DOE/CF-0185
Volume 5

Department of Energy
FY 2023 Congressional Budget Request

Science

DOE/CF-0185
Volume 5

Department of Energy
FY 2023 Congressional Budget Request

Science

Printed with soy ink on recycled paper

FY 2023 Congressional Budget

Science

Table of Contents

DEPARTMENT OF ENERGY
Appropriation Summary
(dollars in thousands)

Department of Energy	FY 2021 Enacted	FY 2022 Annualized CR	FY2023 Request	FY 2023 vs. FY 21 Enacted	
				$	%
Department of Energy					
Energy Efficiency and Renewable Energy	2,861,760	2,861,760	4,018,885	1,157,125	40.4%
Electricity	211,720	211,720	297,386	85,666	40.5%
Cybersecurity, Energy Security, and Emergency Response	156,000	156,000	202,143	46,143	29.6%
Petroleum Reserves					
Strategic Petroleum Reserves	188,000	188,000	214,175	26,175	13.9%
Naval Petroleum & Oil Shale Reserves	13,006	13,006	13,004	-2	0.0%
SPR - Petroleum Account	1,000	1,000	8,000	7,000	700.0%
Northeast Home Heating Oil Reserves	6,500	6,500	7,000	500	7.7%
Subtotal, Petroleum Reserves	**208,506**	**208,506**	**242,179**	**33,673**	16.1%
Grid Deployment Office	-	-	90,221	90,221	N/A
Federal Energy Management Program (FEMP)	-	-	169,661	169,661	N/A
Office of Manufacturing & Energy Supply Chains (MESC)	-	-	27,424	27,424	N/A
Office of State and Community Energy Programs (SCEP)	-	-	726,897	726,897	N/A
Nuclear Energy	1,357,800	1,357,800	1,518,460	160,660	11.8%
Nuclear Waste Disposal	27,500	27,500	10,205	-17,295	-62.9%
Fossil Energy and Carbon Management	750,000	750,000	893,160	143,160	19.1%
Uranium Enrichment Decontamination and Decommissioning Fund (UED&D)	841,000	841,000	822,421	-18,579	-2.2%
Energy Information Administration	126,800	126,800	144,480	17,680	13.9%
Non-Defense Environmental Cleanup	319,200	319,200	323,249	4,049	1.3%
Science	7,026,000	7,026,000	7,799,211	773,211	11.0%
Office of Technology Transitions	-	-	21,558	21,558	N/A
Office of Clean Energy Demonstrations	-	-	214,052	214,052	N/A
Advanced Research Project Agency-Energy	427,000	427,000	700,150	273,150	64.0%
Departmental Administration	166,000	166,000	397,203	231,203	139.3%
Indian Energy Policy and Programs	22,000	22,000	150,039	128,039	582.0%
Office of Inspector General	57,739	57,739	106,808	49,069	85.0%
Loan Programs					
Title 17 - Innovative Technology Loan Guarantee Program (1)	29,000	29,000	168,206	139,206	480.0%
Advanced Technology Vehicles Manufacturing Loan Program	5,000	5,000	9,800	4,800	96.0%
Tribal Energy Loan Guarantee Program	2,000	2,000	1,860	-140	-7.0%
Subtotal, Loan Programs	**36,000**	**36,000**	**179,866**	**143,866**	**399.6%**
Subtotal, Energy Programs	**14,595,025**	**14,595,025**	**19,055,658**	**4,460,633**	**30.6%**
National Nuclear Security Administration					
Federal Salaries and Expenses	443,200	443,200	496,400	53,200	12.0%
Weapons Activities	15,345,000	15,345,000	16,486,298	1,141,298	7.4%
Defense Nuclear Nonproliferation	2,260,000	2,260,000	2,346,257	86,257	3.8%
Naval Reactors	1,684,000	1,684,000	2,081,445	397,445	23.6%
National Nuclear Security Administration	**19,732,200**	**19,732,200**	**21,410,400**	**1,678,200**	**8.5%**
Environmental and Other Defense Activities					
Defense Environmental Cleanup	6,426,000	6,426,000	6,914,532	488,532	7.6%
Defense UED&D Fund (2)	-	-	-	-	N/A
Other Defense Activities	920,000	920,000	978,351	58,351	6.3%
Subtotal, Environmental and Other Defense Activities	**7,346,000**	**7,346,000**	**7,892,883**	**546,883**	**7.4%**
Nuclear Energy (050)	149,800	149,800	156,600	6,800	4.5%
Subtotal, Atomic Energy Defense Activities	**27,228,000**	**27,228,000**	**29,459,883**	**2,231,883**	**8.2%**
Power Marketing Administrations					
Southeastern Power Administration (SEPA)	-	-	-	-	N/A
Southwestern Power Administration (SWPA)	10,400	10,400	10,608	208	2.0%
Western Area Power Administration	89,372	89,372	98,732	9,360	10.5%
Falcon and Amistad Operating and Maintenance Fund	228	228	228	0	0.0%
Colorado River Basins Marketing Fund	-21,400	-21,400	-8,568	12,832	-60.0%
Subtotal, Power Marketing Administrations	**78,600**	**78,600**	**101,000**	**22,400**	**28.5%**
Subtotal, Department of Energy	**41,901,625**		**48,616,541**	**6,714,916**	**16.0%**
Federal Energy Regulatory Commission	-	-	-	-	N/A
Receipts and Offsets					
Excess Fees and Recoveries, FERC	-9,000	-9,000	-9,000	-	0.0%
Title XVII Loan Guar. Prog Section 1703 Negative Credit Subsidy Receipts	-	-	-7,000	-7,000	N/A
UED&D Fund Discretionary Payments	-		-417,000	-417,000	N/A
Receipts and offsets	**-9,000**	**-9,000**	**-433,000**	**-424,000**	**4711.1%**
Department of Energy	**41,892,625**	**41,892,625**	**48,183,541**	**6,290,916**	**15.0%**

DEPARTMENT OF ENERGY
Appropriation Summary
(dollars in thousands)

Department of Energy	FY 2021 Enacted	FY 2022 Annualized CR	FY2023 Request	FY 2023 vs. FY 21 Enacted	
				$	%
DOE Budget Function					
NNSA Defense (050) Total	19,732,200	19,732,200	21,410,400	1,678,200	8.5%
Non-NNSA Defense Total	7,495,800	7,495,800	8,049,483	553,683	7.4%
Defense (050)	**27,228,000**	**27,228,000**	**29,459,883**	**2,231,883**	**8.2%**
Science (250)	7,026,000	7,026,000	7,799,211	773,211	11.0%
Energy (270)	7,638,625	7,638,625	10,924,447	3,285,822	43.0%
Non-Defense (Non-050)	**14,664,625**	**14,664,625**	**18,723,658**	**4,059,033**	**27.7%**

(1) The FY 2021 and FY 2022 Continuing Resolution entries for Title 17 and ATVM do not reflect rescissions of prior year emergency balances enacted in Public Law 116-260. Including the rescissions, the final amounts for Title 17 and ATVM would be -$363 million and -$1,903 million, respectively.

(2) In the FY 2023 Request, Defense Uranium Decontaination and Decommissioning is requested within the Defense Environmental Cleanup Appropriation.

Science

Science

Science
Proposed Appropriation Language

For Department of Energy expenses including the purchase, construction, and acquisition of plant and capital equipment, and other expenses necessary for science activities in carrying out the purposes of the Department of Energy Organization Act (42 U.S.C. 7101 et seq.), including the acquisition or condemnation of any real property or any facility or for plant or facility acquisition, construction, or expansion, and purchase of not more than [35] *35* passenger motor vehicles *including one ambulance* for replacement only, [$7,026,000,000] *$7,799,211,000*, to remain available until expended: [Provided] *provided*, [That] *that* of such amount, [$192,000,000] *$211,211,000* shall be available until September 30, [2023] *2024*, for program direction.

Note.—A full-year 2022 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2022 (Division A of P.L. 117-43, as amended). The amounts included for 2022 reflect the annualized level provided by the continuing resolution.

Explanation of Change

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

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 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request
$7,026,000	$7,026,000	$7,799,211

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 (U.S.). 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 2021 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/Science-Features/Science-Highlights.

Highlights and Major Changes in the FY 2023 Request
The FY 2023 Request for SC is $7,799.2 million, an increase of 11.0 percent above the FY 2021 Enacted level, to implement the Administration's objectives 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 2023 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 accelerator and energy technologies.

The Request increases investments in Administration priorities including basic research on climate change and clean energy, artificial intelligence (AI) and machine learning (ML), and biopreparedness. SC's Reaching a New Energy Sciences Workforce (RENEW) initiative doubles to expand targeted efforts to increase participation and retention of individuals from underrepresented groups in SC research activities. SC initiates three new research initiatives to include SC Energy Earthshots; Funding for Accelerated, Inclusive Research (FAIR); and Accelerate Innovations in Emerging Technologies (Accelerate). The Request also supports ongoing investments in priority areas including microelectronics, critical materials, quantum information science (QIS), exascale computing, fundamental science to transform manufacturing, and accelerator science and technology. These initiatives position SC to address new research opportunities through more collaborative, cross-program efforts.

In FY 2023, SC requests funding for three new research initiatives:

- SC Energy Earthshots: The SC Energy Earthshots initiative will support both small group awards and larger center awards through the Energy Earthshot Research Centers (EERCs). EERCs will bring together multi-investigator, multi-disciplinary teams to address key research challenges at the interface between basic research and applied research and development activities. EERCs will entail collaboration within each team awards involving academic, national laboratory, and industrial researchers by SC and DOE energy technology offices, establishing a new era of cross-office research cooperation.
- Funding for Accelerated, Inclusive Research (FAIR): The FAIR initiative will provide focused investment on enhancing research on clean energy, climate, and related topics at Minority Serving Institutions (MSIs), including attention to underserved and environmental justice regions. The activities will improve the capability of MSIs to perform and propose competitive research and will build beneficial relationships between MSIs and DOE national laboratories and facilities.
- Accelerate Innovations in Emerging Technologies (Accelerate): The Accelerate initiative will support scientific research to accelerate the transition of science advances to energy technologies. The goal is to drive scientific discovery to sustainable production of new technologies across the innovation continuum, to provide experiences in working across this continuum for the workforce needed for industries of the future, and to meet the nation's needs for abundant clean energy, a sustainable environment, and national security.

The Request supports SC's basic research portfolio, which includes extramural grants and contracts supporting nearly 29,000 researchers located at over 300 institutions and the 17 DOE national laboratories, spanning all fifty states and the District of Columbia. In FY 2023, SC's suite of 28 scientific user facilities will continue to provide unmatched tools and capabilities for nearly 34,000 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 also continues to update its business processes for awards management and research related activities to advance diversity, equity, and inclusion in its extramural research programs. SC allocates Working Capital Fund charges for common administrative services to the research programs and the Program Direction account.

SC supports the following FY 2023 Research Initiatives.

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Office of Science				
Fundamental Science to Transform Advanced Manufacturing	–	–	27,000	27,000
Biopreparedness Research Virtual Environment (BRaVE)	–	–	51,756	51,756
Accelerator Science and Technology Initiative	11,411	11,411	28,872	17,461
Microelectronics	30,182	30,183	47,701	17,519
Quantum Information Science	270,391	276,464	293,426	23,035
Integrated Computational & Data Infrastructure	11,974	14,321	–	-11,974
Critical Materials/Minerals	17,000	17,000	25,000	8,000
Revolutionizing Polymers Upcycling	14,500	14,500	14,500	–
Artificial Intelligence and Machine Learning	124,354	126,308	169,000	44,646
Exascale Computing	479,945	445,000	268,000	-211,945
Reaching a New Energy Sciences Workforce (RENEW)	–	–	60,000	60,000
Advanced Computing	–	–	37,661	37,661
Funding for Accelerated, Inclusive Research (FAIR)	–	–	35,508	35,508
Accelerate Innovations in Emerging Technologies	–	–	40,051	40,051
National Virtual Climate Laboratory (NVCL)	–	–	3,000	3,000
Climate Resilience Centers	–	–	5,000	5,000
Urban Integrated Field Laboratory	–	–	22,000	22,000
SC Energy Earthshots	–	–	204,250	204,250
Total, Research Initiatives	**959,757**	**935,187**	**1,332,725**	**+372,968**

Note:

- *The Integrated Computational and Data Initiative is rolled into Advanced Computing Initiative in FY 2023.*

Highlights of the FY 2023 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 U.S. The ASCR Request of $1,068.7 million, is an increase of $53.7 million, or 5.3 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 includes $227.0 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 $150.0 million of this effort will go to the Argonne Leadership Computing Facilities to continue deployment of the exascale systems and support for early science users and Exascale Computing Project (ECP) project teams. To ensure progress during and after ECP, the Request increases support for basic research in applied math and computer science, as well as the Scientific Discovery through Advanced Computing (SciDAC) institutes, while transitioning research and development efforts from ECP. The Request supports new activities to support the FAIR initiative to expand clean energy research and capabilities at MSIs; the Accelerate initiative to support fundamental research that accelerates the transition of science to technologies; and the SC Energy Earthshots initiative, including the establishment of new Energy Earthshot Research Centers. ASCR's Applied Mathematics and Computer Science programs will develop new scalable energy efficient algorithms and software. The Request also supports additional SciDAC partnerships with the Department's Applied Energy programs, NIH, and other agencies, to improve emergency response as well as investments to broaden and use the foundation of AI. Investments in QIS testbeds, Centers, and networking are maintained. Efforts under the advanced computing infrastructure that enables data-driven science are expanded to address increasing demand from upgrades at Office of Science user facilities. The Request also continues 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 advanced computing infrastructure. The Request also provides robust support for ASCR user facilities operations to ensure the availability of high-performance computing and networking to the scientific community as well as upgrades to maintain U.S. leadership in these essential areas. This includes planning for an upgrade to the National Energy Research Scientific Computing Center (NERSC). To increase participation and retention of underrepresented groups in areas relevant to ASCR, the Request continues support for the Computational Science Graduate Fellowship and RENEW.

- *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 $2,420.4 million is an increase of $175.4 million, or 7.8 percent, above the FY 2021 Enacted level. The Request focuses resources on the highest priorities in early-stage fundamental research, operation and maintenance of a complementary suite of scientific user facilities, and facility upgrades. High priority areas in core research include clean energy, critical materials/minerals, manufacturing including next-generation microelectronics, biopreparedness, QIS, data science including AI/ML and related infrastructure, exascale computing, and accelerator science and technology. The Request includes funding for the FAIR initiative to expand clean energy research and capabilities at MSIs and the Accelerate initiative to support fundamental research that accelerates the transition of science to technologies. In the SC Energy Earthshots Initiative, the Request includes support for a new research modality of Energy Earthshot Research Centers, which will address key research challenges at the interface between currently supported basic research and applied research and development activities, to realize the stretch goals of the DOE Energy Earthshots. The Request continues 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 recompetition and the Fuels from Sunlight Energy Innovation Hub awards. The Request also increases funds for the DOE Established Program to Stimulate Competitive Research, to strengthen participation of underrepresented institutions and regions, and for RENEW, with targeted efforts to increase participation and retention of underrepresented groups in research areas relevant to BES. BES maintains a balanced suite of complementary tools, including supporting operations of five x-ray light sources, two neutron sources, and five nanoscale science research centers (NSRCs) at approximately 90 percent of the funding level required for normal operations based on a 2018 baseline. The Request provides continuing support for the ongoing construction activities for the Advanced Photon Source Upgrade (APS-U), Advanced Light Source Upgrade (ALS-U), Linac Coherent Light Source-II High Energy (LCLS-II-HE), Proton Power Upgrade (PPU), Second Target Station (STS), and Cryomodule Repair and Maintenance Facility (CRMF). The Request continues two Major Item of Equipment projects: the NSLS-II Experimental Tools-II project for the phased build-out of beamlines at NSLS-II and the NSRC Recapitalization project. The Request provides Other Project Costs to begin planning for the NSLS-II Experimental Tools-III (NEXT-III) and High Flux Isotope Reactor Pressure Vessel Replacement (HFIR-PVR) projects.

- *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 $903.7 million is an increase of $150.7 million, or 20.0 percent, above the FY 2021 Enacted level. All BER research is informed by the community and the federally chartered BER Advisory Committee. The U.S. and the world face profound challenges due to climate change with a narrow window of opportunity to pursue action to avoid the most catastrophic impacts. The Request for Biological Systems Science supports a possible five-year renewal for the Bioenergy Research Centers (BRCs). The renewed BRCs will provide new, fundamental research underpinning the production of clean energy and chemicals from sustainable biomass resources for translation of basic research results to industry. The BRCs will continue clean energy innovative research while initiating new inter-BRC collaborations to tackle complex clean energy challenges. The Accelerate initiative will focus on emerging technologies to develop capabilities that scale from laboratory fabricated ecosystems to field ecosystems, through the use of integrated sensor networks and the development and application of novel in situ sensors, imaging, Omics analysis, and autonomous controls and continuous data acquisition and analysis. These technologies can be deployed in the future at user facilities to bring new capabilities for climate science and clean energy research, broadening the impact and providing equitable access to underrepresented communities. Biopreparedness Research Virtual Environment (BRaVE) will increase to 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. BER contributes to the SC Energy Earthshots initiative through initiation of Earthshot Energy Research Centers, as well as enhancing cross-cutting research on negative carbon emissions, through understanding the key factors controlling soil carbon residence over time through detailed characterization of soil-plant-microbe-environment processes governing carbon turnover. Additional core research to underpin emerging and future Earthshots will also be initiated. Computational Biosciences efforts will support the initiative on Advanced Computing 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 complementing tools and approaches at Office of Science user facilities for predictive understanding of biological processes. BER will participate in the FAIR initiative to provide focused investment on enhancing biological research on clean energy, climate, and related topics at MSIs, including attention to underserved and environmental justice regions. 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 Integrative Artificial Intelligence Framework for Earth System Predictability (AI4ESP) effort will develop advanced software, AI, and unsupervised learning approaches for running on future DOE computer architectures accelerating predictive capabilities and reducing uncertainty across the DOE climate model-data-experiment enterprise. Research on coastal estuaries will be continued, with a focus on the Chesapeake Bay, Puget Sound, and Great Lakes, adding clean water related research. Research involving field-based observing and modeling will be enhanced through Urban Integrated Field Laboratories to incorporate environmental justice as a key tenet of research involving climate-sensitive regions. Additionally, the National Virtual Climate Laboratory (NVCL) will continue to further provide unified access to climate science to MSIs and HBCUs, connecting frontline communities with the key climate science capabilities and workforce training opportunities at the DOE national laboratories. Planning and implementation activities continue for a network of climate resilience centers affiliated with an HBCU or MSIs; the centers will serve as the translational agent connecting BER climate science with broader socioeconomic and environmental justice issues for equitable solutions. All activities will enhance research capacity at the affiliated universities and bring interdisciplinary strength and diversity to DOE's climate research. The Data Management effort will continue data archiving and management capabilities, including AI/ML tools. The Request supports operations of BER's three scientific user facilities: the DOE Joint Genome Institute (JGI), the Environmental Molecular Sciences Laboratory (EMSL), and the Atmospheric Radiation Measurement Research Facility (ARM). The ARM user facility will initiate campaigns using the aerial capability. All BER facilities will continue a multiyear instrumentation refresh to ensure these facilities are delivering the state-of-the-art capabilities required by the scientific community. BER increases support for the SC-wide RENEW initiative.

- *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 $723.2 million is an increase of $51.2 million, or 7.6 percent, above the FY 2021 Enacted level. The Request is aligned with the recommendations of the recent Long-Range Plan (LRP) developed by the Fusion Energy Sciences Advisory Committee. The Request supports research and facility operations at the DIII-D national fusion facility at 90 percent 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) as well as enhanced collaborative research at other facilities to support the NSTX-U research program priorities. The Request continues to support collaborations by U.S. scientists at overseas superconducting tokamaks and stellarators and other international facilities with unique capabilities, enabled by U.S. hardware and intellectual contributions; continues to support research activities in AI/ML for both fusion energy and discovery plasma science applications and in QIS both at the QIS Research Centers and for core research addressing FES priorities. The Request supports research activities in Materials, Fusion Nuclear Science, Advanced Manufacturing, and Enabling R&D; continues to support research activities both in Theory and Advanced Computing activities and Scientific Discovery through Advanced Computing (SciDAC) in partnership with ASCR; and continues to support research activities in both High-Energy-Density Laboratory Plasmas 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 (INFUSE) program and through initiation of a new milestone-based cost-share program. The Request provides support for the U.S. Contributions to ITER project focusing on the design, fabrication, and delivery of in-kind hardware components for Subproject 1, provides construction cash contributions to support the ITER Organization assembly and installation of the hardware contributions from all the ITER Members; and continues to support an ITER Research program to prepare the U.S. fusion community to take full advantage of ITER Operations. 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 continues to address a key recommendation in the LRP by supporting the "Future Facilities Studies" activity focused on the design of next step facilities like a Fusion Pilot Plant. The Request also initiates a new activity to support research on the scientific foundation and technologies for inertial fusion energy, following a key recommendation in the LRP. FES will increase its support for the RENEW initiative with targeted efforts to increase participation and retention of underrepresented groups in areas relevant to FES. In addition, FES will participate in two new SC research initiatives, FAIR and Accelerate.

- *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 $1,122.0 million is an increase of $76.0 million, or 7.3 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. High priority areas for core research include theoretical and experimental activities in pursuit of discovery science; fostering a diverse, highly skilled workforce; building R&D capacity; and conducting world-leading advanced technology R&D. In partnership with SC programs, HEP ensures broad access to exascale computing resources and promotes AL/ML, QIS, microelectronics, accelerator science and technology, and accelerate innovations in emerging technologies research to address cross-cutting challenges across the HEP program. Through RENEW, HEP broadens reach and increases pathways for physics and engineering students, and through FAIR, HEP invests in S&T infrastructure at MSIs. The Request will continue support for the multi-disciplinary QIS Research Center, Superconducting Quantum Materials and

Systems (SQMS), involving 20 institutions and led by the Fermi National Accelerator Laboratory (FNAL). The Request will continue 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 Request will also continue five Major Item of Equipment (MIE) projects: Accelerator Controls Operations Research Network (ACORN), Cosmic Microwave Background Stage 4 (CMB-S4), High-Luminosity Large Hadron Collider (HL-LHC) Accelerator, and A Toroidal LHC Apparatus (ATLAS) and Compact Muon Solenoid (CMS) Detector Upgrade Projects. The Fermilab Accelerator Complex and the Facility for Advanced Accelerator Experimental Tests II (FACET-II) will continue operations at 87 and 91 percent respectively 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.

- *Nuclear Physics (NP)* supports experimental and theoretical research to discover, explore, and understand all forms of nuclear matter. The NP Request of $739.2 million is an increase of $26.2 million, or 3.7 percent, above the FY 2021 Enacted level. The Request supports safe, efficient, and cost-effective operations of four NP scientific user facilities at 90 percent optimal. 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 (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 gold and platinum. The Facility for Rare Isotope Beams (FRIB), which began operations in FY 2022, produces nuclei with extreme neutron-to-proton ratios to reveal the nature of nuclear binding and the structure of nuclei at the limit of nuclear existence. To maintain U.S. leadership throughout this century and to extend well beyond current scientific capabilities, NP supports R&D and Preliminary Engineering Design for the Electron-Ion Collider (EIC) 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 (GRETA), a ton-scale detector for neutrinoless double beta decay to determine if the neutrino is its own antiparticle, the High Rigidity Spectrometer (HRS) to realize the full scientific potential of FRIB, and the Measurement of a Lepton-Lepton Electroweak Reaction (MOLLER) MIE at JLab. NP is the primary steward of the nation's fundamental nuclear physics research portfolio, providing over 95 percent of the investment in the U.S. nuclear physics basic research. The Request supports this research portfolio through support for 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. 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 artificial intelligence and machine learning which can benefit nuclear physics research and NP accelerator operations. The Request supports continued participation in the microelectronics initiative, with an emphasis on unique devices capable of surviving in cryogenic and high radiation environments and the RENEW activity with targeted efforts ensure a future nuclear physics workforce that is creative, innovative, and capable of meeting the Nation's needs via proactive stewardship of talent with diverse ideas and backgrounds. The Request includes support for two new initiatives: FAIR to further enhance diversity, equity, and inclusion in nuclear physics, and Accelerate to research how imaging advances within nuclear physics can apply to other fields.

- *Isotope R&D and Production (IRP) or DOE Isotope Program (DOE IP)* supports National Preparedness for critical isotope production and distribution to mitigate gaps and disruptions in supply chains of isotopes even during times of national crisis; efforts include mitigating U.S. dependence on foreign supply of key isotopes. The IRP Request is $97.5 million. Isotopes are high-priority commodities of strategic importance for the nation and are essential in medical diagnosis and treatment, discovery science, clean energy, national security, advanced manufacturing, space exploration and communications, biology, archeology, quantum information science, climate and environmental 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, enabling emerging technology and promoting U.S. scientific, technical and industrial strengths. A high priority remains the dedicated research effort to develop large scale production capabilities of the alpha-emitter actinium-225 (Ac-225) that has shown stunning success in the treatment of diffuse cancers and infections. The Request continues support for the U.S. Stable Isotope Production and Research Center, which will provide significant stable isotope production capacity for the nation, mitigating dependence on sensitive countries. 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, cost effectively repurposing unwanted product. The Request maintains effort in the Advanced Manufacturing initiative, pursuing innovative approaches to robotics, target manufacturing, such as ink jet printing of thin film targets for isotope production, modular automated systems for radioisotope purification and processing, and modern enrichment technology. As part of the Biopreparedness Research Virtual Environment (BRaVE) Initiative, the DOE IP continues to advance the development of the Radioisotope Science Center research project in a disadvantaged area near the University of Missouri Research Reactor (MURR) to bring more science opportunities and high-tech jobs to an impoverished area, while also mitigating single point failures in core competencies and capabilities. Funding will further develop the conceptual design of a new long-term facility at ORNL, the Radioisotope Processing Facility (RPF). This will increase the limited radiochemical processing capabilities in the DOE complex and enable the Program to make available certain new isotopes and provide nuclear assurance of the Nation's readiness to respond to disruptions in global isotope supply chains. Critical efforts continue in the ongoing SC Quantum Information Science (QIS) initiative that will enable the domestic production of isotopes of interest for QIS. Funding continues participation in the RENEW initiative, supporting the Isotope Program Traineeship to promote innovative and transformative approaches to isotope production and processing, including advanced manufacturing, artificial intelligence and machine learning, and robotics; the Traineeship emphasizes participation of minority serving institutions and increasing the diversity and equity of workforce development opportunities in the Program. The Request also supports two new initiatives. Investment in the FAIR initiative will support investments at specific institutions in disadvantaged areas in order to promote environmental justice through place-based science and the provision of technical jobs and capabilities associated with isotope research and production. Participation in the Accelerate Initiative advances the readiness of novel medical isotopes that have shown great promise for cancer and disease diagnosis and treatment for use in innovative radiopharmaceutical therapeutics through the support of translational research in coordination with the NIH.

- *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 partnerships to advance new technologies for use in SC's scientific facilities and in commercial products. The ARDAP Request of $27.4 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 inclusive workforce development. Also, the Request supports participation in the new FAIR initiative. The Request supports operation of the Brookhaven National Laboratory Accelerator Test Facility at 94 percent of optimal. Accelerator Production activities support partnerships to develop advanced superconducting wire and cable, superconducting accelerators, and advanced radiofrequency power sources for accelerators.

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. Collaboration of research activities and facilities at the DOE national laboratories and partnership-encouraging funding mechanisms facilitate research integration within the basic and applied research communities. SC's R&D coordination also occurs at the interagency level. Specific collaborative activities are highlighted in the "Basic and Applied R&D Coordination" sections of each individual SC program budget justification narrative.

High-Risk, High-Reward Research[a]

SC incorporates high-risk, high-reward, basic research elements in all of its research portfolios; each SC research program considers a significant proportion of its supported research as high-risk, high-reward. Because advancing the frontiers of science also depends on the continued availability of state-of-the-art scientific facilities, SC constructs and operates national scientific facilities and instruments that comprise the world's most sophisticated suite of research capabilities. SC's basic research is integrated within program portfolios, projects, and individual awards; as such, it is not possible to quantitatively separate the funding contributions of particular experiments or theoretical studies that are high-risk, high-reward from other mission-driven research in a manner that is credible and auditable. SC incorporates high-risk, high-reward basic research elements in its research portfolios to drive innovation and challenge current thinking, using a variety of mechanisms to develop topics: Federal advisory committees, triennial Committees of Visitors, program and topical workshops, interagency working groups, National Academies' studies, and special SC program solicitations. Many of these topics are captured in formal reports, e.g., *Chemical Upcycling of Polymers,* Basic Energy Sciences report (2019)[b]; *Basic Research Needs for Microelectronics*, joint BES, ASCR, and HEP workshop (2018)[c]; *Basic Research Needs for Scientific Machine Learning; Core Technologies for Artificial Intelligence*, ASCR workshop (2018)[d]; *Building for Discovery: Strategic Plan for U.S. Particle Physics in the Global Context*, by the High Energy Physics Advisory Panel (2014)[e]; *From Long-distance Entanglement to Building a Nationwide Quantum Internet: Report of the DOE Quantum Internet Blueprint Workshop,* ASCR workshop report (2020)[f]; *Opportunities for Basic Research for Quantum Computing in Chemical and Materials Sciences*, Basic Energy Sciences report (2017); *Opportunities for Basic Research for Next-Generation Quantum Systems*, Basic Energy Sciences report (2017) [g]; *Basic Research Needs for Transformative Manufacturing* (2020)[h]; *Basic Research Needs Workshop on Quantum Materials for Energy Relevant Technology,* BES workshop report (2016)[i]; *Grand Challenges for Biological and Environmental Research: Progress and Future* Vision, by the BER Advisory Committee (2017)[j]; *Genome Engineering for Materials Synthesis*, BER workshop report (2018)[k]; *Plasma: at the Frontier of Scientific Discovery*, FES workshop report (2017)[l]; *Powering the Future: Fusion and Plasmas*, FES Advisory Committee Long Range Plan (2020)[m]; *FES Roundtable on QIS* (2018)[n]; *Advancing Fusion with Machine Learning,* joint FES-ASCR workshop report (2019)[o]; *Isotope Research and Production Opportunities and Priorities*, by the Nuclear Science Advisory Committee (NSAC) (2015)[p]; and *Nuclear Physics Long Range Plan*, by the Nuclear Science Advisory Committee (NSAC, 2015)[q] and *Quantum Computing and Quantum Information Sciences (QIS),* by NSAC (2019)[l]; *Office of Science User Facilities: Lessons from the COVID Era and Visions for the Future*; SC workshop report (2020)[r].

Scientific Workforce

For more than 60 years SC and its predecessors have fostered a vibrant ecosystem for the training of a highly skilled scientific and technological workforce. In addition to the undergraduate internships, graduate thesis research, and visiting

---

[a] In compliance with the reporting requirements in the America COMPETES Act of 2007 (P.L. 110-69, section 1008)
[b] https://science.osti.gov/-/media/bes/pdf/BESat40/Polymer_Upcycling_Brochure.pdf
[c] https://science.osti.gov/-/media/bes/pdf/reports/2019/BRN_Microelectronics_rpt.pdf
[d] https://science.energy.gov/ascr/community-resources/program-documents/
[e] http://science.osti.gov/~/media/hep/hepap/pdf/May%202014/FINAL_P5_Report_Interactive_060214.pdf
[f] https://www.osti.gov/biblio/1638794/
[g] https://science.osti.gov/~/media/bes/pdf/reports/2018/Quantum_computing.pdf
[h] https://science.osti.gov/-/media/bes/pdf/reports/2020/Transformative_Mfg_Brochure.pdf?la=en&hash=95094B9257DCFD506C04787D96EEDD942EB92EEC
[i] https://science.osti.gov/~/media/bes/pdf/reports/2016/BRNQM_rpt_Final_12-09-2016.pdf
[j] https://science.osti.gov/~/media/ber/berac/pdf/Reports/BERAC-2017-Grand-Challenges-Report.pdf
[k] https://science.osti.gov/-/media/ber/pdf/community-resources/2019/GEMS_Report_2019.PDF?la=en&hash=0D7092AD5416A28207F0F95F94E00921D308A113
[l] https://science.osti.gov/~/media/fes/pdf/program-news/Frontiers_of_Plasma_Science_Final_Report.pdf
[m] https://science.osti.gov/-/media/fes/fesac/pdf/2020/202012/FESAC_Report_2020_Powering_the_Future.pdf?la=en&hash=B404B643396D74CE7EDAB3F67317E326A891C09C
[n] https://science.osti.gov/-/media/fes/pdf/workshop-reports/FES-QIS_report_final-2018-Sept14.pdf
[o] https://science.osti.gov/-/media/fes/pdf/workshop-reports/FES_ASCR_Machine_Learning_Report.pdf
[p] https://science.osti.gov/~/media/ber/pdf/community-resources/Technologies_for_Characterizing_Molecular_and_Cellular_Systems.pdf
[q] https://science.osti.gov/np/nsac/reports/
[r] https://science.osti.gov/-/media/bes/pdf/reports/2021/SC_User_Facilities_rpt_print.pdf

faculty opportunities provided through SC's Office of Workforce Development for Teachers and Scientists, to sustain a strong workforce pipeline for DOE mission, the SC research program offices support undergraduates, graduate students, and postdoctoral researchers through sponsored research awards at universities and the DOE national laboratories nationwide. The research program offices also support targeted undergraduate and graduate-level training in areas critically important to DOE mission (such as those associated with scientific user facilities) but not readily available in universities, such as particle accelerator and detector physics, neutron and x-ray scattering, nuclear chemistry, instrumentation, isotope R&D, and computational sciences at the leadership computing level. To help attract critical talent for stimulating fresh ideas and forward thinking, SC supports the Early Career Research Program, which funds individual research programs to identify and award outstanding rising scientists early in their careers in the disciplines supported by SC[s]. To retain highly accomplished researchers, SC initiated the Distinguished Scientist Fellows opportunity to recognize leading DOE laboratory staff and sponsoring their innovative efforts to enrich, sustain, and promote scientific and academic excellence in SC mission research and community at large through partnership between institutions of higher education and national laboratories. SC coordinates with other DOE offices and other agencies on best practices for STEM training programs and evidence-based program evaluation efforts through internal DOE working groups and active participation in all the inter-agency working groups of the National Science and Technology Council's Committee on Science, Technology, Engineering, and Mathematics Education (CoSTEM). 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 continues the activity, Reaching a New Energy Sciences Workforce (RENEW), for targeted efforts to expand participation and retention of HBCUs and other MSIs, community colleges, and individuals from underrepresented groups in SC research and workforce development 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. The Request continues support for these honorary awards.

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.

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

Future Year Energy Program
(dollars in thousands)

	FY 2023 Request	FY 2024	FY 2025	FY 2026	FY 2027
Office of Science	$7,799,211	$7,977,000	$8,162,000	$8,350,000	$8,542,000

Outyear Priorities and Assumptions
In the FY 2012 Consolidated Appropriations Act (P.L. 112-74), Congress directed the Department to include a future-years energy program (FYEP) in subsequent requests that reflects the proposed appropriations for five years. This FYEP shows outyear funding for each account for FY 2024 - FY 2027. The outyear funding levels use the growth rates from and match the outyear account totals published in the FY 2023 President's Budget for both the 050 and non-050 accounts. Actual future budget request levels will be determined as part of the annual budget process.

Office of Science priorities in the outyears include the following:

- Increase investments in Administration priorities 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.
- Ensure optimal operations of all scientific user facilities.
- Continue to invest in infrastructure and utility upgrades at all national laboratories.
- Invest in ongoing and new line-item construction projects and major items of equipment to ensure the United States maintain world leading and state-of-the-art scientific user facilities.

Science
Funding by Congressional Control

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted ($)	FY 2023 Request vs FY 2021 Enacted (%)
Advanced Scientific Computing Research					
ASCR Research	846,055	886,000	991,741	+145,686	+17.22%
17-SC-20, SC Exascale Computing Project (ECP)	168,945	129,000	77,000	-91,945	-54.42%
Total, Advanced Scientific Computing Research	**1,015,000**	**1,015,000**	**1,068,741**	**+53,741**	**+5.29%**
Basic Energy Sciences					
BES Research	1,856,000	1,940,800	2,127,239	+271,239	+14.61%
Construction					
21-SC-10, Cryomodule Repair & Maintenance Facility, (CRMF), SLAC	1,000	1,000	10,000	+9,000	+900.00%
19-SC-14, Second Target Station (STS), ORNL	29,000	32,000	32,000	+3,000	+10.34%
18-SC-10, Advanced Photon Source Upgrade (APS-U), ANL	160,000	101,000	9,200	-150,800	-94.25%
18-SC-11, Spallation Neutron Source Proton Power Upgrade (PPU), ORNL	52,000	17,000	17,000	-35,000	-67.31%
18-SC-12, Advanced Light Source Upgrade (ALS-U), LBNL	62,000	75,100	135,000	+73,000	+117.74%
18-SC-13, Linac Coherent Light Source-II-High Energy (LCLS-II-HE), SLAC	52,000	50,000	90,000	+38,000	+73.08%
13-SC-10 - Linac Coherent Light Source-II (LCLS-II), SLAC	33,000	28,100	–	-33,000	-100.00%
Total, Construction	**389,000**	**304,200**	**293,200**	**-95,800**	**-24.63%**
Total, Basic Energy Sciences	**2,245,000**	**2,245,000**	**2,420,439**	**+175,439**	**+7.81%**

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted ($)	FY 2023 Request vs FY 2021 Enacted (%)
Biological and Environmental Research					
BER Research	753,000	753,000	903,685	+150,685	+20.01%
Construction					
Total, Biological and Environmental Research	**753,000**	**753,000**	**903,685**	**+150,685**	**+20.01%**
Fusion Energy Sciences					
FES Research	415,000	446,000	482,222	+67,222	+16.20%
Construction					
20-SC-61, Matter in Extreme Conditions (MEC) Petawatt Upgrade, SLAC	15,000	5,000	1,000	-14,000	-93.33%
14-SC-60, U.S. Contributions to ITER	242,000	221,000	240,000	-2,000	-0.83%
Total, Construction	**257,000**	**226,000**	**241,000**	**-16,000**	**-6.23%**
Total, Fusion Energy Sciences	**672,000**	**672,000**	**723,222**	**+51,222**	**+7.62%**
High Energy Physics					
HEP Research	794,000	750,065	824,020	+30,020	+3.78%
Construction					
18-SC-42, Proton Improvement Plan II (PIP-II), FNAL	79,000	90,000	120,000	+41,000	+51.90%
11-SC-40, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment	171,000	176,000	176,000	+5,000	+2.92%
11-SC-41, Muon to Electron Conversion Experiment, FNAL	2,000	13,000	2,000	–	–
Total, Construction	**252,000**	**279,000**	**298,000**	**+46,000**	**+18.25%**
Total, High Energy Physics	**1,046,000**	**1,029,065**	**1,122,020**	**+76,020**	**+7.27%**

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted ($)	FY 2023 Request vs FY 2021 Enacted (%)
Nuclear Physics					
NP Operation and Maintenance	690,700	624,000	719,196	+28,496	+4.13%
Construction					
14-SC-50, Facility for Rare Isotope Beams (FRIB), MSU	5,300	–	–	-5,300	-100.00%
20-SC-51, U.S. Stable Isotope Production and Research Center (SIPRC)	12,000	–	–	-12,000	-100.00%
20-SC-52, Electron Ion Collider (EIC), BNL	5,000	5,000	20,000	+15,000	+300.00%
Total, Construction	**22,300**	**5,000**	**20,000**	**-2,300**	**-10.31%**
Total, Nuclear Physics	**713,000**	**629,000**	**739,196**	**+26,196**	**+3.67%**
Isotope R&D and Production					
IRP Research	–	72,000	85,451	+85,451	–
Construction					
20-SC-51, U.S. Stable Isotope Production and Research Center (SIPRC), ORNL	–	12,000	12,000	+12,000	–
Total, Construction	**–**	**12,000**	**12,000**	**+12,000**	**–**
Total, Isotope R&D and Production	**–**	**84,000**	**97,451**	**+97,451**	**–**
Accelerator R&D and Production					
ARDAP Research	–	16,935	27,436	+27,436	–
Total, Accelerator R&D and Production	**–**	**16,935**	**27,436**	**+27,436**	**–**
Workforce Development for Teachers and Scientists					
WDTS	29,000	29,000	41,300	+12,300	+42.41%
Total, Workforce Development for Teachers and Scientists	**29,000**	**29,000**	**41,300**	**+12,300**	**+42.41%**

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted ($)	FY 2023 Request vs FY 2021 Enacted (%)
Science Laboratories Infrastructure					
PILT	4,650	4,820	4,891	+241	+5.18%
Oak Ridge Landlord	5,860	6,430	6,559	+699	+11.93%
SLI F&I	29,790	17,200	15,200	-14,590	-48.98%
OR Nuclear Operations	26,000	20,000	20,000	-6,000	-23.08%
Construction					
21-SC-71, Princeton Plasma Innovation Center (PPIC), PPPL	150	900	10,000	+9,850	+6,566.67%
21-SC-72, Critical Infrastructure Recovery & Renewal (CIRR), PPPL	150	2,000	4,000	+3,850	+2,566.67%
21-SC-73, Ames Infrastructure Modernization (AIM)	150	–	–	-150	-100.00%
20-SC-71, Critical Utilities Rehabilitation Project (CURP), BNL	20,000	26,000	13,000	-7,000	-35.00%
20-SC-72, Seismic and Safety Modernization (SSM), LBNL	5,000	27,500	27,500	+22,500	+450.00%
20-SC-73, CEBAF Renovation and Expansion (CEBAF), TJNAF	2,000	10,000	2,000	–	–
20-SC-74, Craft Resources Support Facility (CRSF), ORNL	25,000	–	–	-25,000	-100.00%
20-SC-75, Large Scale Collaboration Center (LSCC), SLAC	11,000	12,000	30,000	+19,000	+172.73%
20-SC-76, Tritium System Demolition and Disposal (TSDD), PPPL	13,000	6,400	–	-13,000	-100.00%
20-SC-77, Argonne Utilities Upgrade (AU2), ANL	500	500	8,000	+7,500	+1,500.00%
20-SC-78, Linear Assets Modernization Project (LAMP), LBNL	500	500	23,425	+22,925	+4,585.00%
20-SC-79, Critical Utilities Infrastructure Revitalization (CUIR), SLAC	500	500	25,425	+24,925	+4,985.00%
20-SC-80, Utilities Infrastructure Project (UIP), FNAL	500	500	20,000	+19,500	+3,900.00%
19-SC-71, Science User Support Center (SUSC), BNL	20,000	38,000	–	-20,000	-100.00%
19-SC-73, Translational Research Capability (TRC), ORNL	22,000	21,500	–	-22,000	-100.00%
19-SC-74, BioEPIC, LBNL	20,000	35,000	45,000	+25,000	+125.00%
18-SC-71, Energy Sciences Capability (ESC), PNNL	23,000	–	–	-23,000	-100.00%
17-SC-71, Integrated Engineering Research Center (IERC), FNAL	10,250	10,250	–	-10,250	-100.00%
Total, Construction	**173,700**	**191,550**	**208,350**	**+34,650**	**+19.95%**
Total, Science Laboratories Infrastructure	**240,000**	**240,000**	**255,000**	**+15,000**	**+6.25%**

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted ($)	FY 2023 Request vs FY 2021 Enacted (%)
Safeguards and Security					
S&S	121,000	121,000	189,510	+68,510	+56.62%
Total, Safeguards and Security	**121,000**	**121,000**	**189,510**	**+68,510**	**+56.62%**
Program Direction					
PD	192,000	192,000	211,211	+19,211	+10.01%
Total, Program Direction	**192,000**	**192,000**	**211,211**	**+19,211**	**+10.01%**
Total, Office of Science	**7,026,000**	**7,026,000**	**7,799,211**	**+773,211**	**+11.00%**

SBIR/STTR funding:

- FY 2021 Enacted: SBIR $159,540,000 and STTR $22,440,000 (SC only)
- FY 2022 Annualized CR: SBIR $164,796,000 and STTR $23,186,000 (SC only)
- FY 2023 Request: SBIR $182,160,000 and STTR $25,614,000 (SC only)

Advanced Scientific Computing Research

Overview

The mission of the Advanced Scientific Computing Research (ASCR) program 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 applications and Department of Energy (DOE) mission needs. ASCR's partnerships, including new efforts with the applied technology offices, activities to broaden participation of under-served communities, 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 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, and stockpile stewardship without testing. Computational science allows researchers 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 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 strengthen our clean energy economy and ensure all Americans share the benefits from those investments. 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 scales 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 and technology development and deployment.

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 redefine and construct the foundation for a new 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, the applied technology offices, other agencies, 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 at the exascale and beyond to accelerate progress in delivering a clean energy future, understanding and addressing climate change, broadening the impact of our investments in science, and increasing the competitive advantage of U.S. industry.

Highlights of the FY 2023 Request

The FY 2023 Request of $1,068.7 million for ASCR will strengthen U.S. leadership in strategic computing with operation and allocation of the Nation's first exascale computing system and testing of a second system, broadening the foundations of AI and QIS, and expanding the infrastructure and partnerships that enables data-driven science and technology—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 Computing Project (ECP) deployment, the Request prioritizes foundational research in Applied Mathematics and Computer Science and the transition of critical technologies from the ECP. Investments will continue to emphasize foundational research to address the combined challenges of increasingly heterogeneous architectures and the changing ways in which HPC systems are used, the development of new scalable energy efficient algorithms and software, directed basic research to address specific challenges for the new Energy Earthshot Research Centers, and incorporating AI and ML into simulations and data intensive applications while increasing greater connectivity with distributed resources, including other SC user facilities. The Computational Partnerships activity will continue to infuse the latest developments in applied math and computer science into strategic applications, including areas such as 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. The Request increases support for ASCR's Computational Partnerships to support SC initiatives; extends SciDAC partnerships to DOE's applied technology offices and mission critical ECP applications, including interagency partnerships to actively build workflows that ensure rapid and robust response to emerging pandemic, biothreat, and public health emergencies; and expands the SciDAC Institutes to fully incorporate exascale software and libraries. The Request also sustains increased 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 Research Centers (NQISRCs), quantum internet, and testbeds. ASCR will continue to partner with the other SC programs to support the multi-disciplinary NQISRCs. 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 regional quantum testbeds, which provide researchers with access to novel, early-stage quantum computing and networking resources and services, and basic research in quantum information will continue. In FY 2023, ASCR will begin to enable the sustainability of critical ECP software for use on emerging technology testbeds.

- ASCR increases support for 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. Science and Technology (S&T) ecosystem.

- The Funding for Accelerated, Inclusive Research (FAIR) initiative will provide focused investment on enhancing research on clean energy, climate, and related topics at minority serving institutions, including attention to underserved and environmental justice regions. The activities will improve the capability of MSIs to perform and propose competitive research and will build beneficial relationships between MSIs and DOE national laboratories and facilities.

- ASCR will also participate in the Accelerate initiative through support for scientific research that will accelerate the transition of science advances to energy technologies. These new efforts will drive scientific discovery toward sustainable production of new technologies across the innovation continuum, to provide experiences in working across this continuum for the workforce needed for industries of the future, and to meet the nation's needs for abundant clean energy, a sustainable environment, and national security.

- Energy Earthshot Research Centers (EERCs), a new modality of research to be launched in FY 2023, building on the success of SC's Energy Frontier Research Centers (EFRCs) and the SciDAC program, will bring together multi-investigator, multi-disciplinary teams to perform energy-relevant research with a scope and complexity beyond what is possible in standard single-investigator or small-group awards. Beyond complementing and expanding the scope of the EFRCs and SciDAC, the EERCs will address the research challenges at the interface between currently supported basic research, applied research, and development activities, with support from both SC and the applied technology offices.

<u>Facility Operations</u>

- FY 2023 marks the beginning of the exascale era for the U.S. research community with full operations and competitive allocation of the Nation's first exascale computing system at the Oak Ridge Leadership Computing Facility (OLCF), a system called Frontier that was deployed in calendar year 2021, and acceptance and operations for early science and the ECP applications on a second exascale computing system at the Argonne Leadership Computing Facility (ALCF), a system called Aurora. The Request 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 operations costs at the Leadership Computing Facilities, at 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 completion of the Department's Exascale Computing Initiative (ECI), which includes the SC-Exascale Computing Project (SC-ECP). In addition, the Request supports the NERSC-10 upgrade, planned to start in FY 2022, including site preparations and long lead procurements, to address rising demand for production computing across the SC programs.

- 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. In addition, the diversity of data- and compute-intensive research workflows is expanding rapidly. In FY 2023, ASCR will continue planning for a new High Performance Data Facility (HPDF), to satisfy the unique requirements of state-of-the-art real-time experimental/observational workflows. The NERSC-10 and HPDF projects will each drive unique technological innovation in system architectures and services beyond what is available in the commercial cloud and will inform planning for future upgrades at the LCFs.

<u>Projects</u>

- The ASCR FY 2023 Request includes $227.0 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 delivered in calendar year 2021 and a second in 2022 to address national needs. Of this effort, $150.0 million of facility operations funding will go to the ALCF to deploy and operate Aurora and testbeds in support of the ECP project teams.

Advanced Scientific Computing Research
FY 2023 Research Initiatives

Advanced Scientific Computing Research supports the following FY 2023 Research Initiatives.

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Accelerate Innovations in Emerging Technologies	–	–	5,000	+5,000
Advanced Computing	–	–	15,332	+15,332
Artificial Intelligence and Machine Learning	56,866	58,820	73,000	+16,134
Biopreparedness Research Virtual Environment (BRaVE)	–	–	11,183	+11,183
Exascale Computing	438,945	404,000	227,000	-211,945
Funding for Accelerated, Inclusive Research (FAIR)	–	–	4,073	+4,073
Integrated Computational & Data Infrastructure	11,974	14,321	–	-11,974
Microelectronics	5,182	5,183	5,183	+1
Quantum Information Science	98,402	100,695	101,194	+2,792
Reaching a New Energy Sciences Workforce (RENEW)	–	–	10,000	+10,000
SC Energy Earthshots	–	–	50,000	+50,000
Total, Research Initiatives	**611,369**	**583,019**	**501,965**	**-109,404**

Note:
- *The Integrated Computational and Data Initiative is rolled into Advanced Computing Initiative in FY 2023.*

Advanced Scientific Computing Research
Funding

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Advanced Scientific Computing Research				
Applied Mathematics Research	48,570	48,570	71,938	+23,368
Computer Sciences Research	46,827	49,388	70,326	+23,499
Computational Partnerships	76,194	73,892	97,861	+21,667
Advanced Computing Research	88,274	96,112	113,598	+25,324
Energy Earthshot Research Centers	–	–	25,000	+25,000
Total, Mathematical, Computational, and Computer Sciences Research	**259,865**	**267,962**	**378,723**	**+118,858**
High Performance Production Computing	113,786	115,963	115,033	+1,247
Leadership Computing Facilities	381,075	408,113	407,772	+26,697
High Performance Network Facilities and Testbeds	91,329	93,962	90,213	-1,116
Total, High Performance Computing and Network Facilities	**586,190**	**618,038**	**613,018**	**+26,828**
17-SC-20 SC Exascale Computing Project	**168,945**	**129,000**	**77,000**	**-91,945**
Subtotal, Advanced Scientific Computing Research	**1,015,000**	**1,015,000**	**1,068,741**	**+53,741**
Total, Advanced Scientific Computing Research	**1,015,000**	**1,015,000**	**1,068,741**	**+53,741**

SBIR/STTR funding:

- FY 2021 Enacted: SBIR $25,736,000 and STTR $3,620,000
- FY 2022 Annualized CR: SBIR $27,495,000 and STTR $3,869,000
- FY 2023 Request: SBIR $30,775,000 and STTR $4,327,000

Advanced Scientific Computing Research
Explanation of Major Changes

(dollars in thousands)

	FY 2023 Request vs FY 2021 Enacted
Mathematical, Computational, and Computer Sciences Research	**+$118,858**

The Computer Science and Applied Mathematics activities will: continue to increase their efforts on foundational research and long-term basic research efforts that explore and prepare for emerging technologies such as quantum networking and computing; begin to transition critical technologies from the Exascale Computing Project into core research efforts; develop new scalable energy efficient algorithms and software; address specific challenges for the Energy Earthshot Research Centers; and address the challenges of data intensive science and the development of critical tools, including AI/ML, to enable an integrated computational and data infrastructure. Computational Partnerships will increase to support SC initiatives; extend SciDAC partnerships to DOE's Applied Energy programs and mission critical ECP applications, including interagency partnerships and emergency preparedness, and to expand the SciDAC Institutes to fully incorporate exascale software and libraries. The Advanced Computing Research activity continues to robustly support the National QIS Research Centers, quantum testbeds, and regional quantum networking testbeds, in close coordination with the other SC programs, to expand user access to quantum resources. Increased funding will enable the sustainability of critical ECP software for use on emerging technology testbeds. This subprogram also increases support for 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 sustains increased support for the Computational Sciences Graduate Fellowship. The subprogram also supports ASCR's participation in SC's new Accelerate and FAIR initiatives to expand participation, accelerate innovation, reduce impacts from climate change, and advance clean energy technologies and infrastructure.

High Performance Computing and Network Facilities	**+$26,828**

The OLCF will provide full operations and competitive allocation of the Nation's first exascale computing system, Frontier, deployed in calendar year 2021. The ALCF will complete acceptance testing and early science/ECP access to the Aurora exascale computing system, deployed in calendar year 2022. Both facilities will provide testbed resources to explore new technologies. In addition, funding supports operation of the 125 petaflop NERSC-9 Perlmutter system, site preparations and long-lead procurements for NERSC-10, and the ESnet-6 upgrade in accordance with the project baselines. To address the significant growth in the rate and volume of data from SC scientific user facilities, ASCR also initiated planning for a new High Performance Data Facility (HPDF) initiated in the FY 2022 Request to satisfy the unique requirements of state-of-the-art real-time experimental/observational workflows to support the explosion of data and also serve as the anchor for the integrated computational and data infrastructure efforts. Funding for all facilities supports operations, including power, equipment, staffing, testbeds, lease payments, and planning for future upgrades.

	(dollars in thousands)
	FY 2023 Request vs FY 2021 Enacted
Exascale Computing The FY 2023 Request will support efforts to deploy SC-ECP applications and ecosystem on both exascale architectures in partnership with the ASCR facilities. The decrease represents a shift in focus within the project as it matures beyond delivery to the execution of applications' challenge problems and implementation of software technologies to meet the Key Performance Parameters (KPPs) on the exascale systems delivered in 2021 and 2022.	**-$91,945**
Total, Advanced Scientific Computing Research	**+$53,741**

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, Scientific Data, Large Scale Networking, AI, High End 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 National Nuclear Security Administration (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 Networking and Information Technology R&D Subcommittee of the NSTC Committee on Technology, ASCR also coordinates with programs across the Federal Government. In FY 2023, cross-agency interactions and collaborations will continue in coordination with the Office of Science and Technology Policy.

Program Accomplishments

Supercomputing Versus COVID-19 – Round Two, Understanding COVID Variants

The SARS-CoV-2 pandemic has entered a new phase with the emergence of variants of concern (VOC) that are more contagious and could undermine the protection of vaccines. Substitutions in the spike protein have been identified with new variants but do not fully explain the success of fast-spreading variants, like the Delta and Omicron variants. A research team at ORNL used a computational systems biology approach to process more than 900,000 SARS-CoV-2 genomes and map spatiotemporal relationships, revealing other critical attributes of successful variants. Comparisons to earlier dominant mutations and protein structural analyses indicate that the increased transmission is promoted by the combination of functionally complementary mutations in both the spikes and in other regions of the SARS-CoV-2 proteome. They found that the currently known VOCs have common mutations in proteins involved in immune-antagonism and replication performance, suggesting a convergent evolution of the virus. Critically, they found that VOCs often occur with a sudden doubling of the number of mutations in that strain, which indicates recombination events—where two different strains infect the same person and, in the process of replicating, merge their genetic material—that facilitate the combination of mutations in spike and other proteins that together lead to new, more infectious and increasingly immune escaping variants. This indicates that extensive community distribution of numerous SARS-CoV-2 variants increases the probability of future recombination events, further accelerating the evolution of the virus.

Toward an Integrated Scientific Data Infrastructure - Addressing Urgent Challenges in Real Time

Scientists working remotely from Turkey leveraged the National Energy Research Scientific Computing Center (NERSC) and the Linac Coherent Light Source (LCLS) at SLAC National Accelerator Laboratory, via the ESnet, to capture detailed images of the structure of the SARS-CoV-2 virus, focusing on two of the viral proteases—enzymes that make the virus's life cycle possible—and how to keep them from functioning. By understanding the molecular structure of the proteases, researchers can identify proteins that bind to them and interfere with their role in viral reproduction. The goal is to inhibit these two enzymes with chemical compounds contributed from the COVID-19 Moonshot initiative that may eventually lead to antiviral treatments in humans, a key step toward next generation treatments for COVID-19. During and after the experiments, the team utilized NERSC's Cori supercomputer and ESnet's high-speed optical network to process data and provide results in real time, allowing the researchers to monitor the experiment, begin analysis, and make changes as necessary. This enables the study of small differences in atomic structure in near real time, even while working remotely, to guide decision-making during the experiment. Analysis of the findings from these experiments is ongoing but the work is also shaping the development of the ASCR scientific data facility concept, exposing challenges and identifying areas where more work is needed.

ASCR Inside: Taking AI to Extreme Scales for Science

Scientists at Los Alamos National Laboratory and the SLAC National Accelerator Laboratory, working in collaboration with NVIDIA, Facebook, and other industrial and academic teams, leveraged ASCR's long-standing investments in the Legion data-centric parallel-programming system to create the FlexFlow large-scale machine-learning toolkit. This toolkit allows practitioners with workflows programmed with widely-used machine-learning frameworks and interfaces, such as Keras/TensorFlow, PyTorch, and ONNX, to utilize large-scale resources to train machine-learning models of unprecedented size and faster than ever. Efficiently using large-scale resources enabled a 15x reduction in model-training times, bringing a key benchmark workflow from 18 hours to 1.2 hours. The increased turn-around time was enabled by scaling the workflow to use over 750 Graphics Processing Units (GPUs), a feat made possible using the FlexFlow framework build on Legion, an R&D 100 Award winner in 2020. The workflow acceleration contributed to urgent scientific work aimed at discovering new drugs to treat cancer and COVID-19.

Getting Real About Uncertainty in Sea Level Rise
A team of DOE-supported ice sheet and climate modeling scientists contributed to improved quantitative estimates for the range of future sea level rise expected from melting glaciers and ice sheets, as recently reported on in the journal *Nature.*[t] This study was also cited in Chapter 9 of the 6th assessment report from the International Panel on Climate Change (IPCC), "Ocean, Cryosphere and Sea Level Change." For this study, the team of 84 international researchers used NERSC to run the largest and most sophisticated set of climate and land ice models to date, combining nearly 900 simulations from 38 international modeling groups to improve not only the median projections of future sea level rise but also estimates for the associated uncertainties. These multi-model ensembles were combined via statistical emulation to build probabilistic projections of future sea level rise from all sources of land ice. The projections show that limiting global warming to 1.5°C above pre-industrial temperatures would cut projected 21st century sea level rise from land ice in half, relative to currently pledged emissions reductions, from approximately 25 cm to 13 cm in the best-case scenario. However, under the worst-case scenario, with much more melting than snowfall in the Antarctic, ice losses there could be five times larger, increasing the median land ice contribution to 42 cm of sea level rise under current policies and pledges, with a 5 percent chance of sea level rise exceeding 50 cm even under 1.5°C warming. Results from this study confirm that Antarctica remains a critical focus for reducing future uncertainty in sea level rise; due to substantial uncertainty in how strongly warm ocean waters will erode floating parts of the ice sheet from beneath, a process that now is the focus of DOE's Energy Exascale Earth System Model.

Supercomputing Powers Energy Savings
Residential and commercial buildings consume nearly three-quarters of U.S. electricity—during peak hours, the share reaches 80 percent. The annual energy bill is nearly $412 billion. Simulating that energy use on a broad scale can help identify ways to reduce it, cutting greenhouse gas emissions in the process. Researchers at Oak Ridge National Laboratory used the Argonne Leadership Computing Facility for data-intensive simulations of a "digital twin" of the more than 178,000 buildings in Chattanooga, Tennessee. They studied how different energy conservation measures might result in cost savings. The AutoBEM simulation of Chattanooga buildings, which also uses EnergyPlus and OpenStudio, two DOE tools for modeling buildings energy use, found that 99 percent of buildings would realize energy savings from employing the existing energy efficiency technologies evaluated. The effort is part of a larger goal to model all of the Nation's 125 million buildings. A conservation measure of the impact of simple changes like improved HVAC efficiency, space sealing, insulation or lighting could have the potential to offset 500 to 3,000 pounds of carbon dioxide per building, the researchers concluded.

Delivering the Exascale Ecosystem
The Exascale Computing Project (ECP) is building a comprehensive software ecosystem consisting of more than 20 applications and 80 software packages that use more than 10 compilers and 10 programming models on a range of target hardware architectures (from laptops to exascale). The legacy of these efforts will be a computational ecosystem that accelerates U.S. capabilities in scientific simulation and artificial intelligence (AI), unlocking the potential of Exascale computers and preparing us for future systems that will build on our legacy. The complexity of this ecosystem, with over one million combinations, is being managed and simplified for the entire scientific and AI user community through the creation of ECP's Extreme-Scale Scientific Software Stack (E4S). E4S (https://e4s.io) is lowering the barrier to entry for users and developers in the DOE and other U.S. government agencies, industries, and universities. The E4S has aggressively evolved, providing 80 distinct turn-key HPC and AI products grouped into thematic software development kits (SDKs). Application codes that build on top of E4S benefit from guaranteed version compatibility, access to the latest stable features integrated into each quarterly release, and advanced build environment features that can improve build times by a factor of ten. The last E4S release contains support for GPU architectures and is installed on DOE and NSF pre-exascale systems, enabling the portability promise that is central to the success of future U.S. supercomputing.

---

[t] Edwards, T. L. and 82 others. Nature, 593(7857), 74–82, https://www.nature.com/articles/s41586-021-03302-y

Physics-Informed Machine Learning
The accelerating pace of observational data from experiments far outpaces our ability to understand it. Despite the promise and some preliminary success, most machine learning approaches are unable to extract interpretable information and knowledge from this data deluge. Moreover, purely data-driven models may fit observations, but predictions may be physically inconsistent or implausible. A research team led by PNNL and Brown University, funded by ASCR, are leading a new and rapidly expanding branch of ML, called physics-informed ML, which takes well-known ML algorithms and modifies them to enforce physical laws. Physics-informed ML seamlessly integrates data and mathematical physics models, even in partially understood, uncertain and complex large-scale problems. This may lead to specialized network architectures that have many advantages: noisy data can be integrated where it couldn't be integrated before; the amount of data required to train a model is greatly reduced; the need for expensive mesh generation can be eliminated; hidden physics can be exposed; and high-dimensional problems can be made tractable. Physics-informed ML is being used to: enhance the resolution of 4-D flow MRI assessments of blood flow and vascular function; predict turbulent transport on the edge of magnetic confinement fusion devices; and study transitions between metastable states in complex systems as well as potential applications in quantum chemistry. Their work was published in Nature Reviews in May 2021.

