353	157,984
Nuclear Physics	133,267	129,353	157,984
Research - Accelerator R&D and Production	0	0	350
Accelerator R&D and Production	0	0	350
Workforce Development for Teachers & Scientists	237	0	0
Facilities and Infrastructure (SLI)	0	0	3,900
22-SC-72, Infrastructure Improvements (TJII), TJNAF	0	0	1,000
20-SC-73, CEBAF Renovation and Expansion, TJNAF (19-SC-73)	2,000	2,000	10,000
Construction - Science Laboratories Infrastructure	2,000	2,000	11,000
Science Laboratories Infrastructure	2,000	2,000	14,900
Safeguards and Security - SC	3,037	3,037	4,819
Total Thomas Jefferson National Accelerator Facility	**139,915**	**135,170**	**178,053**
Thomas Jefferson Site Office			
Program Direction - SC	2,148	1,812	2,253
Total Thomas Jefferson Site Office	**2,148**	**1,812**	**2,253**
Washington Headquarters			
Research - Advanced Scientific Computing Research	108,321	88,623	114,657
Advanced Scientific Computing Research	108,321	88,623	114,657
Research - Basic Energy Sciences	125,115	439,674	156,830
Basic Energy Sciences	125,115	439,674	156,830
Research - Biological & Environmental Research	30,112	6,170	99,121
Biological and Environmental Research	30,112	6,170	99,121
Research - Fusion Energy Sciences	143,174	124,899	168,532
Fusion Energy Sciences	143,174	124,899	168,532
Research - High Energy Physics	94,790	68,224	100,907
High Energy Physics	94,790	68,224	100,907
Operations and Maintenance - Nuclear Physics	79,483	67,784	28,313
20-SC-51, U.S. Stable Isotope Production and Research Center, (SIPRC)	0	0	12,000
Construction - Nuclear Physics	0	0	12,000
Nuclear Physics	79,483	67,784	40,313
Research - Isotope R&D and Production	0	0	78,000
Isotope R&D and Production	0	0	78,000

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request Detail
Research - Accelerator R&D and Production	0	0	7,774
Accelerator R&D and Production	0	0	7,774
Facilities and Infrastructure (SLI)	38,578	29,590	0
Science Laboratories Infrastructure	38,578	29,590	0
Safeguards and Security - SC	11,669	17,096	18,876
Program Direction - SC	97,902	105,832	113,763
Total Washington Headquarters	**729,144**	**947,892**	**898,773**
Grants			
Research - Advanced Scientific Computing Research	17,464	18,097	18,691
Advanced Scientific Computing Research	17,464	18,097	18,691
Research - Basic Energy Sciences	136,088	500	500
Basic Energy Sciences	136,088	500	500
Research - Biological & Environmental Research	162,707	112,395	75,645
Biological and Environmental Research	162,707	112,395	75,645
Research - Fusion Energy Sciences	98,693	87,028	69,873
Fusion Energy Sciences	98,693	87,028	69,873
Research - High Energy Physics	95,362	112,670	108,056
High Energy Physics	95,362	112,670	108,056
Operations and Maintenance - Nuclear Physics	58,959	0	0
14-SC-50, Facility for Rare Isotope Beams, MSU	40,000	5,300	0
Construction - Nuclear Physics	40,000	5,300	0
Nuclear Physics	98,959	5,300	0
Research - Accelerator R&D and Production	0	0	2,600
Accelerator R&D and Production	0	0	2,600
Total Grants	**609,273**	**335,990**	**275,365**
Undesignated LPI			
Research - Advanced Scientific Computing Research	25,687	49,552	125,339
Advanced Scientific Computing Research	25,687	49,552	125,339
Research - Basic Energy Sciences	40,822	0	392,928
Basic Energy Sciences	40,822	0	392,928
Research - Biological & Environmental Research	0	106,090	123,767
Biological and Environmental Research	0	106,090	123,767
Research - Fusion Energy Sciences	25,594	42,456	20,951
Fusion Energy Sciences	25,594	42,456	20,951
Research - High Energy Physics	61,240	28,708	45,002
High Energy Physics	61,240	28,708	45,002
Operations and Maintenance - Nuclear Physics	26,433	52,345	41,019
Nuclear Physics	26,433	52,345	41,019
Research - Accelerator R&D and Production	0	0	4,942
Accelerator R&D and Production	0	0	4,942
Workforce Development for Teachers & Scientists	0	29,000	35,000
Total Undesignated LPI	**179,776**	**308,151**	**788,948**
Total Funding by Site for TAS_0222 - Science	**7,000,000**	**7,026,000**	**7,440,000**

GENERAL PROVISIONS-DEPARTMENT OF ENERGY
[(INCLUDING TRANSFER OF FUNDS)]

SEC. 301. (a) No appropriation, funds, or authority made available by this title for the Department of Energy shall be used to initiate or resume any program, project, or activity or to prepare or initiate Requests For Proposals or similar ar-rangements (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 Agree-ment in excess of the limits in subparagraph (A) or (B).