Transferring Technology to Broaden the Impact of Research Investments
An ASCR-supported team at ORNL and Georgia Tech is working with General Motors (GM) to leverage their R&D 100 award-winning AI software system, Multinode Evolutionary Neural Networks for Deep Learning (MENNDL), to improve the performance of autonomous vehicles. GM licensed MENNDL for use in vehicle technology and design. MENNDL uses an evolutionary approach that leverages high performance computers to explore the different design parameters available for an AI network. Market experts anticipate that the autonomous vehicles market size will be $60 billion U.S. dollars by 2030. However, testing of autonomous vehicles remains limited, and simulations remain in their infancy. For automakers like GM, MENNDL can be used to accelerate advanced driver assistance technology by tackling one of the biggest questions facing the adoption of this technology: How can cars quickly and accurately perceive their surroundings to navigate safely through them?

Building a Quantum Infrastructure
Throughout 2021, ASCR continued to build DOE's quantum research and development infrastructure. ASCR's quantum computing testbeds expanded their user base to provide more communities with fully transparent access to novel quantum computing hardware, enabling foundational research to explore high-risk, high-reward approaches. The Quantum Scientific Computing Open User Testbed (QSCOUT), the only open quantum computing testbed in the world based on trapped ions, was recognized with an R&D 100 Award. The National Quantum Information Science Research Centers, Office of Science's flagship investment in quantum information science, expanded their partnerships to include the expertise and resources of 71 institutions, including EPSCOR and Minority Serving Institutions and small businesses, to push the envelope in quantum R&D, to create and steward the ecosystem needed to drive economic competitiveness, and to foster the growth of the Nation's quantum workforce. In addition, researchers at Brookhaven National Laboratory and Stony Brook University have established the most advanced regional quantum network in the U.S. to demonstrate a quantum connection between two remote atomic clouds separated by 97 miles, which was the longest experiment of its type in the world.

Launching the Exascale Era
The Department achieved a major milestone in 2021 by deploying the Nation's first exascale computing system, Frontier, at Oak Ridge National Laboratory. This system also delivered on the Department's stretch goal of 20MW per exaflop—reducing energy utilization (watts per flop) by a factor of 3.42 over the pre-exascale systems. The facility also shared a systemic analysis of detailed energy utilization data from Summit, the pre-exascale system, through a paper at the Supercomputing 21 conference that was recognized as "Best Paper" at this seminal international workshop. The facility is currently working with more than thirty science and engineering applications, supported by the Exascale Computing Initiative, that are getting ready for, and eager to gain access to, this unique resource. These include mission critical areas such as climate, clean energy, subsurface science, advanced materials, and an array of big data and "AI at scale" capabilities.

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 coupled with Artificial Intelligence and Machine Learning (AI/ML) are central to progress at the frontiers of science and to our most challenging engineering problems, particularly in climate science. 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 intelligent 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. New ASCR partnerships through the Funding for Accelerated, Inclusive Research (FAIR) and Reaching a New Energy Sciences Workforce (RENEW) programs will further broaden and diversify the applied mathematics and computer science research communities. 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. With the completion of ECP, research efforts will need to transition critical elements of the exascale software ecosystem to support sustainability and fund continued development of co-design activities. 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 critical elements of the exascale software ecosystem and new paradigms of compute-intensive and data-intensive applications, AI and scientific machine learning, and scientific workflows 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 broadly 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.

<u>Applied Mathematics Research</u>

The Applied Mathematics activity supports basic research leading to fundamental mathematical advances and computational breakthroughs across DOE and SC missions. Basic research in scalable algorithms and libraries, multiscale and 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 and protect the privacy of sensitive datasets. In addition, this activity will support partnerships between mathematicians and computer scientists to develop energy efficient algorithms and methods that scale from intelligent sensors to HPC to support decarbonizing industry.

Computer Science 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 HPC and networking systems in the country as well as the tools and data infrastructure to enable the real-time exploration and understanding of extreme scale and complex data from both simulations and experiments. Through the continued development of adaptive software tools, it aims to make high performance scientific computers and networks even more productive and efficient to solve scientific challenges while attempting to reduce domain science application complexity as much as possible. ASCR Computer Science research also 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 use 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 partnership with the other SC programs and their scientific user facilities, the Computer Science activity supports research that addresses the need to seamlessly and intelligently integrate simulation, data analysis, and other tasks into comprehensive workflows. These workflows will gather data from the edge of experiments and connect simulation and AI at HPCs to support 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. In addition, this activity supports partnerships between mathematicians and computer scientists to develop energy efficient algorithms and methods that scale from intelligent sensors to HPC to support decarbonizing industry.

Computational Partnerships

The Computational Partnerships activity 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, including Biopreparedness Research Virtual Environment (BRaVE), allowing distributed networks of scientists to work together on multidisciplinary research priorities and/or national emergency challenges.

The Computational Partnerships activity also supports collaborations in the areas of data analysis, and future computing. Collaborative and data analysis projects enable large, distributed research teams to share data and develop tools incorporating AI/ML 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 advanced computing data infrastructure and computing environment. In addition, interdisciplinary teams enable development of new algorithms and software stack targeted for future computing platforms, including QIS, as well as partnerships with Basic Energy Sciences (BES) to understand extreme materials and chemistries for energy and with both BES and Biological and Environmental Research (BER) to advance research in clean water technologies through the use of AI and HPC. The activity also supports the FAIR initiative and the Accelerate Initiative which will provide focused investment on enhancing research on clean energy, climate, and related topics at minority serving institutions, including attention to underserved and environmental justice regions.

Advanced Computing Research

This activity supports research focused on development of emerging computing technologies such as QIS and neuromorphic efforts as well as investments in microelectronics in partnership with the other SC program offices, Research and Evaluation Prototypes (REP), and ASCR-specific investments in cybersecurity and workforce including the Computational Sciences Graduate Fellowship (CSGF) and the SC-wide 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 (NQISRCs), as well as quantum computing testbeds and building a quantum internet to connect the NQISRCs 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 other MSIs, typically individuals from groups historically underrepresented in STEM, as well as students from communities disproportionally affected by social, economic, and health burdens of the energy system, 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 computing, AI, and capabilities beyond Moore's Law such as QIS.

<u>Energy Earthshot Research Centers</u>

The Department of Energy's Energy Earthshots will accelerate breakthroughs of more abundant, affordable, and reliable clean energy solutions within the decade to address the climate crisis. The Energy Earthshots are designed to drive integrated program development across DOE's science, applied technology offices, and ARPA-E, and take an 'all R&D community' approach to leading science and technology innovations to address tough technological challenges and cost hurdles, and rapidly advance solutions to help achieve our climate and economic competitiveness goals. From a science perspective, many research gaps for the Energy Earthshots cut across many topics and will provide a foundation for other energy technology challenges, including biotechnology, critical minerals/materials, energy-water, subsurface science (including geothermal research), and materials and chemical processes under extreme conditions for nuclear applications. These gaps require multiscale computational and modeling tools, new AI and ML—technologies, real-time characterization—including in extreme environments—and development of the scientific base to co-design processes and systems rather than individual materials, chemistries, and components.

Toward that end, ASCR will contribute to the establishment of Energy Earthshot Research Centers (EERCs), a new modality of research to be launched in FY 2023, building on the success of SC's Energy Frontier Research Centers (EFRCs) and the SciDAC program. The EERCs will bring together multi-investigator, multi-disciplinary teams to perform energy-relevant research with a scope and complexity beyond what is possible in standard single-investigator or small-group awards. Beyond complementing and expanding the scope of the EFRCs and SciDAC, the EERCs will address the research challenges at the interface between currently supported basic research, applied research, and development activities, with support from both SC and the applied technology offices. EERCs will entail co-funding of team awards involving academic, national laboratories, and industrial researchers, establishing a new era of cross-office research cooperation. The funding will focus efforts directly at the interfaces of current research efforts, ensuring that directed fundamental research and capabilities at SC user facilities tackle the most challenging barriers identified in the applied research and demonstration activities to bridge the R&D gaps and realize the stretch goals of the Energy Earthshots.

In FY 2023, the Request supports a joint Funding Opportunity Announcement (FOA) to be released by three program offices in the Office of Science Basic Energy Science (BES), ASCR, and Biological and Environmental Research (BER), and DOE applied technology offices for the initial cohort of EERCs. Emphasis will be on the current Energy Earthshots topics and those announced by DOE prior to release of the FOA.

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Mathematical, Computational, and Computer Sciences Research	**+$259,865**	**+$378,723**	**+$118,858**
Applied Mathematics Research	$48,570	$71,938	+$23,368
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. The Request also supports the basic research needs for the EERCs and the transition of critical Applied Math efforts from the ECP into core research areas.	Funding will increase to support core research efforts, foundational AI/ML research, and transitioning ECP efforts back into core research areas. Also, funding will support basic research in support of specific applied math challenges in the EERCs. In addition, increases will support partnerships between mathematicians and computer scientists to develop energy efficient algorithms and methods and continued investments in physics-informed, multiscale algorithms that are critical for BER's Integrative Artificial Intelligence Framework for Earth System Predictability.

(dollars in thousands)

FY 2021 Enacted	FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Computer Science Research $46,827	$70,326	+$23,499
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 QIS. The Request will support basic research needs of the EERCs, and transition of critical software efforts from the ECP into core research areas.	Funding will increase to support core research investments; directed basic research in support of specific computer science challenges in the EERCs, emerging technology efforts, including AI, to enable an integrated computational and data infrastructure; and transitioning critical elements of the exascale software ecosystem into core research areas. In addition, funding will support partnerships between mathematicians and computer scientists to develop energy efficient scalable algorithms and methods.

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Computational Partnerships	$76,194	$97,861	+$21,667
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, QIS, and Advanced Computing will continue. The partnership with NIH will continue to leverage DOE infrastructure to ensure that data is widely available for SC's AI development efforts. Efforts focused on enabling widespread use of DOE HPC resources by Federal agencies in support of emergency preparedness and response will increase. 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. 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. Also, the Request will support the FAIR initiative and the transition of mission critical Exascale Computing Project applications, such as the on-going partnership with the National Cancer Institute and co-design activities, into Computational Partnerships.	The increase will support SciDAC contributions to Accelerate and FAIR as well as new SciDAC partnerships with DOE's Applied Energy programs and other agencies to improve response to national emergencies.

(dollars in thousands)

FY 2021 Enacted	FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Advanced Computing Research $88,274	$113,598	+$25,324
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 NQISRCs, quantum computing testbed efforts, and regional quantum internet testbeds. The Request allows REP to continue strategic investments in emerging technologies, microelectronics, and development of a plan to sustain the software developed under ECP. Small investments in cyber security will continue. The Request will sustain increased 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 computational science, AI at scale, and beyond Moore's Law capabilities such as QIS. The Request will increase support for 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 maintaining and sustaining critical ECP software for use on emerging technology testbeds as well as increasing investments in quantum internet and RENEW.

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Energy Earthshot Research Centers	$ —	$25,000	+$25,000
No funding in FY 2021.		The Request supports a joint Funding Opportunity Announcement (FOA) to be released by the Office of Science (BES, ASCR, and BER) and the DOE Applied Technology Offices for the initial cohort of EERCs. Emphasis will be on the current Earthshot topics and those announced by the Department prior to release of the FOA.	Funding will establish EERCs as a collaboration between SC programs and the Applied Technology programs to bridge the R&D gaps and realize the stretch goals of the Energy Earthshots initiative.

Note:

- *Funding for the subprogram above, includes 3.65 percent 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 (HPC) and Network Facilities subprogram supports the operations of forefront computational and networking user facilities to meet critical mission needs. ASCR operates three HPC user facilities: the National Energy Research Scientific Computing Center (NERSC) at Lawrence Berkeley National Laboratory (LBNL), which provides HPC 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 HPC 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.

The HPC and Network Facilities subprogram regularly gathers strategic user requirements from stakeholders across SC and DOE, including the other SC research programs, SC scientific user facilities, DOE national laboratories, and other stakeholders. ASCR gathers these user requirements through formal processes, including workshops and technical reviews, to inform planning for upgrade projects, development of services, and implementation of user programs. The insights ASCR gains from these user requirements activities are also vital to a broad spectrum of ASCR and SC strategic efforts. Examples of this insight include identification of emerging research directions, emerging trends in usage of computing and data resources, and industry innovations in computing architectures and technologies. ASCR continues to observe an accelerating pace of innovation in computing technology, through and beyond the exascale era.

Allocation of ASCR HPC 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) allocation program provides access to the LCFs; the ASCR Leadership Computing Challenge (ALCC) allocation program provides a path for critical DOE mission applications to access LCFs and NERSC, and a mechanism to address urgent national emergencies and priorities.

The core strength of the ASCR facilities is the dedicated staff who work to maximize user productivity and science impact, operate and maintain world-leading computing and networking resources, while simultaneously executing major upgrade projects. None of the ASCR facilities have suffered significant operational impacts during the COVID-19 pandemic.

ASCR HPC facilities received CARES Act funding in FY 2020 to support COVID-19 research teams through the COVID-19 HPC Consortium, a partnership between industry, national and international federal agencies, national laboratories, and academia. DOE deployed customized computing hardware to each HPC facility to better address specific COVID-19 research needs; dozens of research projects used millions of hours of compute time to provide new insights about the virus, variants, the disease, and the pandemic, including: how the virus infects cells, exploration of treatment options, understanding mutations, 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. Eventually, this hardware will be integrated into the facilities' user programs, providing additional HPC resources available for peer-reviewed, competitive research with emphasis on biological and medical research.

<u>High Performance Production Computing</u>

This activity supports the NERSC user facility at LBNL to deliver high-end production computing resources and data 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 half 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 spans a wide range of HPC experience, from world leading experts to students. 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 ASCR'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 came 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 addition, the diversity of data- and compute-intensive research workflows is expanding rapidly. The FY 2023 Request, will continue planning for two projects intended together to provide SC with increased computing capacity and capability to meet user requirements in the second half of this decade. ASCR will continue preparations for a NERSC-10 upgrade project that is intended to provide SC with an innovative, flexible HPC platform to serve an even greater diversity of NERSC users. ASCR will also continue planning efforts for a new High Performance Data Facility (HPDF), a high performance computing and data management facility designed from the ground up to satisfy the unique requirements of state-of-the-art real-time experimental/observational workflows. The NERSC-10 and HPDF projects will each drive unique technological innovation in system architectures and services beyond what is available in the commercial cloud. As real-time user demand for HPC resources grows, ASCR foresees the strategic need for operational resilience through geographic diversity of its HPC resources. In addition, some workflows may have latency requirements that necessitate geographic proximity to HPC resources. NERSC-10 and HPDF will complement each other in this regard.

Leadership Computing Facilities

The LCFs are national resources built to enable open scientific computational applications, including industry applications, that harness the full potential of extreme-scale leadership computing to accelerate discovery and innovation. The success of this effort is built on the gains made in the Exascale Computing Project (ECP), Research and Evaluation Prototypes (REP) and ASCR research efforts. The LCFs' experienced staff provides support to INCITE and ALCC projects, scaling tests, early science applications, and tool and library developers; their efforts are also critical to the success of industry partnerships.

The OLCF at ORNL currently operates and competitively allocates the Nation's first exascale computing system, an HPE-Cray/AMD exascale system (Frontier), deployed in calendar year 2021; the 200 pf IBM/NVIDIA OLCF-4 system (Summit); and other testbeds and supporting resources. Recent scientific highlights from Summit include: AI-driven multiscale simulations that illuminate the disease mechanisms of SARS-CoV-2 including the mechanisms linked to the inflammatory response in some patients; the rapid screening of drug candidates and the development of therapeutics for COVID; training deep neural networks to understand glass-like quantum materials with potential applications in electronic devices, quantum computers, and superconductors; simulating the Earth's atmosphere for a full season at 1-square-kilometer grid-spacing to improve weather forecasting and climate predictions; first-of-their-kind 3D flow simulations of gas turbine jet engines that are providing breakthrough insights quickly and accurately to influence the design process for improved fuel efficiency and more durable jet engines; bridging classical Molecular Dynamics and AI to produce complex simulations that are both large and accurate—simulating for the first time more than 100 million atoms, with ab initio accuracy, a thousand times faster than ever before. 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 to accelerate the development of high-technology products. These efforts often result in upgrades to in-house computing resources at U.S. companies.

The Argonne Leadership Computing Facility (ALCF) at ANL operates the 8.5 pf Intel/Cray ALCF-2 system (Theta) and HPC testbeds, such as the Polaris (A-19) system, to prepare their users and SC-ECP applications and software technology for the ALCF-3 upgrade, to be known as Aurora. Aurora, the Nation's second exascale system, will be 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. Recent scientific highlights from the ALCF include: developing CityCOVID, an agent-based model capable of capturing the dynamics of heterogeneous, interacting, adaptive agents at a granular level of detail to track COVID-19 transmission and to simulate a variety of interventions and future scenarios; training a deep neural network to find more energy-efficient separation processes to reduce the energy footprint of the chemical industries; the largest ever collection of 3D investigations of the physics of core-collapse supernovae to better understand the origin of the elements in the universe, measure gravitational waves, and interpret laboratory nuclear reaction rate measurements in light of stellar nucleosynthesis; large-scale molecular dynamics simulations that help to elucidate the mechanisms of helium transport and tungsten surface deformation that may degrade material stability on the primary plasma-facing divertor material in ITER; one of the largest cosmological structure formation simulations ever performed to help with planning and analysis of current and upcoming sky surveys; and developing a novel method to provide high-quality 3D reconstructions of heavily scattering samples to enable software reconstructions beyond-depth-of-focus on the APS Upgrade (APS-U) facility. Through INCITE, ALCF also enables industrial applications, for example, by helping scientists and engineers to optimize manufacturing of non-woven materials, such as those used in protective masks, to reduce energy requirements without impacting performance. 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. The LCFs have begun planning for upgrades that would expand the capacity and capabilities of these unique National resources to keep pace with demand and foreign investments.

High Performance Network Facilities and Testbeds

This activity supports the Energy Sciences Network (ESnet), SC's high performance network user facility. ESnet is recognized as a global leader in the research and education network community, with a multi-decade track record of developing innovative network architectures and services, and reliable operations designed for 99.9 percent uptime for connected sites.

ESnet is the circulatory system that enables the DOE science mission. ESnet delivers highly reliable data transport capabilities optimized for the requirements of large-scale science. 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. The number of connected sites has also expanded significantly in recent years and continues to grow. 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 currently executing a complete upgrade of its backbone network, the ESnet-6 upgrade project, which commenced construction in FY 2020 and is anticipated to complete construction in FY 2022. In FY 2021, the ESnet-6 project achieved a mid-project milestone of acceptance and commissioning of the coast-to-coast ESnet6 optical infrastructure, culminating in the successful phased migration of all current ESnet traffic onto this new, advanced optical backbone.

In addition, ESnet operates a network R&D Testbed user program, which is linked to the National Science Foundation's FABRIC mid-scale instrumentation project, providing the nation's academic research community a unique terabit-scale research platform for next generation internet research.

Advanced Scientific Computing Research
High Performance Computing and Network Facilities

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request		Explanation of Changes FY 2023 Request vs FY 2021 Enacted	
High Performance Computing and Network Facilities	**$586,190**		**$613,018**		**+$26,828**
High Performance Production Computing	$113,786		$115,033		+$1,247
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 user facility, including user support, power, space, system leases, and staff. The Request will also support decommissioning of the Cori system; site preparations, design and long-lead procurements for the NERSC-10 upgrade; and full operations and allocation of Perlmutter. In addition, funding will also support continued design of the High Performance Data Facility.		Funding will support site preparations, design and long-lead procurement for the NERSC-10 upgrade and continued planning for the High Performance Data Facility.	
National Energy Research Scientific Computing Center (NERSC)	$113,786		*$115,033*		*+$1,247*
Funding will support operations at the NERSC facility, including user support, power, space, system leases, and staff.		The Request will support operations at the NERSC user facility, including user support, power, space, system leases, and staff. The Request will also support decommissioning of the Cori system, site preparations, design and long-lead procurements for the NERSC-10 upgrade, and full operations and allocation of Perlmutter. In addition, funding will also support continued design of the High Performance Data Facility.		Funding will support site preparations, design and long-lead procurement for the NERSC-10 upgrade and continued planning for the High Performance Data Facility.	

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Leadership Computing Facilities	$381,075	$407,772	+$26,697
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 operations and allocation of exascale systems at OLCF and ALCF.	Funding will support increased power, system leases, maintenance, and space costs at both OLCF and ALCF to support operation of the exascale systems.
Leadership Computing Facility at ANL	*$152,955*	*$160,165*	*+$7,210*
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 and Polaris systems. The ALCF will complete acceptance of the ALCF-3 exascale system, Aurora, which will be deployed in calendar year 2022 and will provide access for early science applications and the Exascale Computing Project. Competitive allocation of Aurora will begin through ALCC for some exascale ready teams.	Increase will support increased power, system leases, maintenance, and space costs at ALCF to support operation of the Aurora exascale system.
Leadership Computing Facility at ORNL	*$228,120*	*$247,607*	*+$19,487*
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 support operations at the OLCF facility, including user support, power, space, system leases, maintenance, and staff. The Request will also support full operation and competitive allocation of the Frontier exascale system, Summit, and other testbeds.	Funding will support increased power, system leases, maintenance, and space costs at OLCF to support operation of the Frontier exascale system.

(dollars in thousands)

FY 2021 Enacted	FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
High Performance Network Facilities and Testbeds $91,329	$90,213	-$1,116
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 project to build the next generation network with new equipment, increased capacity, and an advanced programmable network architecture, in accordance with the project baseline.	Funding will support the ESnet-6 upgrade project in accordance with the project baseline; the pace of capacity growth under core operations will be slowed.

Note:
- *Funding for the subprogram above, includes 3.65 percent 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 2023 Request includes $77,000,000 for the SC-ECP. These funds will provide for the demonstration of the exascale ecosystem through the execution of the applications and software on the exascale systems and completion of Key Performance Parameters 1-3. Deployment and acceptance of exascale systems in calendar years 2021–2023 will be at 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 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Construction	**$168,945**	**$77,000**	**-$91,945**
17-SC-20, SC Exascale Computing Project	$168,945	$77,000	-$91,945
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 and final execution of applications and software technology to meet the specified Key Performance Parameters that will demonstrate the development of an exascale ecosystem, which is the target of the project.	FY 2023 will be the final year of funding for the ECP applications teams. The funding will decrease to reflect the shift in focus within the project on execution of applications' challenge problems to meet the Key Performance Parameters on the exascale systems delivered in 2021 and 2022.

Advanced Scientific Computing Research
Capital Summary

(dollars in thousands)

	Total	Prior Years	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Capital Operating Expenses						
Capital Equipment	N/A	N/A	31,809	16,809	5,000	-26,809
Total, Capital Operating Expenses	**N/A**	**N/A**	**31,809**	**16,809**	**5,000**	**-26,809**

Capital Equipment

(dollars in thousands)

	Total	Prior Years	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Capital Equipment						
Total, Non-MIE Capital Equipment	N/A	N/A	31,809	16,809	5,000	-26,809
Total, Capital Equipment	**N/A**	**N/A**	**31,809**	**16,809**	**5,000**	**-26,809**

Advanced Scientific Computing Research
Funding Summary

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Research	428,810	396,962	455,723	+26,913
Facility Operations	586,190	618,038	613,018	+26,828
Total, Advanced Scientific Computing Research	**1,015,000**	**1,015,000**	**1,068,741**	**+53,741**

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 2021 Enacted	FY 2021 Current	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Scientific User Facilities - Type A					
National Energy Research Scientific Computing Center	**113,786**	**109,707**	**115,963**	**113,030**	**-756**
Number of Users	8,329	8,751	8,500	8,500	+171
Achieved Operating Hours	–	8,465	–	–	–
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%	98.6%	100.0%	100.0%	–
Argonne Leadership Computing Facility	**152,955**	**147,992**	**159,047**	**160,165**	**+7,210**
Number of Users	1,174	1,168	1,300	1,300	+126
Achieved Operating Hours	–	6,990	–	–	–
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%	99.8%	100.0%	100.0%	–
Oak Ridge Leadership Computing Facility	**228,120**	**220,089**	**249,066**	**247,607**	**+19,487**
Number of Users	1,546	1,696	1,500	1,500	-46
Achieved Operating Hours	–	69,988	–	–	–
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%	99.7%	100.0%	100.0%	–

	FY 2021 Enacted	FY 2021 Current	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
	(dollars in thousands)				
Energy Sciences Network	**91,329**	**87,995**	**93,962**	**90,213**	**-1,116**
Number of Users	–	68	–	–	–
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%	–
High Performance Data Facility	**–**	**–**	**–**	**2,003**	**+2,003**
Total, Facilities	**586,190**	**565,783**	**618,038**	**613,018**	**+26,828**
Number of Users	11,049	11,683	11,300	11,300	+251
Achieved Operating Hours	–	94,203	–	–	–
Planned Operating Hours	31,361	31,361	31,361	31,361	–
Optimal Hours	31,361	31,361	31,361	31,361	–

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 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Number of Permanent Ph.Ds (FTEs)	814	825	825	+11
Number of Postdoctoral Associates (FTEs)	349	365	365	+16
Number of Graduate Students (FTEs)	520	535	535	+15
Number of Other Scientific Employment (FTEs)	217	220	220	+3
Total Scientific Employment (FTEs)	**1,900**	**1,945**	**1,945**	**+45**

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 2023 Request for the Office of Science (SC) Exascale Computing Project (SC-ECP) is $63,000,000 of Total Estimated Cost (TEC) funding and $14,000,000 of Other Project Costs (OPC) funding. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-2/3 Approve Performance Baseline. The project achieved CD-2/3 on February 25, 2020. The Total Project Cost (TPC) of the SC portion of ECP is $1,326,206,000 with the total combined SC and National Nuclear Security Administration (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 SC and NNSA and addresses Department of Energy (DOE) science and national security mission requirements.

Other activities included in the ECI but not the SC-ECP include $150,000,000 in FY 2023 to support the final acceptance of the exascale system at the Argonne Leadership Computing Facility (ALCF). Procurement costs of exascale systems, which is not included in the SC-ECP, are 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 2023 Request supports investments in the ECP technical focus areas—application development, software technology and hardware and integration—to support the deployment of a capable exascale software ecosystem and execution of applications' challenge problems on the exascale systems delivered in calendar year 2021 and 2022 to meet the project's Key Performance Parameters (KPPs). The funding decrease reflects the completion, in FY 2022, of the majority of the scaling necessary to move execution of the software from the smaller test and development systems to the exascale systems.

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	2/25/20	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
FY 2023	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	2/25/20
FY 2022	2/25/20	1/3/17	2/25/20
FY 2023	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, Total	TPC
FY 2017	—	—	—	311,894	311,894	311,894
FY 2018	—	390,000	390,000	763,524	763,524	1,153,524
FY 2019	—	426,735	426,735	807,230	807,230	1,233,965
FY 2020	—	426,735	426,735	829,650	829,650	1,256,385
FY 2021	—	507,680	507,680	818,526	818,526	1,326,206
FY 2022	—	700,843	700,843	625,363	625,363	1,326,206
FY 2023	—	700,843	700,843	625,363	625,363	1,326,206

Note:

- *FY 2017 funding included in the above table does not include an estimate for TEC and should be considered TBD.*

2. Project Scope and Justification

Scope

Four well-known challenges[u] 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.

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 2021-2022 calendar year timeframe under the ECI.

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

Justification
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.

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

Performance Measure	Threshold	Objective
Exascale performance improvements for mission-critical challenge problems	50 percent of selected applications achieve Figure of Merit improvement greater than or equal to 50x	100 percent of selected applications achieve their KPP-1 stretch goal
Broaden exascale science and mission capability	50 percent of the selected applications can execute their challenge problem[v]	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

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

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
Construction (TEC)			
FY 2019	187,696	187,696	–
FY 2020	174,735	174,735	105,440
FY 2021	160,412	160,412	157,752
FY 2022	115,000	115,000	226,492
FY 2023	63,000	63,000	194,859
Outyears	–	–	16,300
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	157,752
FY 2022	115,000	115,000	226,492
FY 2023	63,000	63,000	194,859
Outyears	–	–	16,300
Total, TEC	**700,843**	**700,843**	**700,843**

(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	9,815
FY 2022	14,000	14,000	9,009
FY 2023	14,000	14,000	17,733
Outyears	14,000	14,000	14,701
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	167,567
FY 2022	129,000	129,000	235,501
FY 2023	77,000	77,000	212,592
Outyears	14,000	14,000	31,001
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)	347,349	347,289	346,360
Production Ready Software	228,356	228,472	217,290
Hardware Partnership	125,138	125,082	131,726
Total, Other (TEC)	**700,843**	**700,843**	**695,376**
Total, TEC	**700,843**	**700,843**	**695,376**
Contingency, TEC	***N/A***	***N/A***	***N/A***
Other Project Cost (OPC)			
Planning Project Management	89,689	89,688	89,688
Application Development (OPC)	221,050	221,050	221,050
Software Research	118,517	118,517	118,517
Hardware Research	196,107	196,108	201,575
Total, Except D&D (OPC)	**625,363**	**625,363**	**630,830**
Total, OPC	**625,363**	**625,363**	**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)

Fiscal Year	Type	Prior Years	FY 2021	FY 2022	FY 2023	Outyears	Total
FY 2017	OPC	311,894	—	—	—	—	311,894
	TPC	311,894	—	—	—	—	311,894
FY 2018	TEC	—	—	—	—	390,000	390,000
	OPC	518,524	—	—	—	245,000	763,524
	TPC	518,524	—	—	—	635,000	1,153,524
FY 2019	TEC	—	—	—	—	426,735	426,735
	OPC	751,230	—	—	—	56,000	807,230
	TPC	751,230	—	—	—	482,735	1,233,965
FY 2020	TEC	174,735	—	—	—	252,000	426,735
	OPC	773,650	—	—	—	56,000	829,650
	TPC	948,385	—	—	—	308,000	1,256,385
FY 2021	TEC	174,735	154,945	—	—	178,000	507,680
	OPC	762,526	14,000	—	—	42,000	818,526
	TPC	937,261	168,945	—	—	220,000	1,326,206
FY 2022	TEC	362,431	160,412	115,000	—	63,000	700,843
	OPC	574,830	8,533	14,000	—	28,000	625,363
	TPC	937,261	168,945	129,000	—	91,000	1,326,206
FY 2023	TEC	362,431	160,412	115,000	63,000	—	700,843
	OPC	574,830	8,533	14,000	14,000	14,000	625,363
	TPC	937,261	168,945	129,000	77,000	14,000	1,326,206

Note:
- FY 2017 funding included in the above table does not include estimate for TEC and should be considered TBD.

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 2023 Budget Request, $150,000,000 is included in the ALCF to complete final acceptance for the system delivered in FY 2022. 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.

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 clean energy technologies, to mitigate the climate and 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 Basic Energy Sciences Advisory Committee (BESAC) report, "A Remarkable Return on Investment in Fundamental Research,"[w] provides key examples of major technological, commercial, and national security impacts, including clean energy technologies, 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—to answer some of the most challenging science questions and to provide insights on the scientific basis for energy technologies. 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 clean energy innovations and economic prosperity.

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

Highlights of the FY 2023 Request

The BES FY 2023 Request of $2,420.4 million is an increase of $175.4 million, or 7.8 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.

Key elements in the FY 2023 Request are summarized below.

<u>Research</u>

The Request supports for a new research modality of Energy Earthshot Research Centers, which will work toward the stretch goals of the DOE Energy Earthshots and will provide a solid bridge between SC and the DOE energy technology offices. The Request continues funding for the Energy Frontier Research Centers (EFRCs), supports the Batteries and Energy Storage Energy Innovation Hub recompetition, and continues the Fuels from Sunlight Hub awards and the National Quantum Information Science (QIS) Research Centers (NQISRCs). In part through increased funding for the Established Program to Stimulate Competitive Research (EPSCoR), the Reaching a New Energy Sciences Workforce (RENEW) initiative, and the new Funding for Accelerated, Inclusive Research (FAIR) initiative, BES will build stronger programs with underrepresented institutions and regions, including investing in a more diverse and inclusive workforce in order to address environmental justice issues.

Core research priorities in the FY 2023 Request include:

- Clean Energy: BES will continue to support clean energy research that leads to reduced impacts from climate change. The United States and the world face profound challenges due to climate change with a narrow window of opportunity to pursue action to avoid the most catastrophic impacts. As part of the Department's efforts to prioritize R&D investments that advance understanding of climate change and the development of mitigation and adaptation solutions, BES will increase research to provide understanding and foundations for clean energy, with investments across the entire portfolio to accelerate innovation to reduce impacts resulting from climate change while advancing clean energy technologies and infrastructure. A few examples:
  - Direct air capture of carbon dioxide: Designing high-selectivity, high-capacity, and high-throughput chemical separations and materials;
  - Hydrogen, Solar: Foundational science to enable carbon-neutral processes for the production, storage, and use of hydrogen in energy and industrial applications; 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.
- SC Energy Earthshots Initiative: In addition to core clean energy research, this initiative includes support for Energy Earthshot Research Centers (EERCs), a new research modality. Engaging both SC and the energy technology offices, EERCs will address key research challenges at the interface between currently supported basic research and applied research and development activities, to bridge the R&D gap. These challenges are vital to realizing the stretch goals of the DOE Energy Earthshots.
- Critical Materials/Minerals: Critical materials and 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 and energy storage. 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: BES increases investments in fundamental science underpinning advanced manufacturing, partnering across SC, with thrusts in circular, clean, low-carbon, and scalable synthesis and processing; transformational operando characterization; multiscale models and tools; and co-design of materials, processes, and products for functionality and use. Research continues on transformative chemistry, materials, and biology for next-generation industries and next-generation tools for elucidating relevant mechanisms for these processes.

- Microelectronics: Also related to Advanced Manufacturing, BES continues its investment in microelectronics with a focus on materials, chemistry, and fundamental device science. BES partners with SC programs to continue support for 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 increases 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 Initiative (ECI): 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.
- Advanced Computing: Partnering with ASCR, BES invests in cost-effective computational, networking, and storage capabilities to transform the national laboratories into an integrated open innovation ecosystem of capabilities, facilities, instruments, and expertise connected via advanced networks and enabling software.
- 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 continue developing and expanding capabilities at user facilities for responsiveness to biological threats and development of advanced instrumentation and expertise to address these research challenges.
- Quantum Information Science (QIS): In support of the National Quantum Initiative, NQISRCs 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. Continued 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): BES increases support for 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.
- Funding for Accelerated, Inclusive Research (FAIR): The FAIR initiative will provide focused investment on enhancing research on clean energy, climate, and related topics at minority serving institutions, including attention to underserved and environmental justice regions. The activities will improve the capability of MSIs to perform and propose competitive research and will build beneficial relationships between MSIs and DOE national laboratories and facilities.
- Accelerate Innovation in Emerging Technologies: The Accelerate initiative will support scientific research to accelerate the transition of science advances to energy technologies. The goal is to drive scientific discovery to sustainable production of new technologies across the innovation continuum, to provide experiences in working across this continuum for the workforce needed for industries of the future, and to meet the nation's needs for abundant clean energy, a sustainable environment, and national security.

<u>Facility Operations</u>

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 90 percent of optimum, the funding level required for normal operations based on a 2018 baseline. Both BES-supported neutron sources, the Spallation Neutron Source (SNS) and the High Flux Isotope Reactor (HFIR), will be operational in FY 2023 and funded at approximately 90 percent of optimum. The Request provides funding for the five Nanoscale Science Research Centers (NSRCs) at approximately 90 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 High Energy (LCLS-II-HE), Proton Power Upgrade (PPU), Second Target Station (STS), and Cryomodule Repair and Maintenance Facility (CRMF) projects. The FY 2023 Request also continues two Major Item of Equipment projects: NSLS-II Experimental Tools-II (NEXT-II) and NSRC Recapitalization. Finally, the Request provides Other Project Costs (OPC) to begin planning for the NSLS-II Experimental Tools-III (NEXT-III) and High Flux Isotope Reactor Pressure Vessel Replacement (HFIR-PVR) projects.

Basic Energy Sciences
FY 2023 Research Initiatives

Basic Energy Sciences supports the following FY 2023 Research Initiatives.

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Accelerate Innovations in Emerging Technologies	–	–	15,000	+15,000
Accelerator Science and Technology Initiative	5,000	5,000	12,000	+7,000
Advanced Computing	–	–	10,000	+10,000
Artificial Intelligence and Machine Learning	20,000	20,000	29,000	+9,000
Biopreparedness Research Virtual Environment (BRaVE)	–	–	21,500	+21,500
Critical Materials/Minerals	17,000	17,000	25,000	+8,000
Exascale Computing	26,000	26,000	26,000	–
Fundamental Science to Transform Advanced Manufacturing	–	–	20,000	+20,000
Funding for Accelerated, Inclusive Research (FAIR)	–	–	20,000	+20,000
Microelectronics	15,000	15,000	30,000	+15,000
Quantum Information Science	92,050	92,050	102,000	+9,950
Reaching a New Energy Sciences Workforce (RENEW)	–	–	10,000	+10,000
Revolutionizing Polymers Upcycling	8,250	8,250	8,250	–
SC Energy Earthshots	–	–	104,250	+104,250
Total, Research Initiatives	**183,300**	**183,300**	**433,000**	**+249,700**

Basic Energy Sciences
Funding

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Basic Energy Sciences				
Scattering and Instrumentation Sciences Research	74,031	78,191	101,963	+27,932
Condensed Matter and Materials Physics Research	170,200	176,864	202,538	+32,338
Materials Discovery, Design, and Synthesis Research	71,189	74,644	98,958	+27,769
Established Program To Stimulate Competitive Research EPSCoR	25,000	25,000	35,000	+10,000
Energy Frontier Research Centers - Materials	57,500	57,500	64,678	+7,178
Energy Earthshot Research Centers - Materials	–	–	25,000	+25,000
Materials Sciences and Engineering - Energy Innovation Hubs	24,088	24,088	25,000	+912
Computational Materials Sciences	13,000	13,000	13,492	+492
Total, Materials Sciences and Engineering	**435,008**	**449,287**	**566,629**	**+131,621**
Fundamental Interactions Research	107,904	112,033	122,939	+15,035
Chemical Transformations Research	112,292	117,752	136,919	+24,627
Photochemistry and Biochemistry Research	82,589	84,321	132,925	+50,336
Energy Frontier Research Centers - Chemical	57,500	57,500	64,678	+7,178
Energy Earthshot Research Centers - Chemical	–	–	25,000	+25,000
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
Total, Chemical Sciences, Geosciences, and Biosciences	**394,285**	**405,606**	**517,711**	**+123,426**

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
X-Ray Light Sources	525,000	552,900	509,425	-15,575
High-Flux Neutron Sources	292,000	295,000	280,754	-11,246
Nanoscale Science Research Centers	139,000	152,500	134,754	-4,246
Other Project Costs	19,000	14,300	17,500	-1,500
Major Items of Equipment	10,500	30,000	50,000	+39,500
Scientific User Facilities, Research	41,207	41,207	50,466	+9,259
Total, Scientific User Facilities (SUF)	**1,026,707**	**1,085,907**	**1,042,899**	**+16,192**
Subtotal, Basic Energy Sciences	**1,856,000**	**1,940,800**	**2,127,239**	**+271,239**
Construction				
21-SC-10, Cryomodule Repair & Maintenance Facility, (CRMF), SLAC	1,000	1,000	10,000	+9,000
19-SC-14, Second Target Station (STS), ORNL	29,000	32,000	32,000	+3,000
18-SC-10, Advanced Photon Source Upgrade (APS-U), ANL	160,000	101,000	9,200	-150,800
18-SC-11, Spallation Neutron Source Proton Power Upgrade (PPU), ORNL	52,000	17,000	17,000	-35,000
18-SC-12, Advanced Light Source Upgrade (ALS-U), LBNL	62,000	75,100	135,000	+73,000
18-SC-13, Linac Coherent Light Source-II-High Energy (LCLS-II-HE), SLAC	52,000	50,000	90,000	+38,000
13-SC-10 - Linac Coherent Light Source-II (LCLS-II), SLAC	33,000	28,100	–	-33,000
Subtotal, Construction	**389,000**	**304,200**	**293,200**	**-95,800**
Total, Basic Energy Sciences	**2,245,000**	**2,245,000**	**2,420,439**	**+175,439**

SBIR/STTR funding:

- FY 2021 Enacted: SBIR $56,592,000 and STTR $7,963,000
- FY 2022 Annualized CR: SBIR $59,161,000 and STTR $8,328,000
- FY 2023 Request: SBIR $63,747,000 and STTR $8,965,000

Basic Energy Sciences
Explanation of Major Changes

	(dollars in thousands) FY 2023 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 of carbon dioxide, energy storage), climate science, critical materials/minerals, exascale (computational materials sciences), data science and AI/ML, advanced computing, advanced manufacturing, microelectronics, BRaVE, QIS, strategic accelerator technology, and RENEW. The Request also includes funding for continued support of the EFRCs, recompetition of the Batteries and Energy Storage Energy Innovation Hub, continuation of the NQISRCs, and the Established Program to Stimulate Competitive Research (EPSCoR). The Request includes funding for the new Energy Earthshot Research Centers and the FAIR and Accelerate initiatives.	**+$131,621**
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), climate science, critical materials/minerals, exascale (computational chemical sciences), data science and AI/ML, advanced computing, advanced manufacturing (including 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 NQISRCs. The Request includes funding for the new Energy Earthshot Research Centers and the FAIR and Accelerate initiatives.	**+$123,426**
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 90 percent of optimum, the funding level required for normal operations based on a 2018 baseline. Both BES-supported neutron sources, the Spallation Neutron Source (SNS) and the High Flux Isotope Reactor (HFIR), will operate at approximately 90 percent of optimum. These facilities will support the BRaVE initiative to maintain capabilities to tackle biological threats. The Request supports all five NSRCs at approximately 90 percent of optimum with funding for continued QIS-related tools development. Research priorities include accelerator science and technology, expansion of instrumentation and expertise for biopreparedness, 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, and provides Other Project Costs (OPC) to begin planning for the NSLS-II Experimental Tools-III (NEXT-III) and High Flux Isotope Reactor Pressure Vessel Replacement (HFIR-PVR) projects.	**+$16,192**

	(dollars in thousands) FY 2023 Request vs FY 2021 Enacted
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 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.	**-$95,800**
Total, Basic Energy Sciences	**+$175,439**

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, as elaborated below. 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 has robust interactions with DOE technology offices through formal and informal coordination activities. Formal coordination includes the Science and Energy Technology Teams (SETTs) that draw on expertise and capabilities stewarded by multiple DOE offices to address forefront energy challenges. For example, BES participates in the Hydrogen SETT, engaging in activities to advance the Hydrogen Energy Earthshot (launched in 2021) aimed at accelerating breakthroughs of more abundant, affordable, and reliable clean energy solutions within the decade.[x] BES also contributes to the Carbon Dioxide Removal SETT and the Carbon Negative Earthshot to address the challenge of long-term removal of carbon dioxide from the atmosphere using a variety of approaches including direct air capture, and the Energy Storage SETT and Long Duration Storage Earthshot to accelerate the development, commercialization, and utilization of next-generation energy storage technologies. BES is also participating in planning for additional Earthshots and crosscutting energy technology areas. In the FY 2023 Request, BES participates in the new SC Energy Earthshots initiative, including the new research modality of Energy Earthshot Research Centers. These Centers will be jointly planned by SC and the DOE energy technology offices, to work toward the stretch goals of the Earthshots by addressing key research challenges at the interface between currently supported basic research and applied research and development activities. Historically, co-siting of research by BES and DOE energy 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 this integration of basic and applied research.

Informal coordination includes participation of BES program managers in regularly scheduled intra-departmental meetings for information exchange and coordination on solicitations, program reviews, and project selections. These interactions cover a broad range of topics including biofuels derived from biomass; solar energy utilization, including solar fuels; 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 energy 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.

Program Accomplishments
Mastering energy efficiency for clean energy processes in electricity, fuels, storage, and carbon capture.
The clean energy future requires efficient processes for energy generation, energy storage, and decarbonization. Recent research has made important steps that can lead to a wide range of efficient technologies.

- Photoinduced charge transfer plays a central role in conversion of light energy into electricity and fuels. Researchers used femtosecond time-resolved X-ray photoemission spectroscopy on an organic system to discover a new mechanism that produces charge carriers from excitations by low-energy photons. This provides new options to efficiently harness light energy for photovoltaic or solar fuels applications.
- Electrochemical processes provide energy-efficient approaches to split water into hydrogen, a carbon-neutral fuel, and oxygen. Platinum group elements—critical elements with limited domestic supply—are commonly used as catalysts to speed up the rate of hydrogen production. Scientists demonstrated that earth-abundant elements can be incorporated in metal–organic frameworks, a porous material, to tune their electrocatalytic properties and yield rates of hydrogen production comparable to those with platinum group elements.
- The stability of interfaces is critical to the performance of many energy storage systems. Cryogenic electron microscopy and cryogenic focused ion beam enabled the characterization of the interface between Li metal and lithium

[x] https://www.energy.gov/eere/fuelcells/hydrogen-shot.

phosphorous oxynitride. The structural and chemical information leads to a robust understanding of the stability of these interfaces and can be extended to study other solid-solid interfaces.

- The ocean contains a lot of carbon dioxide as bicarbonate ions that increases as CO_2 in the air increases. The higher CO_2 concentration in the ocean provides an opportunity for easier CO_2 capture. Scientists recently demonstrated that electrochemical CO_2 capture from ocean water at 70 percent efficiency can be efficiently directly coupled with chemical conversion to CO with 95 percent Faradaic efficiency.

Sustainable, low-carbon, and scalable approaches to transform manufacturing.

The key chemicals and materials of the clean energy future must be produced, synthesized, and extracted by efficient, scalable methods that are sustainable over time in an environmentally sensitive way. Researchers have made significant progress with ammonia production, upcycling of plastics, synthesis science, and extraction of rare earths.

- Nitrogenase enzymes catalyze the conversion of nitrogen and water to ammonia at ambient conditions. In contrast, multistep industrial processes produce ammonia from nitrogen and fossil feedstocks at elevated temperatures and pressures. Researchers coupled the enzyme to an inorganic component that controlled electron transfer, allowing greater insight into the catalytic mechanism. The study demonstrated that hydrogen and ammonia production compete and provided mechanistic insight for development of new catalysts and bio-inorganic hybrids for low-carbon ammonia production.
- Researchers have developed energy-efficient approaches to convert polymers, the primary components of plastics, into valuable products that give a second life to single-use plastics. In one approach, the mechanistic understanding allowed tuning of a dual catalyst to promote low-temperature (under 250^{o}C) conversion of polyethylene to fuels with few byproducts. In another approach, earth-abundant zirconium catalysts coupled with an aluminum reactant allowed conversion of polymers to fatty alcohols that can be used as surfactants.
- Real-time observations and computational modeling of the synthesis of solid-state ceramics yielded a new, simplified model to precisely guide and accelerate this process. Solid-state ceramics are critical for clean energy technologies such as solar cells and batteries, but their preparation is extremely slow and problematic because the process passes through many intermediate states. This computational model explains how to control and accelerate the multistep process and enabled formation of a classic superconducting ceramic 25 times faster than the traditional approach.
- Rare-earth elements—critical materials for modern technology—are difficult to separate from each other because they have similar chemical properties. Scientists have demonstrated an electrochemical approach that forces some of the elements into different oxidation states, making separation possible by means of specially designed extractant molecules. The typical multistep process is reduced to a cleaner, more energy-efficient and scalable single step.
- Crystals made from colloids are valuable in a wide range of applications such as batteries, sensors, and solar cells, but making these crystals with desired properties is quite challenging. A new, robust approach for directing assembly of crystals with desired geometry and properties avoids costly and complex chemical surface engineering and allows tuning properties for new uses. This new method creates precise regions of discrete chemical and physical properties on the surface of particles followed by selective interactions to correctly direct crystal formation.

Materials and chemical sciences enable advances in quantum-based science and technology, and quantum computing enables advances in materials and chemical sciences.

Recent research underscores the two-way relationship between BES-supported science domains and quantum information science. Advances span the areas of molecules for gate operations, understanding of correlated quantum errors, particles for logical operations, and efficient energy computations.

- Scientists studying photovoltaics for light harvesting in molecular crystals uncovered design principles for the light-driven generation and manipulation of long-lived, correlated spin states. A combination of predictive modeling of excited state dynamics, targeted chemical synthesis of molecular systems, and sophisticated time-resolved spectroscopy enabled the discovery of coupled molecules with spin entangled pair states, which could serve as the basis of molecular platforms to perform optically initialized gate operations in quantum information systems operating at room temperature.
- The central challenge in building a quantum computer is error correction. Currently error correction relies on the assumption that errors are not correlated between different quantum bits (or qubits) in the system. Experimental and

modeling research has revealed the existence of correlated errors in multi-qubit superconducting circuits. The data are compatible with absorption in the qubit substrate of cosmic ray muons and gamma rays, giving rise to correlated charge fluctuations in neighboring qubits. These results have major implications for proposed fault tolerant quantum computing and will inform the design of robust next-generation superconducting qubit arrays.

- Researchers have established new experimental evidence of quantum objects called "anyons" that arise from the collective behavior of electrons in two dimensions and were first predicted decades ago. It is also anticipated that a many-anyon system can serve as the basis for quantum computing. Unlike for more well-known particles, moving anyons around each other in solids causes them to acquire a phase factor that can be used to perform logical gate operations on a qubit. As researchers moved anyons in their experimental system they directly observed the expected phase change.
- Quantum computing techniques provide a means to address insurmountable computational barriers for simulating quantum systems on classical computers. Unfortunately, as the number of quantum circuits increases for progressively larger calculations, the opportunity for error also increases. Researchers have demonstrated a mathematical concept known as “connected moments” to compute the total energy of a molecular system using fewer quantum circuits, allowing the equivalent of a full-scale quantum calculation with more modest resources, while also reducing errors.

Confronted by the COVID-19 pandemic, BES user facilities shifted to remote access and conducted research that was instrumental in combating the disease.
BES light sources, neutron sources, and Nanoscale Science Research Centers adapted quickly to changed modes of operation and made key contributions to understanding of the virus, development of vaccines and therapeutics, and fabrication of vital materials.

- User facilities rapidly shifted to remote access and mail-in of material samples in March 2020 to support critical research, mostly devoted to combating the pandemic. Representative topical areas included macromolecular crystallography to study atomic-scale interactions of viral proteins with drug candidates and human proteins, solution state analysis of large and transient macromolecular assemblies, observation of cellular infection, and characterization of respirator filter materials to aid manufacturing.
- More than 700 unique users from more than 125 groups (including most major Pharma companies), using approximately 55 different beamlines at BES light sources and neutron sources, determined more than 450 structures of SARS-CoV-2 proteins with or without potential antivirals or antibodies, leading to more than 80 peer-reviewed publications as of August 2021.
- A decade of studies at APS and SSRL on spike proteins were key to the rapid development and effectiveness of all three SARS-CoV-2 vaccines currently in use in the United States. Furthermore, Pfizer scientists used NSLS-II to research certain structural properties of their vaccine.
- In terms of drug discovery, ALS protein crystallography capabilities supported a large collaboration led by the University of Washington and VIR Biotechnology, which has developed a COVID-19 therapeutic, Sotrovimab, that recently received FDA Emergency Use Authorization. Glaxo-Smith-Kline is now a major ALS partner as the drug approaches commercialization. More candidate drugs developed through research at BES light sources are in clinical trials.
- The Nanoscale Science Research Centers supported research to understand the virus and develop novel detection methods (fast, nanotechnology-based portable diagnostics sensors), synthesize custom nanoparticles for vaccine encapsulation and delivery, improve effectiveness of personal protective equipment (masks, nanoparticle-based antiviral coatings), and develop epidemiological models to predict virus spread.

BES user facilities maintain and enhance their leadership at the cutting edge of research.
From Nobel Prize discoveries to development of new capabilities to engagement of young scientists, BES user facilities stand at the forefront of cutting-edge science.

- The hard x-ray protein crystallography beam lines in ALS Sector 8 contributed strongly to Jennifer Doudna’s 2020 Chemistry Nobel Prize-winning discovery of how a protein, known as CRISPR-Cas9, protects bacteria from viral infections. Her lab’s structural biology research at ALS enabled fundamental understanding of the molecular basis for the ways in which RNA molecules affect the flow of genetic information in cells.

- The X-ray laser-enhanced attosecond pulse generation (XLEAP) system at LCLS has been upgraded to deliver isolated attosecond (billionths of a billionth of a second) pulses with unprecedented bandwidth to several user experiments. Fulfilling the important goal of time-resolved pump/probe experiments, two-color (frequency) sub-femtosecond (millionth of a billionth of a second) pulses, with sub-femtosecond timing control, were successfully delivered to users.
- The new generation of storage rings and high-repetition-rate free electron lasers requires unprecedented accuracy of optical elements, in order to preserve the ultra-high brightness and coherent flux that these sources will produce. Water-cooled solutions have reached the end of their development potential, and so cryo-optics are the logical next step forward. New cryo-optics experiments being carried out at the BES scientific user facilities are expected to be a mainstay of all high-power coherent beamlines in the future.
- A data science algorithm was developed to model the charge distribution in pixeled X-ray sensors. The model will achieve ultimate X-ray coordinate resolution and will enable the NSLS-II Soft Inelastic Scattering beamline to reach its best possible energy resolution. Undergraduate students from Alaska to the local area contributed to the project under the Science Undergraduate Laboratory Internships program, which encourages undergraduates and recent graduates to pursue science, technology, engineering, and mathematics careers by providing research experiences at the DOE laboratories.

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 Basic Energy Sciences Advisory Committee (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 clean 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 the highest-priority fundamental research that supports the DOE mission, including research that will advance the foundational knowledge necessary to accelerate innovation to reduce impacts resulting from climate change while advancing clean energy technologies and infrastructure. 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. This will establish 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 and 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 clean 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, SC National Quantum Information Science Research Centers (NQISRCs), in partnership with other SC programs, and, new in FY 2023, Energy Earthshot Research Centers (in partnership with Advanced Scientific Computing Research (ASCR) and Biological and Environmental Research (BER) and with DOE energy technology offices). These research modalities support multi-investigator, multi-disciplinary research focused on forefront scientific challenges in support of the DOE clean 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 and climate 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 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, such as Minority Serving Institutions (MSIs), individuals from groups historically underrepresented in STEM, and students from communities disproportionately affected by social, economic, and health burdens of the energy system and from EPSCoR jurisdictions.

Scattering and Instrumentation Sciences Research

Advanced characterization tools with very high precision in space and time are essential to understand, predict, and ultimately control matter and energy at the electronic, atomic, and nanoscale levels. Research in Scattering and Instrumentation Science supports innovative techniques and instrumentation development for advanced materials science research with scattering, spectroscopy, and imaging using electrons, neutrons, and x-rays, including development of science to understand ultrafast dynamics. These techniques provide precise and complementary information 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 NQISRCs. 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. Included is 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. This activity supports the Accelerate initiative, which will support scientific research to accelerate the transition of science advances to energy technologies and the Funding for Accelerated, Inclusive Research (FAIR) initiative which will provide focused investment on enhancing research on clean energy, climate, and related topics at minority serving institutions, including attention to underserved and environmental justice communities.

Condensed Matter and Materials Physics Research

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 and innovations to reduce climate change impacts, 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. In FY 2023, these activities will support the SC Energy Earthshots initiative. 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 2023, BES will continue to partner with other SC programs to support the NQISRCs 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 the Advanced Scientific Computing Research (ASCR), High Energy Physics (HEP), Fusion Energy Sciences (FES), and Nuclear Physics (NP) programs, 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.[y] 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.

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

Materials Discovery, Design, and Synthesis Research

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 and design 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, including clean energy and reduction of impacts resulting from climate change. In FY 2023, these activities will support the SC Energy Earthshots initiative.

The BESAC report on transformative opportunities for discovery science reinforced the importance of the continued growth of synthesis science, recognizing the opportunity to realize targeted functionality in materials by controlling the synthesis and assembly of hierarchical architectures and beyond equilibrium matter. In FY 2023 this program will continue to apply materials discovery and synthesis research to understand the unique properties of rare earth and other critical materials and 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 2023 program will focus on implementation awards for larger teams and will consider renewals of the FY 2021 awards as well as proposals for new teams. The technical scope will include a focus on clean energy research and climate science, expanding these important research communities and supporting the Energy Earthshot initiative. 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 twelve years of research activity, the program has produced an impressive breadth of scientific accomplishments, including over 14,000 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 2023, BES will continue EFRC research efforts through awards made in FY 2020 and FY 2022. Scientific emphasis includes research directions identified in recent strategic planning activities, such as investments in clean energy research, climate science, and low-carbon manufacturing.

Energy Earthshot Research Centers

The EERC program is a new modality of research to be launched in FY 2023, building on the success of the Energy Frontier Research Centers. Like the EFRCs, EERCs will bring together multi-investigator, multi-disciplinary teams to perform energy-relevant research with a scope and complexity beyond what is possible in standard single-investigator or small-group awards. Beyond the scope of the EFRCs, EERCs will address the gap between basic research and the applied research and development activities to facilitate the exchange of knowledge between SC and the DOE energy technology offices, which is key to realizing the stretch goals of the Energy Earthshots. EERCs will support team awards involving academic, national lab, and industrial researchers with joint planning by SC and energy technology offices, establishing a new era of cross-office research cooperation. The funding will focus efforts directly at the interface, ensuring that directed fundamental research and capabilities at SC user facilities tackle the most challenging barriers identified in the applied research and development activities.

Existing DOE Energy Earthshots include the Hydrogen Shot, the Long Duration Storage Shot, and the Carbon Negative Shot. Additional topics are under consideration for future announcements. From a science perspective, many research gaps for the Energy Earthshots crosscut all topics and will provide a foundation for other energy technology challenges, including biotechnology, critical minerals/materials, energy-water, subsurface science (including geothermal research), and materials and chemical processes under extreme conditions for nuclear applications. These gaps require multiscale computational and modeling tools, new artificial intelligence and machine learning technologies, real-time characterization, including in extreme environments, and development of the scientific base to co-design processes and systems rather than individual materials, chemistries, and components. EERCs will leverage individual Center research to cross-fertilize the ideas that emerge in one topical area to benefit others with similar challenges accelerating the science, as well as the technologies.

In FY 2023, the Request supports a Funding Opportunity Announcement (FOA) to be released by the Office of Science (BES, Advanced Scientific Computing Research, and Biological and Environmental Research), in coordination with the DOE energy technology offices, for the initial cohort of Energy Earthshot Research Centers. Emphasis will be on the current Earthshot topics and those announced by DOE prior to release of the FOA.

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*[z] 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, which will support research activities through much of FY 2023. In FY 2023, BES plans to issue a Funding Opportunity Announcement to openly recompete the Batteries and Energy Storage Hub program.

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 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,

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

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. In FY 2023, the funding associated with the four-year awards in FY 2019 will be recompeted for both renewal and new awards.

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Materials Sciences and Engineering	**$435,008**	**$566,629**	**+$131,621**
Scattering and Instrumentation Sciences Research	$74,031	$101,963	+$27,932
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, advanced manufacturing, and preparedness for biological threats. The Request supports the RENEW, FAIR, and Accelerate initiatives.	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 the FAIR and Accelerate initiatives, a focus on basic research related to clean energy and advanced manufacturing, and on research opportunities for underrepresented communities and institutions.

(dollars in thousands)

FY 2021 Enacted	FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Condensed Matter and Materials Physics Research $170,200	$202,538	+$32,338
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, and for reduction of climate change impacts. 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 NQISRCs that were initiated in FY 2020. Additional investments will support the SC Energy Earthshots initiative, including the response of materials to environmental conditions, such as temperature, light, corrosive chemicals, and radiation, particularly in the context of future clean energy technologies.	Funding will continue to enhance clean energy and climate 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 support for the SC Energy Earthshots initiative and a focus on research opportunities for underrepresented communities and institutions.

(dollars in thousands)

FY 2021 Enacted	FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Materials Discovery, Design, and Synthesis Research $71,189	$98,958	+$27,769
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 low-carbon manufacturing and reduction of climate change impacts, 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. Additional investments in these topical areas will focus on support for the SC Energy Earthshots initiative.	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 basic research related to clean energy, climate, and advanced manufacturing, on support for the SC Energy Earthshots initiative, and on research opportunities for underrepresented communities and institutions.

(dollars in thousands)

FY 2021 Enacted	FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Established Program to Stimulate Competitive Research (EPSCoR) $25,000	$35,000	+$10,000
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 R&D, including research that underpins DOE energy technology programs, the SC Energy Earthshots initiative, and innovations for climate science. Following the previous year's focus on State-National Laboratory Partnership awards, FY 2023 will emphasize Implementation Awards to larger multiple investigator teams that develop research capabilities in EPSCoR jurisdictions. The FY 2023 funding opportunity will consider new and renewal 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 implementation awards to develop research capabilities in EPSCoR jurisdictions, including clean energy, climate science, and low-carbon manufacturing research. Expanded investments will emphasize climate science and the SC Energy Earthshots initiative. Teams will be encouraged to include institutions serving underrepresented and minority communities. EPSCoR will participate in the SC-wide RENEW and FAIR initiatives to provide training and research opportunities for students and academic institutions not currently well represented in the U.S. S&T ecosystem.

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 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 fourth year of support for the four-year EFRC awards that were made in FY 2020 and the second year of support for awards that were made in FY 2022.	Technical emphasis for the EFRC program will continue to include research directions identified in recent strategic planning activities and aligned with program priorities, including research related to clean energy and low-carbon manufacturing.
Energy Earthshot Research Centers	$ —	$25,000	+$25,000
No funding.		The Request will support a Funding Opportunity Announcement (FOA) to be released by the Office of Science (BES, ASCR, BER), in coordination with the DOE Technology Offices, for the initial cohort of Energy Earthshot Research Centers (EERCs). EERCs will bring together the multi-investigator, multi-disciplinary teams necessary to perform energy-relevant research that bridges the gap between basic research and applied research and development activities. They will emphasize the innovations at the basic-applied interface required to advance the current Energy Earthshot topics and those announced by DOE prior to release of the FOA.	The Request will initiate this new activity.

(dollars in thousands)

FY 2021 Enacted	FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
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 support an open re-competition of the Batteries and Energy Storage Hub program.	Funding will support the initiation of one or more new Batteries and Energy Storage Hub projects.
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. BES plans to issue a Funding Opportunity Announcement in FY 2023 to recompete awards made in FY 2019.	Funding will continue to support research in ongoing awards as well as potential new and renewal awards resulting from an FY 2023 Funding Opportunity Announcement.

Note:

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

Description

Development of innovative clean energy technologies relies on understanding and ultimately controlling transformations of energy among forms and conversions of matter across multiple scales starting at the atomic level. 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-driven chemical transformations. The research addresses how physical and chemical phenomena at the scales of electrons, atoms, and molecules control complex and collective behavior of macroscopic-scale energy and matter conversion systems. At the most fundamental level, research to understand quantum mechanical behavior is rapidly evolving into the ability to control and direct such behavior to achieve desired outcomes. Fundamental knowledge developed through this subprogram can extend the new era of control science to tailor chemical transformations with atomic and molecular precision. The challenge is to achieve predictive understanding of complex chemical, geochemical, and biochemical systems at the same level of detail now known for simpler 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 gas and condensed phases, and at interfaces, based on understanding quantum 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 and subsurface 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 research to advance scientific understanding and accelerate innovation that can reduce impacts that contribute to climate change while advancing clean energy technologies and infrastructure. Support will continue for research to discover chemical processes for low-carbon, efficient, and circular approaches to advanced manufacturing including chemical upcycling of polymers. Related research emphasizes the chemistry, separations, and substitutions of critical elements important for reducing the dependence on critical materials and minerals while promoting innovative and robust manufacturing supply chains. 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 increase 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.

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 interfacial dynamics and 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 it plays 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 that can enable clean energy technologies. The subprogram also partners across SC to support the NQISRCs that were established in FY 2020 and, new in FY 2023, Energy Earthshot Research Centers (in partnership with Advanced Scientific Computing Research (ASCR) and Biological and Environmental Research (BER) and with DOE energy technology offices). 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; the FAIR initiative focused investment on enhancing research on clean energy, climate, and related topics at minority serving institutions; and the Accelerate initiative for scientific research to accelerate the transition of science advances to energy technologies.

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 and their application to probe and control chemical processes. Research supports theory and computation for accurate and efficient descriptions of molecular reactions and chemical dynamics. These efforts provide the foundational knowledge and the state-of-the-art experimental and computational tools necessary to advance the subprogram's research activities and the BES mission, including clean energy approaches that can reduce impacts contributing to climate change.

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 electrons and photons, to characterize and control their behavior. Novel attosecond sources, x-ray free electron laser sources such as the LCLS-II, and ultrafast electron diffraction are used to image the ultrafast 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 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 emerging exascale computing facilities and to optimize use of existing leadership class computers, leveraging U.S. leadership in the development of open-source computational chemistry codes and databases. In the context of the NQISRCs, this research also lays the groundwork for applications of future quantum computers to computational quantum chemistry.

In FY 2023, BES, in partnership with other SC programs, will continue support for the multi-disciplinary multi-institutional QIS centers, initiated in FY 2020. The NQISRCs 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.[aa] 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 knowledge of chemical reactivity, matter and charge transport, and chemical separation and stabilization processes that are foundational for developing future clean energy and advanced manufacturing technologies, and for innovations to mitigate or adapt to climate change. Core research areas include catalysis science, separation science, heavy element chemistry, and geosciences. The research entails use of ultrafast spectroscopy to follow transient species during reactions; advances the 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; develops the mechanistic insight needed to control reaction pathways in diverse catalytic, separation, and geological environments; and develops understanding of chemistry in subsurface and aqueous systems important in sustainable chemical processes.

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

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 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 and rare-earth 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, the distribution and accumulation of elements in the earth upper mantle, and a mechanistic understanding of the origins of subsurface physical properties and the response of earth materials subject to chemo-mechanical stress.

In FY 2023, this activity will continue to support efforts central to transformative approaches to advanced manufacturing,[bb] 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.[cc] In support of the Energy Earthshot initiative, 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, storage, and use. Also supporting the Energy Earthshot initiative, research will increase the fundamental knowledge of subsurface processes across spatial and temporal scales—such as mineralization, crack propagation, and rock fracture—that is critical for developing innovative clean energy technologies for the subsurface. Support will also continue for research to address challenges in critical materials with focus on novel approaches for resource identification and extraction, selective separation, and substitution and use of critical elements. Research will continue to investigate the unique quantum phenomena enabled by f-electron elements, including rare earth elements and actinides. The use of data science and AI/ML approaches will continue to be emphasized in research across the portfolio to accelerate the generation and propagation 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. Research explores the dynamic mechanisms of charge transport and reactivity that advances understanding of 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). 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. Research expands understanding of the influence of complex interfaces and aqueous environments on the dynamics and function of enzymes, natural and artificial membranes, and nano- to meso-scale structures. The resulting mechanistic understanding can inspire new strategies to control reaction pathways critical for clean energy conversions and for innovations to reduce impacts resulting from climate change.

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.

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

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

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 technologies. 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 carbon-neutral 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.

In FY 2023, research will continue to establish a molecular-level understanding of biochemical and photochemical processes. Efforts will build on BES biochemistry and biophysics research to discover and design chemical processes and complex structures that can enable innovations for clean energy technologies, 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 developing new strategies for efficient solar energy use. Research will also address challenges of 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 foundational knowledge critical to the BES mission. In support of the Energy Earthshot initiative, this activity will increase support for research to identify new approaches for harnessing solar energy for chemical conversions, providing knowledge that could enable carbon-neutral hydrogen technologies and advance strategies for other solar fuels. This activity supports the new Accelerate initiative that targets scientific research to accelerate the transition of science advances to energy technologies. This activity provides support for the ongoing SC-wide RENEW initiative and for the new FAIR initiative to build stronger programs at underrepresented institutions, including those in underserved and environmental justice communities, with a focus on enhancing research on clean energy, climate, and related topics.

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 twelve years of research activity, the program has produced an impressive breadth of scientific accomplishments, including over 14,000 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 2023 BES will continue EFRC research efforts through awards made in FY 2020 and FY 2022. Scientific emphasis includes research directions identified in recent strategic planning activities such as investments in clean energy research, climate science, and low-carbon manufacturing.

Energy Earthshot Research Centers

The EERC program is a new modality of research to be launched in FY 2023, building on the success of the Energy Frontier Research Centers. Like the EFRCs, EERCs will bring together multi-investigator, multi-disciplinary teams to perform energy-relevant research with a scope and complexity beyond what is possible in standard single-investigator or small-group awards. Beyond the scope of the EFRCs, EERCs will address the gap between basic research and the applied research and development activities to facilitate the exchange of knowledge between SC and the DOE energy technology offices, which is key to realizing the stretch goals of the Energy Earthshots. EERCs will support team awards involving academic, national lab, and industrial researchers with joint planning by SC and energy technology offices, establishing a new era of cross-office research cooperation. The funding will focus efforts directly at the interface, ensuring that directed fundamental research and capabilities at SC user facilities tackle the most challenging barriers identified in the applied research and development activities.

Existing DOE Energy Earthshots include the Hydrogen Shot, the Long Duration Storage Shot, and the Carbon Negative Shot. Additional topics are under consideration for future announcements. From a science perspective, many research gaps for the Energy Earthshots crosscut all topics and will provide a foundation for other energy technology challenges, including biotechnology, critical minerals/materials, energy-water, subsurface science (including geothermal research), and materials and chemical processes under extreme conditions for nuclear applications. These gaps require multiscale computational and modeling tools, new artificial intelligence and machine learning technologies, real-time characterization, including in extreme environments, and development of the scientific base to co-design processes and systems rather than individual materials, chemistries, and components. EERCs will leverage individual Center research to cross-fertilize the ideas that emerge in one topical area to benefit others with similar challenges—accelerating the science, as well as the technologies.

In FY 2023, the Request supports a Funding Opportunity Announcement (FOA) to be released by the Office of Science (BES, ASCR, and BER), in coordination with the DOE energy technology offices, for the initial cohort of Energy Earthshot Research Centers. Emphasis will be on the current Earthshot topics and those announced by DOE prior to release of the FOA.

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 2023 Request will continue support for these 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.[dd]

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.

[dd] 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 2023 support will continue awards from FY 2021 and FY 2022. This research supports a publicly accessible website[ee] 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

General Plant Projects 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.

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

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Chemical Sciences, Geosciences, and Biosciences	**$394,285**	**$517,711**	**+$123,426**
Fundamental Interactions Research	$107,904	$122,939	+$15,035
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. Continued emphasis will be placed on quantum phenomena underlying QIS, such as coherence and entanglement. Research will expand efforts to understand and control chemical processes and quantum phenomena at the molecular level. In FY 2023 research will emphasize understanding and control of interfacial 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 NQISRCs 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. Investments will continue a focus on clean energy research in underrepresented communities and institutions.

(dollars in thousands)

FY 2021 Enacted	FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Chemical Transformations Research $112,292	$136,919	+$24,627
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 and advanced manufacturing technologies, including chemical upcycling of polymers, and in innovations to reduce climate change impacts. Separation science research will continue to focus on innovative 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 include atomically precise synthesis of new catalysts and studies of chemical processes required to develop clean energy technologies: multiscale phenomena in extreme and constrained environments in the subsurface; separations and extraction of rare earth elements from complex and dilute mixtures; and alternative approaches that reduce use of critical elements.	Funding will emphasize research on catalysis and separation science research for studies of the chemistry of rare earth and platinum-group elements to enable improved extraction, separation, substitution, and reduction in use; for development of innovative approaches to sustainable, energy-efficient carbon and hydrogen cycles; and for reduction of climate change impacts. Support will continue for research to provide the foundational knowledge needed for advanced manufacturing. 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 support for the SC Energy Earthshots initiative and a focus on clean energy research in underrepresented communities and institutions.

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Photochemistry and Biochemistry Research	$82,589	$132,925	+$50,336
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. Studies of light absorption, energy transfer, charge transport, separation processes, and photocatalysis will provide fundamental insights that can lead to innovations in the design of new clean energy systems and processes and in reduction of climate change impacts. Study of biochemical processes and structures will provide a foundation for bio-inspired, biohybrid, and biomimetic systems with desired functions and properties, including design of efficient catalysts and reaction pathways. 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 critical elements in photoabsorbers and catalysts. Biological and chemical studies will investigate how quantum phenomena affect energy conversion efficiency and fidelity. The Request supports the SC Energy Earthshots, FAIR, RENEW, and Accelerate initiatives.	Technical emphasis will include research that targets fundamental science for innovation in clean energy technologies and in reduction of climate change impacts through increased knowledge of 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 the SC Energy Earthshots, FAIR, and Accelerate initiatives, and a focus on clean energy research in underrepresented communities and institutions.

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 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 final year of support for four-year EFRC awards that were made in FY 2020 and the second year of support for awards that were made in FY 2022.	Technical emphasis for the EFRC program will continue to include research directions identified in recent strategic planning activities and aligned with program priorities, including research related to clean energy and low-carbon manufacturing.
Energy Earthshot Research Centers	$ —	$25,000	+$25,000
No funding.		The Request will support a Funding Opportunity Announcement (FOA) to be released by the Office of Science (BES, ASCR, BER), in coordination with the DOE Technology Offices, for the initial cohort of Energy Earthshot Research Centers (EERCs). EERCs will bring together the multi-investigator, multi-disciplinary teams necessary to perform energy-relevant research that bridges the gap between basic research and applied research and development activities. They will emphasize the innovations at the basic-applied interface required to advance the current SC Energy Earthshot topics and those announced by DOE prior to release of the FOA.	Funding will support this new activity in FY 2023.

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
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 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 continue support for prior year awards in priority research areas.

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 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 and FY 2022, with ongoing research to develop public, open-source codes for future exascale computer platforms.	Funding will continue support for prior year awards in priority research areas.
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 percent 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 and all of FY 2021. 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. The BES facilities supported over 12,500 users in FY 2020 and over 11,300 users in FY 2021. 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. All of the user facilities contributed to other COVID-19 activities, including research on masks, characterization of novel manufacturing for medical equipment, and delivery of therapeutics. The BES facilities will continue to support ongoing research efforts to combat COVID-19 and evolve the tools and expertise needed for future public health challenges. In FY 2023, continued support for biological threats at the light and neutron sources is included in the Biopreparedness Research Virtual Environment (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. Facility upgrade projects are underway for the APS, ALS, and LCLS to ensure ongoing world leadership for these facilities.

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. In FY 2023, NEXT-III will receive Other Project Costs support for planning of the next cadre of beamlines.

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.

Current construction projects at SNS focus on maintaining world-leadership for neutron scattering. In addition, for FY 2023 Other Project Costs are requested to initiate planning for replacement of the aging HFIR pressure vessel.

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

Major Items of Equipment

BES supports major item of equipment (MIE) projects to ensure the continual development and upgrade of major scientific instrument capabilities, including fabricating new x-ray and neutron experimental stations, improving NSRC core facilities, additional beamlines for the NSLS II, 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. This 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, such as Minority Serving Institutions (MSIs), individuals from groups historically underrepresented in STEM, and students from communities disproportionately affected by social, economic, and health burdens of the energy system, and from the Established Program to Stimulate Competitive Research (EPSCoR) jurisdictions. This activity will also support the BRaVE initiative, which brings DOE laboratories together to tackle problems of pressing national importance, BES research will continue 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.

Basic Energy Sciences
Scientific User Facilities (SUF)

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Scientific User Facilities (SUF)	**$1,026,707**	**$1,042,899**	**+$16,192**
X-Ray Light Sources	$525,000	$509,425	-$15,575
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 90 percent of optimal, the level for normal operations based on FY 2018 baseline. Facilities will optimize operational support, prioritizing staff support for users, including development of capabilities under the BRaVE initiative.
High-Flux Neutron Sources	$292,000	$280,754	-$11,246
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 90 percent of optimal, the level for normal operations based on FY 2018 baseline. Facilities will optimize operational support, prioritizing staff support for users, including development of capabilities under the BRaVE initiative.
Nanoscale Science Research Centers	$139,000	$134,754	-$4,246
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 approximately 90 percent of optimal, the level for normal operations based on FY 2018 baseline, including support to develop QIS-related research infrastructure and capabilities. Facilities will optimize operational support, prioritizing staff support for users.

(dollars in thousands)

FY 2021 Enacted	FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Other Project Costs $19,000	$17,500	-$1,500
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, the Second Target Station project at ORNL, the Advanced Photon Source Upgrade (APS-U) project at ANL, and the Cryomodule Repair and Maintenance Facility (CRMF) project at SLAC. The Request also initiates OPC for the High Flux Isotope Reactor Pressure Vessel Replacement (HFIR-PVR) project at ORNL and the National Synchrotron Light Source-II (NSLS-II) Experimental Tools-III (NEXT-III) project at BNL.	Funding will support the initiation of planning for the HFIR-PVR project at ORNL and the NSLS-II NEXT-III project at BNL. OPC will support preliminary project plans for these activities.
Major Items of Equipment $10,500	$50,000	+$39,500
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 BNL and the recapitalization project for the NSRCs. Both projects are planning for CD-2/3 approval early in FY 2022.	Funding will support the baseline funding profiles for the NEXT-II and NSRC Recapitalization MIE projects.

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Research	$41,207	$50,466	+$9,259
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. In addition, research will expand to include enabling capabilities for response to biological threats.	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. Funding will support the BRaVE initiative to enable facility capabilities for responsiveness to biological threats. Investment will include research in underrepresented communities and institutions.

Note:

- *Funding for the subprogram above, includes 3.65 percent 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.

21-SC-10, Cryomodule Repair & Maintenance Facility (CRMF), SLAC

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 25,000 gross square foot building to contain the necessary equipment. The building will need a concrete shielded enclosure for cryomodule testing, a control room, a vertical test stand area for testing SRF cavities and components, supplied with cryogenic refrigeration and a 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 6, 2019, with a current TPC range of $70,000,000–$98,000,000. A combined CD-1/3A is projected for 2Q FY 2023.

19-SC-14, Second Target Station (STS), ORNL

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 and CD-2, Approve Performance Baseline, is expected 2Q FY 2025.

18-SC-10, Advanced Photon Source Upgrade (APS-U), ANL

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. At least seven 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 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.

18-SC-11, Spallation Neutron Source Proton Power Upgrade (PPU), ORNL

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, with a Total Project Cost (TPC) of $590,000,000 and CD-3, Approve Start of Construction, is expected in 1Q of FY 2023.

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 continues to assess the impact of COVID-19 on the project’s cost and schedule. A combined CD-2/3 approval is projected for 4Q FY 2023 and CD-4 is projected for 2Q FY 2031.

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Construction	**$389,000**	**$293,200**	**-$95,800**
21-SC-10, Cryomodule Repair & Maintenance Facility (CRMF), SLAC	$1,000	$10,000	+$9,000
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 Request will continue the initial design effort and initiate long-lead procurements and site preparations for civil construction upon associated CD approvals. CD-1/3A is projected for 2Q FY 2023.	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.		The project will continue the activities of planning, R&D, and engineering to mature the project's preliminary design, scope, cost, schedule, and key performance parameters.	Funding will advance progress on the STS project.

(dollars in thousands)

FY 2021 Enacted	FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
18-SC-10, Advanced Photon Source Upgrade (APS-U), ANL $160,000	$9,200	-$150,800
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 Request will support ongoing construction activities to include civil construction associated with the long beamline building. Dark time for installation is projected to begin 2Q FY 2023.	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.	The project will support the installation of additional cryomodules and related radiofrequency systems, operation of the second PPU test target at increased power levels, and construction of the tunnel stub that will facilitate connection to the future Second Target Station.	Funding will advance progress on the PPU project.
18-SC-12, Advanced Light Source Upgrade (ALS-U), LBNL $62,000	$135,000	+$73,000
Funding continues to support engineering, design, R&D prototyping and long lead procurements of construction items and other tasks as required.	The project will continue to advance construction activities making progress towards CD-3, projected for 1Q FY 2023.	Funding will advance progress on the ALS-U project.

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request		Explanation of Changes FY 2023 Request vs FY 2021 Enacted	
18-SC-13, Linac Coherent Light Source-II-High Energy (LCLS-II-HE), SLAC	$52,000		$90,000		+$38,000
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. A combined CD-2/3 approval is projected for 4Q FY 2023 and CD-4 is projected for 2Q FY 2031.		Funding will advance progress on the LCLS-II-HE project.	
13-SC-10 - Linac Coherent Light Source-II (LCLS-II), SLAC	$33,000		$ —		-$33,000
Funding continues to support installation of all remaining major accelerator and x-ray systems and equipment commissioning activities.		No funding is requested in FY 2023.		Final funding for LCLS-II was requested in FY 2022.	

Basic Energy Sciences
Capital Summary

	Total	Prior Years	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
	(dollars in thousands)					
Capital Operating Expenses						
Capital Equipment	N/A	N/A	46,950	65,800	69,500	+22,550
Minor Construction Activities						
General Plant Projects	N/A	N/A	10,000	1,740	15,652	+5,652
Accelerator Improvement Projects	N/A	N/A	30,539	24,431	39,958	+9,419
Total, Capital Operating Expenses	**N/A**	**N/A**	**87,489**	**91,971**	**125,110**	**+37,621**

Capital Equipment

	(dollars in thousands)					
	Total	**Prior Years**	**FY 2021 Enacted**	**FY 2022 Annualized CR**	**FY 2023 Request**	**FY 2023 Request vs FY 2021 Enacted**
Capital Equipment						
Major Items of Equipment						
Scientific User Facilities (SUF)						
NSLS-II Experimental Tools-II (NEXT-II), BNL	87,283	3,283	5,500	15,000	25,000	+19,500
NSRC Recapitalization	74,150	4,150	5,000	15,000	25,000	+20,000
Total, MIEs	N/A	N/A	10,500	30,000	50,000	+39,500
Total, Non-MIE Capital Equipment	N/A	N/A	36,450	35,800	19,500	-16,950
Total, Capital Equipment	**N/A**	**N/A**	**46,950**	**65,800**	**69,500**	**+22,550**

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 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 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	740	8,260	-740
SNS Sample Environment Building	5,392	–	–	–	5,392	+5,392
Total GPPs (greater than or equal to $5M and less than $20M)	N/A	N/A	9,000	740	13,652	+4,652
Total GPPs less than $5M	N/A	N/A	1,000	1,000	2,000	+1,000
Total, General Plant Projects (GPP)	**N/A**	**N/A**	**10,000**	**1,740**	**15,652**	**+5,652**
Accelerator Improvement Projects (AIP)						
AIPs (greater than or equal to $5M and less than $20M)						
Spallation Neutron Source Cold Box-Engineering	10,000	–	–	–	10,000	+10,000
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	–	–
Transmitter #4 (NSLS-II)	5,100	–	–	–	5,100	+5,100
HFIR Beamline SANTA	6,700	–	–	–	6,700	+6,700
Total AIPs (greater than or equal to $5M and less than $20M)	N/A	N/A	14,539	6,250	21,800	+7,261
Total AIPs less than $5M	N/A	N/A	16,000	18,181	18,158	+2,158
Total, Accelerator Improvement Projects (AIP)	**N/A**	**N/A**	**30,539**	**24,431**	**39,958**	**+9,419**
Total, Minor Construction Activities	**N/A**	**N/A**	**40,539**	**26,171**	**55,610**	**+15,071**

Note:

- *The Total funding for the HFIR Guide Hall Extension GPP project is $9,000,000. This project, originally requested in FY 2021, has been delayed. Design efforts will be fully funded in FY 2022 ($740,000) and the remaining funds are requested in FY 2023 ($8,260,000).*

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 will 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-2, Approve Performance Baseline, and CD-3, Approve Start of Construction, on October 13, 2021. The approved total project cost is $94,500,000. The FY 2023 Request of $25,000,000 will continue R&D, prototyping, other supporting activities, and construction/equipment procurements. The project is planning for CD-4 approval early in FY 2027.

Nanoscale Science Research Center (NSRC) Recapitalization Project

The NSRCs started early operations in 2006-2007 and now, over 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 2023 Request of $25,000,000 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 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
21-SC-10, Cryomodule Repair & Maintenance Facility (CRMF), SLAC						
Total Estimated Cost (TEC)	90,300	–	1,000	1,000	10,000	+9,000
Other Project Cost (OPC)	3,700	–	1,000	2,000	–	-1,000
Total Project Cost (TPC)	**94,000**	**–**	**2,000**	**3,000**	**10,000**	**+8,000**
19-SC-14, Spallation Neutron Source Second Target Station (STS), ORNL						
Total Estimated Cost (TEC)	2,143,000	21,000	29,000	32,000	32,000	+3,000
Other Project Cost (OPC)	99,000	32,805	13,000	–	5,000	-8,000
Total Project Cost (TPC)	**2,242,000**	**53,805**	**42,000**	**32,000**	**37,000**	**-5,000**
18-SC-10, Advanced Photon Source Upgrade (APS-U), ANL						
Total Estimated Cost (TEC)	796,500	529,800	156,500	101,000	9,200	-147,300
Other Project Cost (OPC)	18,500	8,500	–	5,000	5,000	+5,000
Total Project Cost (TPC)	**815,000**	**538,300**	**156,500**	**106,000**	**14,200**	**-142,300**
18-SC-11, Spallation Neutron Source Proton Power Upgrade (PPU), ORNL						
Total Estimated Cost (TEC)	257,769	156,000	52,000	17,000	17,000	-35,000
Other Project Cost (OPC)	13,798	10,798	3,000	–	–	-3,000
Total Project Cost (TPC)	**271,567**	**166,798**	**55,000**	**17,000**	**17,000**	**-38,000**

(dollars in thousands)

	Total	Prior Years	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
18-SC-12, Advanced Light Source Upgrade (ALS-U), LBNL						
Total Estimated Cost (TEC)	562,000	136,000	62,000	75,100	135,000	+73,000
Other Project Cost (OPC)	28,000	28,000	–	–	–	–
Total Project Cost (TPC)	**590,000**	**164,000**	**62,000**	**75,100**	**135,000**	**+73,000**
18-SC-13, Linac Coherent Light Source-II-High Energy (LCLS-II-HE), SLAC						
Total Estimated Cost (TEC)	628,000	73,157	55,500	50,000	90,000	+34,500
Other Project Cost (OPC)	32,000	12,000	2,000	3,000	4,000	+2,000
Total Project Cost (TPC)	**660,000**	**85,157**	**57,500**	**53,000**	**94,000**	**+36,500**
13-SC-10, Linac Coherent Light Source II (LCLS-II), SLAC						
Total Estimated Cost (TEC)	1,080,200	1,016,299	35,801	28,100	–	-35,801
Other Project Cost (OPC)	56,200	51,900	–	4,300	–	–
Total Project Cost (TPC)	**1,136,400**	**1,068,199**	**35,801**	**32,400**	**–**	**-35,801**
Total, Construction						
Total Estimated Cost (TEC)	**N/A**	**N/A**	**391,801**	**304,200**	**293,200**	**-98,601**
Other Project Cost (OPC)	**N/A**	**N/A**	**19,000**	**14,300**	**14,000**	**-5,000**
Total Project Cost (TPC)	**N/A**	**N/A**	**410,801**	**318,500**	**307,200**	**-103,601**

Note:

- *The FY 2021 Enacted amounts in the table above include reprogramming of funds from the APS-U project (-$3,500,000) to the LCLS-II-HE project (+$3,500,000) and the LCLS-II project (+$2,801,000). In the table above, the FY 2023 President's Request does not reflect OPC funding to begin planning for the NSLS-II Experimental Tools-III (NEXT-III) and High Flux Isotope Reactor Pressure Vessel Replacement (HFIR-PVR) line-item construction projects.*

Basic Energy Sciences
Funding Summary

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Research	869,500	895,100	1,133,806	+264,306
Facility Operations	956,000	1,000,400	924,933	-31,067
Projects				
Line Item Construction (LIC)	408,000	318,500	310,700	-97,300
Major Items of Equipment (MIE)	10,500	30,000	50,000	+39,500
Total, Projects	**418,500**	**348,500**	**360,700**	**-57,800**
Other	1,000	1,000	1,000	–
Total, Basic Energy Sciences	**2,245,000**	**2,245,000**	**2,420,439**	**+175,439**

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 2021 Enacted	**FY 2021 Current**	**FY 2022 Annualized CR**	**FY 2023 Request**	**FY 2023 Request vs FY 2021 Enacted**
Scientific User Facilities - Type A					
Advanced Light Source	**68,908**	**66,669**	**72,908**	**66,914**	**-1,994**
Number of Users	1,800	1,159	1,400	1,200	-600
Achieved Operating Hours	–	3,002	–	–	–
Planned Operating Hours	3,168	3,168	3,300	2,952	-216
Optimal Hours	3,400	3,400	3,400	3,280	-120
Percent of Optimal Hours	93.2%	88.3%	97.1%	90.0%	-3.2%
Advanced Photon Source	**142,158**	**137,388**	**151,258**	**138,387**	**-3,771**
Number of Users	4,300	3,686	4,000	2,700	-1,600
Achieved Operating Hours	–	4,836	–	–	–
Planned Operating Hours	5,000	5,000	3,980	2,790	-2,210
Optimal Hours	5,000	5,000	4,100	3,100	-1,900
Percent of Optimal Hours	100.0%	96.7%	97.1%	90.0%	-10.0%
National Synchrotron Light Source II	**118,647**	**114,752**	**122,647**	**114,743**	**-3,904**
Number of Users	1,300	1,022	1,600	1,450	+150
Achieved Operating Hours	–	4,484	–	–	–
Planned Operating Hours	4,500	4,500	4,850	4,500	–
Optimal Hours	4,800	4,800	5,000	5,000	+200
Percent of Optimal Hours	93.8%	93.4%	97.0%	90.0%	-3.8%

(dollars in thousands)

	FY 2021 Enacted	FY 2021 Current	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Stanford Synchrotron Radiation Light Source	**44,544**	**43,191**	**49,344**	**43,957**	**-587**
Number of Users	950	1,030	1,350	1,150	+200
Achieved Operating Hours	–	4,915	–	–	–
Planned Operating Hours	5,020	5,020	5,050	4,500	-520
Optimal Hours	5,400	5,400	5,200	5,000	-400
Percent of Optimal Hours	93.0%	91.0%	97.1%	90.0%	-3.0%
Linac Coherent Light Source	**150,743**	**146,478**	**156,743**	**145,424**	**-5,319**
Number of Users	800	720	800	850	+50
Achieved Operating Hours	–	4,499	–	–	–
Planned Operating Hours	4,500	4,500	4,560	4,950	+450
Optimal Hours	4,600	4,600	4,700	5,500	+900
Percent of Optimal Hours	97.8%	97.8%	97.0%	90.0%	-7.8%
Spallation Neutron Source	**183,532**	**177,006**	**185,032**	**178,847**	**-4,685**
Number of Users	730	483	800	420	-310
Achieved Operating Hours	–	4,501	–	–	–
Planned Operating Hours	4,600	4,600	4,350	2,430	-2,170
Optimal Hours	4,900	4,900	4,600	2,700	-2,200
Percent of Optimal Hours	93.9%	91.9%	94.6%	90.0%	-3.9%
High Flux Isotope Reactor	**108,468**	**105,278**	**109,968**	**101,907**	**-6,561**
Number of Users	500	202	560	350	-150
Achieved Operating Hours	–	3,295	–	–	–
Planned Operating Hours	3,100	3,100	3,900	2,520	-580
Optimal Hours	3,300	3,300	4,000	2,800	-500
Percent of Optimal Hours	93.9%	99.8%	97.5%	90.0%	-3.9%

(dollars in thousands)

	FY 2021 Enacted	FY 2021 Current	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Scientific User Facilities - Type B					
Center for Nanoscale Materials	**28,275**	**28,261**	**31,239**	**27,024**	**-1,251**
Number of Users	500	428	480	450	-50
Center for Functional Nanomaterials	**25,113**	**24,296**	**27,913**	**25,424**	**+311**
Number of Users	500	571	520	490	-10
Molecular Foundry	**32,162**	**30,931**	**34,296**	**30,743**	**-1,419**
Number of Users	700	654	750	700	–
Center for Nanophase Materials Sciences	**28,131**	**26,662**	**30,931**	**26,889**	**-1,242**
Number of Users	500	656	580	550	+50
Center for Integrated Nanotechnologies	**25,319**	**23,920**	**28,121**	**24,674**	**-645**
Number of Users	600	721	660	625	+25
Total, Facilities	**956,000**	**924,832**	**1,000,400**	**924,933**	**-31,067**
Number of Users	13,180	11,332	13,500	10,935	-2,245
Achieved Operating Hours	–	29,532	–	–	–
Planned Operating Hours	29,888	29,888	29,990	24,642	-5,246
Optimal Hours	31,400	31,400	31,000	27,380	-4,020

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 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Number of Permanent Ph.Ds (FTEs)	4,860	4,990	5,670	+810
Number of Postdoctoral Associates (FTEs)	1,340	1,400	1,680	+340
Number of Graduate Students (FTEs)	2,090	2,180	2,670	+580
Number of Other Scientific Employment (FTEs)	3,050	3,100	3,310	+260
Total Scientific Employment (FTEs)	**11,340**	**11,670**	**13,330**	**+1,990**

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 2023 Request for the Cryomodule Repair and Maintenance Facility (CRMF) project at SLAC National Accelerator Laboratory is $10,000,000 of Total Estimated Cost (TEC) funding. This project has 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 current preliminary TPC estimate for this project is $94,000,000.

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 6, 2019. This Construction Project Data Sheet (CPDS) is an update of the FY 2022 CPDS and does not include a new start for FY 2023.

FY 2021 funding launched the alternatives analysis and conceptual design activities required for CD-1. The FY 2022 Request continues the analysis of alternatives and matures the conceptual design with expertise from an architectural and engineering (AE) firm. The FY 2023 Request will support planning, engineering, design, R&D, prototyping, long-lead procurements, site preparations for civil construction, and preparing for CD-1 combined with CD-3A long-lead procurements for the cryoplant.

A Federal Project Director, certified to Level I, 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	12/6/19	1Q FY 2021	1Q FY 2021	1Q FY 2022	4Q FY 2022	1Q FY 2023	N/A	1Q FY 2027
FY 2022	12/6/19	4Q FY 2022	4Q FY 2022	4Q FY 2023	2Q FY 2024	2Q FY 2024	N/A	4Q FY 2028
FY 2023	12/6/19	1Q FY 2023	2Q FY 2023	1Q FY 2025	4Q FY 2024	1Q FY 2025	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
FY 2023	4Q FY 2024	2Q 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, Total	TPC
FY 2021	4,000	66,000	70,000	10,000	10,000	80,000
FY 2022	7,000	81,000	88,000	10,000	10,000	98,000
FY 2023	5,600	84,700	90,300	3,700	3,700	94,000

Note:

- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*

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 may include but are not limited to SRF cavities and cryomodules, future capabilities for high brightness electron injectors, and superconducting undulators. The requirements will be refined as the project matures. The initial concept includes a building with a concrete shielded enclosure for cryomodule testing, a control room, a vertical test stand area for testing SRF cavities and components, supplied with cryogenic refrigeration and a 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.

The project includes the potential for later installation of 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. The project is pre-CD-2; the scope included in the alternative selection and cost range will be refined at CD-1.

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 20-23 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, primarily 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 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	19,000 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	–
FY 2023	3,600	3,600	3,000
Outyears	–	–	2,600
Total, Design (TEC)	**5,600**	**5,600**	**5,600**
Construction (TEC)			
FY 2023	6,400	6,400	4,000
Outyears	78,300	78,300	80,700
Total, Construction (TEC)	**84,700**	**84,700**	**84,700**
Total Estimated Cost (TEC)			
FY 2021	1,000	1,000	–
FY 2022	1,000	1,000	–
FY 2023	10,000	10,000	7,000
Outyears	78,300	78,300	83,300
Total, TEC	**90,300**	**90,300**	**90,300**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Other Project Cost (OPC)			
FY 2021	1,000	1,000	59
FY 2022	2,000	2,000	800
FY 2023	–	–	1,000
Outyears	700	700	1,841
Total, OPC	**3,700**	**3,700**	**3,700**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Project Cost (TPC)			
FY 2021	2,000	2,000	59
FY 2022	3,000	3,000	800
FY 2023	10,000	10,000	8,000
Outyears	79,000	79,000	85,141
Total, TPC	**94,000**	**94,000**	**94,000**

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design	4,000	5,650	**N/A**
Design - Contingency	1,600	1,350	**N/A**
Total, Design (TEC)	**5,600**	**7,000**	**N/A**
Site Preparation	8,800	8,000	**N/A**
Equipment	26,160	7,400	**N/A**
Other Construction	25,500	46,850	**N/A**
Construction - Contingency	24,240	18,750	**N/A**
Total, Construction (TEC)	**84,700**	**81,000**	**N/A**
Total, TEC	**90,300**	**88,000**	**N/A**
Contingency, TEC	*25,840*	*20,100*	***N/A***
Other Project Cost (OPC)			
Conceptual Planning	500	500	**N/A**
Conceptual Design	1,700	5,500	**N/A**
Start-up	500	1,500	**N/A**
OPC - Contingency	1,000	2,500	**N/A**
Total, Except D&D (OPC)	**3,700**	**10,000**	**N/A**
Total, OPC	**3,700**	**10,000**	**N/A**
Contingency, OPC	*1,000*	*2,500*	***N/A***
Total, TPC	**94,000**	**98,000**	**N/A**
Total, Contingency (TEC+OPC)	***26,840***	***22,600***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Fiscal Year	Type	Prior Years	FY 2021	FY 2022	FY 2023	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
FY 2023	TEC	—	1,000	1,000	10,000	78,300	90,300
	OPC	—	1,000	2,000	—	700	3,700
	TPC	—	2,000	3,000	10,000	79,000	94,000

Note:

- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*

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	5,500	5,500	286,000	137,500

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 18,600 to 25,000 gross square feet 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 is being acquired under the existing DOE Management and Operations contract.

SLAC is preparing a Conceptual Design Report for the CRMF project and has the required project management systems in place to execute the project.

Preliminary cost estimates 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 2023 Request for Second Target Station (STS) project is $32,000,000 of Total Estimated Cost (TEC) funding and $5,000,000 of Other Project Costs (OPC) 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 current 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 2022 CPDS and does not include a new start for FY 2023.

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 was maturing the accelerator, target, instrument, controls, and conventional civil construction subsystems. A commercial Architect/Engineer (AE) firm was contracted to assist in advancing the planning, engineering, and design. Proposals from scientific community teams for world-class instrument concepts were reviewed and eight were selected for inclusion in the project planning. In FY 2022, the project continues 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.
FY 2023 funds will support advancing the highest priority R&D and design activities including the proton accelerator extraction magnets and power supplies, proton beam window, and neutron optics systems, the Target and Moderator Reflector assemblies, the Bunker Shielding and components, design of the Integrated Control Systems and the design of the machine and personnel protection systems. Due to the extension of the project duration beyond initial projections, the project and program are evaluating the best approach to deliver threshold performance.

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
FY 2023	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, Total	TPC
FY 2020	65,500	1,138,500	1,204,000	45,300	45,300	1,249,300
FY 2021	65,500	1,158,200	1,223,700	45,300	45,300	1,269,000
FY 2022	333,000	1,810,000	2,143,000	99,000	99,000	2,242,000
FY 2023	332,757	1,810,243	2,143,000	99,000	99,000	2,242,000

Note:

- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*

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 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*.

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
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 x 10^{13}n/cm^2/sr/Å/s at 5 Å	peak brightness of 2 x 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	20,360
FY 2022	32,000	32,000	46,000
FY 2023	32,000	32,000	45,000
Outyears	218,757	218,757	221,397
Total, Design (TEC)	**332,757**	**332,757**	**332,757**
Construction (TEC)			
Outyears	1,810,243	1,810,243	1,810,243
Total, Construction (TEC)	**1,810,243**	**1,810,243**	**1,810,243**
Total Estimated Cost (TEC)			
FY 2019	1,000	1,000	–
FY 2020	20,000	20,000	–
FY 2021	29,000	29,000	20,360
FY 2022	32,000	32,000	46,000
FY 2023	32,000	32,000	45,000
Outyears	2,029,000	2,029,000	2,031,640
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	5,916
FY 2022	–	–	10,353
FY 2023	5,000	5,000	5,769
Outyears	48,195	48,195	53,646
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	26,276
FY 2022	32,000	32,000	56,353
FY 2023	37,000	37,000	50,769
Outyears	2,077,195	2,077,195	2,085,286
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	258,000	256,500	**N/A**
Design - Contingency	74,757	76,500	**N/A**
Total, Design (TEC)	**332,757**	**333,000**	**N/A**
Construction	1,290,000	1,291,500	**N/A**
Construction - Contingency	520,243	518,500	**N/A**
Total, Construction (TEC)	**1,810,243**	**1,810,000**	**N/A**
Total, TEC	**2,143,000**	**2,143,000**	**N/A**
Contingency, TEC	*595,000*	*595,000*	***N/A***
Other Project Cost (OPC)			
R&D	22,875	22,875	**N/A**
Conceptual Design	24,750	24,750	**N/A**
Start-up	20,250	20,250	**N/A**
OPC - Contingency	31,125	31,125	**N/A**
Total, Except D&D (OPC)	**99,000**	**99,000**	**N/A**
Total, OPC	**99,000**	**99,000**	**N/A**
Contingency, OPC	*31,125*	*31,125*	***N/A***
Total, TPC	**2,242,000**	**2,242,000**	**N/A**
Total, Contingency (TEC+OPC)	***626,125***	***626,125***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Fiscal Year	Type	Prior Years	FY 2021	FY 2022	FY 2023	Outyears	Total
FY 2020	TEC	2,000	—	—	—	1,202,000	1,204,000
	OPC	11,500	—	—	—	33,800	45,300
	TPC	13,500	—	—	—	1,235,800	1,249,300
FY 2021	TEC	21,000	1,000	—	—	1,201,700	1,223,700
	OPC	32,805	1,000	—	—	11,495	45,300
	TPC	53,805	2,000	—	—	1,213,195	1,269,000
FY 2022	TEC	21,000	29,000	32,000	—	2,061,000	2,143,000
	OPC	32,805	13,000	—	—	53,195	99,000
	TPC	53,805	42,000	32,000	—	2,114,195	2,242,000
FY 2023	TEC	21,000	29,000	32,000	32,000	2,029,000	2,143,000
	OPC	32,805	13,000	—	5,000	48,195	99,000
	TPC	53,805	42,000	32,000	37,000	2,077,195	2,242,000

Note:
- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*

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	59,000	59,000	1,475,000	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

Based on the DOE determination at CD-1, ORNL is acquiring 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 are being 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 2023 Request for the Advanced Photon Source-Upgrade (APS-U) project is $9,200,000 of Total Estimated Cost (TEC) funding and $5,000,000 of Other Project Costs (OPC) funding. 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 2Q FY 2026. This Construction Project Data Sheet (CPDS) is an update of the FY 2022 CPDS and does not include a new start for FY 2023. There are no significant changes.

FY 2021 funding enabled 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 enabled site preparation and civil construction activities for the Long Beamline Building (LBB). The project received and inspected hardware for the storage ring and experimental facilities and advanced the integrated magnet module assembly. FY 2022 funding emphasizes fabrication, procurement, acceptance testing, integration and assembly, and preparing all items for installation in FY 2023. Civil construction for the LBB and final design will be completed. The FY 2023 Request activities emphasize system integration, testing, and assembly in preparation for the storage ring removal and installation during the experimental dark time, tentatively scheduled to begin in April 2023.

To date, the project encountered delays in its progress and has required use of both cost and schedule contingency. The COVID-19 pandemic continues to affect personnel, cause supply chain delays in deliveries, and increase costs for procurements/subcontracts. The project and program are carefully monitoring progress and contingency, with options under active evaluation in the event of unacceptable costs/schedule impacts.

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
FY 2023	4/22/10	9/18/15	2/4/16	12/9/18	4Q 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
FY 2023	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, Total	TPC
FY 2018	157,015	561,985	719,000	51,000	51,000	770,000
FY 2019	167,000	590,100	757,100	12,900	12,900	770,000
FY 2020	162,825	633,675	796,500	18,500	18,500	815,000
FY 2021	190,425	606,075	796,500	18,500	18,500	815,000
FY 2022	189,638	606,862	796,500	18,500	18,500	815,000
FY 2023	210,867	585,633	796,500	18,500	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, up to 500 times brighter than the present APS. 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 high energy, hard x-ray light source technology. The six giga-electronvolt (GeV), very low emittance European Synchrotron Radiation Facility-Extremely Brilliant Source (ESRF-EBS) in France came on line in 2020; China initiated construction of the High Energy Photon Source (HEPS) in Beijing, a six GeV hard x-ray synchrotron light source, planned to come on line in 2026; the six GeV PETRA-IV extremely low emittance storage ring at DESY in Hamburg, and SPring-8-II 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).

The APS upgrade will provide a world-class hard x-ray synchrotron radiation facility, with up to 500 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]	> 1×10^{20}	1×10^{22}
Brightness @ 60 keV[1]	> 1×10^{19}	1×10^{21}
New APS-U Beamlines Transitioned to Operations	7	≥ 9

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

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
Design (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	18,200	18,200	23,059
FY 2022	3,029	3,029	5,515
Total, Design (TEC)	**210,867**	**210,867**	**210,867**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
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	143,512	143,512	55,859
FY 2021	138,300	138,300	125,595
FY 2022	97,971	97,971	179,778
FY 2023	9,200	9,200	147,517
Outyears	–	–	37,265
Total, Construction (TEC)	**585,633**	**585,633**	**585,633**
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	166,500	166,500	84,345
FY 2021	156,500	156,500	148,654
FY 2022	101,000	101,000	185,293
FY 2023	9,200	9,200	147,517
Outyears	–	–	37,265
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	–
FY 2023	5,000	5,000	5,748
Outyears	–	–	4,252
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	166,500	166,500	84,345
FY 2021	156,500	156,500	148,654
FY 2022	106,000	106,000	185,293
FY 2023	14,200	14,200	153,265
Outyears	–	–	41,517
Total, TPC	**815,000**	**815,000**	**815,000**

Note:

– *In FY 2021, the Office of Science (SC) reprogrammed $2,200,000 of FY 2019 funds, $3,500,000 of FY 2020 funds, and $3,500,000 of FY 2021 funds to the LCLS-II-HE project at SLAC. The FY 2019, FY 2020, and FY 2021 Budget Authority in the table above reflects the reprogrammings. The funds for FY 2023 are required 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	209,868	187,921	166,962
Design - Contingency	999	1,717	9,696
Total, Design (TEC)	**210,867**	**189,638**	**176,658**
Equipment	503,727	478,809	465,180
Other Construction	17,000	17,000	17,000
Construction - Contingency	64,906	111,053	137,662
Total, Construction (TEC)	**585,633**	**606,862**	**619,842**
Total, TEC	**796,500**	**796,500**	**796,500**
Contingency, TEC	*65,905*	*112,770*	*147,358*
Other Project Cost (OPC)			
Conceptual Planning	1,000	1,000	1,000
Conceptual Design	7,500	7,500	7,500
Start-up	8,662	7,570	7,100
OPC - Contingency	1,338	2,430	2,900
Total, Except D&D (OPC)	**18,500**	**18,500**	**18,500**
Total, OPC	**18,500**	**18,500**	**18,500**
Contingency, OPC	*1,338*	*2,430*	*2,900*
Total, TPC	**815,000**	**815,000**	**815,000**
Total, Contingency (TEC+OPC)	***67,243***	***115,200***	***150,258***

5. Schedule of Appropriations Requests

(dollars in thousands)

Fiscal Year	Type	Prior Years	FY 2021	FY 2022	FY 2023	Outyears	Total
FY 2018	TEC	162,500	—	—	—	556,500	719,000
	OPC	8,500	—	—	—	42,500	51,000
	TPC	171,000	—	—	—	599,000	770,000
FY 2019	TEC	222,500	—	—	—	534,600	757,100
	OPC	8,500	—	—	—	4,400	12,900
	TPC	231,000	—	—	—	539,000	770,000
FY 2020	TEC	515,500	—	—	—	281,000	796,500
	OPC	8,500	—	—	—	10,000	18,500
	TPC	524,000	—	—	—	291,000	815,000
FY 2021	TEC	535,500	150,000	—	—	111,000	796,500
	OPC	8,500	—	—	—	10,000	18,500
	TPC	544,000	150,000	—	—	121,000	815,000
FY 2022	TEC	533,300	160,000	101,000	—	2,200	796,500
	OPC	8,500	—	5,000	—	5,000	18,500
	TPC	541,800	160,000	106,000	—	7,200	815,000
FY 2023	TEC	529,800	156,500	101,000	9,200	—	796,500
	OPC	8,500	—	5,000	5,000	—	18,500
	TPC	538,300	156,500	106,000	14,200	—	815,000

Note:

– *In FY 2021, the Office of Science (SC) reprogrammed $2,200,000 of FY 2019 funds, $3,500,000 of FY 2020 funds, and $3,500,000 of FY 2021 funds to the LCLS-II-HE project at SLAC. The FY 2023 Request in the table above reflects the reprogrammings. The funds for FY 2023 are required 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	18,000	18,000	450,000	450,000

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

7. D&D Information

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

	Square Feet
New area being constructed by this project at ANL	24,000-25,000
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"	24,000-25,000
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	—

The gross square feet of the LBB is approximately 25,000, which will house two APS-U beamlines extending beyond the current APS experimental facilities and the support laboratories. This includes the square feet for the Activated Materials Laboratory, funded by the Office of Nuclear Energy.

8. Acquisition Approach

ANL is acquiring 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 has 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 is procuring 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 is 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 is 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 2023 Request for the Proton Power Upgrade (PPU) project is $17,000,000 of Total Estimated Cost (TEC) funding. The Total Project Cost (TPC) is $271,567,000.

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 in 4Q FY 2028. This Construction Project Data Sheet (CPDS) is an update of the FY 2022 CPDS and does not include a new start for FY 2023.

In FY 2021, the project continued 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 initiated equipment installation in the klystron gallery. In FY 2022, the project will prioritize the remaining 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, installation of the first two cryomodules in the accelerator, and advancing the target knowledge base by running the first PPU test target during SNS operations. In FY 2023, the project will operate the second PPU test target at increased power levels; install two additional cryomodules and related radiofrequency systems, begin first target station upgrades to support high-flow target gas injection; and start construction of the tunnel stub that will facilitate connection to the future Second Target Station.

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	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
FY 2023	1/7/09	8/1/17	4/4/18	10/6/20	2Q FY 2022	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
FY 2023	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, Total	TPC
FY 2020	27,300	210,000	237,300	12,700	12,700	250,000
FY 2021	46,700	189,502	236,202	13,798	13,798	250,000
FY 2022	40,000	217,802	257,802	13,798	13,798	271,600
FY 2023	45,300	212,469	257,769	13,798	13,798	271,567

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	$\geq 1.6 \times 10^{14}$ protons at 1.25 GeV	$\geq 2.24 \times 10^{14}$ 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	9,600	9,600	11,746
FY 2022	–	–	3,700
FY 2023	–	–	1,000
Outyears	–	–	580
Total, Design (TEC)	**45,300**	**45,300**	**45,300**
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	42,400	42,400	41,249
FY 2022	17,000	17,000	65,000
FY 2023	17,000	17,000	48,000
Outyears	15,769	15,769	19,844
Total, Construction (TEC)	**212,469**	**212,469**	**212,469**
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	52,995
FY 2022	17,000	17,000	68,700
FY 2023	17,000	17,000	49,000
Outyears	15,769	15,769	20,424
Total, TEC	**257,769**	**257,769**	**257,769**

(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	–	–	92
FY 2021	3,000	3,000	111
FY 2022	–	–	650
FY 2023	–	–	1,800
Outyears	–	–	1,534
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	41,166
FY 2021	55,000	55,000	53,106
FY 2022	17,000	17,000	69,350
FY 2023	17,000	17,000	50,800
Outyears	15,769	15,769	21,958
Total, TPC	**271,567**	**271,567**	**271,567**

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design	36,960	32,000	32,000
Design - Contingency	8,340	8,000	8,000
Total, Design (TEC)	**45,300**	**40,000**	**40,000**
Construction	168,502	163,452	163,466
Construction - Contingency	43,967	54,350	54,303
Total, Construction (TEC)	**212,469**	**217,802**	**217,769**
Total, TEC	**257,769**	**257,802**	**257,769**
Contingency, TEC	*52,307*	*62,350*	*62,303*
Other Project Cost (OPC)			
R&D	2,408	2,408	2,408
Conceptual Design	7,250	7,250	7,250
Other OPC Costs	3,480	3,480	3,480
OPC - Contingency	660	660	660
Total, Except D&D (OPC)	**13,798**	**13,798**	**13,798**
Total, OPC	**13,798**	**13,798**	**13,798**
Contingency, OPC	*660*	*660*	*660*
Total, TPC	**271,567**	**271,600**	**271,567**
Total, Contingency (TEC+OPC)	***52,967***	***63,010***	***62,963***

5. Schedule of Appropriations Requests

(dollars in thousands)

Fiscal Year	Type	Prior Years	FY 2021	FY 2022	FY 2023	Outyears	Total
FY 2020	TEC	101,000	—	—	—	136,300	237,300
	OPC	10,300	—	—	—	2,400	12,700
	TPC	111,300	—	—	—	138,700	250,000
FY 2021	TEC	156,000	5,000	—	—	75,202	236,202
	OPC	10,798	3,000	—	—	—	13,798
	TPC	166,798	8,000	—	—	75,202	250,000
FY 2022	TEC	156,000	52,000	17,000	—	32,802	257,802
	OPC	10,798	3,000	—	—	—	13,798
	TPC	166,798	55,000	17,000	—	32,802	271,600
FY 2023	TEC	156,000	52,000	17,000	17,000	15,769	257,769
	OPC	10,798	3,000	—	—	—	13,798
	TPC	166,798	55,000	17,000	17,000	15,769	271,567

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	9,325	9,325	373,000	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

Based on the DOE determination at CD-1, the PPU project is being 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 is partnering 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 have been sought and are being applied as appropriate 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 2023 Request for the Advanced Light Source Upgrade (ALS-U) project is $135,000,000 of Total Estimated Cost (TEC) funding. The project has a Total Project Cost (TPC) of $590,000,000.

Significant Changes

The ALS-U was initiated in FY 2018. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-2, Approve Performance Baseline, approved on April 2, 2021. This Construction Project Data Sheet (CPDS) is an update of the FY 2022 CPDS and does not include a new start for FY 2023.

FY 2021 funding continued support of planning, engineering, design, R&D, prototyping activities, and long-lead procurements. FY 2022 funding continues support of planning, engineering, design, R&D, prototyping, and procurements of both long-lead components for the accumulator ring installation as well as start of major procurements for the storage ring systems and components. In addition, FY 2022 funding will support advancing the design for the radiation shielding and required seismic upgrades. FY 2023 funding will continue support of planning, engineering, design, R&D, prototyping, testing, and procurements with an emphasis on accumulator, beamline, insertion device, and storage ring procurements and continue installation of the accumulator ring in the ALS tunnel.

As final design and long-lead time procurements progress, COVID-19 impacts have required use of both cost and schedule contingency. The COVID-19 pandemic continues to affect personnel, cause supply chain delays in deliveries, and increase costs for staff/procurements/subcontracts. The project and program are carefully monitoring progress, cost estimates, and contingency, with options under active evaluation in the event of unacceptable cost/schedule impacts.

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
FY 2023	9/27/16	4/30/18	9/21/18	4/2/21	4Q FY 2022	1Q FY 2023	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
FY 2023	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, Total	TPC
FY 2019	39,000	243,000	282,000	38,000	38,000	320,000
FY 2020	89,750	248,250	338,000	30,000	30,000	368,000
FY 2021	89,750	290,450	380,200	30,000	30,000	410,200
FY 2022	135,711	426,289	562,000	28,000	28,000	590,000
FY 2023	134,340	427,660	562,000	28,000	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	29,770	29,770	30,386
FY 2021	33,570	33,570	32,775
FY 2022	20,000	20,000	28,947
FY 2023	–	–	14,681
Outyears	–	–	5,497
Total, Design (TEC)	**134,340**	**134,340**	**134,340**
Construction (TEC)			
FY 2019	25,000	25,000	–
FY 2020	30,230	30,230	6,260
FY 2021	28,430	28,430	12,415
FY 2022	55,100	55,100	31,211
FY 2023	135,000	135,000	123,604
Outyears	153,900	153,900	254,170
Total, Construction (TEC)	**427,660**	**427,660**	**427,660**
Total Estimated Cost (TEC)			
FY 2018	16,000	16,000	–
FY 2019	60,000	60,000	22,054
FY 2020	60,000	60,000	36,646
FY 2021	62,000	62,000	45,190
FY 2022	75,100	75,100	60,158
FY 2023	135,000	135,000	138,285
Outyears	153,900	153,900	259,667
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	3,262
Outyears	–	–	4,440
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	39,908
FY 2021	62,000	62,000	45,190
FY 2022	75,100	75,100	60,158
FY 2023	135,000	135,000	138,285
Outyears	153,900	153,900	264,107
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	101,098	95,702	92,967
Design - Contingency	33,242	40,009	38,778
Total, Design (TEC)	**134,340**	**135,711**	**131,745**
Construction	150,093	N/A	142,165
Equipment	171,743	300,615	161,449
Construction - Contingency	105,824	125,674	126,641
Total, Construction (TEC)	**427,660**	**426,289**	**430,255**
Total, TEC	**562,000**	**562,000**	**562,000**
Contingency, TEC	*139,066*	*165,683*	*165,419*
Other Project Cost (OPC)			
R&D	4,971	8,200	8,241
Conceptual Planning	2,000	2,000	2,000
Conceptual Design	12,100	12,100	12,100
Start-up	2,000	2,000	2,000
OPC - Contingency	6,929	3,700	3,659
Total, Except D&D (OPC)	**28,000**	**28,000**	**28,000**
Total, OPC	**28,000**	**28,000**	**28,000**
Contingency, OPC	*6,929*	*3,700*	*3,659*
Total, TPC	**590,000**	**590,000**	**590,000**
Total, Contingency (TEC+OPC)	***145,995***	***169,383***	***169,078***

5. Schedule of Appropriations Requests

(dollars in thousands)

Fiscal Year	Type	Prior Years	FY 2021	FY 2022	FY 2023	Outyears	Total
FY 2019	TEC	10,000	—	—	—	272,000	282,000
	OPC	12,000	—	—	—	26,000	38,000
	TPC	22,000	—	—	—	298,000	320,000
FY 2020	TEC	89,000	—	—	—	249,000	338,000
	OPC	28,000	—	—	—	2,000	30,000
	TPC	117,000	—	—	—	251,000	368,000
FY 2021	TEC	136,000	13,000	—	—	231,200	380,200
	OPC	28,000	—	—	—	2,000	30,000
	TPC	164,000	13,000	—	—	233,200	410,200
FY 2022	TEC	136,000	62,000	75,100	—	288,900	562,000
	OPC	28,000	—	—	—	—	28,000
	TPC	164,000	62,000	75,100	—	288,900	590,000
FY 2023	TEC	136,000	62,000	75,100	135,000	153,900	562,000
	OPC	28,000	—	—	—	—	28,000
	TPC	164,000	62,000	75,100	135,000	153,900	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	—	—	—	—

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

Based on the DOE determination at CD-1, Lawrence Berkeley National Laboratory (LBNL) is acquiring the ALS-U project under the existing DOE Management and Operations (M&O) contract.

The ALS-U project 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 are being competitively bid and awarded based on best value to the government. The M&O contractor's performance is being evaluated through the annual laboratory performance appraisal process.

Lessons learned from other SC projects and other similar facilities are being 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 2023 Request for the Linac Coherent Light Source-II High Energy (LCLS-II-HE) project is $90,000,000 of Total Estimated Cost (TEC) funding and $4,000,000 of Other Project Costs (OPC) funding. 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. Pending CD-2 reviews, the project's TPC estimate is likely to exceed the current level of $660,000,000, and could approach $710,000,000 when COVID-driven cost and schedule increases are included.

Significant Changes

The LCLS-II-HE project was initiated in FY 2019. 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. The LCLS-II-HE project is continuing to assess the impact of COVID-19 on the project's cost, schedule, and project milestones. The combined CD-2/3 approval is projected for 4Q FY 2023 and CD-4 is now projected for 2Q FY 2031. This Construction Project Data Sheet (CPDS) is an update of the FY 2022 CPDS and does not include a new start for FY 2023.

FY 2021 funding continued engineering, design, R&D, prototyping, and long-lead procurements of construction items. FY 2022 funding supports engineering, design, R&D, prototyping, continuing long-lead procurements, and advancing the preliminary and final designs. Priority activities include initiating the low emittance injector design and cryomodule production at the partner labs. FY 2023 funding will continue engineering, design, R&D, prototyping, long-lead procurements, low emittance injector designs, cryomodule production at the partner labs, and preparations for baselining the project, and will start prototype gun production.

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
FY 2023	12/15/16	3/23/18	9/21/18	4Q FY 2023	3Q FY 2025	4Q FY 2023	N/A	2Q FY 2031

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

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
FY 2023	4Q FY 2023	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, Total	TPC
FY 2019	34,000	266,000	300,000	20,000	20,000	320,000
FY 2020	34,000	314,000	348,000	20,000	20,000	368,000
FY 2021	34,000	374,000	408,000	20,000	20,000	428,000
FY 2022	39,000	589,000	628,000	32,000	32,000	660,000
FY 2023	39,000	589,000	628,000	32,000	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, generated by a superconducting electron source, 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. 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	9,554
FY 2022	6,000	6,000	15,000
FY 2023	3,000	3,000	4,000
Outyears	2,000	2,000	7,432
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	31,957	31,957	19,620
FY 2021	47,500	47,500	41,497
FY 2022	44,000	44,000	50,000
FY 2023	87,000	87,000	75,000
Outyears	357,343	357,343	398,613
Total, Construction (TEC)	**589,000**	**589,000**	**589,000**
Total Estimated Cost (TEC)			
FY 2018	8,000	8,000	–
FY 2019	25,200	25,200	4,400
FY 2020	39,957	39,957	22,504
FY 2021	55,500	55,500	51,051
FY 2022	50,000	50,000	65,000
FY 2023	90,000	90,000	79,000
Outyears	359,343	359,343	406,045
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	1,507
FY 2022	3,000	3,000	4,000
FY 2023	4,000	4,000	2,500
Outyears	11,000	11,000	16,680
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	43,957	43,957	26,585
FY 2021	57,500	57,500	52,558
FY 2022	53,000	53,000	69,000
FY 2023	94,000	94,000	81,500
Outyears	370,343	370,343	422,725
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 from this project to support the LCLS-II project at SLAC. The Prior Year Budget Authority in the table above reflects this reprogramming. Also in FY 2021, a total of $10,000,000 in current year and prior year funding was reprogrammed to the LCLS-II-HE project 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	35,000	**N/A**
Design - Contingency	4,000	4,000	**N/A**
Total, Design (TEC)	**39,000**	**39,000**	**N/A**
Construction	33,000	N/A	**N/A**
Site Preparation	9,000	8,000	**N/A**
Equipment	468,000	410,000	**N/A**
Other Construction	N/A	29,000	**N/A**
Construction - Contingency	79,000	142,000	**N/A**
Total, Construction (TEC)	**589,000**	**589,000**	**N/A**
Total, TEC	**628,000**	**628,000**	**N/A**
Contingency, TEC	*83,000*	*146,000*	***N/A***
Other Project Cost (OPC)			
R&D	15,000	12,000	**N/A**
Conceptual Planning	2,000	2,000	**N/A**
Conceptual Design	2,000	2,000	**N/A**
Start-up	8,000	8,000	**N/A**
OPC - Contingency	5,000	8,000	**N/A**
Total, Except D&D (OPC)	**32,000**	**32,000**	**N/A**
Total, OPC	**32,000**	**32,000**	**N/A**
Contingency, OPC	*5,000*	*8,000*	***N/A***
Total, TPC	**660,000**	**660,000**	**N/A**
Total, Contingency (TEC+OPC)	***88,000***	***154,000***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Fiscal Year	Type	Prior Years	FY 2021	FY 2022	FY 2023	Outyears	Total
FY 2019	TEC	5,000	—	—	—	295,000	300,000
	OPC	2,000	—	—	—	18,000	20,000
	TPC	7,000	—	—	—	313,000	320,000
FY 2020	TEC	50,000	—	—	—	298,000	348,000
	OPC	12,000	—	—	—	8,000	20,000
	TPC	62,000	—	—	—	306,000	368,000
FY 2021	TEC	86,000	14,000	—	—	308,000	408,000
	OPC	12,000	2,000	—	—	6,000	20,000
	TPC	98,000	16,000	—	—	314,000	428,000
FY 2022	TEC	66,657	52,000	50,000	—	459,343	628,000
	OPC	12,000	2,000	3,000	—	15,000	32,000
	TPC	78,657	54,000	53,000	—	474,343	660,000
FY 2023	TEC	73,157	55,500	50,000	90,000	359,343	628,000
	OPC	12,000	2,000	3,000	4,000	11,000	32,000
	TPC	85,157	57,500	53,000	94,000	370,343	660,000

Note:

– *In FY 2021, the Office of Science reprogrammed $19,343,211.24 of prior year funds from this project to support the LCLS-II project at SLAC. The Prior Year Budget Authority in the table above reflects this reprogramming. Also in FY 2021, a total of $10,000,000 in current year and prior year funding was reprogrammed to the LCLS-II-HE project 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 2031
Expected Useful Life	25 years
Expected Future Start of D&D of this capital asset	FY 2056

Related Funding Requirements
(dollars in thousands)

	Annual Costs		Life Cycle Costs	
	Previous Total Estimate	Current Total Estimate	Previous Total Estimate	Current Total Estimate
Operations, Maintenance and Repair	21,500	21,500	537,500	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.