(2) The Secretary of Energy shall submit to the Committees on Appropriations of both Houses of Congress within 15 days of the conclusion of each quarter a report detailing each grant allocation or discretionary grant award totaling less than $1,000,000 provided during the previous quarter.

(3) The notification required by paragraph (1) and the report required by paragraph (2) shall include the recipient of the award, the amount of the award, the fiscal year for which the funds for the award were appropriated, the account and program, project, or activity from which the funds are being drawn, the title of the award, and a brief description of the activity for which the award is made.

(c) The Department of Energy may not, with respect to any program, project, or activity that uses budget authority made available in this title under the heading "Department of Energy-Energy Programs", enter into a multiyear contract, award a multiyear grant, or enter into a multiyear cooperative agreement unless-

(1) the contract, grant, or cooperative agreement is funded for the full period of performance as anticipated at the time of award; or

(2) the contract, grant, or cooperative agreement includes a clause conditioning the Federal Government's obligation on the availability of future year budget authority and the Secretary notifies the Committees on Appropriations of both Houses of Congress at least 3 days in advance.

(d) Except as provided in subsections (e), (f), and (g), the amounts made available by this title shall be expended as authorized by law for the programs, projects, and activities specified in the "Final Bill" column in the "Department of Energy" table included under the heading "Title III-Department of Energy" in the ex-planatory 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 substan-tial 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 practic-able, but not later than 3 days after the date of the activity to which a require-ment or restriction would otherwise have applied. Such notice shall include an explanation of the substantial risk under paragraph (1) that permitted such waiver.

(h) The unexpended balances of prior appropriations provided for activities in this Act may be available to the same appropriation accounts for such activities established pursuant to this title. Available balances may be merged with funds in the applicable established accounts and thereafter may be accounted for as one fund for the same time period as originally enacted.

SEC. 302. Funds appropriated by this or any other Act, or made available by the transfer of funds in this Act, for intelligence activities are deemed to be specifically authorized by the Congress for purposes of section 504 of the National Security Act of 1947 (50 U.S.C. 3094) during fiscal year [2021] 2022 until the enactment of the Intelligence Authorization Act for fiscal year [2021] 2022.

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 require-ments.

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. 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. 306. (a) Of the offsetting collections, including unobligated balances of such collections, in the "Department of Energy-Power Marketing Administra-tion-Colorado River Basins Power Marketing Fund, Western Area Power Admin-istration", $21,400,000 shall be transferred to the "Department of the Interior-Bur-eau of Reclamation-Upper Colorado River Basin Fund" for the Bureau of Reclam-ation to carry out environmental stewardship and endangered species recovery efforts.

(b) No funds shall be transferred directly from "Department of Energy-Power Marketing Administration-Colorado River Basins Power Marketing Fund, Western Area Power Administration" to the general fund of the Treasury in the current fiscal year.]

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 appro-priation 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 depart-ment, 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 require-ments for each authority.]

SEC. [503]*502*. None of the funds made available by this Act may be used in contravention of Executive Order No. 12898 of February 11, 1994 (Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations).

SEC. [504]*503*. (a) None of the funds made available in this Act may be used to maintain or establish a computer network unless such network blocks the viewing, downloading, and exchanging of pornography.

(b) Nothing in subsection (a) shall limit the use of funds necessary for any Federal, State, Tribal, or local law enforcement agency or any other entity carrying out criminal investigations, prosecution, or adjudication activities.

[SEC. 505. (a) Requirements relating to non-Federal cost-share grants and co-operative agreements for the Delta Regional Authority under section 382D of the Agricultural Act of 1961 and Consolidated Farm and Rural Development Act (7 U.S.C. 2009aa-3) are waived for grants awarded in fiscal year 2020 and in sub-sequent years in response to economic distress directly related to the impacts of the Coronavirus Disease (COVID-19).

(b) Requirements relating to non-Federal cost-share grants and cooperative agreements for the Northern Border Regional Commission under section 15501(d) of title 40, United States Code, are waived for grants awarded in fiscal year 2020 and in subsequent years in response to economic distress directly related to the impacts of the Coronavirus Disease (COVID-19).

(c) Requirements relating to non-Federal cost-share grants and cooperative agreements for the Denali Commission are waived for grants awarded in fiscal year 2020 and in subsequent years in response to economic distress directly re-lated to the impacts of the Coronavirus Disease (COVID-19).]

SEC. [506]*504*. Of the unavailable collections currently in the United States Enrichment Corporation Fund, [$291,000,000] $415,670,000 shall be transferred to and merged with the Uranium Enrichment Decontamination and Decommis-sioning Fund and shall be available only to the extent provided in advance in ap-propriations Acts.