8. Acquisition Approach

Based on the DOE determination at CD-1, SLAC National Accelerator Laboratory is acquiring the LCLS-II-HE project under the existing DOE Management and Operations (M&O) contract.

SLAC has completed a Conceptual Design Report for the LCLS-II-HE project and is in the preliminary design phase, 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 operating and are maintained as a SLAC-wide resource.

SLAC is partnering with other laboratories for design and procurement of key technical subsystem components. Technical system designs 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 is fully exploiting 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 are exploited fully in planning and executing LCLS-II-HE.

Biological and Environmental Research

Overview

The mission of the Biological and Environmental Research (BER) program is to support transformative science and scientific user facilities to achieve a predictive understanding of complex biological, Earth, and environmental systems for clean energy and climate innovation. 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 evidence-based climate solutions with a focus on environmental justice. 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 (including Artificial Intelligence [AI] and Machine Learning [ML]), and experimental approaches. Foundational knowledge of the structure and function of these systems underpins the ability to leverage natural processes for clean 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 seek 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 User 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 2023 Request

The FY 2023 Request for BER is $903.7 million. BER will enhance its research on climate science by:

- Expansion of 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;
- Utilizing the enhanced National Virtual Climate Laboratory (NVCL), to serve as a one stop portal to advance access to climate science and as a workforce training and outreach arm from the DOE national laboratories; and
- Continued planning for a network of climate centers, affiliated with Historically Black Colleges or Universities (HBCUs) or Minority Serving Institutions (MSIs).
- New investments in AI approaches for improving earth system predictability.

The four Bioenergy Research Centers (BRCs) will be reviewed for potential renewal and enhanced to initiate new cross-BRC collaborative research addressing clean energy challenges. BER will initiate the Energy Earthshot Research Centers (EERCs) to bring together multi-investigator, multi-disciplinary teams to remove barriers to implementation of the innovations emerging from basic science into potential solutions for technological challenges and are vital to realizing the stretch goals of the DOE Energy Earthshots. Complementing and expanding the scope of the Energy Frontier Research Centers (EFRCs) and SciDAC, aligned with both SC and the technology offices, EERCs will address key research challenges at the interface between currently supported basic research and applied research and development activities, to bridge the R&D gap. BER will also support early discovery stage research underpinning future and emerging Earthshots. BER research will also support six new activities to: 1) examine the global carbon carrying capacity of terrestrial ecosystems; 2) enhance investment in AI approaches for improving earth system predictability; 3) support the Accelerate Innovation in emerging technologies (Accelerate) initiative to develop sensors that scale from laboratory fabricated ecosystems to field ecosystems; 4) continue support for novel quantum science for biological systems and continued support of crosscutting SC QIS Research Centers; 5) expand the Biopreparedness Research Virtual Environment (BRaVE); 6) and commence activities in low carbon biodesign approaches as well as new bio-based and bioinspired materials and foundational bioenergy research underpinning new biotechnology and the bioeconomy. BER will continue a pilot project to study complex coastal estuaries, including the Chesapeake Bay, Puget Sound, and the Great Lakes.

Key elements in the FY 2023 Request include:

<u>Research</u>

- Within Genomic Sciences, in FY 2022 the BRCs will undergo a merit review for a possible 5-year renewal. Pending the successful outcome of that review, in FY 2023, the BRCs will provide new, fundamental research underpinning the production of clean energy and chemicals from sustainable biomass resources for translation of basic research results to industry. The BRCs will continue clean energy innovative research while initiating new inter-BRC collaborations to tackle complex clean energy challenges. BRaVE will provide the cyber infrastructure, computational platforms, and next generation experimental research capabilities and workflows within a single portal allowing distributed networks of scientists to work together on multidisciplinary research priorities and/or national emergency challenges. BER will invest in efforts to identify core biodesign rules translatable to energy efficient, low carbon manufacturing of functional properties of novel biological polymers. New efforts on developing lab to field sensors will complement 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 support Advanced Computing 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 complementing tools and approaches at Office of Science user facilities for predictive understanding of biological processes.
- BER will participate in the new Funding for Accelerated, Inclusive Research (FAIR) initiative to provide focused investment on enhancing biological research on clean energy, climate, and related topics at minority serving institutions, including attention to underserved and environmental justice regions. The activities will improve the capability of MSIs to perform and propose competitive research and will build beneficial relationships between MSIs and DOE national laboratories and facilities.

- 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 expand and enhance activities to utilize advanced software and AI/ML for running on future DOE computer architectures. The Data Management effort will 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 Great Lakes. Research involving field-based observing and modeling will be expanded through Urban IFLs to incorporate environmental justice as a key tenet of research involving climate-sensitive regions. Additionally, the National Virtual Climate Lab (NVCL) will be fully implemented and continue unified access to climate science to MSIs and HBCUs, connecting frontline communities with the key climate science capabilities and workforce training opportunities at the DOE national laboratories. Planning activities continue for a network of climate centers affiliated with an HBCU or MSIs; the centers will serve as the translational agents connecting BER climate science with broader socioeconomic and environmental justice issues for equitable solutions. All activities will enhance research capacity at the affiliated universities and bring interdisciplinary strength and diversity to DOE's climate research.
- BER will expand support for 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.

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 complete deployment near Houston, TX to conduct the aerosol-convection interactions experiment and then be prepared and deployed to San Diego. A second mobile unit will continue the study on water and energy cycles in mountainous watersheds. A third will begin operations in the southeastern U.S. in FY 2023. Acceptance testing and evaluation will be completed on the crewed aircraft. Research flight operations will begin in late FY 2023.
- 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 continue a multiyear instrumentation refresh to ensure these facilities are delivering the capabilities required by the scientific community.

Biological and Environmental Research
FY 2023 Research Initiatives

Biological and Environmental Research supports the following FY 2023 Research Initiatives.

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Accelerate Innovations in Emerging Technologies	–	–	5,000	+5,000
Advanced Computing	–	–	5,183	+5,183
Artificial Intelligence and Machine Learning	3,000	3,000	8,000	+5,000
Biopreparedness Research Virtual Environment (BRaVE)	–	–	14,000	+14,000
Climate Resilience Centers	–	–	5,000	+5,000
Exascale Computing	15,000	15,000	15,000	–
Fundamental Science to Transform Advanced Manufacturing	–	–	3,000	+3,000
Funding for Accelerated, Inclusive Research (FAIR)	–	–	1,935	+1,935
National Virtual Climate Laboratory (NVCL)	–	–	3,000	+3,000
Quantum Information Science	12,000	14,500	14,500	+2,500
Reaching a New Energy Sciences Workforce (RENEW)	–	–	6,000	+6,000
Revolutionizing Polymers Upcycling	6,250	6,250	6,250	–
SC Energy Earthshots	–	–	50,000	+50,000
Urban Integrated Field Laboratory	–	–	22,000	+22,000
Total, Research Initiatives	**36,250**	**38,750**	**158,868**	**+122,618**

Biological and Environmental Research
Funding

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Biological and Environmental Research				
Genomic Science	277,574	257,817	338,185	+60,611
Biomolecular Characterization and Imaging Science	45,000	45,000	45,000	–
Biological Systems Facilities & Infrastructure	80,000	84,500	85,000	+5,000
Total, Biological Systems Science	**402,574**	**387,317**	**468,185**	**+65,611**
Atmospheric System Research	36,000	35,924	39,000	+3,000
Environmental System Sciences	87,777	91,500	127,500	+39,723
Earth and Environmental Systems Modeling	100,674	100,461	118,000	+17,326
Earth and Environmental Systems Sciences Facilities and Infrastructure	125,975	137,798	151,000	+25,025
Total, Earth and Environmental Systems Sciences	**350,426**	**365,683**	**435,500**	**+85,074**
Subtotal, Biological and Environmental Research	**753,000**	**753,000**	**903,685**	**+150,685**
Total, Biological and Environmental Research	**753,000**	**753,000**	**903,685**	**+150,685**

SBIR/STTR funding:

- FY 2021 Enacted: SBIR $23,850,000 and STTR $3,352,000
- FY 2022 Annualized CR: SBIR $23,738,000 and STTR $3,339,000
- FY 2023 Request: SBIR $28,054,000 and STTR $3,945,000

Biological and Environmental Research
Explanation of Major Changes

	(dollars in thousands)
	FY 2023 Request vs FY 2021 Enacted
Biological Systems Science	**+$65,611**

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. Pending the outcome of a merit review, FY 2023 begins a five-year renewal term for the BRCs, which will provide new, fundamental research underpinning the production of clean energy and chemicals from sustainable biomass resources for translation of basic research results to industry and expand ambitious collaborative approaches to address the clean energy challenges. 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. Increased 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. The Funding for Accelerated, Inclusive Research (FAIR) initiative will provide focused investment on enhancing clean energy genomic research at minority serving institutions. New emerging technologies will develop capabilities that scale from laboratory fabricated ecosystems to field ecosystems, through the use of integrated automated sensor networks, complementing new efforts 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. Research will be enhanced for BRaVE, providing the integrated computational and experimental platforms and workflows for multidisciplinary research, and new focus on low carbon approaches for creating new bio-based and bioinspired materials. Computational Biosciences will focus on an integrated computational platform, building out the National Microbiome Data Collaborative and continuing to add functionality to the Systems Biology Knowledgebase. Development of new bioimaging, measurement and characterization approaches through the Biomolecular Characterization and Imaging Science activity will include expanded integrative imaging and analysis platforms, including using QIS materials, to understand the expression, structure, and function of genome information encoded within cells. BER will initiate the EERCs to bring together multi-investigator, multi-disciplinary teams to remove barriers to implementation of the innovations emerging from basic science into potential solutions for technological challenges and are vital to realizing the stretch goals of the DOE Energy Earthshots. Complementing and expanding the scope of the EFRCs and SciDAC, aligned with both SC and the technology offices, EERCs will address key research challenges at the interface between currently supported basic research and applied research and development activities, to bridge the R&D gap.

	(dollars in thousands)
	FY 2023 Request vs FY 2021 Enacted
Earth and Environmental Systems Sciences The Request continues to support the development of high-resolution Earth system modeling, analysis, and intercomparison capabilities focused on DOE mission needs for evidence-based energy and infrastructure resilience and security. The new Integrative Artificial Intelligence Framework for Earth System Predictability (AI4ESP) effort will motivate the radical acceleration of predictive capabilities across the DOE climate model-data-experiment enterprise, taking advantage of emerging AI techniques, such as deep learning supporting climate science. Environmental System Science will increase support of the Urban Integrated Field Sites (IFLs) providing new place-based data for informing Earth system models. Research on coastal estuaries will be continued, with a focus on the Chesapeake Bay, Puget Sound, and Great Lakes, as well as increased focus on the role of watersheds and clean water. The National Virtual Climate Laboratory (NVCL) will continue its role as a unified access point for workforce training and engagement with key climate science capabilities at the DOE labs; an enhanced RENEW will leverage the NVCL to address workforce and capacity building at under-represented institutions. Planning will continue for a new network of climate centers. 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 complete deployment to the Houston, TX area and then be redeployed to San Diego; the second unit will continue observations in the upper Colorado River watershed; and the third unit will initiate full operations in the southeastern U.S. acceptance testing and evaluation will be completed on the crewed aircraft. Research flight operations will begin in late FY 2023. EMSL will focus on biological and environmental molecular science and new technologies for molecular microbial phenotyping. Data management activities will enhance applying advanced analytics to observations and environmental field data.	**+$85,074**
Total, Biological and Environmental Research	**+$150,685**

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 energy 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
Biological Systems Science conducts fundamental genomic science on plants and microorganisms across a broad range of biological applications including biosystems design and environmental research. The portfolio also includes the development of enabling computational, analytical, and bioimaging capabilities for hypothesis-based experimental research.
New biosystems design research led to the development of the iPROBE system, a cell-free machine learning-informed framework for testing multiple biosynthetic pathways in rapid fashion. The system was used to accelerate the design of an optimized metabolic pathway for 3-hydroxybutryate production in *Clostridium* species. This new approach reduced the time needed to develop engineered strains from months to weeks and could be used to optimize pathways for a range of other compounds including biofuels and bioproducts. New microbiome research conducted as part of a 6-year prairie soil warming experiment in central Oklahoma led to the observation that soil microbial community networks grew larger, more complex, and more stable over time, providing insight into the effect of soil warming on soil microbial communities as a proxy for understanding effects under warmer climate scenarios. New multi-modal bioimaging capabilities integrating four different types of spatial and chemical measurement techniques were developed to image cells on pollen grains. The results show the importance of a multimodal approach to microscopy to image processes within complex biosystems.

Bioenergy Research Centers are focused on research to fill basic science knowledge gaps for the commercial production of biofuels and bioproducts, including sustainable production of biomass, plant feedstock development, and biomass deconstruction and conversion.

Notable accomplishments include:

- The Center for Advanced Bioenergy and Bioproduct Innovation (CABBI) engineered grasses to hyper-accumulate tri-acylglyerides (TAGs), oils that can be easily transformed to biodiesel and other specialty lubricants and compounds.
- At the Joint BioEnergy Institute (JBEI), over expression of a metabolic gene (QsuB) resulted in the over production of protocatechuate (PCA) in sorghum, an aromatic precursor to biofuel compounds and a range of other chemicals. The result is another step towards crops engineered to produce specific fuels and chemicals.
- The Center for Bioenergy Innovation (CBI) demonstrated the production of C-lignin in plants, an alternate lignin form found in seed coats. The finding is important as a potential tool to alter lignin composition in bioenergy crops to improve biofuel production.
- The Great Lakes Bioenergy Research Center (GLBRC) developed modified plants to over produce terpenoid compounds. These versatile molecules can be further converted to flavors, scents, and other commodity chemicals normally produced from petroleum.

Earth and Environmental Systems Sciences conducts research to improve the predictability of the Earth system at different scales, with particular focus on the interdependencies of the physical, biogeochemical, and human processes that govern variability, change, and the evolution of extreme climate events.

An analysis and comparison of tropical cyclone observations and computer simulations in the DOE Energy Exascale Earth System Model (E3SM) showed that improvements in high resolution model biases can alleviate errors in tropical cyclone simulations and improve predictability in Earth system models. In linking regional modeling to Earth system modeling efforts, perennial bioenergy crops were incorporated into the global Community Terrestrial System Model for the first time, enabling simulation and understanding of feedbacks among bioenergy crops and Earth system processes at local, regional, and global scales. Atmospheric researchers studied aerosols in a cloud chamber under varied water vapor concentrations and found that turbulent fluctuations led to cloud formation at much lower relative humidity levels than which occur under average steady state conditions, potentially leading to new parameterizations for Earth system models. Ecologists conducting a field warming and elevated CO_2 experiment in a high-latitude forest found increased fine-root growth, particularly in shrub vegetation, highlighting a mechanism that enables shrubs to rapidly adapt to warmer and drier conditions.

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 reference genome for the switchgrass bioenergy crop, based on the collection of 700+ switchgrass plants from 25 states, and established ten experimental switchgrass plots across 1,100 miles to enable testing of climate adaptations with switchgrass biology;
- The Environmental Molecular Sciences Laboratory (EMSL) analyzed differences in predicted and observed light absorption from atmospheric soot, and found that particle shape and composition could explain the variation in light absorption, thereby improving estimates of black carbon effects on the global radiation balance; and
- The Atmospheric Radiation Measurement (ARM) user facility used a machine learning approach to represent cloud processes at scales too small to be resolved by global climate models and succeeded with a new machine learning technique that outperformed current model formulations.

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 from a genome-based perspective to define the functional principles that drive living systems, from microbes and microbial communities to plants and other whole organisms and microbiomes. The research will pursue the fundamental science needed to understand, predict, manipulate, and design biological systems that underpin innovations for clean energy production and biotechnology and enhance our understanding of natural, DOE-relevant environmental processes needed to promote social equity and enhance response to the climate crisis.

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. These problems 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 on open access computational platforms into models that can be iteratively tested and validated to advance a predictive understanding of biological systems.

The subprogram supports the operation of the DOE Bioenergy Research Centers (BRCs) and the DOE Joint Genome Institute (JGI) scientific user facility.

Genomic Science
The Genomic Science activity supports research seeking to reveal the fundamental principles that drive biological systems relevant to DOE missions in clean energy and climate 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 decarbonized bioeconomy, understanding the role of biological systems in the environment, including carbon capture and sequestration, 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. Systems biology research on microorganisms with potential bioenergy/bioproduct-relevant traits will yield new pathways to convert plant biomass to a range of fuels, chemicals, and bioinspired products and biomaterials. Efforts in biosystems design research builds on existing genomics-based research and develops broad-based, secure gene-editing techniques in plants and microbes for a wide variety of advanced biotechnologies. Together these efforts will yield a broader range of platform organisms to be employed in a range of clean energy and biotechnology applications underpinning a more decarbonized bioeconomy. The climate related science supports new approaches and systems to support low carbon biomanufacturing, especially with respect to genome-enabled engineering and design of biomaterials, along with developing new emerging technologies and integrated automated sensors that scale from laboratory-fabricated ecosystems to field ecosystems in support of the Accelerate initiative. BER's contribution towards understanding and anticipating the convergence of advanced genome 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 Funding for Accelerated, Inclusive Research (FAIR) initiative will provide opportunities to enhance clean energy genome research at minority serving institutions, including attention to underserved and environmental justice communities.

The Energy Earthshot Research Centers (EERCs) program is a new modality of research to be launched in FY 2023, building on the success of the Energy Frontier Research Centers (EFRCs). Like the EFRCs and the Scientific Discovery through Advanced Computing (SciDAC) program, EERCs will bring together multi-investigator, multi-disciplinary teams to perform energy-relevant research with a scope and complexity beyond what is possible in standard or small-group awards. Complementing and expanding the scope of the EFRCs and SciDAC, aligned with both SC and the energy technology offices, EERCs will address key research challenges at the interface between currently supported basic research and applied research and development activities, to bridge the R&D gap. These challenges are barriers to implementation of the innovations emerging from basic science into potential solutions for technological challenges and are vital to realizing the stretch goals of the DOE Energy Earthshots. EERCs' team awards will entail collaboration involving academic, national laboratories, and industrial researchers with SC and the DOE technology offices, establishing a new era of cross-office research cooperation. BER funding will focus efforts directly at the interface, ensuring that directed biological fundamental research and capabilities at SC user facilities tackle the most challenging barriers identified in the applied research and development activities.

Existing DOE Energy Earthshots include the Hydrogen Shot, the Long Duration Storage Shot, and the Carbon Negative Shot. Additional topics are under consideration for future announcements. From a science perspective, many research gaps for the Energy Earthshots crosscut all topics and will provide a foundation for other energy technology challenges, including biotechnology, critical minerals/materials, energy-water, subsurface science (including geothermal research), and materials and chemical processes under extreme conditions for nuclear applications. These gaps require multiscale computational and modeling tools, new artificial intelligence and machine learning technologies, real-time characterization, including in extreme environments, and development of the scientific base to co-design processes and systems rather than individual materials, chemistries, and components. EERCs will leverage individual Center research to cross-fertilize the ideas that emerge in one topical area to benefit others with similar challenges—accelerating the science, as well as the technologies.

Biopreparedness Research Virtual Environment (BRaVE) will continue to 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 challenges and provide a ready resource to quickly address urgent national emergencies as 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/or sequestration 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 Advanced Computing initiative.

The 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 sustainable innovative processes for clean bioenergy and a range of bioproducts from inedible cellulosic biomass supporting a more decarbonized bioeconomy. Research will accelerate genome engineering, using AI/ML techniques, in plants and microbes to expand the range of products that can be produced from sustainable plant biomass, expand understanding of plant-microbe interactions to inform better agronomic practices for clean bioenergy production, develop new plant varieties with expanded capabilities for sustainable product production and increased collaboration among the broader research community including Historically Black Colleges and Universities (HBCUs) and within rural communities where new crop-based clean energy and bioproduct production could spark new industries and bioeconomic development.

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 activity will enable development of new multimodal 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 includes efforts in QIS-enabled concepts for imaging and to advance design of sensors and detectors based on correlated materials, 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 sequester 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 and the NMDC. Related efforts use genomic information to infer natural product production from microorganisms and plants. These advanced capabilities are part of the DOE JGI 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 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Biological Systems Science	**$402,574**	**$468,185**	**+$65,611**
Genomic Science	$277,574	$338,185	+$60,611
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 research on microorganisms with advantageous bioenergy and bioproduct traits. Biosystems design research will accelerate the ability to design plants and microorganisms with specific beneficial low carbon clean energy, bioproduct and biomaterials production traits. New efforts will support emerging technologies to develop integrated automated sensors that scale from laboratory fabricated ecosystems to field ecosystems as part of the new Accelerate initiative.	Funding increase will support new research on microorganisms with clean energy and bio-inspired bioproduct-relevant traits to broaden the range of platform organisms available for biotechnology use, for cross-cutting goals supporting a more decarbonized bioeconomy and the Carbon Negative Earthshot. To support Accelerate, new emerging technologies will integrate *in situ* sensors, imaging, Omics analysis, and autonomous controls and continuous data acquisition and analysis. New funds support genome science opportunities at MSIs.

(dollars in thousands)

FY 2021 Enacted	FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
	BER will launch Energy Earthshot Research Centers to address key biological research challenges at the interface between currently supported basic research and applied research and development activities. Environmental Genomics will continue plant functional genomics research to understand genotype to phenotype translations leading to beneficial bioenergy or bioproduct traits in potential bioenergy crops. Environmental microbiome science continues efforts to understand the functions of environmentally relevant microbial communities in a variety of ecosystems. The Biopreparedness Research Virtual Environment (BRaVE) will expand to build out a computational platform and experimental workflow through which a distributed network of data and experimental capabilities can be accessed by multidisciplinary teams of scientists working together on urgent multiprogram priorities. The Funding for Accelerated, Inclusive Research (FAIR) initiative strengthens clean energy genomic research at minority serving institutions, building partnerships with the DOE national labs.	

(dollars in thousands)

FY 2021 Enacted	FY 2023 Request	Explanation of Changes FY 2023 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 research efforts within Genomic Science by providing bioinformatics, simulation and modeling capabilities through the KBase platform and within the NMDC. Both platforms will continue integrative activities among each other within the Advanced Computing Initiative and with the JGI.	Funding will support continued development of new analysis capabilities within KBase and NMDC for genomic science supporting clean energy research towards a more decarbonized bioeconomy. The activity will also support the Advanced Computing initiative.
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 undergo a FY 2022 merit review for a possible 5-year renewal to support multidisciplinary clean energy research underpinning a broader bio-based economy. The renewal will allow the BRCs to broaden their collaborative activities to accelerate plant and microbial genome engineering with AI/ML techniques to diversify the range of products that can be sustainably produced from plant biomass, expand understanding of plant-microbe interactions to create better agronomic practices for clean bioenergy production, develop new plant varieties with expanded capabilities for biofuels and bioproduct production and increase collaboration among the broader research community (including HBCUs) and within rural communities where new crop-based clean energy and bioproduct production could spark new industries and bioeconomy development.	If renewed, the four BRCs will expand their collaborative activities to accelerate genome engineering for plants and microbes, expand sustainability research through research on plant-microbe interactions, develop new plant varieties with an expanded range of biofuels and bioproducts, and engage a broader spectrum of the research community (including HBCUs) and rural communities where this research could lead to new bioeconomy opportunities.

(dollars in thousands)

FY 2021 Enacted	FY 2023 Request	Explanation of Changes FY 2023 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 multimodal bioimaging research will provide new capabilities to characterize, measure, visualize and test hypotheses on plant and microbial cell function and metabolism. Quantum-enabled science concepts for imaging techniques will continue.	No change.
Biological Systems Facilities & Infrastructure $80,000	$85,000	+$5,000
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 sequences and new analysis techniques for complex plant and microbiome samples. Integrative activities with KBase and the NMDC will provide new cross-platform capabilities for users. Genome-based discovery efforts for natural product production in microbial isolates continues in concert with expanded metagenomics analysis techniques. The multi-year instrument and equipment refresh will continue at a reduced pace to support the integrative activities with KBase and the NMDC.	Funding will support expanded integrative efforts with KBase and the NMDC to provide new analysis capabilities for microbiome science. The continuing instrument and equipment refresh will be slowed to support the expanded integrative activities with KBase and the NMDC.

Note:

- *Funding for the subprogram above, includes 3.65 percent 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 oceanic and Great Lakes systems; 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 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 increasing opportunities provided by machine learning (ML) and emerging technologies. The research will pursue the fundamental scientific understanding necessary to inform the design, development, financing, and deployment pathways of climate friendly technical solutions that promote social equity and enhance urban resilience in response to the climate crisis.

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) 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 to improve scientific understanding of atmospheric and climate processes involving clouds, aerosols, precipitation, 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.

Atmospheric System Research
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 provide three-dimensional measurements of a variety of aerosol types that includes natural, brown, and black carbon; cloud, aerosols, and precipitation microphysics under a variety of dynamical conditions; and turbulence and convection over a range of spatially varying environmental and thermodynamical 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 that limit the predictability of atmospheric processes, properties, and dynamical evolution. Using integrated, scalable testbeds 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.

Environmental System Sciences
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, clean water, environmental stewardship and identifying equitable solutions to the Nation's most vulnerable communities. 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.

Research activities will expand place-based Urban Integrated Field Laboratories (IFLs) in support of climate science. The Urban IFLs are 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 that can be deployed to urban and suburban regions; and addressing environmental justice by enabling neighborhood scale evaluation of climate impacts and energy needs. The Urban IFL scope targets a greater set of urban regions, integrates field data within a next generation Earth System Modeling framework, and creates a science capability to advance climate and energy research as a unified co-dependent system. The enhanced 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.

BER will continue support for 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. The National Virtual Climate Laboratory (NVCL) will continue to provide greater access to climate science to Historically Black Colleges and Universities (HBCUs), Tribal Colleges and Universities (TCUs), Hispanic Serving Institutions (HSIs), and other Minority Serving Institutions (MSIs), connecting frontline communities with the key climate science capabilities at the DOE national laboratories. A network of climate centers that are affiliated with MSIs will complete planning, with a focus on developing climate resilience solutions that can be deployed to America's communities.

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 new Integrative Artificial Intelligence Framework for Earth System Predictability (AI4ESP) effort will motivate the radical acceleration of predictive capabilities across the DOE climate model-data-experiment enterprise, taking advantage of emerging AI and unsupervised learning techniques, 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 computationally efficient model adaptable to DOE's Leadership Computing Facility supercomputer architectures (including Exascale computational systems), with greater sophistication and fidelity for high resolution simulation of extreme phenomena and complex processes in heterogeneous landscapes. 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 and environmental justice. New modeling efforts will support emerging Earthshot topics.

Earth and Environmental Systems Sciences Facilities and Infrastructure

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

ARM is a multi-laboratory, multi-platform, multi-site, national scientific user facility, providing the world's most comprehensive, continuous, and precise observations of clouds, aerosols, 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 2023, ARM will continue operations at the three fixed sites. One mobile facility will complete deployment to the Houston, TX area for Tracking Aerosol Convection Interactions Experiment (TRACER), where scientists are using a sophisticated precipitation radar together with radiosonde and aerosol measurements to learn more about cloud and aerosol interactions in deep convection, and then be prepared and deployed to San Diego. 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 in the activity called Surface Atmosphere Integrated Field Laboratory (SAIL). The third mobile unit will complete its installation at a site in the southeastern U.S. with long term 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 uncrewed aerial system (UAS) and crewed aircraft. Acceptance testing and evaluation on the crewed 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 late 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. Enhanced research across the Earth and Environmental Systems Sciences portfolio that involves hybrid capabilities based on the combination of physics-based and machine learning and artificial intelligence research will further these objectives.

The BER Data Management activity will focus efforts on archiving scientifically useful data from the Earth System Grid Federation, 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 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Earth and Environmental Systems Sciences	**$350,426**	**$435,500**	**+$85,074**
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 continue 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 data from the TRACER and SAIL campaigns. ASR will continue to make use of data generated by Large Eddy Simulations at the ARM Oklahoma site.	The continuing research will focus on using the new observations from ARM field studies including the FY 2020 Arctic campaign and initial TRACER and SAIL data to inform Earth system model development.

(dollars in thousands)

FY 2021 Enacted	FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Environmental System Sciences $87,777	$127,500	+$39,723
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 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) expand to support climate science. The National Virtual Climate Lab (NVCL) will be fully implemented and continue to provide access to the single portal to DOE lab climate capabilities. Planning will continue for a network of climate centers focused on resilience. The Request also expands support for RENEW to provide undergraduate and graduate training opportunities for students and academic institutions not currently well represented in the U.S. S&T ecosystem.	Funding will continue investments in field experiments and process modeling activities associated with the terrestrial-aquatic project located in the mid-Atlantic, Great Lakes, and Puget Sound, and will support new observations, enhanced modeling, and data-model synthesis, along with focused efforts to understand the role that watersheds play in providing clean water. The Urban IFLs will target an increased 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. Also, funding will support climate science and the continuation of the NVCL that will provide access through a single portal to partner the capabilities at the DOE national laboratories with key stakeholders from underrepresented and impacted communities through training and outreach for equitable climate resilience solutions. Funding also supports the RENEW initiative through engagement with the NVCL.

(dollars in thousands)

FY 2021 Enacted	FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Earth and Environmental Systems Modeling $100,674	$118,000	+$17,326
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 more advanced exascale computing architectures. The E3SM version 2 will begin to incorporate AI and unsupervised learning capabilities and enable more sophisticated research based on higher model resolution, through the Integrative Artificial Intelligence Framework for Earth System Predictability (AI4ESP). 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 also supports foundational modeling in support of Energy Earthshot topics.	Funding will continue 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. The Integrative Artificial Intelligence Framework for Earth System Predictability (AI4ESP) activity will feature development of novel approaches for automated feature detection and unsupervised learning techniques in heterogeneous multi-scale laboratory and field data; data quality validation; edge computing; nonlinear and multiscale data assimilation methodologies; model parameter estimation; and hybrid prediction model architectures that combine physics with AI/ML across multiple aspects of climate models. New investments also support earth system modeling underpinning emerging Earthshot topics including energy-water.
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), mid-latitude-Arctic interactions, and high-resolution studies of urban and urban-rural transition regions.	Funding will continue to support research with a shift in emphasis from the science of Arctic-midlatitude interactions to examine heterogeneous and boundary regions that also include urban regions as well as coastal zones that encompass the mid-Atlantic, the Great Lakes, and Puget Sound.

(dollars in thousands)

FY 2021 Enacted	FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Earth and Environmental Systems Sciences Facilities and Infrastructure $125,975	$151,000	+$25,025
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 complete installation and begin operations at a location in the southeastern U.S. The Request prioritizes all ARM activities for critical observations needed to improve the E3SM model. ARM will continue deployment of its second mobile facility to Colorado; and it will prepare and deploy its first mobile facility to San Diego. Scientists will use the precipitation radars together with sophisticated meteorological instrumentation to learn more about cloud and aerosol interactions in a variety of geographic domains, including 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. The ARM support for the Urban IFL for climate science will continue as well as continue a multi-year instrumentation refresh.	Funding will support ARM site operations, and a mobile facility will continue its deployment to the Colorado Rockies. A second mobile facility will be prepared for and deployed to a new field campaign in San Diego. The aerial facility will be available for research in FY 2023.
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 emphasize new science that requires combinations of advanced technologies, such as mass spectrometry, live cell imaging, Quiet Wing, Dynamic Transmission Electron Microscopy, and high-performance computing. Planning for a multi-year instrumentation refresh continues, including a microbial molecular phenotyping capability.	Funding will promote multi-disciplinary science using various combinations of EMSL's most sophisticated instrumentation.

(dollars in thousands)

FY 2021 Enacted	FY 2023 Request	Explanation of Changes FY 2023 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 enhance support to maintain existing and new 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 using machine learning to advance scientific insight based on the fusion of model generated and observed data.

Note:
- *Funding for the subprogram above, includes 3.65 percent 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 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Capital Operating Expenses						
Capital Equipment	N/A	N/A	7,700	11,200	21,000	+13,300
Total, Capital Operating Expenses	**N/A**	**N/A**	**7,700**	**11,200**	**21,000**	**+13,300**

Capital Equipment

(dollars in thousands)

	Total	Prior Years	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Capital Equipment						
Total, Non-MIE Capital Equipment	N/A	N/A	7,700	11,200	21,000	+13,300
Total, Capital Equipment	**N/A**	**N/A**	**7,700**	**11,200**	**21,000**	**+13,300**

Biological and Environmental Research
Funding Summary

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Research	571,089	555,432	708,185	+137,096
Facility Operations	181,911	197,568	195,500	+13,589
Total, Biological and Environmental Research	**753,000**	**753,000**	**903,685**	**+150,685**

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 2021 Enacted	FY 2021 Current	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Scientific User Facilities - Type B					
Environmental Molecular Sciences Laboratory	**45,000**	**43,054**	**53,000**	**53,000**	**+8,000**
Number of Users	525	801	850	850	+325
Joint Genome Institute	**80,000**	**77,117**	**84,500**	**85,000**	**+5,000**
Number of Users	1,550	2,180	2,200	2,200	+650
Atmospheric Radiation Measurement Research Facility	**72,672**	**70,110**	**75,798**	**87,000**	**+14,328**
Number of Users	900	960	975	1,010	+110
Total, Facilities	**197,672**	**190,281**	**213,298**	**225,000**	**+27,328**
Number of Users	2,975	3,941	4,025	4,060	+1,085

Biological and Environmental Research
Scientific Employment

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Number of Permanent Ph.Ds (FTEs)	1,510	1,510	1,740	+230
Number of Postdoctoral Associates (FTEs)	375	375	450	+75
Number of Graduate Students (FTEs)	530	530	640	+110
Number of Other Scientific Employment (FTEs)	375	375	430	+55
Total Scientific Employment (FTEs)	**2,790**	**2,790**	**3,260**	**+470**

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. To achieve its mission, FES strives to develop a well-trained STEM workforce, guided by the principles of diversity, equity, and inclusion.

Importantly, high-temperature laboratory fusion plasmas at hundreds of millions of degrees are being exploited to become the basis for a future clean energy source. Once developed, fusion will provide a clean energy source well-suited for on-demand, dispatchable electricity production, supplementing intermittent renewables and fission. Energy from fusion will be carbon-free, inherently safe, with a virtually limitless fuel supply, and without the production of long-lived radioactive waste. Developing fusion energy is the motivation for the FES subprograms focused on study of the "burning plasma" state of matter, for which self-heating from fusion reactions exceeds external heating and leads to net energy production.

The frontier area of high-power, long-pulse 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. The DIII-D National Fusion Facility and the National Spherical Torus Experiment-Upgrade (NSTX-U) are world-leading Office of Science (SC) user facilities for experimental research, used by scientists from national laboratories, universities, and industry research groups, to optimize magnetic confinement regimes. Partnerships with the emerging fusion private sector could potentially shorten the time for developing fusion energy by combining efforts to resolve common scientific and technological challenges; along with the Innovation Network for Fusion Energy (INFUSE) voucher program, FES will initiate a milestone-based cost-share fusion enterprise program. In addition, FES will initiate an inertial fusion energy science and technology program.

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. FES supports several Scientific Discovery through Advanced Computing (SciDAC) centers, in partnership with the Advanced Scientific Computing Research (ASCR) program. U.S. scientists use international partnerships to conduct research on overseas tokamaks and stellarators with unique capabilities. The development of novel materials that can withstand enormous heat and neutron exposure is important for fusion and the design basis for a fusion pilot plant (FPP).

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. Plasma science is wide-ranging, with various types of plasma comprising 99 percent of the visible universe. Practical applications of plasmas are found in microelectronics fabrication, nanomaterial synthesis, and space weather forecasting. 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 economic and societal impact.

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 advanced computing.

Decisions about the direction of the FES program and its activities are informed by the recent strategic plan "Powering the Future: Fusion and Plasmas"[ff] from the Fusion Energy Sciences Advisory Committee (FESAC), as well as reports from the National Academies of Sciences, Engineering, and Medicine (NASEM) and community workshops. Specific projects are selected through rigorous peer review and the application of validated standards.

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

Highlights of the FY 2023 Request

The FY 2023 Request is $723.2 million. The Request is aligned with recommendations in the recent FESAC Long-Range Plan (LRP), including addressing science and technology needs for the design basis of an FPP. Key elements in the FY 2023 Request include:

<u>Research</u>

- DIII-D research: Evaluate negative triangularity as an integrated reactor scenario, mitigate drift effects in small angle slot divertor, map the operational space of the ITER Baseline Scenario, and validate plasma stability limits in high beta discharges.
- NSTX-U research: Support focused efforts on plasma startup and initial machine commissioning, along with collaborative research at other facilities for addressing program priorities.
- Partnerships with private fusion efforts: Expand public-private partnerships in critical fusion research areas by establishing a new milestone-based cost-share program and continuing the INFUSE program.
- Inertial fusion energy: Establish a new program to develop the scientific foundation and technologies that could facilitate the transition from laboratory inertial confinement fusion experiments to inertial fusion energy.
- Enabling technology, fusion nuclear science, and materials: Support research on high-temperature superconductors, materials, blanket/fuel cycle research, and advanced manufacturing.
- Scientific Discovery through Advanced Computing: Continue development of an integrated simulation capability, expanding it from whole-device to whole-facility modeling, in partnership with the ASCR program under SciDAC.
- 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 and AI/ML: Support the National Quantum Initiative, including the SC National QIS Research Centers (NQISRCs), along with a core research portfolio to advance developments in QIS and related technology. Enhance support of AI/ML activities for fusion and discovery plasma science.
- ITER research: Continue support for a national team for ITER research to ensure the U.S. fusion community takes full advantage of ITER research operations.
- Future Facilities Studies: Enhance the future facilities studies activity to address one of the highest-priority recommendations in the FESAC LRP for the design of an FPP.
- Reaching a New Energy Sciences Workforce (RENEW): Enhance support for 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.
- Funding for Accelerated, Inclusive Research (FAIR): The FAIR initiative will provide focused investment on enhancing research on clean energy, climate, and related topics at minority serving institutions (MSIs), including attention to underserved and environmental justice regions. The activities will improve the capability of MSIs to perform and propose competitive research and will build beneficial relationships between MSIs and DOE national laboratories and facilities.
- Accelerate Innovations in Emerging Technologies (Accelerate): The Accelerate initiative will support scientific research to accelerate the transition of science advances to energy technologies. The goal is to drive scientific discovery to sustainable production of new technologies across the innovation continuum, to provide experiences in working across this continuum for the workforce needed for industries of the future, and to meet the nation's needs for abundant clean energy, a sustainable environment, and national security.

<u>Facility Operations</u>

- DIII-D operations: Support 22 weeks of facility operations, representing 90 percent of the optimal run time, and complete ongoing machine and infrastructure refurbishments and improvements.
- NSTX-U recovery and operations: Continue the recovery and repair activities. NSTX-U Operations will support machine assembly and hardware commissioning.

Projects

- U.S. hardware development and delivery to ITER: Support the continued design, fabrication, and delivery of U.S. in-kind hardware systems, including the continued fabrication and delivery of the Central Solenoid magnet system. Other U.S. contributed hardware systems include tokamak cooling water, tokamak exhaust processing, electron and ion heating transmission lines, diagnostics, tokamak fueling, disruption mitigation, vacuum auxiliary, and roughing pumps.
- Petawatt laser facility upgrade for HEDLP science: Support design activities for a world-leading upgrade to the Matter in Extreme Conditions (MEC) instrument on the Linac Coherent Light Source-II (LCLS-II) facility at SLAC. MEC-U scope includes a new underground experimental facility, two experimental target chambers, petawatt and kilo-joule lasers, facility access tunnel, and support building with control room.
- Major Item of Equipment (MIE) project for plasma-material interaction research: Continue to support the Material Plasma Exposure eXperiment (MPEX) MIE project in executing the approved performance baseline and continuation of approved long-lead procurements. MPEX scope includes the design, fabrication, installation, and commissioning of the MPEX linear plasma device, and associated facility modification and reconfiguration.

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 2023 Research Initiatives.

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Accelerate Innovations in Emerging Technologies	–	–	6,000	+6,000
Advanced Computing	–	–	2,000	+2,000
Artificial Intelligence and Machine Learning	7,000	7,000	11,000	+4,000
Fundamental Science to Transform Advanced Manufacturing	–	–	3,000	+3,000
Funding for Accelerated, Inclusive Research (FAIR)	–	–	2,000	+2,000
Microelectronics	5,000	5,000	5,000	–
Quantum Information Science	9,520	10,000	10,000	+480
Reaching a New Energy Sciences Workforce (RENEW)	–	–	6,000	+6,000
Total, Research Initiatives	**21,520**	**22,000**	**45,000**	**+23,480**

Fusion Energy Sciences
Funding

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Fusion Energy Sciences				
Advanced Tokamak	127,038	127,868	127,122	+84
Spherical Tokamak	104,331	104,331	101,100	-3,231
Theory & Simulation	42,000	49,000	51,000	+9,000
GPP/GPE Infrastructure	2,640	2,640	1,500	-1,140
Public-Private Partnerships	5,000	6,000	32,000	+27,000
Artificial Intelligence and Machine Learning	7,000	7,000	11,000	+4,000
Inertial Fusion Energy (IFE)	–	–	3,000	+3,000
Total, Burning Plasma Science: Foundations	**288,009**	**296,839**	**326,722**	**+38,713**
Long Pulse: Tokamak	15,000	15,000	15,000	–
Long Pulse: Stellarators	8,500	8,500	7,500	-1,000
Materials & Fusion Nuclear Science	49,000	57,410	54,500	+5,500
Future Facilities Studies	–	3,000	4,000	+4,000
Total, Burning Plasma Science: Long Pulse	**72,500**	**83,910**	**81,000**	**+8,500**
ITER Research	–	2,000	2,000	+2,000
Total, Burning Plasma Science: High Power	**–**	**2,000**	**2,000**	**+2,000**

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Plasma Science and Technology	32,700	40,000	37,000	+4,300
Measurement Innovation	3,000	3,000	3,000	–
Quantum Information Science (QIS)	9,520	10,000	10,000	+480
Advanced Microelectronics	5,000	5,000	5,000	–
Other FES Research	4,271	5,251	3,500	-771
Reaching a New Energy Sciences Workforce	–	–	6,000	+6,000
FES-Funding for Accelerated, Inclusive Research (FAIR)	–	–	2,000	+2,000
FES-Accelerate Innovations in Emerging Technologies	–	–	6,000	+6,000
Total, Discovery Plasma Science	**54,491**	**63,251**	**72,500**	**+18,009**
Subtotal, Fusion Energy Sciences	**415,000**	**446,000**	**482,222**	**+67,222**
Construction				
20-SC-61, Matter in Extreme Conditions (MEC) Petawatt Upgrade, SLAC	15,000	5,000	1,000	-14,000
14-SC-60, U.S. Contributions to ITER	242,000	221,000	240,000	-2,000
Subtotal, Construction	**257,000**	**226,000**	**241,000**	**-16,000**
Total, Fusion Energy Sciences	**672,000**	**672,000**	**723,222**	**+51,222**

SBIR/STTR funding:

- FY 2021 Enacted: SBIR $12,352,000 and STTR $1,740,000
- FY 2022 Annualized CR: SBIR $13,216,000 and STTR $1,863,000
- FY 2023 Request: SBIR $14,487,000 and STTR $2,036,000

Fusion Energy Sciences
Explanation of Major Changes

	(dollars in thousands) FY 2023 Request vs FY 2021 Enacted
Burning Plasma Science: Foundations The Request for DIII-D will support 22 weeks of research operations which is 90 percent of the optimal run time, as well as completion of facility enhancements to maintain the world-leading status of the facility. Funding for the NSTX-U program will support the recovery activities and maintain collaborative research at other facilities to support NSTX-U research program priorities. A new milestone-based cost-share program with private fusion industry will be initiated, as well as a new research program in inertial fusion energy science and technology. SciDAC will maintain emphasis on whole-facility modeling. 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.	**+38,713**
Burning Plasma Science: Long Pulse The Request will continue to provide support for high-priority international collaboration activities, both for tokamaks and stellarators. Materials research and fusion nuclear science research programs are focused on high priorities, such as advanced plasma-facing and structural materials and also blanket and fuel cycle research. The Request supports construction activities for the MPEX MIE project and continues long-lead procurements; the reduction in funding is consistent with the MPEX project CD-1 approved cost range. The Request continues support for a Future Facilities Studies program to address one of the highest recommendations in the FESAC LRP for the design of an FPP.	**+8,500**
Burning Plasma Science: High Power The Request will continue support for establishing an ITER Research program to prepare the U.S. fusion community to take full advantage of ITER research operations.	**+$2,000**

	(dollars in thousands) FY 2023 Request vs FY 2021 Enacted
Discovery Plasma Science For General Plasma Science, the Request will emphasize 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, 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 National QIS Research Centers (NQISRCs) established in FY 2020 and the core research portfolio stewarded by FES. Support for the SC initiative on advanced microelectronics will continue. The RENEW initiative will increase to provide undergraduate and graduate training opportunities for students and academic institutions under-represented in the U.S. S&T ecosystem, in alignment with a recommendation in the FESAC LRP. This subprogram will also support the FAIR initiative to enhance research on clean energy, climate, and related topics at Minority Serving Institutions, including attention to underserved and environmental justice communities; and the Accelerate initiative to support scientific research to accelerate the transition of science advances to energy technologies.	**+18,009**
Construction FES will continue to support design activities for a world-leading upgrade to the MEC facility. The U.S. Contributions to ITER project will continue design, fabrication, and delivery of First Plasma hardware, including continued fabrication and delivery of the central solenoid superconducting magnet modules. The Request supports funding for construction financial contributions to the ITER Organization.	**-16,000**
Total, Fusion Energy Sciences	**+51,222**

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 manages a joint program with NNSA in HEDLP physics and continues to support awards under joint solicitations with the Advanced Research Projects Agency-Energy (ARPA-E). 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
Disruption and runaway electron mitigation techniques advanced through coupled experiment and theory collaborations.
U.S. researchers are developing new control methods to ensure safe operation of tokamaks. One method deployed on the DIII-D National Fusion Facility uses boron-filled diamond shell pellets to quickly cool, or quench, the plasma. Quenching is often done by injecting a large quantity of a gas or a cryogenically frozen solid into the plasma, cooling it from the outside and releasing the confined heat outward. The new approach reverses the process by cooling the inner plasma first, so that the released heat is still trapped by the outer plasma regions as it is converted to light. New simulations that reproduce DIII-D results show that under the right conditions the outer edge of the magnetized plasma continues to confine heat until nearly all the heat in the plasma core is converted, thereby protecting the outer wall. A second method studied on DIII-D and the Joint European torus in the U.K. involves injection of cryogenically frozen deuterium into high energy runaway electron beams, triggering a plasma instability that reduces confinement of the electrons and allows benign plasma termination. New data from DIII-D and JET are being used to explore whether this approach can potentially solve one of the major issues of future reactors based on the tokamak.

U.S. researchers are keeping it cool.
One challenge facing tokamaks is how to keep the plasma core hot enough that fusion can occur while maintaining low edge temperatures, so the tokamak walls do not melt. For the first time, impurity radiation was used in DIII-D's new small angle slot divertor to reduce exhaust heat, a process known as divertor detachment. Researchers performed the first simultaneous observation of plasma cooling without degrading plasma performance. In related work, the same advanced divertor control algorithm was used to sustain plasmas with excellent core confinement by integrating divertor detachment with an additional internal transport barrier further inside the plasma. When the injected radiative gases dissipate heat and cool the edge plasma, this tends to further reduce turbulence, and isolation the high-temperature core from the walls. This internal transport barrier is created by tailoring the shape of the plasma current in a way that is known to reduce plasma turbulence.

Gain in the fast lane: fast-ion confinement improved in advanced tokamak scenarios.
A key ingredient to any fusion reactor is the ability to keep energetic ions in the plasma, since these particles undergo fusion reactions more readily and also keep the plasma hot. However, too many fast ions in the core of the plasma can trigger instabilities that cause fast ions to move out from the core, similar to how a sandpile cannot become too steep. In DIII-D, advanced tokamak experiments have utilized the upgraded neutral beam injection (NBI) system to double the amount of NBI power that can be injected off-axis. This distributes the fast-ions more evenly across the plasma, enabling improved fast-ion confinement and plasma performance. New experiments using the combination of off-axis beam power and an electron cyclotron current drive resulted in increased measured neutron counts from approximately 70 percent of the classically predicted rates with on-axis NBI to 95 percent using off-axis NBI. This demonstrates improved fast-ion confinement and shows that it is possible to use flexible control tools to optimize the advanced tokamak scenarios envisioned for compact fusion power plants and ITER's peak performance goals.

High-performance computing and AI/ML help develop a predictive formulation for the heat-flux width in tokamaks.
Predicting the width of the narrow channel through which the power produced in the core plasma is exhausted to the material surfaces is a critical issue for ITER and future fusion reactors. The heat-flux width determines whether the plasma

facing components (PFCs), including the divertor plates, can survive the extreme heat fluxes anticipated in reactor-grade plasmas which can be comparable to the heat fluxes in rocket nozzles and spacecrafts during reentry. While several formulas for the heat-flux width exist, they predict very narrow widths for ITER raising concerns about whether the PFCs would fail prematurely. Large-scale simulations performed by a PPPL-led multi-institutional SciDAC team on the SC leadership computing facilities showed that when turbulence effects are properly considered, the resulting heat-flux width is much larger, relaxing the constraints on the PFCs. However, these extreme-scale simulations are computationally expensive. The SciDAC researchers used AI/ML techniques and large datasets from their first-principles simulations to develop a physics-informed surrogate formula that reproduces the heat-flux widths observed in the present tokamaks and the predicted heat-flux width on ITER. This capability will be invaluable for ITER and for the design of future fusion reactors, including the FPP.

SNAP Machine Learning Interatomic Potential Reproduces Key Hydrogen Surface Interactions.
Researchers at Sandia National Laboratories, University of Tennessee, and Los Alamos National Laboratory have developed new a machine-learned interatomic potential for studying plasma interactions with fusion reactor materials using atomistic modeling. Previously, spectral neighbor analysis potentials (SNAP) have been successfully developed to study beryllium interactions with tungsten surfaces. This work has now been extended to hydrogen, which makes up most of the plasma impinging on the divertor surface. The new potential was trained to handle a range of surface environments and reproduces the adsorption energies and surface diffusion barriers, as compared to density functional theory for low energy crystallographic orientations. Understanding both the microstructural changes caused by hydrogen and the retention of hydrogen in the divertor is critical for designing future divertor materials and machine learning methods are an enabling technology to accelerate atomistic simulations of these processes.

Super-X divertors in spherical tokamaks can really take the heat.
For the first time, a Super-X divertor has been experimentally realized in the Mega Ampere Spherical Tokamak-Upgrade (MAST-U) at the Culham Centre for Fusion Energy in the UK. The idea for this technology originated with U.S. scientists at the University of Texas - Austin, where theorists showed that specially shaped magnetic fields can expand the area that hot plasma exhaust strikes, thereby reducing the heat absorbed by the surrounding materials. In fusion, where the generated internal plasma temperatures are hotter than the core of the sun, reducing the exhausted heat in a way that does not vaporize the surrounding materials of the reactor is essential. These initial MAST-U results showed that a Super-X divertor can reduce this material heat loading by more than a factor of ten, which may prove sufficient for future fusion power plant designs.

Continuous Cryogenic Pellet-Fueling System for Wendelstein 7-X Shows Promise.
Continuous injection of cryogenic deuterium-hydrogen pellets is required on the German stellarator, Wendelstein 7-X (W7-X), to maintain reactor-like plasma densities and enhanced confinement in long-pulse operation. W7-X is designed to sustain high-performance plasmas for up to 30 minutes. Exploratory experiments on W7-X demonstrated that the injection of 50, 2-mm hydrogen pellets at a velocity of 200 m/s could sustain a high-density plasma heated with 5 MW of microwave power with electrons and ions at temperatures of about 3 keV for about a second. Physics analysis shows that these pellet-fueled plasmas have reduced turbulent transport, which improves the plasma energy confinement. A U.S- led international team is now constructing a continuous, high-speed pellet system to fuel W7-X plasmas in quasi steady-state conditions with plasma experiments starting in 2022.

The Material Plasma Exposure eXperiment (MPEX) Project receives approval to begin Long-Lead Procurements.
The scientific demonstration of magnetic fusion energy as an environmentally sustainable and economically competitive energy source will require mastering of materials science issues associated with the plasma-material interface. The MPEX Project will deliver a world leading capability enabling the testing of plasma-facing materials and components under reactor-relevant plasma loading conditions. As part of the tailoring strategy, the MPEX project is utilizing long-lead procurements which are necessary to ensure the timely, cost-effective delivery of the MPEX work scope while minimizing overall project risk. These long-lead procurements include six superconducting and one resistive magnet subsystems, two gyrotrons, a high voltage power supply, and facility reconfiguration and enhancements, totaling $44.6M in cost. The MPEX project received formal Approval of Long-Lead Procurements (CD-3A) on October 29th, 2020, a major milestone for the project.

FES and ARPA-E collaboration on Fusion Technology R&D
The Department of Energy's Advanced Research Projects Agency-Energy (ARPA-E) and FES oversaw the issuance of a joint solicitation aimed at supporting innovative R&D on a range of fusion enabling technologies. The program, known as Galvanizing Advances in Market-aligned fusion for an Overabundance of Watts (GAMOW) prioritized R&D in 1) technologies and subsystems between the fusion plasma and balance of plant, 2) cost-effective, high-efficiency, high-duty-cycle driver technologies, and 3) cross-cutting areas such as novel fusion materials and advanced and additive manufacturing for fusion-relevant materials and components. The program was aimed at bridging the gap in traditional mission spaces of FES and ARPA-E, where applicants were encouraged to leverage and build on foundational SC-FES research programs while ensuring that market-aware techno-economic analyses informed project goals consistent with ARPA-E directives. The joint program made 14 awards with an execution period over the next three years and a total funding of $30M, equally shared between the two programs.

Researchers offer a new definitive test to explain auroras.
The shimmering displays of the aurora borealis have always fascinated humankind, but a demonstration of how auroral electrons are accelerated down towards the Earth where collisions with molecules in the thin upper atmosphere cause the emission of auroral light has remained elusive. According to theory, Alfvén waves accelerate electrons toward Earth, causing them to precipitate and produce auroras. Although space-based measurements provide strong support of this theory, limitations inherent to spacecraft and rocket measurements have prevented a definitive test. For the first time, using laboratory experiments on the Large Plasma Device at UCLA's Basic Plasma Science Facility, researchers from the University of Iowa, Wheaton College, and UCLA have discovered a direct link between energy transfer from Alfvén waves to electrons that causes auroras. The electrons were shown to "surf" on the electric field of the Alfvén wave, a phenomenon known as Landau damping, in which the energy of the wave is transferred to the accelerated electrons, analogous to a surfer catching a wave and being continually accelerated as the surfer moves along with the wave.

LaserNetUS: Tomographic Imaging with an intense laser-driven multi-MeV Photon Source.
Scientists from Los Alamos National Laboratory in collaboration with Colorado State University successfully demonstrated multi-MeV Photon radiography with intense lasers. Photon sources with energy >1 MeV are of significant interest for imaging and radiography of dense objects in inertial fusion energy, stockpile stewardship, industry, and homeland security applications. This work was enabled by LaserNetUS, a consortium of ten institutions, including both academic and national laboratories, funded by FES to advance laser-driven discovery science and translational research that produces societal benefit.

U.S. hardware development and delivery to ITER.
Increased design and fabrication continued for all systems within the U.S. responsibility. Two of the seven ITER Central Solenoid magnet modules were successfully delivered to the international ITER site in France.

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.
- Support for public-private partnerships through the INFUSE activity and the establishment of a new cost-share milestone-based partnership program.
- Research on inertial fusion energy science and technology.
- Research on small-scale magnetic confinement experiments.
- 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, such as high-temperature superconducting (HTS) magnets, needed to support continued improvement and capabilities of the experimental program and current and future facilities.
- Infrastructure improvements at PPPL and other DOE laboratories where fusion research is ongoing.
- Research on AI/ML relevant to fusion and plasma science.

Research in the Burning Plasma Science: Foundations area in FY 2023 will focus on high-priority scientific issues in alignment with the recommendations in the recent FESAC LRP, including addressing key science and technology needs in the design basis for an FPP.

<u>Advanced Tokamak</u>

The Advanced Tokamak (AT) element is a major pillar of the FES research portfolio, supporting a broad range of activities focused on closing gaps in the scientific and technical basis for the tokamak approach to fusion energy. The advanced tokamak is an integrated fusion energy system that simultaneously achieves a stationary plasma state characterized by high plasma pressure, high fractions of self-generated (bootstrap) plasma current, adequate heat and particle confinement, and levels of heat and particle exhaust that are compatible with plasma-facing surfaces. Generating and sustaining such states requires optimization of the configuration via experimental and theoretical studies, as well as multifaceted control algorithms that rely on efficient actuators and validated plasma models. The AT activity comprises several research lines to support the accompanying R&D in these areas, including the DIII-D National Fusion Facility, Enabling Research and Development, and Small-scale AT research.

The DIII-D user facility at General Atomics 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. The current DIII-D five-year plan aims to deliver three major goals: (1) enable a successful ITER research program; (2) develop the physics basis for and validation of the Advanced Tokamak path to a U.S. fusion pilot plant; and (3) advance the physics understanding of fusion science across a broad front, developing validated predictive capabilities to project solutions to future devices and maintaining U.S. world leadership in fusion science. The DIII-D program has the long-term objective to establish the physics basis for an integrated core-edge solution in a fusion power plant.

Enabling Research and Development (R&D) is aimed at advancing the plasma-supporting technologies required for the realization of fusion energy. Magnets are an integral feature of magnetic fusion configurations, and a primary focus of this element is to support R&D aimed at the development of magnets with higher fields, operating temperatures, and reliability, opening the way towards a FPP. In addition, this element supports the development of heating and current drive technologies, which need substantial advancement in order to meet performance, efficiency, and lifetime goals for an FPP. Enabling R&D also supports the development of plasma fueling and disruption mitigation systems, which are required to enable high-power, steady-state plasma discharges.

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. Recent efforts are focused on improving fusion plasma control physics for advanced tokamaks.

Spherical Tokamak

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 pilot plant than other plasma confinement geometries. In FY 2023, 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, high-reward, 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 Advanced Computing.

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 in partnership with ASCR. The new portfolio will build upon the SciDAC-4 portfolio that was focused on integration and whole-device modeling and expand its scope to whole-facility modeling, addressing recommendations in the FESAC long-range plan and also providing a consistent set of high-fidelity tools for design and performance assessment of FPP concepts.

The Advanced Computing for Fusion element supports efforts that address the growing data needs of fusion research, resulting from both experimental and large-scale simulation efforts, by investing in enhanced data infrastructure capabilities. This element also aims to integrate fusion-relevant capabilities developed under the Exascale Computing Project into the FES program.

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

INFUSE provides private-sector fusion companies with access to the expertise and facilities of DOE's national laboratories and other supported institutions to overcome critical scientific and technological hurdles in pursuing development of fusion energy systems. 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 Fusion Enterprise Cost Share Program is a new milestone-based program with 50/50 cost-share between DOE and the private sector. It aims at accelerating the closing of technological gaps for multiple fusion pilot plant concepts by working closely with the private sector.

Artificial Intelligence and Machine Learning

The objective is to support research on the development and application of AI/ML techniques that can have a transformative impact on FES mission areas. Research addresses recommendations from the 2018 FESAC report on "Transformative Enabling Capabilities for Efficient Advance toward Fusion Energy,"[gg] is informed by the findings of the joint 2019 FES-ASCR workshop on "Advancing Fusion with Machine Learning,"[hh] 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; plasma diagnostics; extraction of models from experimental and simulation data; and extreme data algorithms. Supported activities encompass multiple FES areas, including magnetic fusion, materials science, and discovery plasma science, and contribute to the development of FPP design tools.

Strategic Accelerator Technology

The objective is to leverage expertise across SC to maximize research and development progress in high-temperature superconducting (HTS) magnets for future fusion facilities. A key aspect is the support of the High Field Vertical Magnet Test Stand at Fermi National Laboratory, which is being funded jointly with High Energy Physics (HEP). This test stand will be a world-leading capability for testing conductors.

Inertial Fusion Energy

This activity supports development of the scientific foundation and technologies for inertial fusion energy. Improved knowledge of driver-target physics, understanding of physical limits on design parameters applicable across drivers, advanced concepts for increasing gain, and high-repetition-rate drivers and targets are all critical to advancing IFE concepts.

[gg] https://science.osti.gov/-/media/fes/fesac/pdf/2018/TEC_Report_15Feb2018.pdf
[hh] 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 2023 Request		Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Burning Plasma Science: Foundations	**$288,009**		**$326,722**	**+$38,713**
Advanced Tokamak	$127,038		$127,122	+$84
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 22 weeks of operations at the DIII-D facility, which is 90 percent of optimal. Research will continue to exploit innovative current drive systems to assess their potential as actuators for a fusion pilot plant and to optimize plasma performance. Upgrades include increasing electron cyclotron power, completing the installation of the high-field-side lower hybrid current drive system and commencing experiments, and increasing the power of the neutral beam injection system. The Request will continue supporting research in high-temperature superconducting magnet technology, plasma heating and current drive, plasma fueling, and other enabling technologies for fusion. The Request will continue support for small-scale AT experiments.		The increase will support DIII-D operations, research aligned with the FESAC Long-Range Plan, and upgrades.

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Spherical Tokamak	$104,331	$101,100	-$3,231
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 support the remaining NSTX-U Recovery fabrication and machine reassembly activities, and begins to support the commissioning of auxiliary heating systems in preparation for plasma operations. Research efforts will focus on studies utilizing a variety of domestic and international spherical tokamak facilities; these studies are aligned with the mission of the NSTX-U program, which contributes to the development of the design basis for a next-step FPP. The Request will continue to support small-scale ST studies dedicated to simplifying and reducing the capital cost of future fusion facilities.	Operations funding will support the continuation of the NSTX-U Recovery activities. Research funding will focus on the highest-priority scientific objectives, which are aligned with the FESAC Long-Range Plan.
Theory & Simulation	$42,000	$51,000	+$9,000
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 efforts at universities, national laboratories, and private industry focused on the fundamental theory of magnetically confined plasmas and the development of a predictive capability for magnetic fusion. The Request will continue to support the SciDAC portfolio with emphasis on whole-facility modeling, in alignment with the Long-Range Plan recommendations, and also provide a consistent set of high-fidelity tools for design and performance assessment of FPP concepts. The Request will also support Advanced Computing, including investments in enhanced data infrastructure capabilities to address the growing data needs of fusion research.	Research efforts will focus on the highest-priority activities, including continuing support of the SciDAC portfolio.

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 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 continue to support infrastructure improvements, repair, maintenance, and environmental monitoring at PPPL and other DOE laboratories.	The funding will continue to support infrastructure improvements.
Public-Private Partnerships	$5,000	$32,000	+$27,000
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 continue to support the INFUSE program, providing the private-sector with access to DOE developed capabilities at both national laboratories and universities. The Request also initiates a cost-share milestone-based program for private fusion companies.	The funding increase will support the new cost-share milestone-based public-private partnership program.
Artificial Intelligence and Machine Learning	$7,000	$11,000	+$4,000
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 a competitive solicitation to identify multi-institutional collaborations focused on deploying AI/ML applications across FES program elements.	The level of effort will be strengthened to support distributed data capabilities and the development of FPP design tools.

(dollars in thousands)

FY 2021 Enacted	FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Inertial Fusion Energy $ —	$3,000	+$3,000
No funding in FY 2021.	The Request will establish a new IFE program to support the priority research opportunities in scientific foundations and technologies that will be identified in the planned FY 2022 Basic Research Needs Workshop for IFE.	The funding will initiate a new program in IFE.

Note:

- *Funding for the subprogram above, includes 3.65 percent 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: Long Pulse

Description

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

<u>Long Pulse: Tokamak</u>

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. Collaborative research on international facilities with capabilities not available in the U.S. aims at building the science and technology required to control, sustain, and predict a burning plasma, as described in the FESAC LRP.[ii] Multidisciplinary teams work together to close key gaps in the design basis for an FPP, 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-like scenarios and mature diagnostic suites.

<u>Long Pulse: Stellarators</u>

This activity supports research on stellarators, which offer the potential of steady-state confinement regimes without transient events such as 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 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 formal partnership status for the U.S. Accordingly, the U.S. is participating fully in W7-X research and has full 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 FESAC Long-Range Plan, the quasi-symmetric stellarator is the leading U.S. approach to develop disruption-free, low-recirculating-power fusion configurations.

<u>Materials & Fusion Nuclear Science</u>

The Materials and Fusion Nuclear Science activity seeks to address the significant scientific and technical gaps between current-generation fusion experiments and a future FPP, as recommended by the FESAC LRP. 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 FPP. The SC initiative on Fundamental

[ii] https://usfusionandplasmas.org/

Science to Transform Advanced 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. 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, e.g., an FPP, as recommended by the FESAC LRP.

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Burning Plasma Science: Long Pulse	**$72,500**	**$81,000**	**+$8,500**
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 the second budget period for U.S. teams conducting research on international facilities, which will help close key gaps in the design basis for an FPP.	No change.
Long Pulse: Stellarators	$8,500	$7,500	-$1,000
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.		In the next W7-X experimental campaign, the Request will support research on turbulent transport, stability and edge physics, and boundary and scrape-off-layer physics. The Request will continue to support experiments on domestic stellarators in regimes relevant to the mainline stellarator magnetic confinement efforts.	Research efforts will emphasize the highest-priority topics.

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Materials & Fusion Nuclear Science	$49,000	$54,500	+$5,500
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 continue to support research activities in these areas, consistent with the recommendations of the FESAC Long-Range Plan. This includes continued development of critical technologies for an FPP, such as plasma-facing components, structural and functional materials, and breeding-blanket and tritium-handling systems. The Request will also continue to support research into advanced manufacturing technologies consistent with the SC initiative in this area. Finally, the Request will continue to support the MPEX MIE project, with efforts focused on construction following the combined baselining and approval of construction in FY 2022.	The Request will increase support for the materials and fusion nuclear science research programs and advanced manufacturing technologies. Funding for the MPEX project will decrease, consistent with the planned funding profile.
Future Facilities Studies	$ —	$4,000	+$4,000
No funding in FY 2021.		The Request will support the Future Facilities Studies activity to conduct design studies for an integrated fusion plant, e.g., an FPP, consistent with the FESAC Long-Range Plan recommendation.	Funding will enhance the level of effort of this activity.

Note:
- *Funding for the subprogram above, includes 3.65 percent 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.

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 of Q = 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 EU, India, Japan, South Korea, and Russia. More information about the U.S. Contributions to the ITER project is provided in the FES Construction section.

ITER Research

To ensure that 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 FESAC LRP. A Basic Research Needs workshop is being held in FY 2022 to identify the highest-priority research and engagement opportunities for the U.S. in order to maximize the benefit of its participation in ITER.

Fusion Energy Sciences
Burning Plasma Science: High Power

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Burning Plasma Science: High Power	**$ —**	**$2,000**	**+$2,000**
ITER Research	$ —	$2,000	+$2,000
No Funding in FY 2021.		The Request will support the highest-priority research and engagement opportunities identified in the Basic Research Needs workshop that is being held in FY 2022.	Funding will support highest-priority research.

Note:

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

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 the following activities:

Plasma Science and Technology
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 Lab Plasmas (HEDLP): Research directed at exploring the behavior of plasmas at extreme conditions of temperature, density, and pressure, including relativistic high energy density (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.

Measurement Innovation
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[jj] 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 quantum simulation capabilities for fusion and plasma science, quantum sensing for plasma diagnostics, HEDLP techniques to form novel quantum materials, and plasma science tools to simulate and control quantum systems. FES also participates in supporting the SC-wide crosscutting QIS research centers.

Advanced Microelectronics

The Advanced Microelectronics activity supports discovery 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 is informed by the recent Long-Range Plan developed by FESAC, the NASEM Plasma 2020 decadal survey report, and a planned FY 2022 workshop on plasma science for microelectronics fabrication.

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 (USBPO); 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 under-represented in the U.S. S&T ecosystem and aligns with a recommendation in the FESAC LRP.

Funding for Accelerated, Inclusive Research (FAIR)

This activity supports the Funding for Accelerated, Inclusive Research (FAIR) initiative which will provide focused investment on enhancing research on clean energy, climate, and related topics at Minority Serving Institutions (MSIs), including attention to underserved and environmental justice regions.

Accelerate Innovations in Emerging Technologies (Accelerate)

This activity supports the Accelerate initiative, which will support scientific research to accelerate the transition of science advances to energy technologies.

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

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Discovery Plasma Science	**$54,491**	**$72,500**	**+$18,009**
Plasma Science and Technology	$32,700	$37,000	+$4,300
General Plasma Science	*$15,000*	*$19,000*	*+$4,000*
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.		The Request will support core research at the frontiers of basic and low temperature plasma science, as well as operations of and user-led experiments on collaborative research facilities.	Funding will support core research at universities and national laboratories.
High Energy Density Lab Plasmas	*$15,700*	*$18,000*	*+$2,300*
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 basic and translational science, MEC and LaserNetUS operations and user support, and the SC-NNSA joint program.	Funding will support core research at universities and national laboratories.
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 innovative and transformative diagnostics.	No change.
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 priority research opportunities identified in the 2018 Roundtable Workshop Report. It will also continue to support the SC QIS Research Centers.	Funding will continue to support priority research.

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 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 support high priority research and the continuation of laboratory awards made through a competitive lab call and review in FY 2021.	No change.
Other FES Research	$4,271	$3,500	-$771
Funding supports U.S. Burning Plasma Organization (USBPO) activities, peer reviews for solicitations, outreach programs, and FESAC.		The Request will continue to support programmatic activities such as the FES Postdoctoral Research Program, the FES Fusion and Plasma Science Outreach programs, USBPO, peer reviews for FES solicitations and project activities, and FESAC.	Funding supports highest-priority activities.
Reaching a New Energy Sciences Workforce (RENEW)	$ —	$6,000	+$6,000
No funding in FY 2021.		The Request will support the RENEW initiative to provide undergraduate and graduate training opportunities for students and academic institutions under-represented in the U.S. S&T ecosystem and aligns with a recommendation in the FESAC Long-Range Plan.	The funding will enhance support of the RENEW activities.
Funding for Accelerated, Inclusive Research (FAIR)	$ —	$2,000	+$2,000
No funding in FY 2021.		This activity supports the Funding for Accelerated, Inclusive Research (FAIR) initiative, which will provide focused investment on enhancing research on clean energy, climate, and related topics at Minority Serving Institutions, including attention to underserved and environmental justice communities.	The funding supports the FAIR initiative.

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Accelerate Innovations in Emerging Technologies	$ —	$6,000	+$6,000
No funding in FY 2021.		This activity supports the Accelerate initiative, which will support scientific research to accelerate the transition of science advances to energy technologies.	The funding supports the Accelerate initiative.

Note:

- *Funding for the subprogram above, includes 3.65 percent 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"[kk] 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-1 (CD-1), "Approve Alternative Selection and Cost Range," on October 4, 2021. The FY 2023 Request of $1,000,000 will support preliminary design activities. The estimated total project cost range is $264,000,000 to $461,000,000.

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 to 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 carbon-free fusion energy pilot plant that will keep the U.S. competitive internationally. Construction of ITER is a collaboration among the U.S., European Union, Russia, Japan, India, Republic of Korea, and China, governed under 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 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 2023 Request of $240,000,000 will support the continued systems design, fabrication of First Plasma hardware, and financial contributions for IO operations. The estimated total project cost range is $4,700,000,000 to $6,500,000,000, which includes all U.S. in-kind hardware and financial construction contributions through the completion of ITER.

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. The U.S. involvement in ITER will help to advance the promise of carbon-free, inherently safe, and abundant fusion energy.

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

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Construction	**$257,000**	**$241,000**	**-$16,000**
20-SC-61, Matter in Extreme Conditions (MEC) Petawatt Upgrade, SLAC	$15,000	$1,000	-$14,000
The Enacted budget supports design activities, preparation for developing a project baseline, and long-lead procurements for an upgrade to MEC.		The Request will continue to support design activities and preparation for developing a project performance baseline.	Funding will support critical preparation activities for baseline.
14-SC-60, U.S. Contributions to ITER	$242,000	$240,000	-$2,000
The Enacted budget supports continued design and fabrication of In-kind hardware systems for the First Plasma subproject (SP-1).		The Request will continue to support continued design and fabrication of In-kind hardware systems for the SP-1 and requested construction financial contributions.	Funding will support in-kind and financial contributions.

Fusion Energy Sciences
Capital Summary

(dollars in thousands)

	Total	Prior Years	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Capital Operating Expenses						
Capital Equipment	N/A	N/A	27,020	31,020	22,000	-5,020
Minor Construction Activities						
General Plant Projects	N/A	N/A	2,000	2,000	1,500	-500
Total, Capital Operating Expenses	**N/A**	**N/A**	**29,020**	**33,020**	**23,500**	**-5,520**

Capital Equipment

(dollars in thousands)

	Total	Prior Years	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Capital Equipment						
Major Items of Equipment						
Burning Plasma Science: Long Pulse						
Material Plasma Exposure eXperiment (MPEX)	100,579	33,084	21,000	25,000	14,000	-7,000
Total, MIEs	N/A	N/A	21,000	25,000	14,000	-7,000
Total, Non-MIE Capital Equipment	N/A	N/A	6,020	6,020	8,000	+1,980
Total, Capital Equipment	**N/A**	**N/A**	**27,020**	**31,020**	**22,000**	**-5,020**

Notes:
- *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.*
- *In FY 2021, additional funding of $7,996,000 above the Enacted level was provided for the MPEX MIE. The adjusted TEC Total is $108,575,000.*

Fusion Energy Sciences
Minor Construction Activities

(dollars in thousands)

	Total	Prior Years	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
General Plant Projects (GPP)						
Total GPPs less than $5M	N/A	N/A	2,000	2,000	1,500	-500
Total, General Plant Projects (GPP)	**N/A**	**N/A**	**2,000**	**2,000**	**1,500**	**-500**
Total, Minor Construction Activities	**N/A**	**N/A**	**2,000**	**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.*

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 FY 2023 Request will allow the project to execute the approved performance baseline and continuation of approved long-lead procurements. MPEX scope includes the design, fabrication, installation, and commissioning of the MPEX linear plasma device, and associated facility and infrastructure modifications and reconfiguration. The CD-1 was approved on February 3, 2020, with a TPC cost range of $86,000,000–$175,000,000.

Fusion Energy Sciences
Construction Projects Summary

(dollars in thousands)

	Total	Prior Years	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
20-SC-61, Matter in Extreme Conditions (MEC) Upgrade						
Total Estimated Cost (TEC)	448,700	8,487	15,000	5,000	1,000	-14,000
Other Project Cost (OPC)	13,500	6,100	2,000	–	–	-2,000
Total Project Cost (TPC)	**462,200**	**14,587**	**17,000**	**5,000**	**1,000**	**-16,000**
14-SC-60, U.S. Contributions to ITER						
Total Estimated Cost (TEC)	3,330,198	1,613,617	242,000	221,000	240,000	-2,000
Other Project Cost (OPC)	70,302	70,302	–	–	–	–
Total Project Cost (TPC)	**3,400,500**	**1,683,919**	**242,000**	**221,000**	**240,000**	**-2,000**
Total, Construction						
Total Estimated Cost (TEC)	**N/A**	**N/A**	**257,000**	**226,000**	**241,000**	**-16,000**
Other Project Cost (OPC)	**N/A**	**N/A**	**2,000**	**–**	**–**	**-2,000**
Total Project Cost (TPC)	**N/A**	**N/A**	**259,000**	**226,000**	**241,000**	**-18,000**

Note:
- *In FY 2021, funding was reduced to $800,000,000 for MEC OPC. The adjusted TPC with FY 2021 Current funding is $461,000,000.*

Fusion Energy Sciences
Funding Summary

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Research	260,149	289,149	337,722	+77,573
Facility Operations	129,211	129,211	129,000	-211
Projects				
Line Item Construction (LIC)	259,000	226,000	241,000	-18,000
Major Items of Equipment (MIE)	21,000	25,000	14,000	-7,000
Total, Projects	**280,000**	**251,000**	**255,000**	**-25,000**
Other	2,640	2,640	1,500	-1,140
Total, Fusion Energy Sciences	**672,000**	**672,000**	**723,222**	**+51,222**

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 2021 Enacted	FY 2021 Current	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Scientific User Facilities - Type A					
DIII-D National Fusion Facility	**121,000**	**114,971**	**121,000**	**123,000**	**+2,000**
Number of Users	830	429	515	515	-315
Achieved Operating Hours	–	748	–	–	–
Planned Operating Hours	720	720	800	864	+144
Optimal Hours	960	960	880	960	–
Percent of Optimal Hours	75.0%	77.9%	90.0%	90.0%	+15.0%
Unscheduled Down Time Hours	–	102	–	–	–
National Spherical Torus Experiment-Upgrade	**101,331**	**95,092**	**101,331**	**98,100**	**-3,231**
Number of Users	372	358	372	373	+1
Total, Facilities	**222,331**	**210,063**	**222,331**	**221,100**	**-1,231**
Number of Users	1,202	787	887	888	-314
Achieved Operating Hours	–	748	–	–	–
Planned Operating Hours	720	720	800	864	+144
Optimal Hours	960	960	880	960	–
Unscheduled Down Time Hours	–	102	–	–	–

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 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Number of Permanent Ph.Ds (FTEs)	846	888	964	+118
Number of Postdoctoral Associates (FTEs)	104	109	120	+16
Number of Graduate Students (FTEs)	282	296	322	+40
Number of Other Scientific Employment (FTEs)	1,261	1,322	1,441	+180
Total Scientific Employment (FTEs)	**2,493**	**2,615**	**2,847**	**+354**

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 2023 Request for the Matter in Extreme Conditions (MEC) Petawatt Upgrade project is $1,000,000. The project has a preliminary estimated Total Project Cost (TPC) range of $264,000,000 to $461,000,000. 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. It will utilize 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.

Significant Changes

The MEC Petawatt Upgrade project was initiated in FY 2019. 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. The project achieved CD-1, "Approve Alternative Selection and Cost Range," on October 4, 2021, and will initiate the TEC-funded preliminary design phase.

The upper-end of the cost range increased from $372,000,000 to $461,000,000 and from a CD-4 date of 1Q FY 2028 to 4Q FY 2029. The increases in cost and schedule were implemented in order to address the uncertainty associated with budget requests and future appropriations.

A Level III 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	TBD	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
FY 2023	1/4/19	3/9/21	10/4/21	3Q FY 2024	3Q FY 2024	3Q FY 2024	TBD	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

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC, Except 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
FY 2023	23,487	425,213	448,700	12,300	12,300	461,000

Note:

- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*
- *Increase from FY 2022 due to funding uncertainty which increased cost contingency amounts.*

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 target 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), composed of an access tunnel, an experimental hall with 12,000 to 17,000 square feet, a stand-alone control room, 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 Sciences, Engineering, and Medicine (NASEM) 2017 study titled "Opportunities in Intense Ultrafast Lasers: Reaching for the Brightest Light[ll]" found that about 80 percent to 90 percent of the high-intensity laser systems are overseas, and all the highest-power lasers currently under 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

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

the SLAC National Accelerator Laboratory has demonstrated exquisite ultrafast measurements of the material structural response to radiation. The upgrade includes the 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 address 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*.

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

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	8,487	–	–
FY 2021	15,000	23,487	–
FY 2022	–	–	23,487
Total, Design (TEC)	**23,487**	**23,487**	**23,487**
Construction (TEC)			
FY 2022	5,000	5,000	5,000
FY 2023	1,000	1,000	1,000
Outyears	419,213	419,213	419,213
Total, Construction (TEC)	**425,213**	**425,213**	**425,213**
Total Estimated Cost (TEC)			
FY 2020	8,487	–	–
FY 2021	15,000	23,487	–
FY 2022	5,000	5,000	28,487
FY 2023	1,000	1,000	1,000
Outyears	419,213	419,213	419,213
Total, TEC	**448,700**	**448,700**	**448,700**

(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	800	800	2,782
FY 2022	–	–	30
Outyears	5,400	5,400	5,400
Total, OPC	**12,300**	**12,300**	**12,300**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Project Cost (TPC)			
FY 2019	1,600	1,600	280
FY 2020	12,987	4,500	3,808
FY 2021	15,800	24,287	2,782
FY 2022	5,000	5,000	28,517
FY 2023	1,000	1,000	1,000
Outyears	424,613	424,613	424,613
Total, TPC	**461,000**	**461,000**	**461,000**

Note:
- *This project has not received CD-2 approval; therefore, funding 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	14,787	17,000	**N/A**
Design - Contingency	8,700	3,000	**N/A**
Total, Design (TEC)	**23,487**	**20,000**	**N/A**
Construction	129,093	161,798	**N/A**
Equipment	138,076	115,191	**N/A**
Construction - Contingency	158,044	68,111	**N/A**
Total, Construction (TEC)	**425,213**	**345,100**	**N/A**
Total, TEC	**448,700**	**365,100**	**N/A**
Contingency, TEC	*166,744*	*71,111*	***N/A***
Other Project Cost (OPC)			
R&D	350	350	**N/A**
Conceptual Planning	4,650	850	**N/A**
Conceptual Design	1,900	1,900	**N/A**
Other OPC Costs	3,800	2,400	**N/A**
OPC - Contingency	1,600	1,400	**N/A**
Total, Except D&D (OPC)	**12,300**	**6,900**	**N/A**
Total, OPC	**12,300**	**6,900**	**N/A**
Contingency, OPC	*1,600*	*1,400*	***N/A***
Total, TPC	**461,000**	**372,000**	**N/A**
Total, Contingency (TEC+OPC)	***168,344***	***72,511***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Fiscal Year	Type	Prior Years	FY 2021	FY 2022	FY 2023	Outyears	Total
FY 2020	TEC	1,000	—	—	—	—	1,000
	OPC	1,600	—	—	—	—	1,600
	TPC	2,600	—	—	—	—	2,600
FY 2021	TEC	15,000	5,000	—	—	170,400	190,400
	OPC	6,100	—	—	—	3,500	9,600
	TPC	21,100	5,000	—	—	173,900	200,000
FY 2022	TEC	15,000	15,000	5,000	—	327,000	362,000
	OPC	6,100	2,000	—	—	1,900	10,000
	TPC	21,100	17,000	5,000	—	328,900	372,000
FY 2023	TEC	8,487	15,000	5,000	1,000	419,213	448,700
	OPC	6,100	800	—	—	5,400	12,300
	TPC	14,587	15,800	5,000	1,000	424,613	461,000

Note:

- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	4Q FY 2029
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	21,200	21,200	931,000	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

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 2023 Request for the U.S. ITER project is $240,000,000 of Total Estimated Cost (TEC) funding. The Total Project Cost (TPC) for the U.S. Contributions to ITER (U.S. ITER) project is $3,400,500,000, including $2,500,000,000 for Subproject-1 (SP-1), First Plasma Hardware for U.S. ITER and $900,500,000 estimated for cash contributions. Sections of this Construction Project Data Sheet (CPDS) have been tailored accordingly to reflect the unique nature of the U.S. ITER project. Research results from the ITER project, if successful, are expected to contribute to the development of a fusion pilot plant. Fusion energy could provide a carbon-free, inherently safe energy source that will be a significant contributor to ameliorating climate change.

As outlined in the May 2016 Secretary of Energy's Report to Congress, DOE expected 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 FY 2023.

The financial contributions to the IO operational costs during construction are shared among the seven Members and constitute the third element of the U.S. ITER Total Project Cost that funds the entirety of ITER construction. These funds are used by the IO to provide, among other items, design integration, nuclear licensing, regulatory engagement, construction of the complex, project management, and assembly and installation of in-kind components.

Significant Changes

The FY 2023 Request of $240,000,000 will support the continued design and fabrication of "in-kind" hardware systems and construction financial contributions to the ITER Organization. This includes continued fabrication and delivery of the Central Solenoid (CS) magnet system, which consists of seven superconducting magnet modules. In FY 2022, the U.S. is scheduled to ship the second and third CS magnet modules and continue the design and fabrication efforts associated with other "In-kind" hardware systems. The U.S. ITER project will have obligated more than $1,500,000,000 through the end of FY 2022, of which more than 80 percent is to U.S. industry, universities, and DOE laboratories.

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

A Federal Project Director with a level-I certification has been assigned to this Project, and is currently pursuing higher-level certification.

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
FY 2023	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
FY 2023	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);*
- *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).*

Project Cost History

At the time of CD-1 approval in January 2008, the preliminary cost range was $1,450,000,000 to $2,200,000,000. Until 2016, however, it was not possible to confidently baseline the project due to delays early on 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 $4,000,000,000 to $6,500,000,000 would likely encompass the final TPC. This range, recommended in 2013, was included in subsequent President's Budget Requests. In May 2016, the Secretary of Energy 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 an Independent 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-1 Revised (CD-1R) range of $4,700,000,000 to $6,500,000,000. 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 $2,500,000,000. Starting in FY 2022, the table below includes both SP-1 and cash contributions.

Subproject 1 (First Plasma Hardware for U.S. ITER) and Cash Contributions
(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Cash Contributions	TEC, Total	OPC, Except D&D	OPC, Total	TPC
FY 2006	—	1,038,000	—	1,038,000	84,000	84,000	1,122,000
FY 2007	—	1,077,051	—	1,077,051	44,949	44,949	1,122,000
FY 2008	—	1,078,230	—	1,078,230	43,770	43,770	1,122,000
FY 2009	—	266,366	—	266,366	38,075	38,075	304,441
FY 2010	—	294,366	—	294,366	70,019	70,019	364,385
FY 2011	—	379,366	—	379,366	65,019	65,019	444,385
FY 2012	—	394,366	—	394,366	75,019	75,019	469,385
FY 2013	—	617,261	—	617,261	82,124	82,124	699,385
FY 2014	—	806,868	—	806,868	73,159	73,159	880,027
FY 2015	—	942,578	—	942,578	80,341	80,341	1,022,919
FY 2016	—	1,092,544	—	1,092,544	80,341	80,341	1,172,885
FY 2017	696,025	1,723,334	—	2,419,359	80,641	80,641	2,500,000
FY 2018	696,025	1,723,334	—	2,419,359	80,641	80,641	2,500,000
FY 2019	696,025	1,723,334	—	2,419,359	80,641	80,641	2,500,000
FY 2020	696,025	1,733,673	—	2,429,698	70,302	70,302	2,500,000
FY 2021	696,025	1,733,673	—	2,429,698	70,302	70,302	2,500,000
FY 2022	503,262	1,926,436	1,158,000	3,587,698	70,302	70,302	3,658,000
FY 2023	483,126	1,946,572	900,500	3,330,198	70,302	70,302	3,400,500

Notes:
- *From FY 2006 through FY 2014, ITER was a MIE.*
- *From FY 2009 to FY 2016, the TPC for U.S. ITER was not reported.*
- *Starting in FY 2017, TPC estimates 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.*

2. Project Scope and Justification

ITER, currently the largest science experiment in the world, is a major fusion research facility under construction in St. Paul-lez-Durance, France by an international partnership of seven Members or domestic agencies, specifically, the U.S., China, the EU, India, the Republic of Korea, Japan, and the Russian Federation. ITER is co-owned and co-governed by the seven Members. 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 Member entered the project 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 contribute one-eleventh (9.09 percent) of the ITER facility’s construction cost. The IO is a designated international legal entity located in France.

Scope

U.S. Contributions to ITER – Construction Project Scope

The overall U.S. ITER project includes three major elements:

- Hardware components, built under the responsibility of the U.S., 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.
- 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 currently 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)
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[mm]) 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)

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

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 planned experimental outcomes expected from ITER: The first 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 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 following 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. Contributions to the ITER Project will not deliver an integrated operating facility, but rather In-kind hardware contributions, which represent a portion of 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 needed, which requires IO approval of the final designs (see Table 1 on previous page for more detail).

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
Total, Design (TEC)	**483,126**	**483,126**	**483,126**
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	41,527
FY 2022	136,117	136,117	136,117
FY 2023	170,000	170,000	170,000
Outyears	543,578	543,628	819,732
Total, Construction (TEC)	**1,946,572**	**1,946,644**	**1,946,644**

(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
FY 2023	70,000	70,000	70,000
Outyears	470,003	470,003	470,003
Total, Cash Contributions (TEC)	**900,500**	**900,500**	**900,500**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
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	101,527
FY 2022	221,000	221,000	221,000
FY 2023	240,000	240,000	240,000
Outyears	1,013,581	1,013,631	1,289,735
Total, TEC	**3,330,198**	**3,330,270**	**3,330,270**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Other Project Cost (OPC)			
FY 2006	3,449	3,449	1,110
FY 2007	16,000	16,000	7,607
FY 2008	-74	-74	7,513
FY 2009	15,000	15,000	5,072
FY 2010	20,000	20,000	7,754
FY 2011	13,000	13,000	10,032
FY 2012	333	311	22,302
FY 2013	2,560	2,560	5,984
FY 2014	–	–	2,090
FY 2015	–	–	600
FY 2016	34	34	–
FY 2017	–	-50	58
FY 2018	–	–	2
FY 2019	–	–	106
Total, OPC	**70,302**	**70,230**	**70,230**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Project Cost (TPC)			
FY 2006	19,315	19,315	9,391
FY 2007	60,000	60,000	39,257
FY 2008	26,070	26,070	34,278
FY 2009	124,000	124,000	54,949
FY 2010	135,000	135,000	83,540
FY 2011	80,000	80,000	97,478
FY 2012	105,000	104,966	134,765
FY 2013	124,000	124,034	129,863
FY 2014	199,500	199,500	188,980
FY 2015	150,000	150,000	130,686
FY 2016	115,034	115,034	106,519
FY 2017	50,000	49,950	123,175
FY 2018	122,000	122,000	98,187
FY 2019	132,000	132,000	156,832
FY 2020	242,000	242,000	160,338
FY 2021	242,000	242,000	101,527
FY 2022	221,000	221,000	221,000
FY 2023	240,000	240,000	240,000
Outyears	1,013,581	1,013,631	1,289,735
Total, TPC	**3,400,500**	**3,400,500**	**3,400,500**

Notes:

- *The total project cost (TPC) shown above is only for SP-1 In-kind and cash contributions through the completion of SP-1. SP-2 is expected to be baselined in FY 2023 and when combined with SP-1 and cash contributions, will bring the entire project TPC to within the CD-1 (R) cost range of $4,700,000,000–$6,500,000,000.*
- *In FY 2012, prior year actuals were adjusted to incorporate project funds used at PPPL and DOE. Obligation adjustments reflect year-end PPPL settlement funding.*
- *Starting in FY 2014, this project is funded as a Congressional control point. Appropriations prior to FY 2014 reflect major item of equipment funding.*
- *FY 2016 funding for taxes and tax support is included in the FY 2017 Hardware funding amount.*
- *All Appropriations for the U.S. Contributions to ITER project include both funding for SP-1 and funding for Cash Contributions.*
- *Cash Contributions includes cash payments, secondees, taxes and tax support and are considered separate from the SP-1 TPC.*
- *TEC: Obligations and costs through FY 2021 reflect actuals; obligations and costs for FY 2022 and the outyears are estimates.*

4. Details of Project Cost Estimate

The overall U.S. Contributions to ITER project has an approved revised CD-1 Cost Range (CD-1R). DOE chose to divide the project hardware scope into two distinct subprojects (FP SP-1, and Post-FP or SP-2) so that an initial portion of the project that was mature enough to baseline could be accomplished. The baseline for SP-1 ($2,500,000,000) was approved in January 2017. Baselining of SP-2 is expected in FY 2023; SP-2 design work is underway which is included in SP-1 scope. An Independent Project Review (IPR) of U.S. 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. 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	483,126	503,262	573,660
Design - Contingency	N/A	N/A	122,365
Total, Design (TEC)	**483,126**	**503,262**	**696,025**
Construction	1,696,355	1,696,355	**N/A**
Equipment	N/A	N/A	1,362,521
Construction - Contingency	250,217	230,081	371,152
Total, Construction (TEC)	**1,946,572**	**1,926,436**	**1,733,673**
Cash Contributions	900,500	N/A	**N/A**
Total, Cash Contributions (TEC)	**900,500**	**N/A**	**N/A**
Total, TEC	**3,330,198**	**2,429,698**	**2,429,698**
Contingency, TEC	*250,217*	*230,081*	*493,517*
Other Project Cost (OPC)			
OPC, Except D&D	70,302	70,302	70,302
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	**3,400,500**	**2,500,000**	**2,500,000**
Total, Contingency (TEC+OPC)	***250,217***	***230,081***	***493,517***

Notes:

- *In the table above, the current total estimate includes cash contributions estimate to align with the TPC budget request. The Baseline information represents only the SP-1 project.*
- *Current total estimated design reflects work done prior to CD-2/3. When determining how best to incorporate design work after CD-2/3, DOE treated the remaining design work the same as all other scope to be accomplished under SP-1.*

5. **Schedule of Appropriations Requests**

(dollars in thousands)

Fiscal Year	Type	Prior Years	FY 2021	FY 2022	FY 2023	Outyears	Total
FY 2006	TEC	1,038,000	—	—	—	—	1,038,000
	OPC	84,000	—	—	—	—	84,000
	TPC	1,122,000	—	—	—	—	1,122,000
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	TEC	266,366	—	—	—	—	266,366
	OPC	38,075	—	—	—	—	38,075
	TPC	304,441	—	—	—	—	304,441
FY 2010	TEC	294,366	—	—	—	—	294,366
	OPC	70,019	—	—	—	—	70,019
	TPC	364,385	—	—	—	—	364,385
FY 2011	TEC	379,366	—	—	—	—	379,366
	OPC	65,019	—	—	—	—	65,019
	TPC	444,385	—	—	—	—	444,385
FY 2012	TEC	394,366	—	—	—	—	394,366
	OPC	75,019	—	—	—	—	75,019
	TPC	469,385	—	—	—	—	469,385
FY 2013	TEC	617,261	—	—	—	—	617,261
	OPC	82,124	—	—	—	—	82,124
	TPC	699,385	—	—	—	—	699,385
FY 2014	TEC	806,868	—	—	—	—	806,868
	OPC	73,159	—	—	—	—	73,159
	TPC	880,027	—	—	—	—	880,027
FY 2015	TEC	942,578	—	—	—	—	942,578
	OPC	80,341	—	—	—	—	80,341
	TPC	1,022,919	—	—	—	—	1,022,919
FY 2016	TEC	1,092,544	—	—	—	—	1,092,544
	OPC	80,341	—	—	—	—	80,341
	TPC	1,172,885	—	—	—	—	1,172,885

(dollars in thousands)

Fiscal Year	Type	Prior Years	FY 2021	FY 2022	FY 2023	Outyears	Total
FY 2017	TEC	1,182,244	—	—	—	1,237,115	2,419,359
	OPC	80,641	—	—	—	—	80,641
	TPC	1,262,885	—	—	—	1,237,115	2,500,000
FY 2018	TEC	1,170,244	—	—	—	1,249,115	2,419,359
	OPC	80,641	—	—	—	—	80,641
	TPC	1,250,885	—	—	—	1,249,115	2,500,000
FY 2019	TEC	1,245,244	—	—	—	1,174,115	2,419,359
	OPC	80,641	—	—	—	—	80,641
	TPC	1,325,885	—	—	—	1,174,115	2,500,000
FY 2020	TEC	1,478,617	—	—	—	951,081	2,429,698
	OPC	70,302	—	—	—	—	70,302
	TPC	1,548,919	—	—	—	951,081	2,500,000
FY 2021	TEC	1,613,617	107,000	—	—	709,081	2,429,698
	OPC	70,302	—	—	—	—	70,302
	TPC	1,683,919	107,000	—	—	709,081	2,500,000
FY 2022	TEC	1,613,617	242,000	221,000	—	1,511,081	3,587,698
	OPC	70,302	—	—	—	—	70,302
	TPC	1,683,919	242,000	221,000	—	1,511,081	3,658,000
FY 2023	TEC	1,613,617	242,000	221,000	240,000	1,013,581	3,330,198
	OPC	70,302	—	—	—	—	70,302
	TPC	1,683,919	242,000	221,000	240,000	1,013,581	3,400,500

Notes:

- *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.*
- *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.*
- *Prior to FY 2015, the requests were for a major item of equipment broken out by TEC, OPC, and TPC.*
- *Starting in FY 2022, the table above includes both SP-1 and cash contributions.*

6. Related Operations and Maintenance Funding Requirements

The U.S. Contributions to ITER operations phase is to begin with initial integrated commissioning activities with an assumed useful life of 20 to 25 years. The fiscal year in which commissioning activities begin depends on the international ITER project schedule, which currently indicates 2025. As a result of COVID-19 and other known delays, the overall ITER project is being re-baselined to update cost and schedule estimates.

Start of Operation or Beneficial Occupancy	12/2025
Expected Useful Life	30–35 years
Expected Future Start of D&D of this capital asset	2058-2063

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 five 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 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, to use 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 use best value, competitive source-selection procedures to the maximum extent possible, including foreign firms on the tender/bid list when necessary. 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 provides reliable availability and support to users for operating facilities. HEP's work allows the U.S. to remain a global leader in international particle physics research and collaboration.

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"[nn] 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.

[nn] 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 2023 Request

The FY 2023 Request for $1,122.0 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.

Key elements in the FY 2023 Request include:

Research

The Request will provide 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 will provide support to foster a diverse, highly skilled, American workforce, and to build R&D capacity and conduct world-leading R&D in the following initiatives:

- Accelerator Science and Technology Initiative (ASTI): In coordination with the Accelerator R&D and Production (ARDAP) program, HEP will continue support for mid- to long-term R&D to maintain a leading position in key accelerator technologies that define SC's competitive advantage.
- Advanced Computing: This initiative will maximize the Nation's investment in Exascale Computing to ensure that researchers will have the ability to intuitively meld and orchestrate AI-enabled advanced computing, instruments, and data to accelerate discovery and innovation. HEP, along with the other SC programs, will work with the national laboratories to ensure broad access to exascale computing resources. This effort will create an integrated system of scientific user facilities, connected via advanced networks and enabling software, accessible to U.S. researchers via the internet and remote virtual platforms, to join as equal partners in DOE's team science model to solve the Nation's biggest challenges.
- AI/ML: HEP leads cutting edge research to tackle the challenges of extracting signals of signature particle physics from HEP experimental and simulated data with increasingly high volumes and complexity; to seek solutions for operating accelerators and detectors in real-time and extremely high data rate environments; and to address cross-cutting challenges across the HEP program in coordination with DOE investments in AI/ML efforts.
- Microelectronics: HEP will work together with other SC programs to support multi-disciplinary research to accelerate the advancement of sensor materials, devices, and front-end electronics that will be vital to future progress in high energy physics.
- QIS: 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. HEP is the lead program supporting the Superconducting Quantum Materials and Systems (SQMS) Center involving 20 institutions and led by the Fermi National Accelerator Laboratory (FNAL). SQMS has a particular focus on extending the coherence lifetime of quantum states to reduce error rates in quantum computing and improve the sensitivity of quantum sensors for dark matter candidates and other precision measurements.
- Reaching a New Energy Sciences Workforce (RENEW): HEP will support 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 diverse students and academic institutions not currently well represented in the U.S. Science & Technology ecosystem.
- Funding for Accelerated, Inclusive Research (FAIR): HEP will support the SC-wide FAIR initiative that provides focused investment on enhancing research on clean energy, climate, and related topics at Minority Serving Institutions (MSIs), including attention to underserved and environmental justice communities. The activities will improve the capability of MSIs to perform and propose competitive research and will build beneficial relationships between MSIs and DOE national laboratories and facilities.
- Accelerate Innovations in Emerging Technologies: HEP will support the SC-wide Accelerate initiative that promotes scientific research to accelerate the transition of science advances to energy technologies. The goal is to drive scientific discovery to sustainable production of new technologies across the innovation continuum, to provide experiences in working across this continuum for the workforce needed for industries of the future, and to meet the nation's needs for abundant clean energy, a sustainable environment, and national security.

Facility Operations

HEP supports two scientific user facilities, the Fermilab Accelerator Complex and the Facility for Advanced Accelerator Experimental Tests II (FACET-II). These facilities will increase operations to 87 and 91 percent, respectively, of optimal. HEP also 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 DOE National Laboratory, including the ATLAS and CMS detectors at the 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 will continue 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 Request will also continue five Major Item of Equipment (MIE) projects: 1) Accelerator Controls Operations Research Network (ACORN); 2) Cosmic Microwave Background Stage 4 (CMB-S4); 3) High-Luminosity (HL-LHC) Accelerator Upgrade Project; 4) HL-LHC ATLAS Detector Upgrade; and 5) HL-LHC CMS Detector Upgrade Projects.

High Energy Physics
FY 2023 Research Initiatives

High Energy Physics supports the following FY 2023 Research Initiatives.

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Accelerate Innovations in Emerging Technologies	–	–	4,000	+4,000
Accelerator Science and Technology Initiative	6,411	6,411	10,000	+3,589
Advanced Computing	–	–	5,146	+5,146
Artificial Intelligence and Machine Learning	33,488	33,488	40,000	+6,512
Funding for Accelerated, Inclusive Research (FAIR)	–	–	2,000	+2,000
Microelectronics	5,000	5,000	7,000	+2,000
Quantum Information Science	45,072	45,072	50,566	+5,494
Reaching a New Energy Sciences Workforce (RENEW)	–	–	8,000	+8,000
Total, Research Initiatives	**89,971**	**89,971**	**126,712**	**+36,741**

High Energy Physics
Funding

	(dollars in thousands)			
	FY 2021 Enacted	**FY 2022 Annualized CR**	**FY 2023 Request**	**FY 2023 Request vs FY 2021 Enacted**
High Energy Physics				
Energy Frontier, Research	68,000	68,438	70,833	+2,833
Energy Frontier, Facility Operations and Experimental Support	53,650	50,642	48,787	-4,863
Energy Frontier, Projects	72,500	72,500	85,000	+12,500
Total, Energy Frontier Experimental Physics	**194,150**	**191,580**	**204,620**	**+10,470**
Intensity Frontier, Research	63,082	62,382	67,644	+4,562
Intensity Frontier, Facility Operations and Experimental Support	166,785	159,500	172,261	+5,476
Intensity Frontier, Projects	3,000	5,000	6,000	+3,000
Total, Intensity Frontier Experimental Physics	**232,867**	**226,882**	**245,905**	**+13,038**
Cosmic Frontier, Research	47,091	44,353	48,512	+1,421
Cosmic Frontier, Facility Operations and Experimental Support	44,500	42,500	47,590	+3,090
Cosmic Frontier, Projects	6,000	4,000	1,000	-5,000
Total, Cosmic Frontier Experimental Physics	**97,591**	**90,853**	**97,102**	**-489**
Theoretical, Computational, and Interdisciplinary Physics, Research	136,362	133,862	163,746	+27,384
Total, Theoretical, Computational, and Interdisciplinary Physics	**136,362**	**133,862**	**163,746**	**+27,384**

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
	(dollars in thousands)			
Advanced Technology R&D, Research	72,833	64,333	67,911	-4,922
Advanced Technology R&D, Facility Operations and Experimental Support	43,262	42,555	44,736	+1,474
Total, Advanced Technology R&D	**116,095**	**106,888**	**112,647**	**-3,448**
HEP Accelerator Stewardship, Research	10,835	–	–	-10,835
HEP Accelerator Stewardship, Facility Operations and Experimental Support	6,100	–	–	-6,100
Total, HEP Accelerator Stewardship	**16,935**	**–**	**–**	**-16,935**
Subtotal, High Energy Physics	**794,000**	**750,065**	**824,020**	**+30,020**
Construction				
18-SC-42, Proton Improvement Plan II (PIP-II), FNAL	79,000	90,000	120,000	+41,000
11-SC-40, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment	171,000	176,000	176,000	+5,000
11-SC-41, Muon to Electron Conversion Experiment, FNAL	2,000	13,000	2,000	–
Subtotal, Construction	**252,000**	**279,000**	**298,000**	**+46,000**
Total, High Energy Physics	**1,046,000**	**1,029,065**	**1,122,020**	**+76,020**

SBIR/STTR funding:

- FY 2021 Enacted: SBIR $22,325,000 and STTR $3,140,000
- FY 2022 Annualized CR: SBIR $21,080,000 and STTR $2,964,000
- FY 2023 Request: SBIR $22,769,000 and STTR $3,202,000

Note:

- *The Accelerator Stewardship subprogram moved to the Accelerator R&D and Production (ARDAP) program starting with the FY 2022 Request.*

High Energy Physics
Explanation of Major Changes

	(dollars in thousands) FY 2023 Request vs FY 2021 Enacted
Energy Frontier Experimental Physics The Request will increase support for research in Advanced Computing efforts to manage very large LHC data sets on exascale computers. Research efforts associated with the HL-LHC ATLAS and HL-LHC CMS Detector upgrade activities will continue. Support will focus on maintaining the U.S.-based computing infrastructure needed during the ongoing LHC run, while funding decreases due to the completion of maintenance and consolidation activities of U.S.-built detector components during the scheduled LHC technical stop that ends in FY 2022. Funding will increase to ramp up fabrication activities for the HL-LHC ATLAS and CMS Detector Upgrades.	**+10,470**
Intensity Frontier Experimental Physics The Request will increase support for research in Advanced Computing efforts to manage very large neutrino data sets on exascale computers, and for a feasibility study for a muon-catalyzed fusion experiment at FNAL. Operations at the Fermilab Accelerator Complex will increase to 87 percent of optimal. Funding will increase support for General Plant Projects (GPP) funding and Special Process Spares. Funding will increase for the ACORN MIE and LBNF/DUNE OPC. Infrastructure improvements at SURF have been slow to get started and therefore funding will be temporarily reduced.	**+13,038**
Cosmic Frontier Experimental Physics The Request will provide reduced funding for the CMB-S4 MIE, focusing support on engineering design activities. Funding will increase support for operations of the Vera C. Rubin Observatory and for research efforts for data collection and analysis on ongoing and new dark matter and dark energy experiments.	**-489**
Theoretical, Computational, and Interdisciplinary Physics The Request will provide new support for the Advanced Computing, RENEW, and FAIR initiatives. Funding will increase support 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. Funding will increase support for innovation and new opportunities in AI/ML.	**+27,384**

	(dollars in thousands) FY 2023 Request vs FY 2021 Enacted
Advanced Technology R&D The Request will provide new support for the Accelerate initiative. Funding will increase support for Microelectronics and for HEP Traineeships in Accelerators and Instrumentation. Funding will focus on ASTI efforts in superconducting magnet development and upgrades to superconducting radio-frequency (SRF) test facilities, and co-fund multi-SC program R&D in superconducting materials. Funding will support increased cryogenic, magnet, and SRF testing at FNAL and new two-beam laser wakefield acceleration experiments at LBNL. Operations at FACET-II will increase to 91 percent optimal.	**-3,448**
HEP Accelerator Stewardship Funding for the Accelerator Stewardship subprogram moves to the Accelerator R&D and Production program.	**-16,935**
Construction The Request will increase support for the civil construction and fabrication of technical components for the PIP-II project.	**+46,000**
Total, High Energy Physics	**+76,020**

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 National QIS Research Center (NQISRCs) 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

First results from Muon g-2 experiment strengthen evidence of new physics (Intensity Frontier Experimental Physics).
The Muon g-2 collaboration published its first physics result in 2021. The result exceeded all prior results in its statistical and systematic precision. The results from the FNAL-based experiment confirm a prior experiment that took data at Brookhaven National Laboratory (BNL) and strengthen the evidence that our understanding of fundamental physics is incomplete. When combined with BNL, the FNAL experimental determination of the muon's anomalous magnetic moment is in tension with the theoretical expectation. There is less than a 1 in 40,000 chance that the difference is merely a statistical fluke. Either there is an additional 18th fundamental particle that has not yet been directly discovered, or there is something amiss with our understanding of the forces governing the known 17. These astounding implications generated the most excitement for the field of particle physics in the mainstream public since the discovery of the Higgs boson in 2013 at CERN. The Muon g-2 experiment uses an intense, energetic beam of subatomic particles called muons that are generated by the powerful Fermilab Accelerator Complex. The muons are circulated in a magnetic storage ring that was transported in one piece from BNL in 2013. Scientists measure how the muon interacts with the ring's magnetic field to better understand its properties and get a glimpse into the quantum world, where particles of all varieties continually blink in and out of existence as they spontaneously generate from the vacuum surrounding the muon. The results published in 2021 were based on a total of 6 percent of the expected total data sample that will be collected by the experiment. The experiment has already collected ten times the data that was used for the first result. The next publication is expected in 2023 and will shrink the experimental uncertainty by another factor of two, with a factor of four expected by the end of the experiment.

LHC data enables sensitive studies of the Higgs boson and searches for exotic particle decays to probe the existence of new physics (Energy Frontier Experimental Physics).
Scientists at the LHC continued their studies of Higgs boson interactions and searched for exotic particles being created in high energy particle collisions. Using AI/ML techniques to enhance their sensitivity, the ATLAS collaboration used the Higgs boson as a tool for discovery by searching for evidence of decays of the Higgs boson where a pair of oppositely charged muons or electrons accompany the photon decay from the Higgs. While this challenging decay channel is predicted by the standard model at a very 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 CMS collaboration probes the possibility of the Higgs boson serving as a portal for the existence of new particles that have not yet been observed but can provide hints of new physics. The presence of such new and exotic particles can be long-lived and thereby travel longer distances before creating observable signatures in the CMS detector. Using the full dataset acquired from the 2015–2018 run, the CMS experiment has placed stringent constraints that bound the phase space for the signal-like evidence of long-lived particles. These analyses demonstrate the potential for discovery as LHC data taking operations continue in FY 2023.

Double advances for Cosmic Frontier dark energy experiments (Cosmic Frontier Experimental Physics).
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, started its full 5-year scientific survey in May 2021. DESI will carry out a spectroscopic survey of roughly 30 million distant galaxies and quasars, which is ten times more than the previous generation of spectroscopic surveys. With the three-dimensional map derived from these data, DESI will measure the expansion history of the last 8 billion years to better than 0.3 percent precision. These distance measurements will allow the tightest constraints to date on the nature of the dark energy that is responsible for the accelerated expansion of the Universe. In addition to the expansion history, DESI will place the most precise limits on the sum of neutrino masses, provide new tests of inflationary models, and measure the growth rate of large-scale structure in the universe to test models of dark energy. Meanwhile, the Legacy Survey of Space and Time (LSST) Camera (LSSTCam), fabricated for the next generation Vera C. Rubin Observatory, a joint DOE and NSF partnership, completed its MIE funded construction phase in 2021. The LSSTCam will complete testing at SLAC before shipment to Chile for integration on the telescope, followed by commissioning of the entire system. DOE and NSF will also partner for the operations phase, to carry out the ten-year LSST imaging survey which is expected to start in 2024.

Emerging Technologies: Superconducting Quantum Materials and Systems (SQMS) Center (Theoretical, Computational, and Interdisciplinary Physics).
The FNAL-led SQMS Center established a multidisciplinary collaboration comprised of more than 250 experts from twenty partner institutions, spanning from U.S. national labs, academia and industry. The Center has successfully accomplished more than 65 new hires, and new fellowships and internship programs have been created and executed, with emphasis on training a new generation of diverse quantum workforce.

- High Coherence Quantum Devices: 3D superconducting radio-frequency (SRF) cavities and 2D qubits from Rigetti computing have been integrated for the first time, demonstrating a record coherence time of the integrated qubit system approximately 40 times above the state of the art. The combined system has now successfully demonstrated quantum operation and constitutes the first important milestone for a 3D SRF-based quantum computer. A round robin testing program is executed, where qubits are traveling from Rigetti to NIST to FNAL to underground facilities in Italy, for the first large scale systematic benchmarking study of qubit performance.
- Physics and Sensing: New schemes for axion and dark matter detection based on the unique SRF high coherence devices have been proposed. Several tests have been carried out to understand the feasibility of such schemes, and for the first time Nb_3Sn cavities have shown to remain superconducting in high magnetic fields, offering an important pathway to improve the sensitivity reach of several dark matter search experiments. The DarkSRF experiment has established a record sensitivity in the search of dark photons and progress has been made in commissioning this experiment in a dilution fridge.
- Algorithms: Quantum simulation of high energy physics has been a key area of research for SQMS. Principal investigators tackled the simulation of dihedral gauge theories on digital quantum computers, which represents a new multi-institution collaboration (FNAL, NASA, Rigetti). In co-design with the SRF based systems under development at the SQMS Center, recent results demonstrate a theoretical approach to studying field theories using a qubit-based simulator.

Construction crews start lowering equipment a mile underground for excavation for Long-Baseline Neutrino Facility (Construction).
The FNAL-hosted Deep Underground Neutrino Experiment (DUNE) is an enormous international scientific effort. More than 1,300 collaborators from over 200 institutions in 33 countries plus CERN aim to shed light on elusive subatomic particles known as neutrinos—and possibly the nature of matter itself. DUNE is also going to be physically enormous. The experiment will send the world's most intense high-energy neutrino beam from the near site in Batavia, Illinois to huge particle detectors 800 miles away at SURF in Lead, South Dakota. Each of the two neutrino detector modules will be four-stories high and over 200 feet long. Construction crews will excavate almost 800,000 tons of rock to create the gigantic caverns of the Long-Baseline Neutrino Facility (LBNF) that will house these detectors. Two years of pre-excavation work was completed, building the necessary systems to move excavated rock from a mile underground to the surface, crush it and then transport it on a 4,200-foot conveyor system for deposit in the Lead Open Cut, in accordance with the wishes of local Native American tribes. On April 5, 2021, Thyssen Mining, the company contracted to carry out the excavation, received the green light to start underground work. Everything required to excavate the LBNF caverns in South Dakota, and build the future particle detectors, must be lowered a mile below the surface of the Earth through a 13- by 5-foot shaft compartment

and then assembled underground, like a ship in a bottle. Thyssen conducted the first underground blast in June. The main cavern excavation work began in August 2021 and will continue for two-and-a-half years.

Successful tests pave the way for FNAL's next-generation particle accelerator; FNAL's new Accelerator Science Program to Increase Representation in Engineering (ASPIRE) fellowship for underrepresented students aims to develop the next generation of accelerator engineers (Construction).

The Proton Improvement Plan II (PIP-II) project includes building a new superconducting proton accelerator to replace the aging linac that serves as the frontend of the Fermilab Accelerator Complex. Once complete, PIP-II will be one of the highest-power linear accelerators in the world. It is the first accelerator project in the U.S. with significant international contributions, with partner institutions in France, India, Italy, Poland, and the United Kingdom. The project successfully completed the operation of the PIP-II Integration Test Facility in 2021. The purpose of the facility was to demonstrate the functionality of the normal conducting frontend of PIP-II by accelerating a proton beam through the frontend and into two prototype superconducting cyromodules. The prototype cryomodules performed as predicted by simulations validating the cryomodules' designs. The facility will now be converted to a cryomodule test-stand where the bulk of the PIP-II cryomodules will be tested with high voltage before being installed into the accelerator.

PIP-II led the development of the ASPIRE fellowship to provide immersive learning experiences at FNAL for undergraduate and masters-level engineering students who are underrepresented in accelerator engineering fields, including Black, LatinX and Indigenous identities, and women. ASPIRE is a partnership between FNAL and colleges and universities. The ASPIRE Fellows participate in the design, development, and construction of world-leading particle accelerators, initially on the PIP-II project. A primary goal of the ASPIRE program is to develop participants into competitive candidates for full-time employment in particle accelerator and related fields upon fellowship completion.

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 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.*
  LHC collisions may possibly produce dark matter particles, and their general properties may be inferred through the behavior of the accompanying normal matter. This "indirect" detection of dark matter is complementary to the ultra-sensitive direct detection experiments in the Cosmic Frontier and Intensity Frontier Experimental Physics subprograms.

<u>Research</u>

The Energy Frontier Experimental Physics subprogram's Research activity supports groups at U.S. academic and research institutions and 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 performing scientific simulations and data analyses. This activity also supports Advanced Computing to ensure broad access to exascale computing resources for HEP researchers. DOE selects research efforts with the highest scientific merit and potential impact based on a competitive peer-review process. In FY 2022, HEP plans to conduct an external peer review of the Energy Frontier laboratory research groups. The findings from the reviews in combination with input on strategic directions from regular, open, community workshops will inform funding decisions of the Energy Frontier subprogram in subsequent years.

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

U.S. LHC Detector Operations supports the maintenance of U.S.-supplied detector systems for the ATLAS and CMS detectors 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.

<u>Projects</u>

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 is contributing 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 at least a factor of ten more data.

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Energy Frontier Experimental Physics	**$194,150**	**$204,620**	**+$10,470**
Research	$68,000	$70,833	+$2,833
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 the Advanced Computing initiative and will continue support for U.S. leadership roles in all aspects of the ATLAS and CMS experimental programs. This includes the analyses of the large physics datasets collected during the LHC run, as well as scientific personnel support for the HL-LHC ATLAS and CMS Detector upgrade activities.	Funding will focus on support for the Advanced Computing initiative and will continue support for data analysis activities during the present LHC run that will be prioritized through a competitive peer review process 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	$48,787	-$4,863
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 continue supporting ATLAS and CMS detector maintenance and operations activities at CERN and the U.S.-based computing infrastructure and resources required to collect, store, and analyze the large volume of LHC data from the LHC run.	Funding will focus on maintaining the U.S.-based computing infrastructure. Funding will decrease due to the completion of maintenance and consolidation activities of U.S.-built detector components.

(dollars in thousands)

FY 2021 Enacted	FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Projects $72,500	$85,000	+$12,500
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 continue supporting the production of quadrupole magnets and crab cavities for the HL-LHC Accelerator Upgrade, and ramp-up of fabrication activities for the HL-LHC ATLAS and CMS Detector Upgrades.	Funding will increase to ramp up fabrication activities for the HL-LHC ATLAS and CMS Detector Upgrades. The HL-LHC Accelerator Upgrade Project will continue fabrication efforts.

Note:
- *Funding for the subprogram above, includes 3.65 percent 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 rare 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 such as reactors 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 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 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.*
  Several observed phenomena are not described by the Standard Model, including the imbalance of matter and antimatter in the universe today. Precision measurements of the properties of known particles may reveal information about what new particles and forces might explain these discrepancies and whether the known forces unify at energies beyond the reach of the LHC.
- *Identify the new physics of dark matter.*
  The lack of experimental evidence from current generation dark matter detectors has led to proposed theoretical models with new particles and forces that rarely interact with normal matter. These theoretical particles and forces are effectively invisible to conventional experiments but may connect to the cosmic dark matter. Experiments use intense accelerator beams at national laboratories outfitted with highly efficient high-rate detectors to explore these theoretical models.

<u>Research</u>

The Intensity Frontier Experimental Physics subprogram's Research activity supports groups at U.S. academic and research institutions and national laboratories. These groups, as part of scientific collaborations, typically have a broad portfolio of responsibilities and leadership roles in support of R&D, experimental design, fabrication, commissioning, operations, and maintenance, and they perform scientific simulations and physics data analyses. This activity also supports Advanced Computing to ensure broad access to exascale computing resources for HEP researchers. DOE selects research efforts with the highest scientific merit and potential impact based on a competitive peer review process. In FY 2018, HEP conducted an external peer review of the Intensity Frontier laboratory research groups; the next review is planned for FY 2023. In FY 2019, HEP conducted a Basic Research Needs (BRN)[oo] workshop to assess the science landscape and new opportunities for dark matter particle searches and identified three priority research directions across the Intensity and Cosmic Frontiers that are beyond the current HEP program's sensitivity. The findings from the reviews and BRN workshop in combination with input on strategic directions from regular and open community workshops will inform funding decisions of the Intensity Frontier subprogram 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 near (SBND) and far (ICARUS) detectors to definitively address measurements of additional neutrino types beyond the three currently

---

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

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. Oak Ridge National Laboratory hosts two HEP experimental efforts to measure neutrino properties and to search for new physics. The experiments leverage the Spallation Neutron Source and High Flux Isotope Reactor facilities, via the byproducts of neutron production, which are muon-type neutrinos and electron-type anti-neutrinos, respectively.

Facility Operations and Experimental Support

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 HEP-supported LZ experiment. SURF will be the home of the DUNE far site detectors being built by the LBNF/DUNE project. The SURF cooperative agreement provides basic services to LBNF/DUNE, and other experiments located at the site.

Projects

In support of LBNF/DUNE, a lease with SDSTA provides the framework for DOE and FNAL to construct federally funded buildings and facilities on non-federal land and to establish a long-term (multi-decade) arrangement for DOE and FNAL to use SDSTA space to host the DUNE neutrino detector. Other Project Costs (OPC) have been identified by the LBNF/DUNE project and DOE for the cost of SURF services used by LBNF/DUNE beyond the basic operational support covered by the SURF cooperative agreement mentioned above.

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.

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Intensity Frontier Experimental Physics	**$232,867**	**$245,905**	**+$13,038**
Research	$63,082	$67,644	+$4,562
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 continue support for core research efforts in all phases of experiments: data collection, analysis, and dissemination; pre-operations activities for Mu2e, and science planning and development for LBNF/DUNE. Funding will support the Advancing Computing initiative to support new software and networking technologies, which will be developed to transport and analyze very large neutrino data sets on exascale computers. Support will enhance muon beam facilities at FNAL to host a joint muon catalyzed fusion experiment.	Funding increase will support advanced software and computing efforts to manage large neutrino data sets on exascale computers, and a feasibility study for a muon catalyzed fusion experiment at FNAL.
Facility Operations and Experimental Support	$166,785	$172,261	+$5,476
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 SURF operations, and the continued fabrication and installation of the SBND experiment and operations of ICARUS as part of the SBN program. The Fermilab Accelerator Complex will run at 87 percent of optimal and includes funding for a minor General Plant Project. Support for Special Process Spares are needed for efficient recovery from unexpected downtime.	Funding increase will support the delivery of particle beams at peak power and provide detector and computing operations at 87 percent of optimal. Support for GPP and Special Process Spares will increase. Infrastructure improvements at SURF have been slow to get started and therefore funding is temporarily reduced until the backlog is cleared.

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Projects	$3,000	$6,000	+$3,000
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 increase support for the ACORN MIE system design and other related engineering activities, and OPC execution support costs at SURF for LBNF/DUNE such as electric power for excavation and construction.	Funding increase will support the ACORN MIE system design activities and the LBNF/DUNE OPC support costs at SURF.

Note:

- *Funding for the subprogram above, includes 3.65 percent 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 described 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. 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 this ancient CMB light 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, as the properties of neutrinos lead to changes in these other measurements. These measurements are complementary to 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. In addition, they perform scientific simulations and 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. In FY 2021, HEP conducted an external peer review of the Cosmic Frontier laboratory research groups. In early FY 2019, HEP conducted a Basic Research Needs (BRN)[pp] workshop to assess the science landscape and new opportunities for dark matter particle searches made possible by recent technology and theoretical advancements. The scientists identified three priority research directions across the Intensity and Cosmic Frontiers that are 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.

Two complementary next-generation, dark energy "Stage 4" experiments will provide increased precision in measuring the history of the expansion of the universe. 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. The Vera C. Rubin Observatory will carry out a ten-year wide-field, ground-based optical and near-

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

infrared imaging Legacy Survey of Space and Time (LSST) that will be used by the Dark Energy Science Collaboration (DESC). 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, and 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. Research activities support the design and science optimization of the planned experiment.

Two complementary next-generation, dark matter particle search experiments 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. A third next-generation experiment, ADMX-G2, searches for axions, another type of possible dark matter particles. To address the priority research directions aligned with the BRN study, technology studies and planning efforts are being carried out for four potential small dark matter search projects in the Cosmic Frontier.

Facility Operations and Experimental Support
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.

DOE's DESI instrumentation is mounted and started its five-year science survey in May 2021 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, using the DOE-provided three billion-pixel LSST camera (LSSTCam), is being commissioned in Chile. DOE and NSF are full partners in the Observatory's operations phase to carry out the ten-year LSST survey, planned to start in late FY 2024. SLAC manages the Observatory's U.S. Data Facility as part of DOE's responsibilities during the operations phase.

The LZ dark matter detector began science operations underground in the Sanford Underground Research Facility (SURF) in Lead, South Dakota in December 2021.

The SuperCDMS-SNOLAB dark matter detector, located at the Sudbury Neutrino Observatory in Sudbury, Canada, is finishing pre-operations activities and is expected to start full science operations in late 2023.

Projects
The next-generation CMB-S4 experiment is a planned partnership with NSF. LBNL leads the efforts for the DOE scope of the CMB-S4 project, which 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. Both arrays are required to reach the full science capabilities.

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Cosmic Frontier Experimental Physics	**$97,591**	**$97,102**	**-$489**
Research	$47,091	$48,512	+$1,421
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 continued research activities on the ADMX-G2, DESI, LZ, and SuperCDMS-SNOLAB experiments, physics preparation for the Vera C. Rubin Observatory, the associated DESC for LSST, and design and planning for new dark matter concepts.	Funding will support research on the Vera C. Rubin Observatory and its associated DESC, and for while design and planning for new dark matter concepts.
Facility Operations and Experimental Support	$44,500	$47,590	+$3,090
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 of DESI, LZ, ADMX-G2, and the start of operations for SuperCDMS-SNOLAB. Commissioning and pre-operations planning efforts will continue for the Vera C. Rubin Observatory and the DESC planning for the LSST survey.	The increase in funding will support the ramp up in operations funds for the Rubin Observatory and the DESC.

(dollars in thousands)

FY 2021 Enacted	FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Projects $6,000	$1,000	-$5,000
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 engineering design efforts for the CMB-S4 project.	The decrease in funding for CMB-S4 will prioritize the engineering design activities.

Note:

- *Funding for the subprogram above, includes 3.65 percent 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 merit and potential impact 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 2023. 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.

This activity supports the Advanced Computing initiative (formerly referred to as Integrated Computational and Data Infrastructure) to ensure broad access to exascale computing resources. This activity will also support the Reaching a New Energy Sciences Workforce (RENEW) initiative to provide undergraduate and graduate training opportunities for diverse students and academic institutions not currently well represented in the U.S. science and technology ecosystem and the Funding for Accelerated, Inclusive Research (FAIR) initiative to provide focused investment on enhancing research on clean energy, climate, and related topics at minority serving institutions.

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 developing common software tools and 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.

Quantum Information Science

The HEP QIS activity supports the “science first” goal of the national QIS strategy and advances both HEP and QIS research. Key subtopics 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. National 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. HEP is the lead program supporting the Superconducting Quantum Materials and Systems (SQMS) Center involving 21 institutions and led by the Fermi National Accelerator Laboratory. SQMS has a particular focus on extending the coherence lifetime of quantum states to reduce error rates in quantum computing and improve the sensitivity of quantum sensors for dark matter candidates and other precision measurements. The HEP QIS core research and Centers activity is part of a broader SC initiative that is conducted in coordination with SC programs, other federal agencies, and the private sector.

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 technological progression. 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.

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Theoretical, Computational, and Interdisciplinary Physics	**$136,362**	**$163,746**	**+$27,384**
Research	$136,362	$163,746	+$27,384
Theory	*$46,284*	*$59,050*	*+$12,766*
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 support world-leading theoretical particle physics research at U.S. universities and national laboratories. The Request will also support RENEW, Advanced Computing, and FAIR.	Funding will increase to support the RENEW, Advanced Computing, and FAIR initiatives.
Computational HEP	*$11,518*	*$14,130*	*+$2,612*
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, which is scheduled to be re-competed in FY 2022, will continue. The Request will continue the Traineeship Program in Computational HEP to address critical HEP workforce needs.	Funding will increase to support HEP CCE and new SciDAC activities.

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Quantum Information Science	*$45,072*	*$50,566*	*+$5,494*
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 interdisciplinary HEP-QIS consortia and lab programs for focused research at the intersection of HEP and QIS, including novel experiments, foundational theory, quantum computing, communications, sensors, and research technology. The Request will support SQMS as part of the National 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*	*$40,000*	*+$6,512*
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 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, including targeted small demonstration efforts and "seed" awards to explore emerging opportunities.	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 for accelerators.

Note:

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

Description

The Advanced Technology Research and Development (R&D) subprogram fosters cutting-edge basic research in the physics of particle beams, accelerator R&D, and R&D for particle and radiation detection. These activities are necessary for continued progress in high energy physics. Longer-term multi-purpose accelerator technology development, applicable to fields beyond HEP, is carried out by the Accelerator R&D and Production program.

General Accelerator R&D

The HEP General Accelerator R&D (GARD) activity supports the science underlying the technologies used in particle accelerators and storage rings, as well as the fundamental physics of charged particle beams. Long-term research goals include developing technologies to enable breakthroughs in particle accelerator size, cost, beam intensity, and control. The GARD activity supports groups at U.S. academic and research institutions and national laboratories performing research activities categorized into five thrust areas: 1) accelerator and beam physics; 2) advanced acceleration concepts; 3) particle sources and targetry; 4) radio-frequency acceleration technology; and 5) superconducting magnets and materials. A community study aimed at establishing a technology roadmap for the accelerator and beam physics thrust is planned for late FY 2022. Community studies for the other HEP GARD thrusts were completed in the past five years.[qq] DOE selects research efforts with the highest scientific merit and potential impact based on a competitive peer-review process. In FY 2018, HEP conducted an external peer review of the GARD laboratory research groups; the next review is planned for FY 2023. 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 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 highly successful U.S. Particle Accelerator School (USPAS). HEP conducted a review of the USPAS Program in late FY 2020 and the review committee found its performance to be excellent. 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.

This activity also supports the Accelerate initiative which will support scientific research to accelerate the transition of science advances to energy technologies.

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

Detector R&D

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. 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 merit and potential impact based on a competitive peer-review process. In FY 2016, HEP conducted an external peer review of the Detector R&D laboratory research groups; the next review is planned for FY 2022. In FY 2020, HEP conducted a Basic Research Needs workshop[rr] 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 reviews and BRN workshop in combination with input on strategic directions from regular, open community studies 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 to benefit from the resultant capabilities in detection, computing, and communications. Five SC programs—ASCR, BES, FES, HEP, and NP—are working together to advance microelectronics technologies. This activity is 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); Argonne Wakefield Accelerator (AWA) in structure-based advanced acceleration concepts; and the Fermilab Integrable Optics Test Accelerator (IOTA), superconducting radio-frequency accelerator and magnet facilities at FNAL. This activity also supports detector test beam and fabrication facilities at FNAL.

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

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Advanced Technology R&D	**$116,095**	**$112,647**	**-$3,448**
Research	$72,833	$67,911	-$4,922
General Accelerator R&D	*$49,574*	*$43,382*	*-$6,192*
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 support capitalizing on the science opportunities at the newly completed FACET-II facility and the second beamline at BELLA; other accelerator R&D activities at DOE national laboratories and universities, including ASTI efforts in superconducting magnet and SRF; and the Traineeship Program for Accelerator Science and Technology. The Request will also support the Accelerate initiative.	Funding will support the Accelerate initiative and additional awards in traineeship activities. With overall reduced funding, support will focus on efforts in superconducting magnet development and upgrades to SRF test facilities, multi-SC program R&D in superconducting materials.
Detector R&D	*$23,259*	*$24,529*	*+$1,270*
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 support world-leading, innovative Detector R&D, provide support to advance microelectronics technologies, and continue the Traineeship Program in HEP Instrumentation.	Funding will support additional awards in traineeship activities.

(dollars in thousands)

FY 2021 Enacted	FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Facility Operations and Experimental Support $43,262	$44,736	+$1,474
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 testing and beam time for experiments at the test facilities at ANL, FNAL, LBNL and SLAC. BELLA operations will now include a second beamline. The Request will provide support for 3,000 hours (91 percent of optimal) of facility operations for FACET-II.	Funding increase will support more hours of cryogenic, magnet, and SRF testing at FNAL; new two-beam laser wakefield acceleration experiments at LBNL; and additional hours of operation for FACET-II.

Note:

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

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 SC 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 2023 Request	Explanation of Changes FY 2023 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.		Funding for FY 2023 is requested in the Accelerator R&D and Production (ARDAP) program.	Funding for FY 2023 is requested in the ARDAP program.
Facility Operations and Experimental Support	$6,100	$ —	-$6,100
Funding supports operation of the BNL ATF at 100 percent of optimal levels.		Funding for FY 2023 is requested in the ARDAP program.	Funding for FY 2023 is requested in the ARDAP program.

Note:

- *Funding for the subprogram above, includes 3.65 percent 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-US. LBNF, with DOE/FNAL leadership and 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 1,300 scientists and engineers from over 200 institutions in over 30 countries. DOE will fund less than one-third of DUNE under the name DUNE-US.

The most recent approved DOE Order 413.3B Critical Decision is CD-3A, approval for Initial Far Site Construction. Following this approval, excavation and construction for the LBNF Far Site conventional facilities started to mitigate risks and minimize delays for providing a facility ready to accept detectors for installation. The preliminary Total Project Cost (TPC) range is $1,260,000,000 to $1,860,000,000, as approved on September 1, 2016, with a preliminary CD-4 date of 4Q FY 2030.

The project completed the reliability improvements needed to support excavation in early 2021 and the excavation work began in April 2021 under the CD-3A authorization. Updated planning and analysis led to an increased scope and TPC for LBNF/DUNE of $3,000,000,000, which is being evaluated prior to establishing the project baseline.

The scale of LBNF/DUNE, annual funding levels, and research and development needs have resulted in the major scope elements of the project maturing at different rates. Baselining the entire scope of the project at once introduced too many uncertainties and was no longer viewed as being in the best interest of DOE. Therefore, a subproject tailoring approach in accordance with DOE Order 413.3B is being developed to reorganize the project's scope into several independent subprojects for improved planning and management control. The definition of the subprojects and the approach to managing subprojects will be approved at CD-1RR (reaffirmation and approval of the CD-1 cost range). The first subproject to be baselined will include the completion of cavern excavation at the Far Site.

<u>11-SC-41, Muon to Electron Conversion Experiment, FNAL</u>
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 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, the approved baseline schedule can no longer be met. The COVID-19 pandemic resulted in unplanned work shutdowns and inefficiencies at the participating universities and laboratories in FY 2020-2021. Further schedule delays were incurred because of actions needed to correct performance issues delaying fabrication of the particle tracking detector and two superconducting magnets being fabricated by a vendor. A baseline change was recommended by an Independent Project Review in February 2021. The Baseline Change Proposal (BCP) is being developed but is not yet submitted or approved. In anticipation of approval of the BCP, $2,000,000 of TEC funding was appropriated in FY 2021, $13,000,000 of TEC funding is requested in FY 2022, and $2,000,000 of TEC funding is requested in FY 2023. None of these additional funds will be available to spend until the BCP is approved and the project is re-baselined.

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Construction	**$252,000**	**$298,000**	**+$46,000**
18-SC-42, Proton Improvement Plan II (PIP-II), FNAL	$79,000	$120,000	+$41,000
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 initiation of civil construction for the balance of the linear accelerator facilities as well as fabrication of technical systems when designs are final, and construction is authorized by CD-3.	Funding increase will support the transition from the design phase of PIP-II, from procurement of the Early Conventional Facilities subproject for the cryogenic plant and from site preparation, to initiation of construction for the linear accelerator facilities as well as fabrication of technical components for the accelerator.
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.		Funding will support continuation of the Far Site civil construction activities for excavation of the underground equipment caverns and connecting drifts (tunnels). Design activities will be completed for the far site detectors and cryogenics systems and the beamline design will be finalized.	Funding will increase to support the excavation of the underground equipment caverns and connecting drifts.

(dollars in thousands)

FY 2021 Enacted	FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
11-SC-41, Muon to Electron Conversion Experiment, FNAL $2,000	$2,000	$ —
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 implementation of corrective actions and increased costs due to schedule delays caused by pandemic response at FNAL and collaborating universities, and by fabrication delays for the tracking detector and two superconducting magnets being fabricated by a vendor.	No change.

High Energy Physics
Capital Summary

	(dollars in thousands)					
	Total	Prior Years	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Capital Operating Expenses						
Capital Equipment	N/A	N/A	91,830	86,830	94,500	+2,670
Minor Construction Activities						
General Plant Projects	N/A	N/A	1,500	1,500	4,000	+2,500
Total, Capital Operating Expenses	**N/A**	**N/A**	**93,330**	**88,330**	**98,500**	**+5,170**

High Energy Physics
Capital Equipment

	(dollars in thousands)					
	Total	**Prior Years**	**FY 2021 Enacted**	**FY 2022 Annualized CR**	**FY 2023 Request**	**FY 2023 Request vs FY 2021 Enacted**
Capital Equipment						
Major Items of Equipment						
Energy Frontier Experimental Physics						
High Luminosity Large Hadron Collider Accelerator Upgrade Project	271,952	123,597	43,000	43,000	30,000	-13,000
High Luminosity Large Hadron Collider ATLAS Upgrade Project	150,485	52,000	16,000	16,000	27,500	+11,500
High Luminosity Large Hadron Collider CMS Upgrade Project	140,950	34,738	13,500	13,500	27,500	+14,000
Intensity Frontier Experimental Physics						
Accelerator Controls Operations Research Network	136,400	–	–	–	1,000	+1,000
Cosmic Frontier Experimental Physics						
Cosmic Microwave Background - Stage 4	353,500	–	1,000	1,000	–	-1,000
Total, MIEs	N/A	N/A	73,500	73,500	86,000	+12,500
Total, Non-MIE Capital Equipment	N/A	N/A	18,330	13,330	8,500	-9,830
Total, Capital Equipment	**N/A**	**N/A**	**91,830**	**86,830**	**94,500**	**+2,670**

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.*

High Energy Physics
Minor Construction Activities

(dollars in thousands)

	Total	Prior Years	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
General Plant Projects (GPP)						
GPPs (greater than or equal to $5M and less than $20M)						
Target Systems Integration Building	1,500	–	1,500	–	–	-1,500
Total GPPs (greater than or equal to $5M and less than $20M)	N/A	N/A	1,500	–	–	-1,500
Total GPPs less than $5M	N/A	N/A	–	1,500	4,000	+4,000
Total, General Plant Projects (GPP)	**N/A**	**N/A**	**1,500**	**1,500**	**4,000**	**+2,500**
Total, Minor Construction Activities	**N/A**	**N/A**	**1,500**	**1,500**	**4,000**	**+2,500**

Notes:

- *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.*
- *The Target Systems Integration Building includes $14,000,000 requested in the FY 2022 President's Budget that brings the total project amount to $15,500,000.*

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 can generate transverse electric fields. The magnets will be assembled at LBNL, BNL, and FNAL, exploiting special expertise and unique capabilities at each laboratory. The FY 2023 Request for TEC funding of $30,000,000 will continue to support the production of quadrupole magnets and crab cavities and maintain international schedule synchronization. The project was stalled by shutdowns at the national laboratories due to COVID-19 and has seen increased costs as a result. In all other respects the project is performing well. The Office of Science (SC) plans a rebaseline review in late FY 2022 to evaluate the needs for additional funding.

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 early FY 2023. 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 2023 Request for TEC funding of $27,500,000 will focus on completion of the final design in anticipation of approval of construction (CD-3) and ramp-up of fabrication activities. The project was stalled by shutdowns at the national laboratories due to COVID-19 and has seen increased costs as a result. SC will evaluate the need for additional funding when the project is baselined in early FY 2023.

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 early FY 2023. 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 2023 Request for TEC funding of $27,500,000 will focus on completion of the final design in anticipation of approval of construction (CD-3) and ramp-up of fabrication activities. The project was stalled by shutdowns at the national laboratories due to COVID-19 and has seen increased costs as a result. SC will evaluate the need for additional funding when the project is baselined in early FY 2023.

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 2Q FY 2023 and CD-2 approval in FY 2024. The FY 2023 Request for TEC funding of $1,000,000 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 planned to be determined by FY 2023. 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. LBNL was selected in August 2020 to lead the efforts in providing the DOE scope for the project. While no TEC funding is requested in the FY 2023 Request, $1,000,000 of OPC funding will enable continued conceptual design and activities needed to inform CD-1 approval as well as planning for the associated systems and infrastructure.

High Energy Physics
Construction Projects Summary

(dollars in thousands)

	Total	Prior Years	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
18-SC-42, Proton Improvement Plan II						
Total Estimated Cost (TEC)	891,200	81,000	79,000	90,000	120,000	+41,000
Other Project Cost (OPC)	86,800	73,594	–	–	–	–
Total Project Cost (TPC)	**978,000**	**154,594**	**79,000**	**90,000**	**120,000**	**+41,000**
11-SC-40, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment						
Total Estimated Cost (TEC)	2,866,375	507,781	171,000	176,000	176,000	+5,000
Other Project Cost (OPC)	133,625	91,625	2,000	4,000	4,000	+2,000
Total Project Cost (TPC)	**3,000,000**	**599,406**	**173,000**	**180,000**	**180,000**	**+7,000**
11-SC-41, Muon to Electron Conversion Experiment						
Total Estimated Cost (TEC)	281,000	250,000	2,000	13,000	2,000	–
Other Project Cost (OPC)	23,677	23,677	–	–	–	–
Total Project Cost (TPC)	**304,677**	**273,677**	**2,000**	**13,000**	**2,000**	**–**
Total, Construction						
Total Estimated Cost (TEC)	**N/A**	**N/A**	**252,000**	**279,000**	**298,000**	**+46,000**
Other Project Cost (OPC)	**N/A**	**N/A**	**2,000**	**4,000**	**4,000**	**+2,000**
Total Project Cost (TPC)	**N/A**	**N/A**	**254,000**	**283,000**	**302,000**	**+48,000**

Note for Mu2e:

- *In anticipation of approval of the Baseline Change Proposal (BCP), $2,000,000 of TEC funding was appropriated in FY 2021, $13,000,000 of TEC funding is requested in FY 2022, and $2,000,000 of TEC funding is requested in FY 2023. 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 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Research	398,203	373,368	418,646	+20,443
Facility Operations	314,297	295,197	313,374	-923
Projects				
Line Item Construction (LIC)	254,000	283,000	302,000	+48,000
Major Items of Equipment (MIE)	79,500	77,500	88,000	+8,500
Total, Projects	**333,500**	**360,500**	**390,000**	**+56,500**
Total, High Energy Physics	**1,046,000**	**1,029,065**	**1,122,020**	**+76,020**

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.

	FY 2021 Enacted	FY 2021 Current	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
	(dollars in thousands)				
Scientific User Facilities - Type A					
Fermilab Accelerator Complex	**130,900**	**126,634**	**130,500**	**141,605**	**+10,705**
Number of Users	2,050	1,725	2,250	2,600	+550
Achieved Operating Hours	–	4,230	–	–	–
Planned Operating Hours	3,640	4,200	5,040	4,975	+1,335
Optimal Hours	4,480	4,480	5,740	5,740	+1,260
Percent of Optimal Hours	81.3%	94.4%	87.8%	86.7%	+5.4%
Accelerator Test Facility	**6,100**	**4,950**	**–**	**–**	**-6,100**
Number of Users	105	80	–	–	-105
Achieved Operating Hours	–	2,998	–	–	–
Planned Operating Hours	2,250	2,250	–	–	-2,250
Optimal Hours	2,500	2,500	–	–	-2,500
Percent of Optimal Hours	90.0%	120.9%	–	–	-90.0%
Unscheduled Down Time Hours	–	590	–	–	–

	(dollars in thousands)				
	FY 2021 Enacted	**FY 2021 Current**	**FY 2022 Annualized CR**	**FY 2023 Request**	**FY 2023 Request vs FY 2021 Enacted**
Facility for Advanced Accelerator Experimental Tests II (FACET II)	**16,000**	**15,526**	**16,000**	**12,085**	**-3,915**
Number of Users	250	111	250	210	-40
Achieved Operating Hours	–	2,778	–	–	–
Planned Operating Hours	3,720	2,440	3,000	3,000	-720
Optimal Hours	3,720	3,720	3,000	3,300	-420
Percent of Optimal Hours	100.0%	74.7%	100.0%	90.9%	-9.1%
Unscheduled Down Time Hours	–	2,162	–	–	–
Total, Facilities	**153,000**	**147,110**	**146,500**	**153,690**	**+690**
Number of Users	2,405	1,916	2,500	2,810	+405
Achieved Operating Hours	–	10,006	–	–	–
Planned Operating Hours	9,610	8,890	8,040	7,975	-1,635
Optimal Hours	10,700	10,700	8,740	9,040	-1,660
Unscheduled Down Time Hours	–	2,752	–	–	–

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

High Energy Physics
Scientific Employment

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Number of Permanent Ph.Ds (FTEs)	780	746	749	-31
Number of Postdoctoral Associates (FTEs)	370	355	356	-14
Number of Graduate Students (FTEs)	485	470	472	-13
Number of Other Scientific Employment (FTEs)	1,585	1,491	1,668	+83
Total Scientific Employment (FTEs)	**3,220**	**3,062**	**3,245**	**+25**

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 2023 Request for the Proton Improvement Project II (PIP-II) is $120,000,000 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 cryo-plant 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 FY 2022, and the planned date for CD-4, Project Completion, is 1Q FY 2033.

In FY 2021 construction was initiated by the ECF subproject for the building that will house the in-kind contribution of the cryoplant; the building is expected to be completed in calendar year 2022. Also in FY 2021, continued design and development work 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 project risk mitigation. In FY 2021, the civil engineering design for the linear accelerator complex was completed. The PIP-II injector test was completed, a significant R&D program that reduced technical risk for the project. Assumptions were refined for the level of in-kind contributions from the international partner laboratories. Anticipated in-kind technical contributions from international partners total $330,000,000 (equivalent to DOE costing).

Legally binding agreements with all countries but France have been signed to cover the planned work. The legally binding agreement with France has been drafted and signatures are expected in the summer of 2022. Non-binding Project Planning Documents (PPDs) that provide additional technical details beyond those provided in the legally binding agreements are being signed by the international partners; so far PPDs have been signed with Italian, Polish, and UK partner institutions.

The FY 2022 Request of $90,000,000 supports completion of the ECF cryo-plant building and completion of CD-3, approval for site preparation and construction for the linear accelerator complex as well as initiation of preconstruction procurement for the accelerator's technical systems as designs are completed.

The FY 2023 Request of $120,000,000 will support construction of the conventional facilities as well as continuation of procurement and fabrication for the technical systems.

A Federal Project Director (FPD) has been assigned to this project and has approved this CPDS. The FPD has Level II certification and is applying for Level-III certification in FY 2022.

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
FY 2023	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
FY 2023	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, Total	TPC
FY 2020	91,000	547,965	638,965	82,035	82,035	721,000
FY 2021	184,000	617,200	801,200	86,800	86,800	888,000
FY 2022	177,000	714,200	891,200	86,800	86,800	978,000
FY 2023	177,000	714,200	891,200	86,800	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 was developed to reduce technical risks for the project, with participation and in-kind contributions from the India Department of Atomic Energy (DAE) Labs. The Test Facility has successfully completed its program and has been converted to a cryomodule test stand for testing the cryomodules for the project.

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.[ss]

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, as well as interest in LBNF/DUNE. The construction phase scope of in-kind contributions is divided between U.S. DOE national laboratories, 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 Wroclaw University of Science and Technology in Poland, tentatively as indicated in the following table of Scope Responsibilities for PIP-II.[tt]

[ss] See Section 8.
[tt] See Section 8.

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

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[uu] 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.[vv]

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*.

[uu] LBNF/DUNE is the DOE Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment.
[vv] "Building for Discovery: Strategic Plan for U.S. Particle Physics in the Global Context," HEPAP, 2014.

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.

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	44,363
FY 2022	40,000	40,000	40,000
FY 2023	7,000	7,000	7,000
Outyears	5,000	5,000	30,055
Total, Design (TEC)	**177,000**	**177,000**	**177,000**
Construction (TEC)			
FY 2020	9,000	9,000	123
FY 2021	26,000	26,000	17,071
FY 2022	50,000	50,000	50,000
FY 2023	113,000	113,000	113,000
Outyears	516,200	516,200	534,006
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	61,434
FY 2022	90,000	90,000	90,000
FY 2023	120,000	120,000	120,000
Outyears	521,200	521,200	564,061
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	–	–	21
Outyears	13,206	13,206	13,390
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	61,455
FY 2022	90,000	90,000	90,000
FY 2023	120,000	120,000	120,000
Outyears	534,406	534,406	577,451
Total, TPC	**978,000**	**978,000**	**978,000**

Notes:

- *Costs through FY 2021 reflect actual costs; costs for FY 2022 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	146,314	149,314	146,314
Design - Contingency	30,686	27,686	30,686
Total, Design (TEC)	**177,000**	**177,000**	**177,000**
Construction	124,009	124,009	124,009
Site Preparation	12,783	12,783	12,783
Equipment	378,705	378,705	378,705
Construction - Contingency	198,703	198,703	198,703
Total, Construction (TEC)	**714,200**	**714,200**	**714,200**
Total, TEC	**891,200**	**891,200**	**891,200**
Contingency, TEC	*229,389*	*226,389*	*229,389*
Other Project Cost (OPC)			
R&D	67,117	67,117	67,117
Conceptual Planning	8,324	8,324	8,324
Conceptual Design	2,855	2,855	2,855
OPC - Contingency	8,504	8,504	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*	*8,504*	*8,504*
Total, TPC	**978,000**	**978,000**	**978,000**
Total, Contingency (TEC+OPC)	***237,893***	***234,893***	***237,893***

5. Schedule of Appropriations Requests

(dollars in thousands)

Fiscal Year	Type	Prior Years	FY 2021	FY 2022	FY 2023	Outyears	Total
FY 2020	TEC	41,000	—	—	—	597,965	638,965
	OPC	77,035	—	—	—	5,000	82,035
	TPC	118,035	—	—	—	602,965	721,000
FY 2021	TEC	81,000	20,000	—	—	700,200	801,200
	OPC	72,529	2,000	—	—	12,271	86,800
	TPC	153,529	22,000	—	—	712,471	888,000
FY 2022	TEC	81,000	79,000	90,000	—	641,200	891,200
	OPC	73,594	—	—	—	13,206	86,800
	TPC	154,594	79,000	90,000	—	654,406	978,000
FY 2023	TEC	81,000	79,000	90,000	120,000	521,200	891,200
	OPC	73,594	—	—	—	13,206	86,800
	TPC	154,594	79,000	90,000	120,000	534,406	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 2023 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.

The project has a preliminary Total Project Cost (TPC) range of $1,260,000,000 to $1,860,000,000 approved for CD-1(R) on November 5, 2015. The preliminary TPC excludes foreign contributions. Since then, the preliminary TPC estimate has grown to approximately $3,000,000,000 which exceeds the upper end of the cost range by over 50 percent. According to DOE policy, if the upper 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.[ww] An Independent Project Review conducted by DOE in January 2021 recommended the cost range be reevaluated with a planned review of new range in FY 2022. A CD-1 Reaffirmation or 'CD-1RR' is planned in FY 2022 to approve the updated cost range, reaffirm the alternative selection, and approve a new tailoring strategy for baselining the project in multiple subprojects.

Significant Changes

This project was initiated in FY 2012. The most recent approved DOE Order 413.3B critical decision is CD-3A Revision, approval for Initial Far Site Construction: reducing the authorized scope for excavation and construction for the LBNF Far Site conventional facilities. The change transferred some of the scope that had been approved by CD-3A to a later authorization decision.

OPC costs that were previously applied to technical integration of the neutrino detectors have been transferred from "Other OPC Costs" to TEC construction contingency. "Other OPC Costs" now are exclusively execution support costs such as electrical power for construction and equipment installation. DOE and the Laboratory are continuing engagement with potential partners. In June 2021, CERN approved contributing a second cryostat to the project.

HEP and Fermilab have arranged for in-kind contributions from international partners to both the facility (valued at approximately $260,000,000) and the experiment (valued at approximately $400,000,000). These amounts identify the cost if DOE would supply the components.

The scale of LBNF/DUNE and various other factors, including annual funding levels and research and development needs, resulted in the major scope elements of the project maturing at different rates. Baselining the entire scope of the project at once introduced too many uncertainties and was no longer viewed as being in the best interest of DOE. Therefore, a subproject tailoring approach in accordance with DOE Order 413.3B is now being developed in order to reorganize the project's scope into several independent subprojects for improved planning and management control. The definition of the subprojects and the approach to managing subprojects will be approved at CD-1RR during FY 2022. The first subproject to be baselined will authorize the completion of cavern excavation at the Far Site.

FY 2021 funding supported the completion of pre-excavation and reliability projects at the far site which enable full scale excavation to begin. FY 2021 funding also supported the design of the near site conventional facilities, beamline systems, the cryogenic systems, and the detectors. The final design of the Near Site conventional facilities was received by the project at the end of FY 2021.

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

The project was evaluated by Independent Project Reviews in January and June 2021. The reviews noted evidence of progress and supported the approach of phasing with subprojects, but identified additional work needed before CD-1RR and baselining of the subprojects.

The FY 2022 Request supports continued work on the excavation of the detector caverns and completion of design activities and continuation of approved site preparation, as well as preproduction and fabrication activities when approved by CD-3.

The FY 2023 Request will support continuation of the Far Site civil construction activities for excavation of the underground equipment caverns and connecting drifts (tunnels). Design activities will be completed for the Far Site detectors and cryogenics systems and the beam-line design will be finalized.

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

<u>Critical Milestone History</u>

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
FY 2023	1/8/10	11/5/15	11/5/15	4Q FY 2023	4Q FY 2023	4Q FY 2023	1Q FY 2034

Notes:
- *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.*
- *The critical milestone dates tabulated for the FY 2023 Request are based on project planning in FY 2022 and will be reviewed by IPR and reevaluated for Critical Decision CD-1RR in 4Q FY 2022.*

CD-0 – Approve Mission Need for a construction project with a conceptual scope and cost range

Conceptual Design Complete – Actual date the conceptual design was completed (if applicable)

CD-1 – Approve Alternative Selection and Cost Range

CD-2 – Approve Performance Baseline

Final Design Complete – Estimated/Actual date the project design will be/was complete(d)

CD-3 – Approve Start of Construction

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
FY 2023	4Q FY 2023	11/5/15	9/1/16	TBD	TBD

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, Total	TPC
FY 2011	102,000	—	102,000	22,180	22,180	124,180
FY 2012	133,000	—	133,000	42,621	42,621	175,621
FY 2016	127,781	655,612	783,393	89,539	89,539	872,932
FY 2017	123,781	1,290,680	1,414,461	85,539	85,539	1,500,000
FY 2018	234,375	1,199,000	1,433,375	102,625	102,625	1,536,000
FY 2019	231,000	1,234,000	1,465,000	95,000	95,000	1,560,000
FY 2020	259,000	1,496,000	1,755,000	95,000	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
FY 2023	455,464	2,410,911	2,866,375	133,625	133,625	3,000,000

Notes:
- *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.*
- *The TPC point estimate tabulated for the FY 2023 Request was increased to $3,000,000,000 in FY 2022 and will be reviewed by Independent Project Review (IPR) and reevaluated by ESAAB in 4Q FY 2022.*
- *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 far detector modules at a greater distance than is used with NuMI experiments.[xx]

For the LBNF/DUNE project, FNAL will be responsible for design, construction and operation of the major components of facilities which enable the DUNE research program (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 large detectors 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.

[xx] 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.

- 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, fabrication of detector components 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 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 fund approximately one half of the DUNE detectors. This excludes the cryostats that hold the detectors. The cryostats will be provided by CERN. The project continues to refine the development of the design and cost estimates as the U.S. DOE contributions to the multinational effort now are better understood. The cost estimate for DOE contributions will be updated as planning continues in preparation for baselining the various subprojects.

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, including significant additional contributions from CERN that are in the process of being finalized. 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. New commitments for detector contributions are being finalized now. 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 will be finalized and approved with each subproject. 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, 120 GeV protons delivered to the absorber and muons observed downstream of the neutrino beamline
Far Site-Conventional Facilities	Caverns excavated for 40 kiloton fiducial detector mass[yy]; beneficial occupancy granted for cavern space to house 20 kiloton fiducial detector mass	Same as the Threshold KPP
Detector Cryogenic Infrastructure	DOE-provided components for cryogenic subsystems installed and pressure tested for 20 kiloton fiducial detector mass	In addition to Threshold KPPs, successfully filled first cryostat detector with LAr
Far Detector	DOE-provided components installed in cryostats to support 20 kiloton fiducial detector mass, with continuous readout of the cold electronics and photon detection systems	In addition to Threshold KPPs, observation of cosmic ray tracks in the first detector module

[yy] 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	90,530	90,530	72,946
FY 2022	81,000	81,000	108,179
FY 2023	–	–	17,584
Total, Design (TEC)	**455,464**	**455,464**	**455,464**
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	80,470	80,470	69,296
FY 2022	95,000	95,000	95,000
FY 2023	176,000	176,000	176,000
Outyears	1,835,594	1,835,594	1,967,385
Total, Construction (TEC)	**2,410,911**	**2,410,911**	**2,410,911**

(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	142,242
FY 2022	176,000	176,000	203,179
FY 2023	176,000	176,000	193,584
Outyears	1,835,594	1,835,594	1,967,385
Total, TEC	**2,866,375**	**2,866,375**	**2,866,375**

(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	1,954
FY 2022	4,000	4,000	4,000
FY 2023	4,000	4,000	4,000
Outyears	32,000	32,000	33,929
Total, OPC	**133,625**	**133,625**	**133,625**

(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	144,196
FY 2022	180,000	180,000	207,179
FY 2023	180,000	180,000	197,584
Outyears	1,867,594	1,867,594	2,001,314
Total, TPC	**3,000,000**	**3,000,000**	**3,000,000**

Notes:

- *Costs through FY 2021 reflect actual costs; costs for FY 2022 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	397,568	**N/A**
Design - Contingency	57,896	48,366	**N/A**
Total, Design (TEC)	**455,464**	**445,934**	**N/A**
Construction	1,134,000	1,134,000	**N/A**
Equipment	700,000	375,000	**N/A**
Construction - Contingency	576,911	435,066	**N/A**
Total, Construction (TEC)	**2,410,911**	**1,944,066**	**N/A**
Total, TEC	**2,866,375**	**2,390,000**	**N/A**
Contingency, TEC	*634,807*	*483,432*	***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	27,625	100,000	**N/A**
OPC - Contingency	20,375	24,375	**N/A**
Total, Except D&D (OPC)	**133,625**	**210,000**	**N/A**
Total, OPC	**133,625**	**210,000**	**N/A**
Contingency, OPC	*20,375*	*24,375*	***N/A***
Total, TPC	**3,000,000**	**2,600,000**	**N/A**
Total, Contingency (TEC+OPC)	***655,182***	***507,807***	***N/A***

Notes:

- *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)

Fiscal Year	Type	Prior Years	FY 2021	FY 2022	FY 2023	Outyears	Total
FY 2011	TEC	12,000	—	—	—	90,000	102,000
	OPC	22,180	—	—	—	—	22,180
	TPC	34,180	—	—	—	90,000	124,180
FY 2012	TEC	17,000	—	—	—	116,000	133,000
	OPC	42,621	—	—	—	—	42,621
	TPC	59,621	—	—	—	116,000	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	436,781	—	—	—	1,318,219	1,755,000
	OPC	91,625	—	—	—	3,375	95,000
	TPC	528,406	—	—	—	1,321,594	1,850,000
FY 2021	TEC	507,781	100,500	—	—	1,868,094	2,476,375
	OPC	91,625	1,000	—	—	31,000	123,625
	TPC	599,406	101,500	—	—	1,899,094	2,600,000
FY 2022	TEC	507,781	171,000	176,000	—	1,535,219	2,390,000
	OPC	91,625	2,000	4,000	—	112,375	210,000
	TPC	599,406	173,000	180,000	—	1,647,594	2,600,000
FY 2023	TEC	507,781	171,000	176,000	176,000	1,835,594	2,866,375
	OPC	91,625	2,000	4,000	4,000	32,000	133,625
	TPC	599,406	173,000	180,000	180,000	1,867,594	3,000,000

Note:

- *All estimates are preliminary.*

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..................	79,100
New area being constructed by this project at Sanford Underground Research Facility (SURF).......	185,700
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"	79,100
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"	185,700
Total area eliminated	—

The new facility square footage estimates are based on the current design and updating the calculation to be consistent with DOE's real estate guidance. New facilities information will be identified and reported in accordance with DOE guidance.

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 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 contracted 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. An excavation subcontract was awarded within budget and excavation construction activities began in FY 2021.

For the LBNF Near Site conventional facilities at FNAL, the laboratory will subcontract with an A/E firm for design and plan to utilize a traditional design-bid-build construction method supported by additional procurements for preconstruction and construction phase services from a professional construction management firm.

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 2023 Request for the Muon to Electron Conversion Experiment (Mu2e) is $2,000,000 of Total Estimated Cost (TEC) funding to support the development of a new technical, cost, schedule, and management baseline 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. 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. Technical progress on all aspects of the project has continued through FY 2021. The project is awaiting the new baseline after resolving contract issues for magnet production.

In anticipation of approval of the BCP, $2,000,000 of TEC funding was appropriated in FY 2021, $13,000,000 of TEC funding is requested in FY 2022, and $2,000,000 is requested in FY 2023. The additional funds cannot be spent until the BCP approval and the project is re-baselined.

A Federal Project Director with Certification 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	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
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
FY 2023	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
FY 2023	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, Total	TPC
FY 2011	35,000	—	35,000	10,000	10,000	45,000
FY 2012	36,500	—	36,500	18,777	18,777	55,277
FY 2013	44,000	—	44,000	24,177	24,177	68,177
FY 2014	61,000	162,000	223,000	26,177	26,177	249,177
FY 2015	47,000	162,900	209,900	23,677	23,677	233,577
FY 2016	57,000	193,000	250,000	23,677	23,677	273,677
FY 2017	57,000	193,000	250,000	23,677	23,677	273,677
FY 2018	60,598	189,402	250,000	23,677	23,677	273,677
FY 2019	60,598	189,402	250,000	23,677	23,677	273,677
FY 2022	60,598	204,402	265,000	23,677	23,677	288,677
FY 2023	60,598	220,402	281,000	23,677	23,677	304,677

Note:

- *In anticipation of Baseline Change Proposal (BCP) approval, $2,000,000 of TEC funding was appropriated in FY 2021, $13,000,000 is requested in FY 2022, and $2,000,000 is requested in FY 2023 and cannot be spent until the BCP approved and project 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.

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."[zz] 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."[aaa]

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.

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

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

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.

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	13,557
FY 2022	13,000	13,000	13,000
FY 2023	2,000	2,000	2,000
Outyears	14,000	14,000	54,414
Total, Construction (TEC)	**220,402**	**220,402**	**220,402**
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	13,557
FY 2022	13,000	13,000	13,000
FY 2023	2,000	2,000	2,000
Outyears	14,000	14,000	54,414
Total, TEC	**281,000**	**281,000**	**281,000**

(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	13,557
FY 2022	13,000	13,000	13,645
FY 2023	2,000	2,000	2,000
Outyears	14,000	14,000	54,414
Total, TPC	**304,677**	**304,677**	**304,677**

Notes:

- *Costs through FY 2021 reflect actual costs; costs for FY 2022 and outyears are estimates.*
- *In anticipation Baseline Change Proposal (BCP) approval, $2,000,000 of TEC funding was appropriated in FY 2021, $13,000,000 is requested in FY 2022, and $2,000,000 is requested in FY 2023 and cannot be spent until the BCP approved and project 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	17,336	13,000
Site Preparation	1,390	1,390	2,000
Equipment	197,976	180,346	133,000
Construction - Contingency	3,700	5,330	45,000
Total, Construction (TEC)	**220,402**	**204,402**	**193,000**
Total, TEC	**281,000**	**265,000**	**250,000**
Contingency, TEC	*3,700*	*5,330*	*53,000*
Other Project Cost (OPC)			
R&D	7,555	7,555	8,200
Conceptual Planning	2,300	2,300	2,300
Conceptual Design	13,177	13,177	13,177
OPC - Contingency	645	645	**N/A**
Total, Except D&D (OPC)	**23,677**	**23,677**	**23,677**
Total, OPC	**23,677**	**23,677**	**23,677**
Contingency, OPC	*645*	*645*	***N/A***
Total, TPC	**304,677**	**288,677**	**273,677**
Total, Contingency (TEC+OPC)	***4,345***	***5,975***	***53,000***

Note:

- *In anticipation of Baseline Change Proposal (BCP) approval, $2,000,000 of TEC funding was appropriated in FY 2021, $13,000,000 is requested in FY 2022, and $2,000,000 is requested in FY 2023 and cannot be spent until BCP approved and the project re-baselined.*

5. Schedule of Appropriations Requests

(dollars in thousands)

Fiscal Year	Type	Prior Years	FY 2021	FY 2022	FY 2023	Outyears	Total
FY 2011	TEC	5,000	—	—	—	30,000	35,000
	OPC	10,000	—	—	—	—	10,000
	TPC	15,000	—	—	—	30,000	45,000
FY 2012	TEC	24,000	—	—	—	12,500	36,500
	OPC	18,777	—	—	—	—	18,777
	TPC	42,777	—	—	—	12,500	55,277
FY 2013	TEC	44,000	—	—	—	—	44,000
	OPC	24,177	—	—	—	—	24,177
	TPC	68,177	—	—	—	—	68,177
FY 2014	TEC	79,000	—	—	—	144,000	223,000
	OPC	26,177	—	—	—	—	26,177
	TPC	105,177	—	—	—	144,000	249,177
FY 2015	TEC	92,000	—	—	—	117,900	209,900
	OPC	23,677	—	—	—	—	23,677
	TPC	115,677	—	—	—	117,900	233,577
FY 2016	TEC	132,100	—	—	—	117,900	250,000
	OPC	23,677	—	—	—	—	23,677
	TPC	155,777	—	—	—	117,900	273,677
FY 2017	TEC	175,600	—	—	—	74,400	250,000
	OPC	23,677	—	—	—	—	23,677
	TPC	199,277	—	—	—	74,400	273,677
FY 2018	TEC	220,000	—	—	—	30,000	250,000
	OPC	23,677	—	—	—	—	23,677
	TPC	243,677	—	—	—	30,000	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
FY 2023	TEC	250,000	2,000	13,000	2,000	14,000	281,000
	OPC	23,677	—	—	—	—	23,677
	TPC	273,677	2,000	13,000	2,000	14,000	304,677

Notes:

- *In anticipation of Baseline Change Proposal (BCP) approval, $2,000,000 of TEC funding was appropriated in FY 2021, $13,000,000 is requested in FY 2022, and $2,000,000 is requested in FY 2023 and cannot be spent until the BCP approved and project re-baselined.*
- *Congress approved an FY 2013 reprogramming for the Mu2e construction project following the submission of the FY 2014 budget with a Total Project Cost of $234,677,000.*

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 percent 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

The mission of the Nuclear Physics (NP) program is to explore one of the enduring mysteries of the universe, the nature of matter: its basic constituents and how they interact to form the elements and the properties we observe. Solving this mystery involves 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, climate, 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 recently 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 scientific 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 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 artificial intelligence and machine learning, 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 a scientific user facility, with data taking for scientific research initiated 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 approximately 95 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 artificial intelligence and machine learning which can benefit nuclear physics research and NP accelerator operations. NP also stewards accelerator research and development (R&D), pursuing next generation electron ion source developments and advancing approaches in superconducting radio frequency (SRF) technologies. In addition, the request supports NP participation in the following SC Initiatives: Microelectronics, Reaching a New Energy Sciences Workforce (RENEW), Funding for Accelerated, Inclusive Research (FAIR), and Accelerate Innovations in Emerging Technologies (Accelerate).

Highlights of the FY 2023 Request

The FY 2023 Request for $739.2 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.

Research

- *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
  - Exploring the fundamental structure of nucleons at the sub-femtometer scale at CEBAF and the future EIC
  - 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 its 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 leading to precision predictions from QCD of nuclear properties and nuclear reactions via Scientific Discovery Through Advanced Computing
  - Curation of reliable, accurate Nuclear Data for basic nuclear research and nuclear technologies
  - Niche capabilities and unique "hands-on" experiences in nuclear science at NP supported University Centers of Excellence
- *Quantum Information Science (QIS)*: Support continues for the SC National QIS Research Centers (NQISRCs) 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.*
- *Artificial Intelligence and Machine Learning (AI/ML)*: As part of the Office of Science's initiative on AI/ML, 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.
- *Reaching a New Energy Sciences Workforce (RENEW)*: NP continues support for 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.
- *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.
- *Funding for Accelerated, Inclusive Research (FAIR):* The FAIR initiative will provide focused investment on enhancing

research on clean energy, climate, and related topics at minority serving institutions, including attention to underserved and environmental justice communities. The activities will improve the capability of MSIs to perform and propose competitive research and will build beneficial relationships between MSIs and DOE national laboratories and facilities.

- *Accelerate Innovations in Emerging Technologies (Accelerate):* The Accelerate initiative will support scientific research to accelerate the transition of science advances to energy technologies. The goal is to drive scientific discovery to sustainable production of new technologies across the innovation continuum, to provide experiences in working across this continuum for the workforce needed for industries of the future, and to meet the nation's needs for abundant clean energy, a sustainable environment, and national security.

<u>Facility Operations</u>

Requested funding directs efforts to operations of the NP scientific user facilities to enable world-class science:

- RHIC operates 3,264 hours (90 percent optimal) to begin the sPHENIX scientific program.
- CEBAF operates for 3,840 hours (91 percent of optimal), enabling highest priority 12 GeV experiments.
- ATLAS operates for 5,952 hours (93 percent of optimal) to enable the most compelling experiments in nuclear structure and astrophysics.
- FRIB operations continues to grow towards full operations as it enters its first full year of user experiments, operating for 3,100 hours (91 percent of optimal).

<u>Projects</u>

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

- Continuation of research and Project Engineering and Design (PED) activities for the Electron-Ion Collider (EIC).
- Continuation of the Gamma-Ray Energy Tracking Array (GRETA) MIE, to enable provision of advanced, high resolution gamma ray detection capabilities for FRIB.
- 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 (TSNLDBD) 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 2023 Research Initiatives

Nuclear Physics supports the following FY 2023 Request Research Initiatives.

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Accelerate Innovations in Emerging Technologies	–	–	4,000	+4,000
Artificial Intelligence and Machine Learning	4,000	4,000	8,000	+4,000
Funding for Accelerated, Inclusive Research (FAIR)	–	–	2,000	+2,000
Microelectronics	–	–	518	+518
Quantum Information Science	13,347	9,847	10,866	-2,481
Reaching a New Energy Sciences Workforce (RENEW)	–	–	6,000	+6,000
Total, Research Initiatives	**17,347**	**13,847**	**31,384**	**+14,037**

Notes:
- *The FY 2021 Enacted funding supporting QIS included $3,500,000 of Isotope Production and Applications for Research and Applications support. Beginning in FY 2022, support for these activities can be found in the Isotope R&D and Production Program Budget Request.*
- *The Integrated Computational and Data Initiative is rolled into Advanced Computing Initiative in FY 2023.*

Nuclear Physics
Funding

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Nuclear Physics				
Medium Energy, Research	41,110	43,800	50,305	+9,195
Medium Energy, Operations	117,201	117,201	143,443	+26,242
Total, Medium Energy Physics	**158,311**	**161,001**	**193,748**	**+35,437**
Heavy Ion, Research	36,313	36,313	43,204	+6,891
Heavy Ion, Operations	181,625	183,552	191,782	+10,157
Heavy Ion, Projects	30,180	24,863	10,000	-20,180
Total, Heavy Ion Physics	**248,118**	**244,728**	**244,986**	**-3,132**
Low Energy, Research	61,763	61,763	68,059	+6,296
Low Energy, Operations	79,379	79,379	125,471	+46,092
Low Energy, Projects	16,000	16,000	23,940	+7,940
Total, Low Energy Physics	**157,142**	**157,142**	**217,470**	**+60,328**
Theory, Research	61,129	61,129	62,992	+1,863
Total, Nuclear Theory	**61,129**	**61,129**	**62,992**	**+1,863**
Isotopes Operations	36,340	–	–	-36,340
Isotopes Research	26,660	–	–	-26,660
Isotopes Projects	3,000	–	–	-3,000
Total, Isotope Development and Production for Research and Applications	**66,000**	**–**	**–**	**-66,000**
Subtotal, Nuclear Physics	**690,700**	**624,000**	**719,196**	**+28,496**

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
	(dollars in thousands)			
Construction				
14-SC-50, Facility for Rare Isotope Beams (FRIB), MSU	5,300	–	–	-5,300
20-SC-51, U.S. Stable Isotope Production and Research Center (SIPRC)	12,000	–	–	-12,000
20-SC-52, Electron Ion Collider (EIC), BNL	5,000	5,000	20,000	+15,000
Subtotal, Construction	**22,300**	**5,000**	**20,000**	**-2,300**
Total, Nuclear Physics	**713,000**	**629,000**	**739,196**	**+26,196**

SBIR/STTR funding:

- FY 2021 Enacted: SBIR $18,685,000 and STTR $2,625,000
- FY 2022 Annualized CR: SBIR $19,564,000 and STTR $2,748,000
- FY 2023 Request: SBIR $21,450,000 and STTR $3,015,000

	(dollars in thousands) FY 2023 Request vs FY 2021 Enacted
Medium Energy Physics	**+35,437**
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 CEBAF accelerator to support 3,840 operating hours (91 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 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 SC QIS initiative. Activities are continued in AI/ML to develop pilot platforms targeting automated optimization of accelerator performance. Funding is also requested to participate 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 and low temperature environments. This subprogram also supports the Accelerate initiative which will support scientific research to accelerate the transition of science advances to energy technologies.	
Heavy Ion Physics	**-3,132**
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 3,264 hour run (at 90 percent optimal), high priority core competencies, and experimental activities to prepare scientific instrumentation and infrastructure for the scientific program. The Request supports commissioning and initial operation of the super Pioneering High Energy Nuclear Interaction eXperiment (sPHENIX), 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 the SC QIS initiative. Activities are continued in AI/ML 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.	

(dollars in thousands)
FY 2023 Request vs FY 2021 Enacted
+60,328

Low Energy Physics

The Request provides support for operations of two low energy user facilities: the ATLAS facility, which operates for 5,952 hours (93 percent optimal), and FRIB, which in its first full year of operation for scientific research, provides beam time for 3,100 hours (91 percent of optimal) to support research and beam studies. FRIB research is supported following FRIB's transition from project completion to operating Scientific User Facility In FY 2022. 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 HRS 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 High Intensity Gamma Source (HIGS) at the Triangle Universities Nuclear Laboratory, and the Center for Experimental Nuclear Physics and Astrophysics (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 TSNLDBD experiment (MIE) to reach unprecedented sensitivities. Funding in Fundamental Symmetries also supports efforts such as the Fundamental Neutron Physics Beamline at the Spallation Neutron Source (SNS) and the continued development of its flagship experiment, the neutron electric dipole moment (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.

Activities continue in AI/ML to develop pilot platforms targeting automated optimization of accelerator performance. Participation in the SC QIS initiative also continues.

	(dollars in thousands) FY 2023 Request vs FY 2021 Enacted
Nuclear Theory 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 distributes 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 AI/ML 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 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. This subprogram also supports the FAIR initiative which will provide focused investment on enhancing research on clean energy, climate, and related topics at minority serving institutions, including attention to underserved and environmental justice regions.	**+1,863**
Isotope Development and Production for Research and Applications In the 2020 Office of Science restructuring, the DOE Isotope Program was pulled out of the Office of Nuclear Physics into its own Program in the Office of Science. Funding for the Isotope Development, Production, Research and Applications Subprogram was moved to the new Isotope R&D and Production Program (DOE Isotope Program) in FY 2022.	**-66,000**
Construction The Request provides funding for the EIC to continue Project Engineering and Design activities.	**-2,300**
Total, Nuclear Physics	**+26,196**

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 LQCD 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. Capabilities and techniques developed for nuclear physics at NP accelerator facilities are used by DOD and NASA to test electronics for radiation sensitivity in furtherance of their missions. NP research develops technological advances relevant to clean energy and 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)); accelerator research and enhancing U.S.-based supply chains for critical accelerator technologies (ARP); and research in developing neutron, gamma, and particle beam sources with applications in cargo screening (NNSA, DHS, and the FBI).

Program Accomplishments
World's Highest Energy Heavy Ion Linear Accelerator Completed: The Facility for Rare Isotope Beams (FRIB), a world leading "microscope" for understanding how protons and neutrons can arrange themselves to form nuclei, the limits of how many species of nuclei can be formed in nature, and how the heaviest nuclei are produced in violent cosmic events, finishes on-time, on-budget construction and will begin early science in spring of 2022. Completing the world's highest energy continuous wave heavy ion accelerator required multiple technological firsts, including a novel high-power target, a high efficiency cryogenic plant, and a novel superconducting radiofrequency resonator system for accelerating a wide range of ion species.

Researching Nuclear Risotto: An interdisciplinary team including nuclear theorists, data scientists, and astronomers has put new limits on the radii of neutron stars with unprecedented accuracy. Neutron stars—one possible final stage in the lives of ordinary stars after their "ordinary matter" has boiled off—consist of the densest matter in the universe. The researchers' approach combined observations of gravitational waves from neutron stars, electromagnetic observations by NASA's Neutron Star Interior Composition Explorer mission and other telescopes, and state-of-the-art theoretical calculations performed at Los Alamos National Laboratory by DOE Nuclear Physics researchers. The results show that typical neutron stars can concentrate approximately 1-2 solar masses in a radius of 11.8 kilometers, placing new stringent constraints on nuclear matter at the limits of existence.

Creating Mass From Energy in the Lab: Although it's been known since Einstein's famous equation $E=mc^2$ that energy and matter are interchangeable, only now have scientists working at the Relativistic Heavy Ion Collider (RHIC) found clear evidence that the collision of two packets of light, called photons, can produce pairs of particles, one matter particle and one antimatter particle—the electron and its antimatter companion—the positron, in this instance. This process was predicted by Gregory Breit and John Wheeler, more than 80 years ago. While e+e- pairs have been produced in high-energy collisions, this observation involved two heavy ions flying past each other at nearly the speed of light without touching. The ultra-high electric field between the two passing nuclei results in photons having enough relative energy to form electron-positron pairs. This result puts focus on an exciting new possibility: lasers being sufficiently energetic to see the Breit-Wheeler process directly, without colliding particle beams.

Rare Carbon Breakup-Mode Constrained for the First Time: Researchers from Texas A&M, LSU, and Washington University at St. Louis have observed, for the first time, the breakup of an excited form of carbon-12 (comprising a nucleus of 6 protons and 6 neutrons) into three so-called alpha-particles (nuclei each containing 2 protons + 2 neutrons). Using a new, highly sophisticated detector at Texas A&M, the direct 3D reconstruction of this three-alpha breakup reaction allowed scientists exceptional insight into the role of the inverse process in synthesizing 12 Carbon and other light nuclei in the early universe.

Heavy Nuclei Have Thick Skins: The PREx Collaboration at the Continuous Electron Beam Accelerator Facility at Thomas Jefferson National Accelerator Facility recently published conclusive evidence confirming that the heavy lead (Pb) nucleus has a neutron skin approximately a third as thick as the radius of the proton—about twice as thick as predicted. The result has deep implications for the physical processes in neutron stars, with connections to recent observations of colliding neutron stars made by the Laser Interferometer Gravitational-Wave Observatory, or LIGO, experiment.

The Quantum Rodeo: Quantum computers offer the potential of solving problems too difficult for classical computers. A team of nuclear physicists have developed a "Rodeo Algorithm for Quantum Computing" offering a new approach, exponentially faster than other well-known algorithms, for preparing energy states of large complex systems on a quantum computer. The Rodeo algorithm is efficient in terms of both computing resources and speed. It requires relatively few qubits and quantum gates, representing a promising future candidate for solving intractable problems in quantum many-body systems vital to nuclear physics, particle physics, condensed matter physics, atomic and molecular systems, and quantum chemistry.

Uncertainty on the Neutron Lifetime is Cut by in Half: Neutrons account for about half of the mass of the matter around us. When inside a nucleus, a neutron is stable. On its own however it is unstable and will decay with a half-life of about 10 minutes. Precisely how long neutrons live is an important quantity in many areas of science, including the accurate description of what happened in the early Universe. High-precision measurements of this lifetime also provide a precise test to probe for new particles and forces beyond what can be measured with colliders like the Large Hadron Collider. A team of researchers from Los Alamos National Laboratory, the Triangle Universities Nuclear Laboratory and several universities has now cut the uncertainty in neutron's lifetime in half using ultracold neutrons from the LANL ultracold neutron source.

Tooling Up to Solve a Major Mystery: The proton is a building block of nature fundamental to everything around us. Despite a century of research however, how the properties of the proton (its mass and spin) are dynamically generated by the quarks and massless gluons inside it remains a mystery. The future Electron-Ion Collider (EIC) aims to solve this mystery by colliding a high-intensity polarized beam of high-energy electrons with protons or larger atomic nuclei. The EIC recently passed a critical milestone, Critical Decision 1 (CD-1), allowing the project to initiate design of the accelerator, detector, and supporting systems. The project to implement the EIC is being carried out by Brookhaven National Laboratory in partnership with Thomas Jefferson National Accelerator Facility.

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 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. 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 Electron-Ion Collider (EIC) facility, to be located at BNL, plans to address this science. DOE approved CD-1, Approve Alternative Selection and Cost Range, in June 2021. TJNAF is partnering with BNL to develop and implement the EIC. Scientists and accelerator physicists, from the Medium Energy subprogram, 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 advanced approaches in superconducting radiofrequency (SRF) technology and 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 artificial intelligence and machine learning (AI/ML) of relevance to nuclear science research and accelerator facility operations. NP continues support for applications of artificial neural networks in the analysis of nuclear physics data. Additionally, NP is supporting technical development at the intersections between real-time ML and control and the optimization of accelerator systems operations and detector design using AI/ML models. Scientists participate in the SC initiative on Microelectronics research and development, emphasizing unique microelectronics that survive in cryogenic and high radiation environments.

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 continues support for honoraria for awards, including the Enrico Fermi Awards and the Ernest Orlando Lawrence Awards.

Research

The Research activity supports high priority research at universities, TJNAF, BNL, ANL, 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 development of scientific and experimental plans for the EIC. 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.

TJNAF Laboratory scientists and many university groups play leadership roles in new experiments in the 12 GeV scientific program, and are engaged in commissioning experiments, instrumentation development, and data taking. Scientists at several national laboratories are engaged in planning for the construction of the EIC and its scientific instrumentation. ANL researchers 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. LANL scientists are leading a new experiment at Fermilab to study whether anti-quarks are in orbit about the spin axis of the proton. 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 at universities and laboratories advance technology and core competencies essential for improving operations of the complex user facilities or developing new facilities within the NP program, including the development of transformative technology for the Nation, including innovative, efficient and cost effective cryogenic systems, high gradient SRF cavities, and novel in-situ plasma processing of cryomodules. Researchers are also engaged in developing ML techniques focused on improving efficiencies of accelerator operations.

This activity also supports the Accelerate initiative which will support scientific research to accelerate the transition of science advances to energy technologies.

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 1,700 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 highest priority investments in cryomodule refurbishment, spares and critical maintenance are supported 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 to improve 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 developed award-winning cryogenics techniques that have led to more cost-effective operations at TJNAF and several other SC facilities; their cryogenics expertise benefitted 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 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Medium Energy Physics	**$158,311**	**$193,748**	**+$35,437**
Research	$41,110	$50,305	+$9,195
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 continue to support researchers to pursue transformative accelerator science to improve operations of current and future NP facilities including applications of AI/ML. Research on Microelectronics is continued 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 supports the Accelerate Innovations in Emerging Technologies (Accelerate) initiative.	The Request will support high priority core scientific workforce at universities and national laboratories conducting research related to CEBAF, RHIC, EIC and other facilities, as well as the Accelerate initiative.

(dollars in thousands)

FY 2021 Enacted	FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Operations $117,201	$143,443	+$26,242
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 3,840 operational hours (91 percent 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 support CEBAF run time hours at approximately 91 percent of optimal operations. Only the highest priority equipment and efforts to improve CEBAF reliability and performance are supported.

Note:
- *Funding for the subprogram above, includes 3.65 percent 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 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 the sPHENIX detector. The sPHENIX detector will be commissioned in FY 2023. 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 more than 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[bbb]. In January 2020, BNL was selected as the location for the EIC and in June 2021, DOE approved CD-1, Approve Alternative Selection and Cost Range. 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 acquisition 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 technical workforce that are essential to the operations of a complex facility like RHIC and eventually, the EIC. They have critical core

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

competencies in collider operations that cannot easily be replaced; their support is embedded in the EIC TPC 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 National Quantum Information Sciences Research Centers (NQISRCs) 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), and ion source technologies. Artificial intelligence and machine learning (AI/ML) applications are pursued to optimize operation of the complex accelerators and detectors at user facilities in the NP program. 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.

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. It will enable the participation of researchers in the complementary heavy ion program at CERN. U.S. scientists will work with their international peers in developing and implementing upgrades to the LHC scientific instrumentation. One such proposed upgrade is the CMS minimum ionizing particle timing detector (MTD) to enhance particle identification for understanding jet quenching, improving heavy flavor hadron measurements, and exploring collectivity in small systems. Heavy Ion research also supports the NQISRCs 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, including advancements in ion source developments, SRF technology, and hadron beam cooling. 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 AI/ML 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 ML and control and the optimization of accelerator systems operations and detector design using AI/ML 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 2023 Request will support high priority capital equipment and accelerator improvement projects at RHIC to promote enhanced and robust operations, such as upgrades to key accelerator infrastructure FY 2023 represents the commissioning of the sPHENIX detector, which will be the key device for the last RHIC data taking campaign. sPHENIX enables 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.

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 2023, funding for RHIC operations continues to be reprioritized to EIC 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 symbiotic, parallel, cost-effective operations of the Brookhaven Linac Isotope Producer Facility (BLIP), supported by the DOE Isotope Program to produce 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 the installation and initiate the commissioning of sPHENIX. Other project costs for the EIC support scientists and accelerator physicists to advance the conceptual design and conduct accelerator and detector R&D. Integration of laboratory core competencies and participation from across the national laboratory complex and universities continues. Accelerator and detector R&D focuses on reduction of technical risks and value engineering. The EIC Other Project Costs (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.

Nuclear Physics
Heavy Ion Physics

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Heavy Ion Physics	**$248,118**	**$244,986**	**-$3,132**
Research	$36,313	$43,204	+$6,891
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. 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. Research activities support the NQISRCs and AI/ML aimed at applications of artificial neural networks to nuclear physics research and the optimization of accelerator performance.	Funding will continue to support high priority core scientific workforce at universities and national laboratories to enhance high priority research at RHIC, the LHC, and for EIC science and detector development.

(dollars in thousands)

FY 2021 Enacted	FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Operations $181,625	$191,782	+$10,157
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 3,264 hours (90 percent optimal). 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.	The Request for RHIC operations will support operations at 90 percent of optimal for commissioning of sPHENIX. RHIC operations in FY 2023 is no longer capped with completion of sPHENIX installation. Reprioritization of effort to support EIC continues.

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Projects	$30,180	$10,000	-$20,180
The FY 2021 Enacted Appropriation includes support for both the sPHENIX MIE, which will study high rate particle jets, and EIC OPC.		The experienced scientists and engineers skilled in collider operations continue to transition from RHIC operations to support EIC activities.	OPC support of EIC activities will continue. The Request does not include funds for sPHENIX, as construction is completed in FY 2022 and the device undergoes commissioning in FY 2023.

Note:

- *Funding for the subprogram above, includes 3.65 percent 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 Physics subprogram includes two scientific activities that focus on using nuclear interactions and decays to answer overarching questions related to Nuclear Structure and Nuclear Astrophysics, and 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 300 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 Neutron-generator Upgrade to the Californium Rare Ion Breeder Upgrade (nuCARIBU) ion source. Technologically cutting-edge and unique instrumentation are a hallmark of ATLAS, and the facility 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 including a cost-effective Multi-User Upgrade (MUU) to address a backlog of compelling experiments.

The Facility for Rare Isotope Beams (FRIB) at Michigan State University (MSU) became an SC scientific user facility in FY 2020 and transitions from construction to operations in FY 2022. It will enter its first full year of operation in FY 2023. FRIB 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 to test the limits of nuclear existence. The Gamma-Ray Energy Tracking Array (GRETA) MIE is one of the primary tools that the nuclear science community has identified as 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 exploit FRIB's fast beam capabilities, enabling the most sensitive experiments across the entire chart of nuclei with the most neutron-rich nuclei available.

Scientists participate in artificial intelligence and machine learning (AI/ML) research, conducting R&D targeting automated optimization of accelerator availability, performance, and operation, as well as software development enabling AI/ML-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 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 Element 120. 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 an 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 super-heavy elements. DOD and NASA exploit materials irradiation capabilities at the 88-Inch Cyclotron 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 four facilities at the Triangle Universities Nuclear Laboratory (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 what role have they played in creating the imbalance between matter and antimatter in our 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 the existence of forces that were present at the dawn of the universe, 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 neutrino-less double beta decay (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 SC steward of neutrino mass measurements and NLDBD. Often in partnership with NSF, NP has invested in neutrino experiments both domestically and overseas, playing critical roles in international experiments that depend on U.S. leadership for their ultimate success: e,g, the Cryogenic Underground Observatory for Rare Events (CUORE, the Karlsruhe Tritium Neutrino Experiment [KATRIN]). In partnership with NSF, NP also 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. The observation of such events would have profound, game changing consequences for present understanding of the physical universe. NP has invested in R&D on candidate technologies for next–generation ton-scale experiments, including crystals of enriched germanium (LEGEND-1000), liquid xenon (nEXO) and lithium molybdenate crystals (CUPID). The Request will provide support for ton-scale research based on one or more of these technologies to progress toward CD-1, Approve Alternative Selection and Cost Range. Ton-Scale NLDBD research is expected to provide unprecedented resolution for the detection of the rare NLDBD process. The NLDBD 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 engaged in Fundamental Symmetries research are particularly well positioned with their expertise in rare signal detection, to engage in research on Quantum Information Science (QIS) and Quantum Computing (QC). They 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 for use in the scientific program initiating in FY 2022. The Request supports leading researchers who worked at other facilities to help lead the FRIB scientific mission. The Request continues the GRETA MIE. It also continues implementation of the High Rigidity Spectrometer. 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 next generation ion sources for accelerators. Scientists utilize AI/ML advances 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 continues 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. Other experiments at the SNS FNPB continue, along with minor construction activities in support of this research. First-generation NLDBD experiments finalize analysis of data, such as the CUORE experiment at Gran Sasso Laboratory in Italy. Conceptual design efforts continue for international ton-scale NLDBD research, 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 nuCARIBU radioactive beam system for accelerated radioactive ion beams, the in-flight radioactive ion separator to increase the intensity of radioactive beams, and a gas-filled analyzer.

The ATLAS facility nurtures a core competency in accelerator science with 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 SC 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 2023, the first full year of operations for the scientific program. The Request supports beam time for the highest priority experiments, improvements to experimental capabilities, and accelerator enhancements to support progress towards reaching full power.

The Request also sustains operations of the 88-Inch Cyclotron for a focused in-house nuclear physics program which includes characterization and searches for new elements and nuclear data measurements.

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Low Energy Physics	**$157,142**	**$217,470**	**+$60,328**
Research	$61,763	$68,059	+$6,296
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. Scientists utilize AI/ML that can promote automated platforms to improve machine performance and reliability and advance detector design and data processing.	The Request will support the highest 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.
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 a strategic mix of efforts for selection in FY 2022. The Request will continue support for U.S. participation in the operations of the international KATRIN experiment.	

(dollars in thousands)

FY 2021 Enacted	FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Operations $79,379	$125,471	+$46,092
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 5,952 hours (93 percent of optimal) 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 second year of operations at FRIB for 3,100 hours (91 percent of optimal) to execute the first full year of 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 the first full year of the physics program, and the highest priority experiments at ATLAS at above 90 percent of optimal.
Projects $16,000	$23,940	+$7,940
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 the HRS research project.	Increase funding will support the GRETA MIE.

Note:

- *Funding for the subprogram above, includes 3.65 percent 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 in the cosmos and what the nature of the neutrino may reveal about the evolution of the early universe.

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, team-based 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 theorists also conduct research related to quantum information science (QIS) and quantum computing (QC). This work is carried out in coordination with and support of other NP/SC efforts including R&D on quantum sensors to enable precision 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 other SC programs, NP continues its role in jointly stewarding NQISRCs which 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 continue to develop cutting-edge techniques based on artificial Intelligence and machine Learning (AI/ML) to accelerate discovery in nuclear science research and optimize the efficiency of accelerator facility operations. NP applications of artificial neural networks in data analysis continue to be enhanced and made more powerful. Future "intelligent" experiments will seek to incorporate next generation AI advances into the optimization of detector design, detector hardware and electronics. The Request also supports technical development at the intersection between real-time ML and control and optimization of accelerator systems operations, with specific focus on improving the reliability and efficiency 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 subprogram as well as the other NP subprograms with the distribution dependent on peer review results of topical proposals.

Research

This activity supports high priority research at ANL, BNL, LANL, LBNL, LLNL, ORNL, 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 varying experimental facets of QIS; overall, the NP Request for QIS continues in FY 2023. 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[ccc] 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.

Within available funding, a new competition in support of SciDAC-5 is planned that will result in new awards in FY 2022. The Request supports the second year of these efforts. In addition to addressing specific problems relevant for nuclear physics research, SciDAC projects continue to serve as critical research for highly trained scientists who can address national needs. A planned competition in support of the next round topical collaborations will result in new awards being made in FY 2022. The Request supports the second year of these efforts as well.

Funding for AI/ML research continues in FY 2023. These activities help develop cutting-edge techniques based on AI of relevance to nuclear science research, accelerator facility operations, and automated machine operations.

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.

This activity also supports the Funding for Accelerated, Inclusive Research (FAIR) initiative which will provide focused investment on enhancing research on clean energy, climate, and related topics at minority serving institutions, including attention to underserved and environmental justice communities.

[ccc] "*Nuclear Physics and Quantum Information Science*" Nuclear Science Advisory Committee, October 2015 (https://science.osti.gov/~/media/np/nsac/pdf/2015LRP/2015_LRPNS_091815.pdf).

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Nuclear Theory	**$61,129**	**$62,992**	**+$1,863**
Research	$61,129	$62,992	+$1,863
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 second year of SciDAC-5 grants and theory topical collaborations. Funding will target investments in an initiative to develop cutting-edge AI/ML techniques of relevance to nuclear science research, and accelerator facility operations. 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. The Request also supports the FAIR initiative.	Funding will support the highest priority research in nuclear theory, growth of the AI/ML and RENEW initiatives, and the start of the FAIR initiative.

(dollars in thousands)

FY 2021 Enacted	FY 2023 Request	Explanation of Changes FY 2023 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 continue the expanded USNDP efforts to collect, evaluate, and disseminate nuclear physics data for basic nuclear research and for applied nuclear technologies and their development initiated in FY 2022.	Funding will support nuclear data efforts of the USNDP.

Note:

- *Funding for the subprogram above, includes 3.65 percent 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 2023 Request	Explanation of Changes FY 2023 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 2023 Request	Explanation of Changes FY 2023 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.

Nuclear Physics
Construction

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 2023 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 contributions.

Over the course of the acquisition 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 later the EIC. The temporary reprioritization of funds from the collider facility operations budget to the construction budget will supplement 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, followed by CD-1, Approve Alternative Selection and Cost Range on June 29, 2021.

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 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 is requested in FY 2023.	The FY 2021 Enacted reflects the final year of funding for FRIB.

Nuclear Physics
Capital Summary

(dollars in thousands)

	Total	Prior Years	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Capital Operating Expenses						
Capital Equipment	N/A	N/A	33,397	28,080	34,988	+1,591
Minor Construction Activities						
General Plant Projects	N/A	N/A	1,579	1,579	2,642	+1,063
Accelerator Improvement Projects	N/A	N/A	4,956	4,956	5,211	+255
Total, Capital Operating Expenses	**N/A**	**N/A**	**39,932**	**34,615**	**42,841**	**+2,909**

Capital Equipment

(dollars in thousands)

	Total	Prior Years	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Capital Equipment						
Major Items of Equipment						
Heavy Ion Physics						
Super Pioneering High Energy Nuclear Interaction Experiment (sPHENIX)	20,577	14,834	5,530	213	–	-5,530
Low Energy Physics						
Gamma-Ray Energy Tracking Array (GRETA), LBNL	55,300	18,900	6,600	6,600	15,500	+8,900
High Rigidity Spectrometer	101,540	1,240	3,000	3,000	3,000	–
MOLLER	47,100	2,000	5,000	5,000	4,000	-1,000
Ton-Scale Neutrinoless Double Beta Decay (NLDBD) MIE	235,540	1,000	1,400	1,400	1,440	+40
Total, MIEs	N/A	N/A	21,530	16,213	23,940	+2,410
Total, Non-MIE Capital Equipment	N/A	N/A	11,867	11,867	11,048	-819
Total, Capital Equipment	**N/A**	**N/A**	**33,397**	**28,080**	**34,988**	**+1,591**

Notes:
- *The High Rigidity 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 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
General Plant Projects (GPP)						
GPPs (greater than or equal to $5M and less than $20M)						
nEDM Experimental Building 2 (EB-2)	9,257	–	–	–	1,000	+1,000
Total GPPs (greater than or equal to $5M and less than $20M)	N/A	N/A	–	–	1,000	+1,000
Total GPPs less than $5M	N/A	N/A	1,579	1,579	1,642	+63
Total, General Plant Projects (GPP)	**N/A**	**N/A**	**1,579**	**1,579**	**2,642**	**+1,063**
Accelerator Improvement Projects (AIP)						
Total AIPs less than $5M	N/A	N/A	4,956	4,956	5,211	+255
Total, Accelerator Improvement Projects (AIP)	**N/A**	**N/A**	**4,956**	**4,956**	**5,211**	**+255**
Total, Minor Construction Activities	**N/A**	**N/A**	**6,535**	**6,535**	**7,853**	**+1,318**

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.*

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. Final funding for sPHENIX is provided in the FY 2022 Request with the project completing in FY 2023.

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 2023 Request for GRETA is $15,500,000 of TEC funding. NP is assessing the impact of constrained funding in FY 2021 and FY 2022.

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 2023 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. 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 2023 Request of $1,440,000 will support the management team and collaboration activities.

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 2020 with a TPC range of $42,000,000 to $60,100,000. The project is working on preliminary engineering and design in advance of a combined CD-2/3 planned in Q2 of FY 2023. CD-4 is expected in Q4 of FY2027. 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 2023 Request for MOLLER of $4,000,000 will support management, engineering, and design work toward CD-2/3.

Nuclear Physics
Minor Construction Description(s)

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

Outfitting of Research and Collaborations Spaces
General Plant Project Details

Project Name:	nEDM Experimental Building 2 (EB-2)
Location/Site:	Oak Ridge National Laboratory
Type:	GPP
Total Estimated Cost:	$9,257,032
Construction Design:	$0
Project Description:	Minor construction of an experimental building at Oak Ridge National Laboratory is needed to support neutron electric dipole moment research. This new experimental building will allow researchers to continue the 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.

Nuclear Physics
Construction Projects Summary

(dollars in thousands)

	Total	Prior Years	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 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	2,600	3,000	–	–	-3,000
Total Project Cost (TPC)	**29,600**	**14,600**	**15,000**	**–**	**–**	**-15,000**
20-SC-52, Electron Ion Collider						
Total Estimated Cost (TEC)	2,061,000	1,000	5,000	5,000	20,000	+15,000
Other Project Cost (OPC)	187,650	10,000	24,650	24,650	10,000	-14,650
Total Project Cost (TPC)	**2,248,650**	**11,000**	**29,650**	**29,650**	**30,000**	**+350**
14-SC-50, Facility for Rare Isotope Beams (FRIB), Michigan State University						
Total Estimated Cost (TEC)	635,500	630,200	5,300	–	–	-5,300
Total Project Cost (TPC)	**635,500**	**630,200**	**5,300**	**–**	**–**	**-5,300**
Total, Construction						
Total Estimated Cost (TEC)	**N/A**	**N/A**	**22,300**	**5,000**	**20,000**	**-2,300**
Other Project Cost (OPC)	**N/A**	**N/A**	**27,650**	**24,650**	**10,000**	**-17,650**
Total Project Cost (TPC)	**N/A**	**N/A**	**49,950**	**29,650**	**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 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Research	225,191	201,221	220,799	-4,392
Facility Operations	414,545	380,132	460,696	+46,151
Projects				
Line Item Construction (LIC)	49,950	29,650	30,000	-19,950
Major Items of Equipment (MIE)	21,530	16,213	23,940	+2,410
Total, Projects	**71,480**	**45,863**	**53,940**	**-17,540**
Other	1,784	1,784	3,761	+1,977
Total, Nuclear Physics	**713,000**	**629,000**	**739,196**	**+26,196**

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 2021 Enacted	**FY 2021 Current**	**FY 2022 Annualized CR**	**FY 2023 Request**	**FY 2023 Request vs FY 2021 Enacted**
Scientific User Facilities - Type A					
Relativistic Heavy Ion Collider	**187,527**	**180,204**	**183,552**	**191,782**	**+4,255**
Number of Users	1,010	917	1,010	1,010	–
Achieved Operating Hours	–	3,410	–	–	–
Planned Operating Hours	3,130	3,130	2,580	3,264	+134
Optimal Hours	3,130	3,130	2,580	3,625	+495
Percent of Optimal Hours	100.0%	100.0%	100.0%	90.0%	-10.0%
Continuous Electron Beam Accelerator Facility	**122,315**	**119,521**	**117,201**	**143,443**	**+21,128**
Number of Users	1,560	1,692	1,620	1,730	+170
Achieved Operating Hours	–	776	–	–	–
Planned Operating Hours	780	780	2,100	3,840	+3,060
Optimal Hours	1,890	1,890	4,220	4,220	+2,330
Percent of Optimal Hours	41.3%	41.3%	49.8%	91.0%	+49.7%
Facility for Rare Isotope Beams	**51,825**	**50,000**	**51,825**	**96,266**	**+44,441**
Number of Users	–	–	400	755	+755
Planned Operating Hours	–	–	600	3,100	+3,100
Optimal Hours	–	–	2,310	3,400	+3,400
Percent of Optimal Hours	–	–	26.0%	91.1%	+91.1%

	(dollars in thousands)				
	FY 2021 Enacted	**FY 2021 Current**	**FY 2022 Annualized CR**	**FY 2023 Request**	**FY 2023 Request vs FY 2021 Enacted**
Argonne Tandem Linac Accelerator System	**24,539**	**24,537**	**22,865**	**24,279**	**-260**
Number of Users	305	272	305	340	+35
Achieved Operating Hours	–	5,483	–	–	–
Planned Operating Hours	5,350	5,350	5,800	5,952	+602
Optimal Hours	5,780	5,780	6,250	6,400	+620
Percent of Optimal Hours	92.6%	92.6%	92.8%	93.0%	+0.4%
Total, Facilities	**386,206**	**374,262**	**375,443**	**455,770**	**+69,564**
Number of Users	2,875	2,881	3,335	3,835	+960
Achieved Operating Hours	–	9,669	–	–	–
Planned Operating Hours	9,260	9,260	11,080	16,156	+6,896
Optimal Hours	10,800	10,800	15,360	17,645	+6,845

Notes:

- *Achieved Operating Hours and Unscheduled Downtime Hours will only be reflected in the Congressional budget cycle which provides actuals.*
- *The MOLLER MIE (CEBAF) and sPHENIX MIE (BNL) are not included in the funding amounts above.*
- *For FY 2022, 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 2022 is the first year of operations after project completion.*
- *For FY 2023, the dollar values for the facilities do not include research amounts.*
- *The FY 2021 Current, does not include SBIR/STTR transfers.*

Nuclear Physics
Scientific Employment

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Number of Permanent Ph.Ds (FTEs)	819	819	856	+37
Number of Postdoctoral Associates (FTEs)	328	328	366	+38
Number of Graduate Students (FTEs)	532	532	524	-8
Number of Other Scientific Employment (FTEs)	1,029	1,029	1,023	-6
Total Scientific Employment (FTEs)	**2,708**	**2,708**	**2,769**	**+61**

Note:
- *Other Scientific Employment (FTEs) includes 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 2023 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) range 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)-1, Approve Alternative Selection and Cost Range, was attained on June 29, 2021. In this Project Data Sheet (PDS), the estimated completion date (CD-4) remains 4Q FY 2033 and still considers the additional schedule contingency that was recommended by peer review. In addition, the preliminary TPC in this PDS reflects continued elaboration of the project scope and shows an increase over the point estimate in the FY 2022 PDS, however, the point estimate remains within the cost range. The project is working to CD-2 which is expected in 3Q FY 2023.

The EIC completed conceptual design on January 12, 2021, and achieved CD-1 on June 29, 2021. The project received in December 2021 three detector collaboration proposals with a report recommending a path forward expected in March 2022. In FY 2022, the EIC team will focus on preliminary design of the infrastructure, collider machine, and detector instrumentation. The team is also developing a list of possible long-lead procurements and considering requesting a CD-3A, Approve Long Lead Procurement, in conjunction with CD-2, Approve Performance Baseline. Of the $30,000,000 TPC funding requested in FY 2023, $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
FY 2023	12/19/19	01/12/21	6/29/2021	3Q 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, Total	TPC
FY 2021	340,000	2,010,000	2,350,000	250,000	250,000	2,600,000
FY 2022	413,000	1,648,000	2,061,000	187,650	187,650	2,248,650
FY 2023	413,000	1,648,000	2,061,000	187,650	187,650	2,248,650

Note:

- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*

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 greater than 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 to 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 planning for 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 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 prior to setting the performance baseline at CD-2. 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, Approve Project Completion.

Performance Measure	Threshold	Objective
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.
Accelerator	Accelerator installed and 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	Detector installed and ready for beam operations.	Inelastic scattering events in the e-p and e-A collisions measured in Detector.
Polarization	Hadron beam polarization of > 50 percent and electron beam polarization of > 40 percent measured at E_{cm} = 100 GeV.	Hadron beam polarization of > 60 percent and electron beam polarization of > 50 percent 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	5,000	5,000	5,000
FY 2023	20,000	20,000	19,500
Outyears	382,000	382,000	382,750
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	5,000	5,000	5,000
FY 2023	20,000	20,000	19,500
Outyears	2,030,000	2,030,000	2,030,750
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	24,650	24,650	26,650
FY 2023	10,000	10,000	11,500
Outyears	118,350	118,350	119,230
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	29,650	29,650	31,650
FY 2023	30,000	30,000	31,000
Outyears	2,148,350	2,148,350	2,149,980
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	291,000	298,000	**N/A**
Design - Contingency	122,000	115,000	**N/A**
Total, Design (TEC)	**413,000**	**413,000**	**N/A**
Construction	1,127,000	1,177,000	**N/A**
Construction - Contingency	521,000	471,000	**N/A**
Total, Construction (TEC)	**1,648,000**	**1,648,000**	**N/A**
Total, TEC	**2,061,000**	**2,061,000**	**N/A**
Contingency, TEC	*643,000*	*586,000*	***N/A***
Other Project Cost (OPC)			
R&D	46,650	46,650	**N/A**
Conceptual Design	11,000	11,000	**N/A**
Other OPC Costs	130,000	93,000	**N/A**
OPC - Contingency	N/A	37,000	**N/A**
Total, Except D&D (OPC)	**187,650**	**187,650**	**N/A**
Total, OPC	**187,650**	**187,650**	**N/A**
Contingency, OPC	***N/A***	*37,000*	***N/A***
Total, TPC	**2,248,650**	**2,248,650**	**N/A**
Total, Contingency (TEC+OPC)	***643,000***	***623,000***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Fiscal Year	Type	Prior Years	FY 2021	FY 2022	FY 2023	Outyears	Total
FY 2021	TEC	1,000	1,000	—	—	2,348,000	2,350,000
	OPC	10,000	1,500	—	—	238,500	250,000
	TPC	11,000	2,500	—	—	2,586,500	2,600,000
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
FY 2023	TEC	1,000	5,000	5,000	20,000	2,030,000	2,061,000
	OPC	10,000	24,650	24,650	10,000	118,350	187,650
	TPC	11,000	29,650	29,650	30,000	2,148,350	2,248,650

6. Related Operations and Maintenance Funding Requirements

Over the course of the acquisition 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 2033
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	167,000	167,000	13,500,000	13,500,000

7. D&D Information

As part of the upgrade and renovation of the existing accelerator facilities, up to 200,000 square feet of new industrial space will be built as service buildings to house mechanical and electrical equipment. The new area being constructed in this project is not replacing existing facilities.

	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 approved 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 based on those that already exist at both laboratories and will evaluate project progress and ensure consistency with DOE Order 413.3B, Program and Project Management for the Acquisition of Capital Assets.

Isotope R&D and Production

Overview

The mission of the DOE Isotope Program (DOE IP) is to:

- Produce and/or distribute stable isotopes and radioisotopes that are in short supply or unavailable in the U.S., including related isotope services.
- Maintain mission readiness of critical national infrastructure and core competencies needed to manufacture isotopes and ensure national preparedness to respond to gaps in supply chains during times of national emergency.
- Conduct research and development (R&D) to develop transformative isotope production, separation, and enrichment technologies to enable federal, academic, and industrial innovation, research, and emerging technologies. Nurture a diverse and inclusive domestic workforce with unique and world-leading core competencies.
- Mitigate U.S. dependence on foreign supplies of isotopes and promote robust domestic supply chains for U.S. economic resilience.

The DOE IP produces high priority radioactive and stable isotopes in short supply for the Nation that no domestic entity has the infrastructure or core competency to meet market demand. The Program is typically the only, or one of few, global or domestic producers for these novel isotopes. Isotopes are high-priority and often rare commodities of strategic importance for the Nation and are essential in medical diagnosis and treatment, discovery science, national security, advanced manufacturing, space exploration and communications, biology, quantum information science, clean energy, climate and environmental science, archaeology, and other fields. Isotopes can directly enable emerging technology, and contribute to the economic, technical, and scientific strength of the United States.

The DOE IP utilizes particle accelerators, research nuclear reactors, modern isotope enrichment capabilities, and radiochemical processing infrastructure throughout the DOE National Laboratory complex and at universities to employ and nurture domestic capabilities to meet national isotope demand. Throughout the COVID-19 pandemic, the DOE IP continued operating as a Department “Mission Essential Function” to ensure isotope availability for a broad suite of applications and intervened multiple times to prevent disruptions in supply chains of critical medical isotopes. The DOE IP works closely with U.S. industry to ensure availability of needed isotopes for their continued stability and planned growth and facilitates commercialization of isotope production to the domestic private sector. The DOE IP supports a world-leading R&D program in innovative isotope production, enrichment, and separations. Isotope manufacturing and R&D activities provide collateral benefits for training and workforce development, and promotion of a future U.S.-based expertise relevant to clean energy, accelerator science, nuclear engineering, nuclear physics, isotope enrichment, and radiochemistry. These disciplines are foundational, not only to isotope production and processing, but underpin many essential aspects of basic and applied nuclear and radiochemical science. Research and production activities develop and employ techniques and platform technologies in artificial intelligence (AI), machine learning (ML), robotics, and advanced manufacturing.

The DOE IP manages federal inventories of isotopes, such as helium-3 for cryogenics, quantum information science (QIS), and national security; Russia is the other major producer of helium-3. The DOE IP is also responsible for the national repository of all stable isotopes that were created by the calutrons (electromagnetic ion separation) developed as part of the Manhattan Project. The calutrons ceased operations in 1998, leaving the U.S. with no broad isotope enrichment capability. Russia has the largest stable isotope enrichment capability world-wide, followed by Urenco in the Netherlands, and then China, which is expanding their capabilities. 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. The DOE IP has developed and is implementing modern stable isotope enrichment capabilities to rebuild domestic manufacturing capabilities, replenish inventories, protect American security, and promote U.S. economic resilience. 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.

All funding for DOE IP is executed through the Isotope Production and Distribution Program revolving fund. The revolving fund maintains its financial viability by utilizing the appropriation for the Isotope R&D and Production Office, along with collections from customers through the sale of isotopes and services. The funds in this Budget Request are used to support mission readiness of the DOE IP infrastructure, staff, and facilities; conduct innovative R&D related to the production, enrichment, and processing of isotopes; and strengthen and develop the highest priority new capabilities to meet the Nation's growing demand of isotopes. The customer collections from sales pay for the activities associated with the actual production, distribution, and related services of the isotope. Isotopes sold to commercial customers and foreign entities are priced to recover the full cost of production, or if a market exists, the market price (whichever is higher). Isotopes for domestic research are sold at a reduced price to promote innovation and scientific advances.

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 for the DOE IP, including sales, contract negotiation, marketing assessment, public outreach, quality control, packaging, and transportation. The NIDC arranges for regular and frequent interfaces between DOE IP and industrial, academic, and medical communities to ensure that strategies are evidence-based and informed by stakeholder interactions. Furthermore, the DOE IP formally canvasses the broad federal community for isotope demands every other year to align priorities with evidence-based program evaluations.

Highlights of the FY 2023 Request

In FY 2023, the DOE IP anticipates increased domestic demand for novel isotopes, especially for medicine, nuclear batteries, space applications, commercial applications, clean energy, national security, biology, discovery research, and quantum computing. The Program enables high priority production and chemical processing capabilities and supports mission readiness to meet high priority demands, and to reduce U.S. dependence on foreign supply chains, particularly Russia and China. The DOE IP continues to promote disaster resilience, operating as a DOE Mission Essential Function in a pandemic environment to ensure availability of isotopes for treatment and diagnosis of cancer and infectious disease, and mitigating disruptions in isotope supply chains as a result of Russian sanctions. A diverse and inclusive workforce is nurtured and trained in advanced manufacturing practices, current Good Manufacturing Practices (cGMP), AI/ML), robotics and transformative isotope enrichment, isotope production, and chemical separations. Attention is paid to promoting career opportunities for engagement in federal science and technology programs, creating jobs in underserved communities.

In FY 2023, mission readiness levels of both radio- and stable isotope production facilities are at an average 80 percent, approximately maintained relative to the FY 2022 Request. This enables the Program to produce high priority isotopes in short supply and mitigate the most critical disruptions in supply chains. On the radioisotope front, there is an effort to develop domestic supply chains of isotopes needed for nuclear batteries and space applications and to mitigate disruptions in Russian supply chains. In stable isotopes, there are global shortfalls for several stable isotope feedstocks that are needed to produce critical medical isotopes to treat and diagnose U.S. patients. These stable isotopes are currently oversubscribed from Russia and the DOE IP strives to ramp up newly established production within available funds. Efforts continue to develop new enrichment technology to promote clean energy and reduce fuel cycle costs and waste.

The FY 2023 Request includes $12.0 million in Total Estimated Cost (TEC) funding, at the same level as the FY 2022 Request, to continue the U.S. Stable Isotope Production and Research Center (SIPRC) at ORNL, which will provide large scale stable isotope production capacity for the Nation. SIPRC will build upon the expertise in gas centrifuge (GC) and electromagnetic isotope separation (EMIS) technology nurtured by the Stable Isotope Production Facility (SIPF) and the Enriched Stable Isotope Prototype Plant (ESIPP); SIPRC relieves U.S. dependence on foreign countries and supports national security and economic resilience. Support continues for the conceptual design of the proposed ORNL Radioisotope Processing Facility (RPF), to address a lack of available radiochemical processing infrastructure within the DOE IP complex to make available isotopes in short supply. Current radiochemical separations infrastructure is oversubscribed and in need of refurbishment, and while the DOE IP has the core competency to fill additional gaps in critical isotope supply chains, there is no available processing infrastructure in which to complete the production of some critical isotopes.

Funding in core research is approximately maintained to support a diverse and inclusive workforce and participation in several Office of Science initiatives increases. The DOE IP increases efforts in the SC Fundamental Science to Transform Advanced Manufacturing Initiative, pursuing innovative approaches to target manufacturing, such as ink jet printing of thin film targets for isotope production, modular automated systems for radioisotope purification and processing, and modern enrichment technology. As part of the Biopreparedness Research Virtual Environment (BRaVE) Initiative, the DOE IP increases support to tackle chemical processing of irradiated reactor targets, which has become a significant obstacle and single point failure in the program. 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. This funding will develop short-term reactor target processing capabilities at the University of Missouri Research Reactor (MURR) Radioisotope Science Center (RSC). The contributions to the MURR RSC will also create jobs in an underserved community in Missouri, enabling new opportunities to become involved in federal science and technology. Critical efforts are modestly increased relative to FY 2021 Enacted in the ongoing SC Quantum Information Science (QIS) Initiative to advance the domestic production of isotopes of interest for QIS. Funding increases participation in the Reaching a New Energy Sciences Workforce (RENEW) initiative, supporting the Isotope Program Traineeship to promote innovative and transformative approaches to isotope production and processing, including advanced manufacturing, artificial intelligence and machine learning, and robotics. The Traineeship provides direct funding and emphasizes participation of minority serving institutions, increasing the diversity and equity of workforce development opportunities in the program. The DOE IP participates in two new initiatives: the Accelerate Innovations in Emerging Technologies by supporting transitional research to advance readiness of novel isotopes to preclinical and clinical medical trials; and the Funding for Accelerated, Inclusive Research (FAIR) initiative which will provide focused research investments at minority serving institutions, including attention to underserved and environmental justice regions.

The FY 2023 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. The FY 2023 Request also supports preparations of 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 being processed by the National Nuclear Security Administration (NNSA) recovery project at the Savannah River Site (SRS) over the next decade.

Research
The DOE IP supports core research groups at Argonne National Laboratory (ANL), Brookhaven National Laboratory (BNL), Idaho National Laboratory (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.

Critical medical isotope production activities in the FY 2023 Request are maintained. In medicine, there is quickly escalating interest in alpha and beta emitters for revolutionary cancer and infectious disease therapy and diagnostics. 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. 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 and manufacturing to make them available. In addition to Ac-225 derived from thorium-229 processing, 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. In partnership with the National Institutes of Health (NIH), the DOE IP continues research facilitating the transition 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 SC BRaVE Initiative, National Preparedness of the DOE IP and its ability to perform effectively in times of national crisis is enhanced by the RSC at MURR. The RSC is planned to be located in the Discovery Ridge Research Park near the University of Missouri and will provide the surrounding underserved rural area with job opportunities in isotope science. Funding also supports scientists and engineers to pursue design of the Radioisotope Processing Facility (RPF) for new long-term capabilities at ORNL.

Competitive research funds to universities and national laboratories support targeted high priority activities, 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, physics, and the semi-conductor industry. Research topics include production of highly enriched lithium-7 and chlorine-37 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, robotics, the application of machine learning and artificial intelligence to isotope production, and production of neptunium-236 for nuclear forensics.

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. Dedicated machines are designed and optimized for isotopes of interest for quantum computing. 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 the alpha-emitter astatine-211 was developed to support research into the use of the isotope in cancer therapy; and MURR which the DOE IP uses for the production of lutetium-177 for cancer therapy research, selenium-75 for biochemical and environmental research, and gold-199 for cancer imaging/therapy and detection of environmental compounds. The newest addition to the University Isotope Network is the University of Alabama-Birmingham cyclotron, which will provide niche medical isotopes through the DOE IP. This partnership also provides job opportunities to expand their workforce and enhance their isotope science activities. Funding also supports implementation of isotope production capabilities at additional facilities at Texas A&M University, the University of Pennsylvania, Duke University, 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 and inclusive workforce essential to the technologies associated with isotope production. In addition to the recently initiated DOE IP Traineeship Program, which continues as the RENEW initiative in the FY 2023 Request, and supports undergraduate and graduate students. 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 chemical 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 Enriched Stable Isotope Prototype Plant (ESIPP) at ORNL, and hot cell facilities for processing and handling irradiated materials and purified products at ORNL, BNL, and LANL. 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 Advanced Test Reactor (ATR) at INL, processing and packaging infrastructure for strontium-90 at PNNL, processing and packaging infrastructure for lithium-6 and lithium-7 at the Y-12 National Security Complex, americium-241 recovery from NNSA plutonium processes at the LANL Plutonium Facility, the extraction and distribution of helium-3 at the Savannah River Site (SRS), and the radioisotope separator at INL for nuclear forensics isotopes.

Funding maintains National Preparedness and mission readiness for the production and radio-chemical separations of isotopes at a growing portfolio of production sites to provide domestic supply chains of critical isotopes not available commercially or domestically; the isotope production and processing costs are paid by the customer. Infrastructure 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; and 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 approved or future radiopharmaceuticals.

DOE IP supports readiness of ESIPP at ORNL to produce research quantities of enriched stable isotopes using electromagnetic separation and centrifuge technologies. The first campaign at ESIPP produced ruthenium-96 to provide the unique target material to the Relativistic Heavy Ion Collider (RHIC) for its planned physics program. A follow-on campaign at ESIPP focuses on production of ytterbium-176, previously only produced in Russia, and needed to produce high priority medical isotopes to treat prostate cancer. Funding also supports the commissioning of gas centrifuges for SIPF.

Some examples of produced isotopes across the DOE IP are:

- actinium-225, actinium-227, cerium-134, scandium-47, scandium-44, holmium-166m, tungsten-188, lutetium-177, strontium-89, strontium-90, tin-117m, vanadium-48, manganese-52, gold-199, cobalt-55, and cobalt-60 for cancer therapy and imaging diagnostics
- bismuth-213, lead-212, astatine-211, copper-67, thorium-227, thorium-228, radium-223, and radium-224 for cancer and infectious disease therapy and research
- americium-241 and californium-252 for oil and gas exploration and production well logging
- cadmium-109 for X-ray fluorescence imaging and environmental research
- barium-133 for quantum computing research, medical standards, and industrial sources
- berkelium-249, americium-243, uranium-238, plutonium-242, plutonium-244, californium-249, californium-251einsteinium-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
- ytterbium-176 as feedstock for isotopes that treat prostate cancer
- nickel-63 for explosives detection
- lithium-6 and helium-3 for neutron detectors for homeland security applications
- strontium-90, promethium-147, and thulium-170 for nuclear batteries
- 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 in which domestic commercial production now exists include strontium-82 for cardiac heart imaging and germanium-68 for medical diagnostics.

<u>Projects</u>

The prototype capabilities of the ESIPP, developed through DOE IP-supported research, demonstrated the feasibility of new EMIS and GC technologies and re-established a small general enriched stable isotope production capability in the U.S. The subsequent SIPF Major Item of Equipment (MIE) at ORNL modestly increases GC production capability. The implementation of SIPF continues to support the commissioning of GCs to produce enriched Xenon-129. Xenon-129 has demonstrated effectiveness in polarized lung imaging and there is currently 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 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-1, Approve Alternative Selection and Cost Range, and Subproject-1 CD-3A, Approve Long Lead Procurement, was received on November 4, 2021. 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 to mitigate dependence on foreign countries. With support from the DOE IP, ORNL is advancing production capabilities for these stable isotopes, primarily through EMIS and GC technologies.

Isotope R&D and Production
FY 2023 Research Initiatives

Isotope R&D and Production supports the following FY 2023 Research Initiatives.

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Accelerate Innovations in Emerging Technologies	–	–	1,051	+1,051
Biopreparedness Research Virtual Environment (BRaVE)	–	–	5,073	+5,073
Fundamental Science to Transform Advanced Manufacturing	–	–	1,000	+1,000
Funding for Accelerated, Inclusive Research (FAIR)	–	–	2,000	+2,000
Quantum Information Science	–	4,300	4,300	+4,300
Reaching a New Energy Sciences Workforce (RENEW)	–	–	4,000	+4,000
Total, Research Initiatives	–	**4,300**	**17,424**	**+17,424**

Note:

- *The DOE Isotope Program was included in the Office of Nuclear Physics Appropriation in FY 2021 and thus did not independently participate in SC research initiatives in FY 2021.*

Isotope R&D and Production
Funding

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Isotope R&D and Production				
Isotopes, Research	–	30,903	38,827	+38,827
Isotopes, Operations	–	41,097	46,624	+46,624
Subtotal, Isotope R&D and Production	**–**	**72,000**	**85,451**	**+85,451**
Construction				
20-SC-51, U.S. Stable Isotope Production and Research Center (SIPRC), ORNL	–	12,000	12,000	+12,000
Subtotal, Construction	**–**	**12,000**	**12,000**	**+12,000**
Total, Isotope R&D and Production	**–**	**84,000**	**97,451**	**+97,451**

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 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 the biennial Workshop on Federal isotope Supply and Demand to collect 5-year projections from all federal agencies across the USG complex to ensure adequate supply and evidence-based Program priorities. The DOE IP participates in Federal Working Groups and Interagency groups to promote communication, including the White House Office of Science and Technology Policy National Science and Technology Council 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 Council 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. SIPRC will produce molybdenum-98 and molybdenum-100, precursors to certain molybdenum-99 production routes to ensure domestic supply chain resilience.

Program Accomplishments

Production of Promethium-147 for Industrial and Medical Applications

ORNL has demonstrated the recovery of promethium-147, an important radioisotope for U.S. industrial applications, from the radiological waste generated during production of plutonium-238, a radioisotope used in space power systems. Promethium-147 is a radioisotope used to measure the thickness of thin plastic films (as in cell phones), as a power source for nuclear batteries, and in medical imaging applications. The isotope was only produced in Russia and the latest information indicates that they are leaving the market causing a supply disruption. By mining plutonium-238 radiological waste, ORNL minimizes its radiological legacy while providing a domestic source for a critically needed radioisotope, promoting U.S. economic resilience. Additional R&D is being advanced on promethium-147 production from the neodymium-146 irradiation route.

ORNL Constructs and Commissions Next-Generation Electromagnetic Isotope Separator

ORNL and DOE IP recently completed construction and commissioning of a second-generation EMIS device which is optimized to separate isotopes of high-mass elements that require very high assay, or purity. The newest EMIS is designed to nominally have five times the resolution over the previous modern EMIS devices, which are actively producing high demand enriched stable isotopes at ORNL. The latest design is being utilized to highly enrich ytterbium-176, which will be used to produce the radiopharmaceutical lutetium-177. Lutetium-177 has been FDA approved to treat certain digestive tract cancers, including pancreatic cancer. This new EMIS is also able to simultaneously produce ytterbium-171, which is being collected for quantum memory. SIPRC will include the second-generation design of EMISs. The enriched ytterbium isotopes are otherwise only available from U.S. constrained calutron inventory or new production in Russia.

Novel Imaging Analog for the Targeted Alpha Therapy Isotope Actinium-225 Facilitates Development of New Treatments

Ac-225 is a tremendously promising radioisotope for treating cancer and is being produced by DOE IP to support medical trials. To facilitate research and promote understanding of the impact and travel of Ac-225 in the body, imaging isotopes are needed that mimic the transport behavior of this therapy isotope. LANL researchers developed and demonstrated the production and purification of cerium-134, which is very well-suited for this task as it attaches efficiently to the same tumor targeting agents as the Ac-225. The novel cerium-134 isotope was sent to collaborators at Lawrence Berkeley National Laboratory where the first positron emission tomography (PET) images were collected, showing how this isotope behaved in a mouse model. This work provides a powerful tool for helping to develop additional Ac-225 based treatments for cancer and other diseases and is generating significant interest from the medical and imaging communities.

Isotope R&D and Production

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Isotope R&D and Production	**$ —**	**$97,451**	**+$97,451**
Isotopes, Research	$ —	$38,827	+$38,827
Isotopes Research was under the Nuclear Physics program in the FY 2021 Enacted Appropriation with a funding level of $29,660,000. As part of the SC reorganization in FY 2020, a separate Office of Isotope R&D and Production was established.		The Request will support 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. economic resilience. The priority R&D will remain 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 transition to medical applications. The Request will maintain 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 maintained. Participation in the Advanced Manufacturing initiative will continue with innovative isotope production technology that can facilitate commercial engagement and the promotion of domestic supply chains, such as “desktop” inkjet printing of production targets. Support for the DOE IP Traineeship Program with a goal to increase the diversity of the workforce as part of RENEW will increase in FY 2023.	Evidence-based research activities will improve or develop innovative isotope production, enrichment, and processing technology with the goal of increasing domestic supplies of critical isotopes for medicine, energy, national security, and other fields. Funding will support high priority efforts in QIS, Advanced Manufacturing, and National Preparedness (BRaVE), while promoting diversity and inclusion in the isotope scientific workforce and providing equitable inclusion opportunities in federal science and technology programs. Participation in the FAIR and Accelerate initiatives will be supported. Funding for competitive research will decrease to support participation in SC initiatives and core research at production facilities. Modest funding will support the continuation of the conceptual design of the RPF at ORNL.

(dollars in thousands)

FY 2021 Enacted	FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
	Research will increase for the BRaVE initiative in partnership with the University of Missouri to address a single point failure in reactor isotope processing and create tech-savvy jobs in an underserved rural area of Missouri with the implementation of the Radioisotope Science Center at MURR. Design for the ORNL RPF project will continue to advance needed chemical processing infrastructure at ORNL. Research to advance isotope harvesting capabilities and expertise at FRIB are roughly maintained. The Request will support participation in the Accelerate initiative which will support scientific research to accelerate the transition of isotope science advances to clinical trials. Also, the Request will support the FAIR initiative which will provide focused investment on enhancing isotope research on clean energy, climate, and related topics at minority serving institutions, including attention to underserved and environmental justice regions.	
Isotopes, Operations $ —	$46,624	+$46,624
Isotopes Operations was under the Nuclear Physics program in the FY 2021 Enacted Appropriation with a funding level of $36,340,000.	The Request will support mission readiness (~80 percent optimum) of the growing portfolio of isotope production and processing sites and nurtures critical core competencies in isotope production and development, promoting robust domestic supply chains for cancer therapy and other applications. Support will maintain NIDC activities to interface with the growing stakeholder community and rapidly expanding isotope portfolio. Funding will continue to support electromagnetic separation technology optimized to heavy elements, enriched radioisotope separation technology, extraction of valuable isotopes from legacy Mark 18-A targets.	Evidence-based activities support readiness to produce stable isotopes, commission new centrifuges, support NIDC, and produce radioisotopes at national lab and university reactors and accelerators.

(dollars in thousands)

FY 2021 Enacted	FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
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 and approved long lead procurements of the U.S. SIPRC.	Progress will continue in design and approved long lead procurements of the U.S. SIPRC to mitigate dependence on foreign supply of isotopes.

Isotope R&D and Production
Construction Projects Summary

(dollars in thousands)

	Total	Prior Years	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
20-SC-51, U.S. Stable Isotope Production and Research Center, ORNL						
Total Estimated Cost (TEC)	213,800	–	–	12,000	12,000	+12,000
Other Project Cost (OPC)	6,600	–	–	3,200	–	–
Total Project Cost (TPC)	**220,400**	**–**	**–**	**15,200**	**12,000**	**+12,000**
Total, Construction						
Total Estimated Cost (TEC)	**N/A**	**N/A**	**–**	**12,000**	**12,000**	**+12,000**
Other Project Cost (OPC)	**N/A**	**N/A**	**–**	**3,200**	**–**	**–**
Total Project Cost (TPC)	**N/A**	**N/A**	**–**	**15,200**	**12,000**	**+12,000**

Notes:
- *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 funding, is $250,000,000.*
- *This project is not baselined.*

Isotope R&D and Production
Funding Summary

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Research	–	24,703	37,827	+37,827
Facility Operations	–	41,097	46,624	+46,624
Projects				
Line Item Construction (LIC)	–	18,200	13,000	+13,000
Total, Projects	**–**	**18,200**	**13,000**	**+13,000**
Total, Isotope R&D and Production	**–**	**84,000**	**97,451**	**+97,451**

Note:

- *Isotope R&D and Production funding was included in the Nuclear Physics program in the FY 2021 Enacted appropriation.*

Isotope R&D and Production
Scientific Employment

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Number of Permanent Ph.Ds (FTEs)	–	34	41	+41
Number of Postdoctoral Associates (FTEs)	–	27	30	+30
Number of Graduate Students (FTEs)	–	23	33	+33
Number of Other Scientific Employment (FTEs)	–	84	103	+103
Total Scientific Employment (FTEs)	**–**	**168**	**207**	**+207**

Notes:
- *Other Scientific Employment (FTEs) includes technicians, engineers, computer professionals and other support staff.*
- *Isotope R&D and Production funding was included in the Nuclear Physics program in the FY 2021 Enacted appropriation.*

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 2023 Request for the U.S. Stable Isotope Production and Research Center (SIPRC) is $12,000,000 of Total Estimated Cost (TEC) funding. The current Total Project Cost (TPC) point estimate is $250,000,000 with a preliminary TPC range of $187,000,000 to $338,000,000.

Significant Changes

This project data sheet (PDS) is an update of the FY 2022 PDS; the project is not a new start in FY 2023. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range and Subproject 1 CD-3A, Approve Long Lead Procurement, which was approved on November 4, 2021. The TPC point estimate and range are a result of advancing project maturity with the completion of conceptual design. FY 2023 funding will continue support for Project Engineering and Design (PED) activities and approved long-lead procurements (CD-3A scope), such as materials for known designs of technologies developed under previous projects. As a result of evidence-based peer review, a second round of long lead procurements (CD-3B), originally planned for 1Q FY 2023, was combined with CD-3A. 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 III 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
FY 2023	1/4/19	2/26/21	11/4/21	4Q FY 2025	4Q FY 2025	4Q FY 2025	1Q FY 2032

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 2023						
Subproject (SP)	**CD-0**	**Conceptual Design Complete**	**CD-1**	**CD-3A**	**CD-2/3**	**CD-4**
SP-1	1/4/19	2/26/21	11/4/21	11/4/21	2Q FY 2024	4Q FY 2030
SP-2	1/4/19	2/26/21	11/4/21	3Q FY 2025	1Q FY 2026	1Q FY 2032
SP-3	1/4/19	2/26/21	11/4/21	1Q FY 2025	1Q FY 2026	2Q FY 2031

Note:
- *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
FY 2023	2Q FY 2024	11/4/21	–

CD-3A for Sub-Project 1 – Approve Long-Lead Procurements, (EMIS components and Facility Site Preparation)
CD-3B for Sub-Project 1 – Approve Long-Lead Procurements for Facility (Site preparations). In FY 2022, CD-3B was combined with CD-3A.

Project Cost History
This project is at CD-1/3A with a preliminary point estimate of $250,000,000 and Total Project Cost (TPC) range of $187,000,000 to $338,000,000. 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, Total	TPC
FY 2020	5,000	—	5,000	500	500	5,500
FY 2021	14,000	274,000	288,000	10,000	10,000	298,000
FY 2022	36,000	203,200	239,200	10,800	10,800	250,000
FY 2023	36,000	201,800	237,800	12,200	12,200	250,000

Note:
- *FY 2020 funding does not provide a full estimate for total TEC and OPC, it only reflects actual TEC and OPC requested as of the FY 2020 Congressional Budget Request. Previous versions of this table reflected TBD for FY 2020 TPC.*

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 considered the optimal number of production systems for each type of technology as part of the alternatives analysis for 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 only broad U.S. stable isotope production capability to enable multiple production campaigns of enriched stable isotopes. SIPRC utilizes innovative technology to establish domestic supply chains of critical stable isotopes and nurtures domestic core competencies in enrichment technologies using centrifuges and electromagnetic ion separators. This will provide domestic supply chains of critical isotopes for industry, medicine, and national security and mitigate U.S. dependencies on foreign suppliers. The current capacity within the United States is insufficient to meet the Nation's growing demands and the current inventory of stable isotopes is being depleted. The SIPRC project will provide an adequately sized building and transformative technology to address our Nation's stable 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 was received November 4, 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.

Summary of preliminary KPPs is indicated below.

Performance Measure	Threshold	Objective
Design/construct building	SP-1: Beneficial occupancy of the facility obtained.	SP-1: Beneficial occupancy of the facility obtained.
Instrumentation design/development	SP-1: Ninety percent (90 percent) of the EMIS machines complete the operability demonstration by running simultaneously with gas for 4 hours.	SP-1: One hundred percent (100 percent) of the EMIS machines complete the operability demonstration by running simultaneously with gas for 4 hours.
	SP-2: a. The SIPRC project will complete the validation and verification (V&V) of the controls system with the completed documentation of the process. b. The SIPRC project will complete documented system leak tests with results meeting the requirements laid out in the systems requirements documents. c. The SIPRC project will complete a mechanical operability test of the completed production GCIS cascade.	SP-2: The SIPRC project will complete a 100Mo gas test of the constructed cascade using molybdenum hexafluoride gas. Evidence of completion will be the report on the results of the gas test.

Performance Measure	Threshold	Objective
	SP-3: a. The SIPRC project will complete the validation and verification (V&V) of the controls system with the completed documentation of the process. b. The SIPRC project will complete documented system leak tests with results meeting the requirements laid out in the systems requirements documents.	SP-3: The SIPRC project will successfully complete an operability test of the TCI's feed and withdrawal system using a defined gas, either surrogate or actual planned SiF4 gas. The system must be able to flow gas at the planned flow rate range per the systems requirements document and withdraw the gas from the system piping into cold traps. Evidence of completion will be a report on the results of this test.

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
FY 2023	6,000	6,000	11,500
Outyears	9,000	9,000	13,000
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
FY 2023	6,000	6,000	7,000
Outyears	180,800	180,800	181,200
Total, Construction (TEC)	**201,800**	**201,800**	**201,800**
Total Estimated Cost (TEC)			
FY 2020	12,000	12,000	–
FY 2021	12,000	12,000	–
FY 2022	12,000	12,000	25,100
FY 2023	12,000	12,000	18,500
Outyears	189,800	189,800	194,200
Total, TEC	**237,800**	**237,800**	**237,800**

(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	3,400	3,400	3,400
Total, OPC	**12,200**	**12,200**	**12,200**

(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
FY 2023	12,000	12,000	18,500
Outyears	193,200	193,200	197,600
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	27,000	**N/A**
Design - Contingency	9,000	9,000	**N/A**
Total, Design (TEC)	**36,000**	**36,000**	**N/A**
Construction	150,000	150,000	**N/A**
Construction - Contingency	51,800	53,200	**N/A**
Total, Construction (TEC)	**201,800**	**203,200**	**N/A**
Total, TEC	**237,800**	**239,200**	**N/A**
Contingency, TEC	*60,800*	*62,200*	***N/A***
Other Project Cost (OPC)			
R&D	2,600	2,600	**N/A**
Conceptual Design	4,100	4,000	**N/A**
Start-up	2,100	1,500	**N/A**
OPC - Contingency	3,400	2,700	**N/A**
Total, Except D&D (OPC)	**12,200**	**10,800**	**N/A**
Total, OPC	**12,200**	**10,800**	**N/A**
Contingency, OPC	*3,400*	*2,700*	***N/A***
Total, TPC	**250,000**	**250,000**	**N/A**
Total, Contingency (TEC+OPC)	***64,200***	***64,900***	***N/A***

5. Schedule of Appropriations Requests[ddd]

(dollars in thousands)

Fiscal Year	Type	Prior Years	FY 2021	FY 2022	FY 2023	Outyears	Total
FY 2020	TEC	5,000	—	—	—	—	5,000
	OPC	500	—	—	—	—	500
	TPC	5,500	—	—	—	—	5,500
FY 2021	TEC	12,000	12,000	—	—	264,000	288,000
	OPC	2,600	3,000	—	—	4,400	10,000
	TPC	14,600	15,000	—	—	268,400	298,000
FY 2022	TEC	12,000	12,000	12,000	—	203,200	239,200
	OPC	2,600	3,000	3,200	—	2,000	10,800
	TPC	14,600	15,000	15,200	—	205,200	250,000
FY 2023	TEC	12,000	12,000	12,000	12,000	189,800	237,800
	OPC	2,600	3,000	3,200	—	3,400	12,200
	TPC	14,600	15,000	15,200	12,000	193,200	250,000

Note:
- *FY 2020 funding does not provide a full estimate for total TEC and OPC, it only reflects actual TEC and OPC requested as of the FY 2020 Congressional Budget Request. Previous versions of this table reflected TBD for FY 2020 TPC.*

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	4Q FY 2030
Expected Useful Life	30 years
Expected Future Start of D&D of this capital asset	2060

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	33,295	N/A	1,106,807
Utilities	N/A	4,053	N/A	133,735
Maintenance and Repair	N/A	2,992	N/A	90,458
Total, Operations and Maintenance	N/A	$40.340	N/A	$1,331,000

[ddd] The project does not have CD-2 approval; FY 2023 schedules and costs are estimates consistent with the updated preliminary point estimate.

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 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 and develops 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 cancer therapy, diagnostic medical imaging, clean energy, explosives detection, quantum computing, advanced manufacturing, nuclear batteries, space exploration, national security, and biological tracers. For example, radioisotopes are used in the diagnosis or treatment of about one-third of all patients admitted to hospitals.[eee] Substantial national and international research, medicine, industry, and national security relies upon the use of isotopes and is strongly dependent on the DOE IP's products and services.

A priority of the DOE IP is to mitigate the Nation's dependency on foreign supply chains of isotopes, particularly those from sensitive countries or essential for facilitating innovative technology. DOE IP continuously assesses isotope needs to inform program direction, including frequent industry stakeholder meetings and biennial federal workshops to evaluate U.S. federal demand 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 DOE IP 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 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, the University of Washington cyclotron, and the new addition of the University of Alabama-Birmingham cyclotron. Reactor facilities include the High Flux Isotope Reactor at Oak Ridge

[eee] https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/med-use-radioactive-materials.html

National Laboratory (ORNL), the University of Missouri Research Reactor, and the Advanced Test Reactor at Idaho National Laboratory. Irradiated targets are processed in associated hot cells and gloveboxes at these facilities. Isotopes are also extracted and purified at the Y-12 National Security Complex near ORNL, the Pacific Northwest National Laboratory, and the Savannah River Site. Enriched stable isotopes are distributed from inventory and produced at ORNL.

In FY 2022, a total of $123.0 million is estimated to be deposited into the revolving fund. This consists of the FY 2022 appropriation of $82.0 million paid into the revolving fund from the Isotope R&D and Production program, plus anticipated collections of $41.0 million to recover costs related to isotope production and isotope services. In FY 2022, the DOE IP expects to sell about 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 seven are high-volume isotopes often with commercial applications and the remaining are lower-volume, mostly research isotopes, which are more expensive to produce and thus not readily available otherwise. Collections in FY 2021 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 that have metastasized. 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 and pediatric lung imaging. Nickel-63 supports national security through its use in detectors for explosives and illicit material, and performance of nuclear batteries. Selenium-75 is used as a radiography source.

As a Mission Essential Function in the DOE, the DOE IP continued isotope production operations throughout the COVID-19 pandemic to mitigate supply chain disruptions 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 DOE IP meet commitments to its stakeholders during the pandemic, but the DOE IP 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 2022, DOE IP expects to make approximately 1,000 shipments of isotopes, which is a 25 percent increase from FY 2021.

Highlights of the FY 2023 Request

For FY 2023, 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 nuclear batteries and power supplies. The FY 2023 Request of the IRP Budget is $97.5 million. Revolving fund resources will be used to address the following priorities in the program:

- Promote world-leading core competencies for isotope production to address gaps in supply chains and the provision of innovative, rare isotopes for high priority applications.
- Through cutting-edge research and advanced manufacturing, introduce novel and critical 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.
- Advance and expand transformative, domestic stable isotope enrichment capabilities.
- Enhance isotope processing capabilities to address a lack of infrastructure limiting the availability of new isotopes, mitigating single point failures to increase the Nation's preparedness for reacting to global supply chain disruptions. Address targeted, high priority critical infrastructure needs.

The FY 2023 Request in the IRP Budget includes $3.0 million to continue the Isotope Harvesting research effort at the Facility for Rare Isotope Beams (FRIB) to extract and process significant quantities of high-value isotopes from the FRIB beam dump. 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 2023 Request in the IRP includes $12.0 million to continue the U.S. Stable Isotope Production and Research Center (SIPRC) at ORNL, to advance stable isotope production capacity for the Nation to commercial scale production of multiple isotopes simultaneously. The U.S. must continue to implement modern technology if it is to become independent of other sensitive countries with greater production capabilities for enriched stable isotopes . This construction project will build upon the developed expertise in centrifuge and electromagnetic ion separation technology nurtured by the Stable Isotope Production Facility (SIPF) Major Item of Equipment, funded through NP and IRP. The IRP Request supports and participates in high priority initiatives for the Department and Administration, including Quantum Information Science, Advanced Manufacturing, National Preparedness in the Biopreparedness Research Virtual Environment (BRaVE), Artificial Intelligence and Machine Learning, Climate/Clean Energy, Reaching a New Energy Sciences Workforce (RENEW), Accelerate Innovations in Emerging Technologies, and Funding for Accelerated, Inclusive Research (FAIR).

Program Accomplishments

Enabling the Development of Innovative Radiopharmaceuticals
The U.S. Food and Drug Administration (FDA) has accepted its Type II Drug Master File (DMF) submission for Actinium-225 Nitrate (thorium-229 derived) developed by the DOE Isotope Program. The alpha-emitting radionuclide and its decay product bismuth-213 have gained considerable interest within the medical community for targeted radiotherapy of cancer and other diseases. A DMF is a confidential, detailed document that is submitted to the FDA with information about facilities, processes, or articles used in the manufacturing, processing, packaging, and storing of human drug products. An active DMF enables clinical investigators or pharmaceutical companies to reference the filing in their regulatory submissions.

Domestic Centrifuge Manufacturing Capability
The DOE IP completed the establishment of a domestic centrifuge manufacturing capability (CMC) at Oak Ridge National Laboratory. The CMC utilizes state-of-the art machinery and advanced manufacturing techniques to support centrifuge fabrication for the Stable Isotope Production Facility (SIPF) MIE, which has modest centrifuge capability, and the Stable Isotope Production and Research Center (SIPRC) which has large electromagnetic separation and centrifuge capability.

UAB joins the DOE IP University Isotope Network
The University of Alabama at Birmingham has officially joined the DOE IP University Isotope Network (UIN). UAB will offer Valladium-48, Manganese-52, and Cobalt-55 medical isotopes to the isotope user community through DOE IP. UAB is the third academic site to join the UIN. This partnership sets the stage for more technical jobs and workforce development at UAB, as well as enhanced isotope production technologies.

Accelerator R&D and Production

Overview

The mission of the Accelerator R&D and Production (ARDAP) program is to help coordinate Office of Science (SC) accelerator R&D; advance accelerator science and technology relevant to the Department, other Federal Agencies, and U.S. industry; foster public-private partnerships to develop, demonstrate, and enable the commercial deployment of accelerator technology; support the development of a skilled, diverse, and inclusive workforce; and provide access to accelerator design and engineering resources. The overarching goal is to ensure a robust pipeline of innovative accelerator technology, train an expert and diverse workforce, and reduce significant supply chain risks by reshoring critical accelerator technology. By ensuring the supply of leading accelerator technology and facilities, ARDAP supports physical science research that provides the foundations for innovative technologies for green energy, medicine, security, and new tools to help clean up the environment and safeguard the water supply.

As the lead Office in the Accelerator Science and Technology Initiative, ARDAP will help coordinate accelerator R&D across SC and initiate new partnerships to move technologies from basic R&D into use at U.S. science facilities and into commercial products that benefit all Americans. 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, strengthen domestic supplies of accelerator technology, and to continue to attract and train the workforce needed to design and operate these facilities.

The ARDAP program is organized into two subprograms: Accelerator Stewardship and Accelerator Production.

Accelerator Stewardship

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 supports curation of software and material properties databases commonly used for accelerator design.

Research activities in cross-cutting accelerator technologies include superconducting magnets and accelerators, beam physics, data analytics-based accelerator controls, simulation software, new particle sources, advanced laser technology, and other transformative research. Early-stage collaboration between academia, DOE national laboratories, and U.S. industry will be fostered, reducing the time to commercialization. Research activities will be informed by the requirements of both future SC facilities and the requirements for medical, industrial, energy, environmental, security, and defense applications. R&D investments made for scientific facilities will be leveraged to enable commercial application of advanced accelerator technologies.

Accelerator Production

The Accelerator Production subprogram supports public-private partnerships to develop 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.

Development activities will support partnerships in advanced superconducting wire and cable, superconducting radiofrequency (RF) cavities, and high efficiency RF power sources for accelerators, among other areas.

Highlights of the FY 2023 Request

The FY 2023 Request for $27.4 million focuses resources on fundamental research, operation and maintenance of a scientific user facility, and production of accelerator technologies in industry. The FY 2023 Request supports innovative research, development, and deployment of accelerator technology, the implementation of the first center-based approach to accelerator R&D, and workforce development. ARDAP participates in the Funding for Accelerated, Inclusive Research (FAIR) initiative which will provide focused investment on enhancing research on clean energy, climate, and related topics at minority serving institutions, including attention to underserved and environmental justice regions.

The FY 2023 Request also supports operation of the Brookhaven National Laboratory (BNL) Accelerator Test Facility (ATF) for 1,736 hours (94 percent of optimal). Accelerator Production activities support partnerships to develop technologies that include advanced superconducting wire and cable, superconducting accelerators, and advanced radiofrequency power sources for accelerators.

Accelerator R&D and Production
FY 2023 Research Initiatives

Accelerator R&D and Production supports the following FY 2023 Research Initiatives.

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Accelerator Science and Technology Initiative	–	–	6,872	+6,872
Funding for Accelerated, Inclusive Research (FAIR)	–	–	1,500	+1,500
Total, Research Initiatives	–	–	**8,372**	**+8,372**

Accelerator R&D and Production
Funding

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Accelerator R&D and Production				
Accelerator Stewardship, Research	–	10,835	15,554	+15,554
Accelerator Stewardship, Facility Operations and Experimental Support	–	6,100	6,000	+6,000
Total, Accelerator Stewardship	**–**	**16,935**	**21,554**	**+21,554**
Accelerator Production, Research	–	–	5,882	+5,882
Total, Accelerator Production	**–**	**–**	**5,882**	**+5,882**
Total, Accelerator R&D and Production	**–**	**16,935**	**27,436**	**+27,436**

SBIR/STTR funding:
- FY 2021 Enacted: SBIR $ — and STTR $ —
- FY 2022 Annualized CR: SBIR $542,000 and STTR $75,000
- FY 2023 Request: SBIR $878,000 and STTR $124,000

Accelerator R&D and Production

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Accelerator R&D and Production	**$ —**	**$27,436**	**+$27,436**
Accelerator Stewardship	$ —	$21,554	+$21,554
Research	*$ —*	*$15,554*	*+$15,554*
The Accelerator Stewardship program is part of the High Energy Physics program in FY 2021 with a funding level of $10,835,000.		The Request will support new research activities at laboratories, universities, and in the private sector on cross-cutting accelerator technologies such as superconducting magnets and accelerators, beam physics, data analytics-based accelerator controls, new particle sources, advanced laser technology R&D, and transformative R&D. The Request supports the FAIR initiative to provide focused investment on enhancing research on clean energy, climate, and related topics at minority serving institutions, including attention to underserved and environmental justice regions.	The Accelerator Stewardship program moved from High Energy Physics to ARDAP in FY 2022, and consequently does not appear in the FY 2021 Enacted budget under ARDAP. Some R&D projects will roll-off at the end of FY 2022 without being renewed to prioritize Accelerator Production activities. Also, the Request will support participation in the new FAIR initiative.
Facility Operations and Experimental Support	*$ —*	*$6,000*	*+$6,000*
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 94 percent of optimal levels.	Funding for the BNL-ATF moved from High Energy Physics to ARDAP in FY 2022, and consequently does not appear in the FY 2021 Enacted budget under ARDAP. BNL-ATF User Facility will continue operations at near optimal levels. Retirement of deferred maintenance and facility upgrades will continue at a reduced pace.

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Accelerator Production	$ —	$5,882	+$5,882
Research	*$ —*	*$5,882*	*+$5,882*
Accelerator Production is a new subprogram created when the Office of Science was reorganized, creating ARDAP.		The Request will increase partnerships and collaborative R&D efforts to develop additional suppliers for critical accelerator technologies for SC scientific facilities. Increased investments will allow technology transfer to proceed faster and across a broader range of component and subsystem technologies. Critical areas include advanced superconducting wire and cable, superconducting RF cavities and associated components, and high efficiency radiofrequency power sources for accelerators. Research partnerships to industrialize technologies for water purification, groundwater decontamination, and wastewater treatment will begin.	ARDAP's Accelerator Production subprogram first began in FY 2022 and consequently does not appear in the FY 2021 Enacted budget. Investment in supply-chain risk reduction activities such as technology maturation, strategic materials purchases, and partnerships will ramp-up to ensure an adequate domestic supply of critical accelerator components for scientific facilities and other critical applications.

Note:

- *Funding for the subprogram above, includes 3.65 percent 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. 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 Basic Energy Sciences, Fusion Energy Sciences, High Energy Physics, Nuclear Physics, and Isotope R&D and Production 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 National Institutes of Health/National Cancer Institute (NIH/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 National Nuclear Security Administration (NNSA) and DOD, the Department of Homeland Security's Domestic Nuclear Detection Office in the Countering Weapons of Mass Destruction Office (DHS/CWMD), and the National Science Foundation/Mathematical and Physical Sciences (NSF/MPS) Division.

Discussions with the NCI, DOD, and 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[fff] 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 750 publications, and the training of 50 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.

[fff] https://science.osti.gov/-/media/hep/pdf/Reports/2020/CASM_WorkshopReport.pdf

Accelerator R&D and Production
Funding Summary

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Research	–	10,835	21,436	+21,436
Facility Operations	–	6,100	6,000	+6,000
Total, Accelerator R&D and Production	**–**	**16,935**	**27,436**	**+27,436**

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 <u>TYPE A</u> 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 2021 Enacted	FY 2021 Current	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Scientific User Facilities - Type A					
Accelerator Test Facility	**–**	**–**	**6,100**	**6,410**	**+6,410**
Number of Users	–	–	112	82	+82
Planned Operating Hours	–	–	2,248	1,736	+1,736
Optimal Hours	–	–	2,250	1,850	+1,850
Percent of Optimal Hours	–	–	99.9%	93.9%	+93.9%
Total, Facilities	**–**	**–**	**6,100**	**6,410**	**+6,410**
Number of Users	–	–	112	82	+82
Planned Operating Hours	–	–	2,248	1,736	+1,736
Optimal Hours	–	–	2,250	1,850	+1,850

Notes:
- *Achieved Operating Hours and Unscheduled Downtime Hours will only be reflected in the Congressional budget cycle which provides actuals.*
- *Funding for the Accelerator Test Facility was funded in the High Energy Physics program prior to FY 2022.*
- *The Brookhaven ATF User Facility will undergo an Accelerator Readiness Review in FY 2023, necessitating a reduction in availability as extensive preparation and review activities take place.*

Accelerator R&D and Production
Scientific Employment

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Number of Permanent Ph.Ds (FTEs)	–	8	14	+14
Number of Postdoctoral Associates (FTEs)	–	3	4	+4
Number of Graduate Students (FTEs)	–	14	23	+23
Number of Other Scientific Employment (FTEs)	–	14	23	+23
Total Scientific Employment (FTEs)	**–**	**39**	**64**	**+64**

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

Workforce Development for Teachers and Scientists

Overview
The mission of the Workforce Development for Teachers and Scientists (WDTS) program is to ensure that Department of Energy (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 user 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. The WDTS discovery learning-based STEM training 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 2023 Request
The FY 2023 Request for $41.3 million prioritizes funding for programs that place highly qualified applicants in STEM learning and authentic research experiences at DOE laboratories and expands training opportunities to students and faculty from Minority Serving Institutions (MSIs) and individuals from underrepresented, underserved groups. The Request increases support for the Reaching a New Energy Sciences Workforce (RENEW) initiative, which will significantly increase outreach to and workforce training opportunities for 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 modernization and evaluation activity, which is critically important for evidence-based management and evaluation practice to sustain 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.

Description

Activities at the DOE Laboratories
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 scientist and engineer mentors 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 mentor. CCI provides dedicated technical training for community college students who are interested in technical careers and provides a pathway for those who plan to pursue further educational objectives beyond community college.

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 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. VFP 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.

As an active participant in the SC-wide RENEW initiative, WDTS coordinates 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 has 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. From October to mid-December in 2021, WDTS completed ten listening sessions with MSIs, community colleges, and underrepresented groups (URGs) to understand the barriers that prevent underrepresented and underserved groups from participating in SC workforce development programs. WDTS is continuing the effort of collecting input from MSIs, community colleges, and underrepresented groups. Additionally, WDTS will, in collaboration with DOE laboratories and SC research programs, continue to develop and implement strategies and mechanisms to remove barriers and facilitate more application/participation by underrepresented and underserved groups, including experimenting with new training models or elements to enable application/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 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, the Smithsonian, the U.S. Geological Survey, and the Department of Homeland Security. 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 320,000 students have participated in the National Science Bowl® throughout its 31-year history, and it is one of the Nation's largest science competitions. WDTS 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 or five students and a teacher who serves as an advisor and coach. WDTS provides central management of its regional events.

Technology Development and On-Line Application

This activity modernizes on-line systems used to manage application solicitations, review applications, and facilitate data collection, curation, and compilation to support 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 assessment by WDTS program staff, and allow more efficient management and execution of programs by DOE laboratory staff. An important feature of the systems is the integration of a data analysis and visualization capability to support evidence-based management and evaluation of programs.

Evaluation

The evaluation activity supports work to assess whether WDTS programs meet established goals. This is accomplished through triennial reviews of its program performers, of WDTS itself, and of program performance. These reviews involve peer reviews and Federal Advisory Committee-commissioned Committee of Visitors reviews. In addition, as an important part of assessing STEM workforce training programs, activities are supported to measure short-term program outcomes and assess longer-term program impact. The supported activities include the compilation and analysis of data and other materials, including pre- and post-participation surveys, participant deliverables, notable outcomes (publications, presentations, patents, etc.), and longitudinal participant tracking/outcome analysis. 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 OSTP/NSTC/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 (https://science.osti.gov/wdts) is the most widely used tool for prospective program participants to obtain information about WDTS, and it provides a gateway to accessing the online applications for the WDTS programs. To help diversify the applicant pool and provide equitable access, outreach is conducted via multiple venues, with intentional brand messaging, such as hosting panels for and giving presentations to targeted stakeholder groups, sharing information with professional societies, and using virtual platforms to host internship and career fairs. WDTS leverages SC's social media resources to amplify the program opportunities to a broad range of stakeholders, including SC research grantees, scientific professional societies, Historically Black Colleges and Universities (HBCUs) and other MSIs, and community colleges with a focus on underrepresented and underserved groups.

WDTS also annually solicits proposals from DOE host laboratories and facilities to develop and execute outreach activities aimed at recruiting more diverse, equitable, and inclusive applicant and participant pools for WDTS laboratory-based programs, and to encourage WDTS program participants to pursue careers supporting the SC and DOE mission, including staffing needs at DOE national laboratories. Emphasis of laboratory outreach activities is on reaching potential applicants who are underrepresented in STEM fields, including building partnerships and 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 institutions pay for shipping costs.

Workforce Development for Teachers and Scientists
Funding

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Workforce Development for Teachers and Scientists				
Science Undergraduate Laboratory Internship (SULI)	13,800	13,800	15,000	+1,200
Community College Internship Program (CCI)	1,900	1,900	2,200	+300
Visiting Faculty Program (VFP)	1,800	1,800	2,100	+300
Office of Science Graduate Student Research (SCGSR) Program	4,600	4,600	5,000	+400
Reaching a New Energy Sciences Workforce (RENEW)	–	–	10,000	+10,000
Internships and Visiting Faculty Activities at DOE Labs	**22,100**	**22,100**	**34,300**	**+12,200**
Albert Einstein Distinguished Educator Fellowship	**1,200**	**1,200**	**1,200**	**–**
National Science Bowl	**2,900**	**2,900**	**3,000**	**+100**
Technology Development and On-Line Application	**700**	**700**	**700**	**–**
Evaluation	**600**	**600**	**600**	**–**
Outreach	**1,500**	**1,500**	**1,500**	**–**
Total, Workforce Development for Teachers and Scientists	**29,000**	**29,000**	**41,300**	**+12,300**

Program Accomplishments

Science Undergraduate Laboratory Internship (SULI) — In FY 2021, approximately 1,053 placements were supported, of which 12.3 percent were from MSIs and approximately 27 percent were women. Among the participants, more than 98 percent reported positive impacts to their educational and career goals, and 99.6 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 2021, 126 placements were supported, with 47.6 percent from MSIs. Among the participants, 99.1 percent would recommend CCI to their peers and more than 98 percent reported positive impacts to their educational and career goals. Nearly 95 percent of participants reported that they would consider a job or career at their host DOE laboratory or facility.

Visiting Faculty Program (VFP) — In FY 2021, 63 faculty and 29 student placements were supported, and of these participants, 49.2 percent of the faculty and 41.4 percent of the students were from MSIs. Among the faculty participants, 16 percent were Black or African American and 22 percent were women. 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 (92 percent), with 96 percent reporting impacts to their educational and career goals, and 100 percent reporting they would recommend VFP to their peers.

Office of Science Graduate Student Research (SCGSR) Program — For FY 2021, the two planned solicitations were released, with one resulting in 65 new awards and the other going through review and selection process; for FY 2022, one of the two planned solicitations has been released for the online application period. As a result of the 2020 SC reorganization, two new program offices (Isotopes R&D and Production and Accelerator R&D and Production) were established, resulting in their research areas added to the SCGSR list.

The mission areas from the two new offices were added to the SCGSR research area list. In FY 2022 and FY 2023, SCGSR program will continue the support of graduate research opportunities at DOE national laboratories in SC mission areas 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 received a steady increase of applications in the four convergence research areas started in FY 2019 and updated through FY 2021 (data science, microelectronics, conservation laws and symmetries, 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. Based on the evidence received in FY 2019-2021, the new convergence research areas will be continued with minor adjustments for the application cycles in FY 2022 and FY 2023.

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 Fall 2020, Spring 2021, and Summer 2021 Terms of the SULI, CCI, and VFP programs were impacted by restricted access and minimum operations status at DOE national laboratories due to the persisting pandemic. WDTS, in collaboration with DOE national laboratories, successfully delivered virtual internships to more than 1,400 undergraduate students from 2-/4-year colleges and universities, graduate students, and visiting faculty from underrepresented institutions. 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 RENEW initiative, WDTS started and will continue working with SC research programs and DOE national laboratories on understanding barriers that prevent underrepresented and underserved groups from participating in WDTS workforce development programs. WDTS will develop strategies/mechanisms to address these barriers. The effort adopts an evidence-based approach, including listening sessions with MSIs, community colleges, and underrepresented groups, and examining application/participation data from multiple terms for areas of development in outreach, selection, and recruitment and retention. 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 2021, one of the six WDTS-sponsored AEF participants held a WDTS office appointment. As part of the efforts to expand federal agency participation, the 2020-2021 cohort included placements at the Smithsonian Institution and the U.S. Geological Survey. WDTS established partnerships with other agencies that have expressed interest, including the U.S. Department of Homeland Security who will host a Fellow during FY 2022. During the pandemic, the AEF participants of the 2020-2021 cohort engaged with their host federal agencies or Congressional offices remotely and actively participated in the program's professional development activities.

National Science Bowl® — In FY 2021, more than 2,720 middle school students (from 355 schools) and 5,740 high school students (from 811 schools) participated in 108 regional competitions, with 44 middle school teams (211 students) and 64 high school teams (307 students) advancing to the National Finals in May 2021. Forty-nine U.S. States, the District of Columbia, and Puerto Rico were represented at regionals. More than 2,000 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, all the regional events and the National Finals were held virtually in 2021. The virtual events, particularly those at the regional competition level, enabled more schools from underrepresented and underserved communities to gain access and participation in the events. Due to the virtual format, more than 250 volunteers served as officials at competitions all over the country in addition to their local event.

Technology Development and On-Line Application — Due to the continued pandemic, significant adaptation of the WDTS Application and Review System (WARS) was made in FY 2020 and through FY 2021 to support the virtual internships, virtual mentoring, and collaborative research opportunities for students and faculty at DOE national laboratories. In FY 2021, a Data analysis And Visualization (DAV) capability was added within WARS to support evidence-based management and evaluation of programs. The DAV integration resulted in the synergy of data collection, data compilation, and data analysis in a streamlined process, which enabled the study from data across multiple attributes and years at various granularity levels. While the integration effort is still ongoing, the newly integrated feature has demonstrated its usefulness in providing annual program data summary reports to all host DOE national laboratories, compiling data and information to support both short-term and longer-term WDTS evaluation projects, and producing quick-turnaround data summary and evidence to address inquiries from public and DOE leadership and to support the Office of Management and Budget and Congressional briefings. In FY 2021, the technical development for an updated NSB online registration system to better support regional and national participants was completed, and the planning for the online management tool for the National Finals was initiated, which will have all travel, lodging, and logistical information accessible within WARS. SC went through a re-organization in FY 2020 and as the result, two new program offices were established (Isotope R&D and Production, and Accelerator R&D and Production). New WARS features were developed so the two new offices and their mission areas could be included in the SCGSR online application system. Additionally, the technical requirements and information architecture for a virtual National Science Bowl® training site on SC's website was continued. Additional development focused on the enhancement of a STEM activity reporting tool with inputs that include event type, sponsorship, targeted audience(s), amplification, and connection to the National STEM Education Plan per OSTP/NSTC/CoSTEM. The goal of this reporting tool is 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.

Evaluation — In FY 2021, WDTS, in collaboration with the evaluation experts at the Oak Ridge Institute for Science and Education (ORISE), examined the existing evaluation activities and developed a work plan for building and sustaining a comprehensive evaluation portfolio to support evidence-based management and evaluation of workforce development programs and initiatives in WDTS and SC. Informed by the best practice in the STEM workforce development community, the plan clearly defined the goal, objectives, scope, and expectations for evaluation activities, and established the structure and mechanism for conducting regular short-term assessments of program outcomes and longer-term program impact studies. A list of candidates for short-term projects were developed, with a focus on understanding the information collected via pre- and post-survey about STEM skills/knowledge, career goals, and diversity and inclusion. In FY 2021, WDTS continued and made good process in the planning for the pilot longitudinal study with ORISE. The study was planned for longitudinal evaluation of the impacts of WDTS-sponsored undergraduate internship programs at DOE national laboratories. A proposed study plan has been developed and an internal view has been completed. The next step is to put the plan through a peer review process to gather feedback from external experts before finalizing it. In the meantime, initial efforts have been made to coordinate the study planning with the timeline needed for fulfilling the requirements of the Paperwork Reduction Act and human subjects related regulations. In support of the RENEW initiative, the knowledge, infrastructure, and capabilities built through the Evaluation activity and plan 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 — In FY 2021, WDTS, in collaboration with DOE national laboratories, completed the development of the DOE complex branded outreach materials. WDTS also supported the distribution of the materials to all DOE laboratories for outreach. In collaboration with ORISE, DOE laboratories, and higher education institutions, WDTS supported and co-hosted a series of virtual events (virtual career fairs and a virtual graduate student recruitment fair) to actively engage MSIs and individuals from underrepresented groups, and to enable equitable access to workforce training opportunities by all. WDTS also supported the development and updates of a comprehensive MSIs database that compiled the MSI designations, Carnegie Classification, institutional information from the Department of Education's Integrated Post-Secondary Data System, and the contact information of key administrators (provost, deans, chairs/directors) for STEM programs/activities at all MSIs. The database also includes the non-MSI institutions that conferred a high level of Associate's, Bachelor's, and Graduate (Master's and Doctoral) degrees to individuals from underrepresented race and ethnicity groups, including African Americans, Indigenous Americans, and Hispanics or Latinos. The MSIs database has been used to support the engagement efforts with MSIs and to promote diversity, equity, and inclusiveness in SC programs and DOE national laboratories.

DOE host laboratories and facilities executed projects aimed at recruiting a more diverse, equitable, and inclusive applicant and participant pool to WDTS laboratory-based training programs, targeting recruitment of individuals traditionally underrepresented in STEM and addressing needs to increase the applicant and participant pool diversity for 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 2021, Argonne National Laboratory, Brookhaven National Laboratory, Oak Ridge National Laboratory, the National Renewable Energy Laboratory, and Oak Ridge National 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 also supported a virtual Graduate School Fair that gave student interns an opportunity to learn about graduate school programs and opportunities directly from university representatives.

WDTS completed the LEDP online system migration from the Office of Scientific and Technical Information to ORISE that integrates LEDP's equipment catalog, applications, reviews, and processing into WDTS online systems. In FY 2021, the summary reporting capability per General Services Administration requirement was completed and the development of an online reporting tool in WARS for LEDP grantee institutions was started, which would collect information on how the donated equipment were used to support STEM education activities by the receiving institutions. By using established online resources, and their capabilities, this migration improves the client experience when accessing and applying for equipment, and 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 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Workforce Development for Teachers and Scientists	**$29,000**	**$41,300**	**+$12,300**
Activities at the DOE Laboratories	$22,100	$34,300	+$12,200
Science Undergraduate Laboratory Internship (SULI)	*$13,800*	*$15,000*	*+$1,200*
Funding for SULI supports approximately 1,132 students.		The Request for SULI will support approximately 988 students with an increased allocation per participant. Over the years, the cost of supporting interns at DOE national laboratories has increased and the housing cost has more than doubled in many places. In addition, increased support is necessary to keep the program competitive in terms of the financial support (stipend and allowance for housing/travel) to individual interns in comparison to other internships programs (such as those supported by NSF and other agencies).	Funding will support 144 fewer students along with the increased allocation per participant.
Community College Internship Program (CCI)	*$1,900*	*$2,200*	*+$300*
Funding for CCI supports approximately 173 students.		The Request for CCI will support approximately 167 students with an increased allocation per participant. Over the years, the cost of supporting interns at DOE national laboratories has increased and the housing cost has more than doubled in many places. In addition, increased support is necessary to keep the program competitive in terms of the financial support to individual interns in comparison to other internships programs (such as those supported by NSF and other agencies).	Funding will support 6 fewer students along with the increased allocation per participant.

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Visiting Faculty Program (VFP)	*$1,800*	*$2,100*	*+$300*
Funding for the VFP supports approximately 67 faculty and 35 students.		The Request for the VFP will support approximately 66 faculty and 32 students with an increased allocation per participant. Over the years, the cost of supporting visiting faculty members at DOE national laboratories has increased and the housing cost has more than doubled in many places. In addition, increased support is necessary to keep the program competitive in terms of the financial support to individual faculty members in comparison to similar programs.	Funding will support 1 fewer faculty and 3 fewer students along with the increased allocation per participant.
Office of Science Graduate Student Research (SCGSR) Program	*$4,600*	*$5,000*	*+$400*
Funding for the SCGSR program supports approximately 180 graduate students. Targeted priority research areas are informed by SC's workforce training needs studies.		The Request for the SCGSR program will support approximately 190 graduate students. Targeted priority research areas will be informed by SC's workforce training needs studies.	Funding will support 10 additional SCGSR participants.
Reaching a New Energy Sciences Workforce (RENEW)	*$ —*	*$10,000*	*+$10,000*
No Funding in FY 2021.		The Request supports continued implementation of the FY 2022 RENEW initiative and a planned growth of the existing workforce training programs/activities.	Funding will double to support an increase in the number of awards at MSIs and for individuals from underrepresented communities.
Albert Einstein Distinguished Educator Fellowship	$1,200	$1,200	$ —
Funding supports 6 Fellows.		The Request will support 6 Fellows.	No change.

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
National Science Bowl®	$2,900	$3,000	+$100
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 National Finals and provide central management of over 110 virtual and in-person regional events, involving more than 14,000 students from all fifty states, the District of Columbia, Puerto Rico, and the U.S. Virgin Islands.	The long-time event venue for the National Finals, the National 4-H Conference Center in Chevy Chase, MD, which provided lodging, meals, and conference space, is closed and being sold. The new venue, for at least 2022 and 2023, is a similar, but more spacious, facility with equivalent security measures. While still much less expensive than using hotels, and much more secure for housing approximately 700 children, the new venue, in Leesburg, Virginia, has increased costs for conference space, taxes, and lodging. Instead of 4–5 students sharing a room, students will have their own small room which will help WDTS, and the venue implement health measures in compliance with the state's COVID-19 guidelines.
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.	No change.

(dollars in thousands)

FY 2021 Enacted	FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Evaluation $600	$600	$ —
Funding continues support for evaluation activities, including data archiving, curation, and analyses.	The Request will support a comprehensive evaluation portfolio with short- and longer-term projects for assessing WDTS program performance and producing knowledge to inform evidence-based management and evaluation practice.	No change.
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 diversity, equity, and inclusion; 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.	No change.

Workforce Development for Teachers and Scientists
Funding Summary

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Other	29,000	29,000	41,300	+12,300
Total, Workforce Development for Teachers and Scientists	**29,000**	**29,000**	**41,300**	**+12,300**

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, consisting of Line-Item Construction Projects and General Plant Projects (GPP), 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 the 10 national laboratories include major research and user facilities, laboratory and office buildings, support facilities, and a vast network of utilities that form the backbone of each site. 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. This resulted 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. To support the core capabilities and achieve the scientific vision, each laboratory's Campus Strategy identifies activities and infrastructure investments such as Line-Item (LI) Construction and General Plant Projects (GPPs). 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 $613.7 million in maintenance, repair, and construction in FY 2021. These investments came from a variety of funding sources including Federal appropriations for line-item and general plant projects and laboratory overhead funding of Institutional GPP (IGPP) projects as well as maintenance and repair. The SLI investments in line-item construction and science-supporting general infrastructure are key elements of this overall investment strategy.

Highlights of the FY 2023 Request

The SLI program Request continues to focus on improving infrastructure across the SC national laboratory complex. The FY 2023 Request does not include any new line-item construction projects.

The Request also supports eleven ongoing construction projects:

1. Princeton Plasma Innovation Center at Princeton Plasma Physics Laboratory (PPPL);
2. Critical Utilities Rehabilitation Project at Brookhaven National Laboratory (BNL);
3. Seismic and Safety Modernization project at Lawrence Berkeley National Laboratory (LBNL);
4. Continuous Electron Beam Accelerator Facility (CEBAF) Renovation and Expansion project at Thomas Jefferson National Accelerator Facility (TJNAF);
5. Large Scale Collaboration Center at SLAC National Accelerator Laboratory (SLAC);
6. Critical Infrastructure Recovery & Renewal at Princeton Plasma Physics Laboratory (PPPL);
7. Argonne Utilities Upgrade project at Argonne National Laboratory (ANL);
8. Linear Assets Modernization Project at LBNL;
9. Critical Utilities Infrastructure Revitalization project at SLAC;
10. Utilities Infrastructure Project at Fermi National Accelerator Laboratory (FNAL), and:
11. Biological and Environmental Program Integration Center (BioEPIC) at LBNL.

These ongoing 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 2023 Request also includes funding for general purpose infrastructure projects that will address emerging, high priority core infrastructure and utility needs across SC laboratories and facilities. Infrastructure needs and priorities for all laboratories are evaluated annually by SLI. Projects 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 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Science Laboratories Infrastructure				
Payment In Lieu of Taxes (PILT)	4,650	4,820	4,891	+241
OR Landlord	5,860	6,430	6,559	+699
Facilities and Infrastructure	29,790	17,200	15,200	-14,590
Oak Ridge Nuclear Operations	26,000	20,000	20,000	-6,000
Subtotal, Science Laboratories Infrastructure	**66,300**	**48,450**	**46,650**	**-19,650**

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Construction				
21-SC-71, Princeton Plasma Innovation Center (PPIC), PPPL	150	900	10,000	+9,850
21-SC-72, Critical Infrastructure Recovery & Renewal (CIRR), PPPL	150	2,000	4,000	+3,850
21-SC-73, Ames Infrastructure Modernization (AIM)	150	–	–	-150
20-SC-71, Critical Utilities Rehabilitation Project (CURP), BNL	20,000	26,000	13,000	-7,000
20-SC-72, Seismic and Safety Modernization (SSM), LBNL	5,000	27,500	27,500	+22,500
20-SC-73, CEBAF Renovation and Expansion (CEBAF), TJNAF	2,000	10,000	2,000	–
20-SC-74, Craft Resources Support Facility (CRSF), ORNL	25,000	–	–	-25,000
20-SC-75, Large Scale Collaboration Center (LSCC), SLAC	11,000	12,000	30,000	+19,000
20-SC-76, Tritium System Demolition and Disposal (TSDD), PPPL	13,000	6,400	–	-13,000
20-SC-77, Argonne Utilities Upgrade (AU2), ANL	500	500	8,000	+7,500
20-SC-78, Linear Assets Modernization Project (LAMP), LBNL	500	500	23,425	+22,925
20-SC-79, Critical Utilities Infrastructure Revitalization (CUIR), SLAC	500	500	25,425	+24,925
20-SC-80, Utilities Infrastructure Project (UIP), FNAL	500	500	20,000	+19,500
19-SC-71, Science User Support Center (SUSC), BNL	20,000	38,000	–	-20,000
19-SC-73, Translational Research Capability (TRC), ORNL	22,000	21,500	–	-22,000
19-SC-74, BioEPIC, LBNL	20,000	35,000	45,000	+25,000
18-SC-71, Energy Sciences Capability (ESC), PNNL	23,000	–	–	-23,000
17-SC-71, Integrated Engineering Research Center (IERC), FNAL	10,250	10,250	–	-10,250
Subtotal, Construction	**173,700**	**191,550**	**208,350**	**+34,650**
Total, Science Laboratories Infrastructure	**240,000**	**240,000**	**255,000**	**+15,000**

Science Laboratories Infrastructure
Explanation of Major Changes

	(dollars in thousands) FY 2023 Request vs FY 2021 Enacted
Infrastructure Support The Request provides funding for general plant projects to address emerging high-priority infrastructure needs across the SC complex; and continues to support Payment in Lieu of Taxes (PILT), nuclear facilities at ORNL, and landlord responsibilities at the Oak Ridge Reservation.	**-19,650**
Construction Funding supports eleven ongoing line-item projects at ANL, BNL, FNAL, LBNL, PPPL, SLAC, and TJNAF.	**+34,650**
Total, Science Laboratories Infrastructure	**+15,000**

Program Accomplishments
Since FY 2006, the SLI program has invested nearly $1.8 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 thirteen 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 1,207,000 gsf of new space and modernized more than 452,000 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 nearly $203,000,000 in 36 laboratory core infrastructure improvement projects (GPP projects with TEC less than $20,000,000) including $133,000,000 in electrical and utility improvements, $35,340,000 in building renovations, $28,800,000 in safety and environmental projects and $5,730,000 in sustainability. Examples of recent SLI investments in core infrastructure include building heating, ventilation, and air conditioning (HVAC) upgrades at BNL, access control upgrades at Ames and Fermi and steam to hydronics conversion at PNNL. SLI also funded electrical substation and building HVAC system improvements at LBNL, cooling tower water reuse at TJNAF and facility improvement including fire protection at the Office of Scientific and Technical Information.

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 either upgraded or replaced as they approach end-of-life. Upgraded facilities have improved reliability, resilience, efficiency, and performance. This subprogram also supports nuclear operations at the Oak Ridge National Laboratory (ORNL), funds stewardship-type needs (e.g., roads and grounds maintenance) across the Oak Ridge Reservation, and funds Payments In Lieu of Taxes (PILT) to local communities around the Argonne National Laboratory (ANL), Brookhaven National Laboratory (BNL), and ORNL. Stewardship-type needs (e.g., roads and grounds maintenance) across the Oak Ridge Reservation are also included.

Facilities and Infrastructure

This activity supports minor construction investments (general plant projects of less than $20,000,000) that address urgent and emerging core infrastructure needs. 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. The Science Laboratories Infrastructure program maintains an active list of critical core infrastructure investment needs. Projects 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 federal 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 2023 Request		Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Infrastructure Support	**$66,300**		**$46,650**	**-$19,650**
Facilities and Infrastructure	$29,790		$15,200	-$14,590
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 support the most critical nuclear operations and facilities at ORNL.
OR Landlord	$5,860		$6,559	+$699
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		$4,891	+$241
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 support anticipated PILT requirements.

Science Laboratories Infrastructure
Construction

Description

The Science Laboratories Infrastructure (SLI) 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. Modernizing infrastructure, some more than 50 years old, supporting the SC national laboratories, will ensure the critical needs of the future science initiatives and world class user facilities are met for decades to come, while minimizing unwanted disruptions through resilience and reliability, ensuring safety and maintainability.

The FY 2023 Request includes funding for eleven ongoing line-item construction projects:

1. Princeton Plasma Innovation Center at PPPL;
2. Critical Infrastructure Recovery & Renewal at PPPL;
3. Critical Utilities Rehabilitation Project at BNL;
4. Seismic and Safety Modernization at LBNL;
5. CEBAF Renovation and Expansion at TJNAF;
6. Large Scale Collaboration Center at SLAC;
7. Argonne Utilities Upgrade at ANL;
8. Linear Assets Modernization Project at LBNL;
9. Critical Utilities Infrastructure Revitalization at SLAC;
10. Utilities Infrastructure Project at FNAL; and
11. Biological and Environmental Program Integration Center at LBNL.

No new line-item construction projects are included within this request.

<u>21-SC-71, Princeton Plasma Innovation Center, PPPL</u>

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, was approved on January 22, 2021. The preliminary estimate for CD-2, Approve Performance Baseline, is anticipated in the second quarter of FY 2024. This project is pre-CD-2; therefore, schedule estimates are preliminary and subject to change. The current preliminary Total Estimated Cost (TEC) range for this project is $78,300,000 to $96,300,000 and the preliminary Total Project Cost (TPC) range is $80,500,000 to $98,500,000. These cost ranges encompass the most feasible preliminary alternative at this time.

<u>21-SC-72, Critical Infrastructure Recovery & Renewal, PPPL</u>

The Critical Infrastructure Recovery & Renewal (CIRR) project at PPPL will revitalize critical infrastructure that supports the PPPL campus. Upgrades that may be completed as part of the 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 current preliminary Total Estimated Cost (TEC) range for this project is $80,100,000 to $96,000,000. The preliminary Total Project Cost (TPC) range for this project is $81,800,000 to $97,700,000. These cost ranges encompass the most feasible preliminary alternatives at this time.

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 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 $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 TEC point estimate for this project is $92,000,000 and the preliminary TPC point 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 at LBNL. Specifically, facilities with large congregation areas, facilities that are necessary for emergency response personnel, and facilities necessary to maintain continuity of operations will be improved. 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 2023. This project is pre-CD-2; therefore, schedule estimates are preliminary and subject to change. This project has a preliminary TEC range of $76,300,000 to $95,400,000 and the preliminary TPC range of $78,500,000 to $97,600,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The preliminary TEC point estimate for this project is $95,400,000 and the preliminary TPC point estimate for this project is $97,600,000.

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 inadequate utility systems that are experiencing frequent failures. This project will renovate 123,000 to 250,000 gross square feet (gsf) of existing space in the CEBAF center and the Applied Research Center (ARC), upgrade high risk utility systems, and provide 82,000 to 150,000 gsf of additional space for visitors, users, research, education, and support.

The most recent DOE Order 413.3B Critical Decision (CD) is CD-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 fourth quarter of FY 2022. This project is pre-CD-2; therefore, schedule estimates are preliminary and subject to change. This project has a preliminary TEC range of $47,000,000 to $96,000,000 and a preliminary TPC range of $50,000,000 to $99,000,000. These cost ranges encompass the most feasible preliminary alternatives at this time.

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 laboratory 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 space that allows needed collaboration in computational science, machine learning, artificial intelligence, exascale computing, data management, data acquisition, simulation, imaging, visualization, and modeling is 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. This project has a preliminary TEC range of $56,000,000 to $90,400,000 and a preliminary TPC range of $58,000,000 to $92,400,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The preliminary TEC point estimate for this project is $64,000,000 and the preliminary TPC point estimate for this project is $66,000,000.

20-SC-77, Argonne Utilities Upgrade, ANL
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-1, Approve Alternative Selection and Cost Range, was approved on July 1, 2021. The preliminary estimate for CD-2, Approve 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 Total Estimated Cost (TEC) range for this project is $172,000,000 to $290,300,000. The preliminary Total Project Cost (TPC) range for this project is $173,000,000 to $291,300,000. These cost ranges encompass the most feasible preliminary alternatives at this time.

20-SC-78, Linear Assets Modernization Project, LBNL
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 communications.

The most recent DOE Order 413.3B Critical Decision (CD) is CD-0, Approve Mission Need, was approved on May 17, 2019. The project's 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 Total Estimated Cost (TEC) range for this project is $164,000,000 to $376,000,000. The preliminary Total Project Cost (TPC) range for this project is $170,000,000 to $382,000,000. These cost ranges encompass the most feasible preliminary alternatives at this time.

20-SC-79, Critical Utilities Infrastructure Revitalization, SLAC
The primary objective of CUIR is to close infrastructure gaps to support multi-program science missions as technologies, instruments, experimental parameters, sensitivities, and complexity associated with evolving science demand increases required reliability, resiliency, and service levels in electrical, mechanical, and civil systems site wide. The CUIR project will address the critical campus-wide utility and infrastructure issues by replacing, repairing, and modernizing the highest risk water/fire protection, sanitary sewer, storm drain, electrical, and cooling water system deficiencies. Subject matter experts responsible for stewardship of the systems have identified these needs through condition assessments, inspections, and recommendations.

The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range, was approved on January 21, 2022. The preliminary estimate for CD-3A, Approve Long Lead Procurements, is anticipated in the second quarter of FY 2023. 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 $160,000,000 to $306,000,000. The preliminary Total Project Cost (TPC) range for this project is $164,500,000 to $310,500,000. These cost ranges encompass the most feasible preliminary alternatives at this time.

20-SC-80, Utilities Infrastructure Project, FNAL
The Utilities Infrastructure Project at FNAL will modernize 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 modernized 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-1, Approve Alternative Selection and Cost Range, was approved on February 23, 2022. The preliminary estimate for CD-2, Approve Performance Baseline, is anticipated in the second quarter of FY 2024. This project is pre-CD-2; therefore, schedule estimates are preliminary and subject to change. The current preliminary Total Estimated Cost (TEC) range for this project is $248,000,000 to $403,000,000 and the preliminary Total Project Cost (TPC) range of $252,000,000 to $407,000,000. These cost ranges encompass the most feasible preliminary alternatives at this time.

<u>19-SC-74, BioEPIC, LBNL</u>
The BioEPIC project will construct a new, state-of-the-art facility with laboratory space to support high performance research by the BER, ASCR and BES programs. LBNL has grown from a pioneering particle and nuclear physics laboratory into a multidisciplinary research facility with broad capabilities in physical, chemical, computational, biological, and environmental systems research in support of the DOE mission. Much of the biological sciences program at LBNL is located offsite and away from the main laboratory and other parts are dispersed across several locations on the LBNL campus. This arrangement has posed a challenge to research and operational capabilities limiting scientific progress and the kind of collaborative science that is required for understanding, predicting, and harnessing the Earth's microbiome for energy and environmental benefits.

The most recent DOE Order 413.3B Critical Decision (CD) is CD-1, CD-2/3, Approve Performance Baseline and Approve Start of Construction, was approved on September 13, 2021. The preliminary estimate for CD-4, Approve Start of Operations, is anticipated in the fourth quarter of FY 2027. The TEC point estimate for this project is $165,000,000 and the TPC point estimate for this project is $167,200,000.

Science Laboratories Infrastructure
Construction

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request		Explanation of Changes FY 2023 Request vs FY 2021 Enacted	
Construction	**$173,700**		**$208,350**		**+$34,650**
21-SC-71, Princeton Plasma Innovation Center, PPPL	$150		$10,000		+$9,850
Funding initiates Project Engineering and Design (PED) activities.		The Request will support ongoing PED activities and initiate construction activities.		Funding will support the continuation of PED activities for this project and initiate construction activities.	
21-SC-72, Critical Infrastructure Recovery & Renewal, PPPL	$150		$4,000		+$3,850
Funding initiates PED activities.		The Request will support ongoing PED activities and initiate construction and associated activities.		Funding will support the continuation of PED activities for this project and enable the initiation of construction and associated activities.	
21-SC-73, Ames Infrastructure Modernization	$150		$ —		-$150
Funding initiates PED activities.		No funding is requested for this project in FY 2023.		No funding is requested for this project in FY 2023.	

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
20-SC-71, Critical Utilities Rehabilitation Project, BNL	$20,000	$13,000	-$7,000
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	$2,000	$ —
Funding supports ongoing PED activities.		The Request will support ongoing PED and construction activities.	Funding will support ongoing PED and 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	$30,000	+$19,000
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	$ —	-$13,000
Funding supports ongoing construction activities.		Final funding for the project is requested in FY 2022.	Final funding for this project is requested in FY 2022.
20-SC-77, Argonne Utilities Upgrade, ANL	$500	$8,000	+$7,500
Funding supports ongoing PED activities.		The Request will support ongoing PED activities.	Funding will support ongoing PED activities for this project.

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
20-SC-78, Linear Assets Modernization Project, LBNL	$500	$23,425	+$22,925
Funding supports ongoing PED activities.		The Request will support ongoing PED activities and early construction activities.	Funding will support ongoing PED activities and the early construction activities for this project.
20-SC-79, Critical Utilities Infrastructure Revitalization, SLAC	$500	$25,425	+$24,925
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	$20,000	+$19,500
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.
19-SC-71, Science User Support Center, BNL	$20,000	$ —	-$20,000
Funding supports construction activities.		Final funding for this project is requested in FY 2022.	Final funding for this project is requested in FY 2022.
19-SC-73, Translational Research Capability, ORNL	$22,000	$ —	-$22,000
Funding supports construction activities.		Final funding for this project is requested in FY 2022.	Final funding for this project is requested in FY 2022.
19-SC-74, BioEPIC, LBNL	$20,000	$45,000	+$25,000
Funding supports construction activities.		The Request will support ongoing construction activities.	Funding will support ongoing construction activities for this project.

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
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.		Final funding for this project is requested in FY 2022.	Final funding for this project is requested in FY 2022.

Science Laboratories Infrastructure
Capital Summary

(dollars in thousands)

	Total	Prior Years	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Capital Operating Expenses						
Minor Construction Activities						
General Plant Projects	N/A	N/A	29,590	17,000	15,000	-14,590
Total, Capital Operating Expenses	**N/A**	**N/A**	**29,590**	**17,000**	**15,000**	**-14,590**

Science Laboratories Infrastructure
Minor Construction Activities

(dollars in thousands)

	Total	Prior Years	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
General Plant Projects (GPP)						
GPPs (greater than or equal to $5M and less than $20M)						
Welcome and Access Center at FNAL	12,500	–	1,000	11,500	–	-1,000
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	5,400	+5,400
Emergency Generator Upgrades, Phase 1 at LBNL	5,500	–	–	–	5,500	+5,500
Total GPPs (greater than or equal to $5M and less than $20M)	N/A	N/A	24,700	13,100	10,900	-13,800
Total GPPs less than $5M	N/A	N/A	4,890	3,900	4,100	-790
Total, General Plant Projects (GPP)	**N/A**	**N/A**	**29,590**	**17,000**	**15,000**	**-14,590**
Total, Minor Construction Activities	**N/A**	**N/A**	**29,590**	**17,000**	**15,000**	**-14,590**

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.*

Science Laboratories Infrastructure
Institutional General Plant Projects (IGPP)

(dollars in thousands)

	Total	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Institutional General Plant Projects (IGPP)					
IGPPs (greater than or equal to $5M and less than $20M)					
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
B/396, User Housing at BNL	19,500	—	19,500	—	—
Autonomous Discovery Lab Renovations at ANL	10,000	—	10,000	—	—
Low Vibration EMF Capability at ORNL	9,600	—	9,600	—	—
4500N Wing 1 Buildout at ORNL	9,000	—	9,000	—	—
Space Renovation Program - Bldg. 368	8,000	—	8,000	—	—
Multiprogram Office Bldg. #2 at ORNL	8,000	—	8,000	—	—
Campus Parking Areas at ORNL	5,000	—	5,000	—	—
Infrastructure Major Upgrades/Improvements at SLAC	8,000	—	8,000	—	—
Former B7 Tensile Structure Installation at LBNL	7,000	—	7,000	—	—
7625 Cooling Tower Replacement at ORNL	7,000	—	7,000	—	—

	(dollars in thousands)				
	Total	**FY 2021 Enacted**	**FY 2022 Annualized CR**	**FY 2023 Request**	**FY 2023 Request vs FY 2021 Enacted**
Space Renovation Programs - Bldg 368 at ANL	8,000	—	—	8,000	+8,000
B71 MEP Modernization at LBNL	13,000	—	—	13,000	+13,000
EGCR campus utilities at ORNL	9,000	—	—	9,000	+9,000
7667 LLW site improvements at ORNL	7,000	—	—	7,000	+7,000
Advanced Secure Communications New Build at PNNL	19,000	—	—	19,000	+19,000
300 Area Utilities Improvements at PNNL	11,000	—	—	11,000	+11,000
General Purpose Lab New Build at PNNL	13,000	—	—	13,000	+13,000
Richland North Office Building New Build at PNNL	13,000	—	—	13,000	+13,000
PNNL Richland Central Infrastructure at PNNL	6,000	—	—	6,000	+6,000
Total IGPPs (greater than or equal to $5M and less than $20M)	282,000	91,900	91,100	99,000	+7,100
Total IGPPs less than $5M	93,942	37,780	27,285	28,877	-8,903
Total, Institutional General Plant Projects (IGPP)	**381,942**	**129,680**	**118,385**	**133,877**	**+4,197**
Total, Minor Construction Activities	**463,032**	**159,270**	**135,385**	**168,377**	**+9,107**

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 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
22-SC-71, Critical Infrastructure Modernization Project, ORNL						
Total Estimated Cost (TEC)	403,329	–	–	1,000	–	–
Other Project Cost (OPC)	4,000	500	750	750	–	-750
Total Project Cost (TPC)	**407,329**	**500**	**750**	**1,750**	**–**	**-750**
22-SC-72, Thomas Jefferson Infrastructure Improvements, TJNAF						
Total Estimated Cost (TEC)	92,000	–	–	1,000	–	–
Other Project Cost (OPC)	1,000	–	1,000	–	–	-1,000
Total Project Cost (TPC)	**93,000**	**–**	**1,000**	**1,000**	**–**	**-1,000**
21-SC-71, Princeton Plasma Innovation Center, PPPL						
Total Estimated Cost (TEC)	96,300	–	150	900	10,000	+9,850
Other Project Cost (OPC)	1,840	1,410	90	–	–	-90
Total Project Cost (TPC)	**98,140**	**1,410**	**240**	**900**	**10,000**	**+9,760**
21-SC-72, Critical Infrastructure Recovery & Renewal, PPPL						
Total Estimated Cost (TEC)	87,300	–	150	2,000	4,000	+3,850
Other Project Cost (OPC)	1,700	1,052	300	–	–	-300
Total Project Cost (TPC)	**89,000**	**1,052**	**450**	**2,000**	**4,000**	**+3,550**
21-SC-73, Ames Infrastructure Modernization						
Total Estimated Cost (TEC)	26,000	–	150	2,000	–	-150
Other Project Cost (OPC)	1,075	75	200	225	–	-200
Total Project Cost (TPC)	**27,075**	**75**	**350**	**2,225**	**–**	**-350**

(dollars in thousands)

	Total	Prior Years	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 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	13,000	-7,000
Other Project Cost (OPC)	1,000	410	590	–	–	-590
Total Project Cost (TPC)	**93,000**	**20,410**	**20,590**	**26,000**	**13,000**	**-7,590**
20-SC-72, Seismic Safety and Infrastructure Upgrades, LBNL						
Total Estimated Cost (TEC)	95,400	10,000	5,000	27,500	27,500	+22,500
Other Project Cost (OPC)	2,200	1,070	–	–	–	–
Total Project Cost (TPC)	**97,600**	**11,070**	**5,000**	**27,500**	**27,500**	**+22,500**
20-SC-73, CEBAF Renovation and Expansion, TJNAF						
Total Estimated Cost (TEC)	87,000	2,000	2,000	10,000	2,000	–
Other Project Cost (OPC)	3,000	1,467	–	–	600	+600
Total Project Cost (TPC)	**90,000**	**3,467**	**2,000**	**10,000**	**2,600**	**+600**
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	850	–	–	–	–
Total Project Cost (TPC)	**41,000**	**15,850**	**25,000**	**–**	**–**	**-25,000**
20-SC-75, Large Scale Collaboration Center, SLAC						
Total Estimated Cost (TEC)	64,000	11,000	11,000	12,000	30,000	+19,000
Other Project Cost (OPC)	2,000	504	–	–	400	+400
Total Project Cost (TPC)	**66,000**	**11,504**	**11,000**	**12,000**	**30,400**	**+19,400**

(dollars in thousands)

	Total	Prior Years	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 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	–	-13,000
Other Project Cost (OPC)	1,000	900	100	–	–	-100
Total Project Cost (TPC)	**33,400**	**13,900**	**13,100**	**6,400**	**–**	**-13,100**
20-SC-77, Argonne Utilities Upgrade, ANL						
Total Estimated Cost (TEC)	215,000	500	500	500	8,000	+7,500
Other Project Cost (OPC)	1,000	700	300	–	–	-300
Total Project Cost (TPC)	**216,000**	**1,200**	**800**	**500**	**8,000**	**+7,200**
20-SC-78, Linear Assets Modernization Project, LBNL						
Total Estimated Cost (TEC)	236,000	500	500	500	23,425	+22,925
Other Project Cost (OPC)	4,980	673	1,230	500	–	-1,230
Total Project Cost (TPC)	**240,980**	**1,173**	**1,730**	**1,000**	**23,425**	**+21,695**
20-SC-79, Critical Utilities Infrastructure Revitalization, SLAC						
Total Estimated Cost (TEC)	204,000	500	500	500	25,425	+24,925
Other Project Cost (OPC)	3,928	323	1,000	–	–	-1,000
Total Project Cost (TPC)	**207,928**	**823**	**1,500**	**500**	**25,425**	**+23,925**
20-SC-80, Utilities Infrastructure Project, FNAL						
Total Estimated Cost (TEC)	310,000	500	500	500	20,000	+19,500
Other Project Cost (OPC)	4,930	1,500	1,530	500	–	-1,530
Total Project Cost (TPC)	**314,930**	**2,000**	**2,030**	**1,000**	**20,000**	**+17,970**
19-SC-71, Science User Support Center at BNL						
Total Estimated Cost (TEC)	85,000	27,000	20,000	38,000	–	-20,000
Other Project Cost (OPC)	1,200	1,200	–	–	–	–
Total Project Cost (TPC)	**86,200**	**28,200**	**20,000**	**38,000**	**–**	**-20,000**

(dollars in thousands)

	Total	Prior Years	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
19-SC-72, Electrical Capacity and Distribution Capability, ANL						
Total Estimated Cost (TEC)	60,000	60,000	–	–	–	–
Other Project Cost (OPC)	1,000	1,000	–	–	–	–
Total Project Cost (TPC)	**61,000**	**61,000**	**–**	**–**	**–**	**–**
19-SC-73, Translational Research Capacity, ORNL						
Total Estimated Cost (TEC)	93,500	50,000	22,000	21,500	–	-22,000
Other Project Cost (OPC)	1,500	1,400	–	–	–	–
Total Project Cost (TPC)	**95,000**	**51,400**	**22,000**	**21,500**	**–**	**-22,000**
19-SC-74, BioEPIC Building						
Total Estimated Cost (TEC)	165,000	20,000	20,000	35,000	45,000	+25,000
Other Project Cost (OPC)	2,200	1,536	–	–	–	–
Total Project Cost (TPC)	**167,200**	**21,536**	**20,000**	**35,000**	**45,000**	**+25,000**
18-SC-71, Energy Sciences Capability, PNNL						
Total Estimated Cost (TEC)	90,000	67,000	23,000	–	–	-23,000
Other Project Cost (OPC)	3,000	1,362	–	1,638	–	–
Total Project Cost (TPC)	**93,000**	**68,362**	**23,000**	**1,638**	**–**	**-23,000**
17-SC-71, Integrated Engineering Research Center at FNAL						
Total Estimated Cost (TEC)	85,000	64,500	10,250	10,250	–	-10,250
Other Project Cost (OPC)	1,000	950	–	50	–	–
Total Project Cost (TPC)	**86,000**	**65,450**	**10,250**	**10,300**	**–**	**-10,250**
Total, Construction						
Total Estimated Cost (TEC)	**N/A**	**N/A**	**173,700**	**195,550**	**208,350**	**+34,650**
Other Project Cost (OPC)	**N/A**	**N/A**	**7,090**	**3,663**	**1,000**	**-6,090**
Total Project Cost (TPC)	**N/A**	**N/A**	**180,790**	**199,213**	**209,350**	**+28,560**

Science Laboratories Infrastructure
Funding Summary

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Projects				
Line Item Construction (LIC)	173,700	191,550	208,350	+34,650
Total, Projects	**173,700**	**191,550**	**208,350**	**+34,650**
Other	66,300	48,450	46,650	-19,650
Total, Science Laboratories Infrastructure	**240,000**	**240,000**	**255,000**	**+15,000**

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 2023 Request for the Princeton Plasma Innovation Center (PPIC) project is $10,000,000 of Total Estimated Cost (TEC) funding. The 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 2023 funds will support Project Engineering and Design (PED) activities, long lead procurement, site preparation activities, and construction activities after the appropriate CD approvals.

A Federal Project Director 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
FY 2023	9/9/19	8/25/20	1/22/21	2Q FY 2024	2Q FY 2024	2Q FY 2024	N/A	1Q FY 2029

CD-0 – Approve Mission Need for a construction project with a conceptual scope and cost range
Conceptual Design Complete – Actual date the conceptual design was completed (if applicable)
CD-1 – Approve Alternative Selection and Cost Range
CD-2 – Approve Performance Baseline
Final Design Complete – Estimated/Actual date the project design will be/was complete(d)
CD-3 – Approve Start of Construction
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
FY 2023	2Q FY 2024	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	OPC, Total	TPC
FY 2021	9,000	100,000	109,000	2,500	2,500	111,500
FY 2022	8,900	87,400	96,300	2,200	2,200	98,500
FY 2023	8,900	87,400	96,300	2,200	2,200	98,500

Notes:
- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*
- *Other Project Costs (OPC) are funded through laboratory overhead.*

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

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.*

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	–
FY 2022	900	900	–
FY 2023	7,850	7,850	6,000
Outyears	–	–	2,900
Total, Design (TEC)	**8,900**	**8,900**	**8,900**
Construction (TEC)			
FY 2023	2,150	2,150	–
Outyears	85,250	85,250	87,400
Total, Construction (TEC)	**87,400**	**87,400**	**87,400**
Total Estimated Cost (TEC)			
FY 2021	150	150	–
FY 2022	900	900	–
FY 2023	10,000	10,000	6,000
Outyears	85,250	85,250	90,300
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	450	450	450
Outyears	340	340	340
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	600	600	450
FY 2022	900	900	–
FY 2023	10,000	10,000	6,000
Outyears	85,590	85,590	90,640
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	7,900	**N/A**
Design - Contingency	1,000	1,000	**N/A**
Total, Design (TEC)	**8,900**	**8,900**	**N/A**
Construction	72,000	72,000	**N/A**
Construction - Contingency	15,400	15,400	**N/A**
Total, Construction (TEC)	**87,400**	**87,400**	**N/A**
Total, TEC	**96,300**	**96,300**	**N/A**
Contingency, TEC	*16,400*	*16,400*	***N/A***
Other Project Cost (OPC)			
Conceptual Planning	300	300	**N/A**
Conceptual Design	1,700	1,700	**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	**98,500**	**98,500**	**N/A**
Total, Contingency (TEC+OPC)	***16,600***	***16,600***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Fiscal Year	Type	Prior Years	FY 2021	FY 2022	FY 2023	Outyears	Total
FY 2021	TEC	—	2,000	—	—	107,000	109,000
	OPC	2,300	—	—	—	200	2,500
	TPC	2,300	2,000	—	—	107,200	111,500
FY 2022	TEC	—	150	7,750	—	88,400	96,300
	OPC	1,410	90	—	—	700	2,200
	TPC	1,410	240	7,750	—	89,100	98,500
FY 2023	TEC	—	150	900	10,000	85,250	96,300
	OPC	1,410	450	—	—	340	2,200
	TPC	1,410	600	900	10,000	85,590	98,500

Notes:
- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*
- *Other Project Costs (OPC) are funded through laboratory overhead.*

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	1Q FY 2029
Expected Useful Life	50 years
Expected Future Start of D&D of this capital asset	1Q FY 2079

Related Funding Requirements
(dollars in thousands)

	Annual Costs		Life Cycle Costs[ggg]	
	Previous Total Estimate	**Current Total Estimate**	**Previous Total Estimate**	**Current Total Estimate**
Operations	1,336	1,336	46,774	46,774
Utilities	198	198	6,936	6,936
Maintenance and Repair	1,518	1,518	53,154	53,154
Total, Operations and Maintenance	3,052	3,052	106,864	106,864

[ggg] Life-Cycle costs will be performed as part of CD-1.

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[hhh]
Area of D&D in this project at other sites	None
Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked"	None
Total area eliminated	13,400

8. Acquisition Approach

The PPPL Management and Operating (M&O) Contractor, Princeton University, is performing 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.

[hhh] With the implementation of OMB's Reduce the Footprint initiative, DOE no longer maintains the space bank. Footprint is managed using the Facility Information Management System, with decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

21-SC-72, Critical Infrastructure Recovery & Renewal, PPPL
Princeton Plasma Physics Laboratory
Project is for Design and Construction

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

Summary

The FY 2023 Request for the Critical Infrastructure Recovery & Renewal (CIRR) project is $4,000,000 of Total Estimated Cost (TEC) funding. The preliminary TEC range for this project is $80,100,000 to $96,000,000. The preliminary Total Project Cost (TPC) range for this project is $81,800,000 to $97,700,000. 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) increasingly unreliable, non-redundant, utility infrastructure is negatively impacting 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 a new start in the FY 2021 Request. 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 2023 funds will continue Project Engineering and Design (PED) activities.

A Federal Project Director with the appropriate certification level was assigned to this project at 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	2Q FY 2021	2/23/21	3Q FY 2024	1Q FY 2024	3Q FY 2024	N/A	4Q FY 2029
FY 2023	9/16/19	2/23/21	2/23/21	3Q FY 2024	2Q FY 2024	3Q 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 2022	1Q FY 2023
FY 2022	3Q FY 2024	3Q FY 2023
FY 2023	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	OPC, Total	TPC
FY 2021	8,000	72,400	80,400	1,500	1,500	81,900
FY 2022	9,800	77,300	87,100	1,900	1,900	89,000
FY 2023	9,950	77,350	87,300	1,700	1,700	89,000

Notes:
- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*
- *Other Project Costs (OPC) are funded through laboratory overhead.*

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. To maintain system operability, it is essential to have reliable infrastructure in place. The current systems are 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 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 maintenance requirements, 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 will generate 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 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
▪ Chilled Water Generation	▪ Improve configuration and efficiency of the Central Chilled Water Plant to ensure distribution of 1,200 tons of cooling capacity to the site.	▪ N/A
▪ Communications Distribution Network	▪ 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 PU Computer Center. ▪ Provide 15,000 linear feet of 24 strand fiber optic cable to support site wide communication.	▪ Threshold plus upgrade additional communication system components to improve security, reliability, and flexibility.
▪ Electrical Distribution & Standby Power	▪ 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.	▪ 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.
▪ HVAC Systems	▪ Upgrade 8 HVAC system equipment for priority buildings on C-Site and D-Site.	▪ Upgrade up to 14 HVAC system equipment for additional buildings to meet sustainability goals and improve maintenance and operations.
▪ Underground Distribution Network	▪ 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 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	–
FY 2022	2,000	2,000	1,000
FY 2023	4,000	4,000	4,000
Outyears	3,800	3,800	4,950
Total, Design (TEC)	**9,950**	**9,950**	**9,950**
Construction (TEC)			
Outyears	77,350	77,350	77,350
Total, Construction (TEC)	**77,350**	**77,350**	**77,350**
Total Estimated Cost (TEC)			
FY 2021	150	150	–
FY 2022	2,000	2,000	1,000
FY 2023	4,000	4,000	4,000
Outyears	81,150	81,150	82,300
Total, TEC	**87,300**	**87,300**	**87,300**

(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	348	348	348
Total, OPC	**1,700**	**1,700**	**1,700**

(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	300
FY 2022	2,000	2,000	1,000
FY 2023	4,000	4,000	4,000
Outyears	81,498	81,498	82,648
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	7,600	**N/A**
Design - Contingency	2,350	2,200	**N/A**
Total, Design (TEC)	**9,950**	**9,800**	**N/A**
Construction	59,500	59,400	**N/A**
Construction - Contingency	17,850	17,900	**N/A**
Total, Construction (TEC)	**77,350**	**77,300**	**N/A**
Total, TEC	**87,300**	**87,100**	**N/A**
Contingency, TEC	*20,200*	*20,100*	***N/A***
Other Project Cost (OPC)			
Conceptual Planning	200	200	**N/A**
Conceptual Design	1,300	1,500	**N/A**
OPC - Contingency	200	200	**N/A**
Total, Except D&D (OPC)	**1,700**	**1,900**	**N/A**
Total, OPC	**1,700**	**1,900**	**N/A**
Contingency, OPC	*200*	*200*	***N/A***
Total, TPC	**89,000**	**89,000**	**N/A**
Total, Contingency (TEC+OPC)	***20,400***	***20,300***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Fiscal Year	Type	Prior Years	FY 2021	FY 2022	FY 2023	Outyears	Total
FY 2021	TEC	—	2,000	—	—	78,400	80,400
	OPC	1,300	—	—	—	200	1,500
	TPC	1,300	2,000	—	—	78,600	81,900
FY 2022	TEC	—	150	2,000	—	84,950	87,100
	OPC	1,052	300	—	—	548	1,900
	TPC	1,052	450	2,000	—	85,498	89,000
FY 2023	TEC	—	150	2,000	4,000	81,150	87,300
	OPC	1,052	300	—	—	348	1,700
	TPC	1,052	450	2,000	4,000	81,498	89,000

Notes:
- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*
- *Other Project Costs (OPC) are funded through laboratory overhead.*

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	N/A

Related Funding Requirements
(dollars in thousands)

	Annual Costs		Life Cycle Costs[iii]	
	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

[iii] Life-Cycle costs will be performed as part of CD-1.

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[jjj]
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.

[jjj] With the implementation of OMB's Reduce the Footprint initiative, DOE no longer maintains the space bank. Footprint is managed using the Facility Information Management System, with decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

20-SC-71, Critical Utilities Rehabilitation Project, BNL
Brookhaven National Laboratory
Project is for Design and Construction

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

Summary

The FY 2023 Request for the Critical Utilities Rehabilitation Project (CURP) is $13,000,000 of Total Estimated Cost (TEC) funding. The preliminary 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. The project will address the most critical vulnerabilities and assure reliable and stable utility services to mission critical facilities. By replacing failure-prone and inefficient equipment the utility systems will be revitalized and made more efficient.

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 is constructing long lead procurements in accordance with the approved CD-3A scope. FY 2023 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
FY 2023	7/20/18	8/16/19	2/6/20	3Q FY 2022	4Q FY 2023	3Q 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
FY 2023	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	OPC, Total	TPC
FY 2020	8,500	76,500	85,000	800	800	85,800
FY 2021	7,100	84,900	92,000	800	800	92,800
FY 2022	10,400	81,600	92,000	1,000	1,000	93,000
FY 2023	10,400	81,600	92,000	1,000	1,000	93,000

Notes:
- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*
- *Other Project Costs (OPC) are funded through laboratory overhead.*

2. Project Scope and Justification

Scope

CURP's scope is to revitalize and upgrade the 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. Also, older feeder cables and inadequate breakers will be replaced to 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. For example, a June 2021 failure of a condensate pipe in the steam system will require approximately $3.2 million of repairs as part of the

CURP project. 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.*

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

Performance Measure	Threshold	Objective
	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
FY 2023	–	–	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	13,000
FY 2023	13,000	13,000	26,000
Outyears	13,000	13,000	42,311
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	20,190
FY 2023	13,000	13,000	28,470
Outyears	13,000	13,000	42,311
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	20,190
FY 2023	13,000	13,000	28,470
Outyears	13,000	13,000	42,311
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	8,320	**N/A**
Design - Contingency	2,080	2,080	**N/A**
Total, Design (TEC)	**10,400**	**10,400**	**N/A**
Construction	65,280	65,280	**N/A**
Construction - Contingency	16,320	16,320	**N/A**
Total, Construction (TEC)	**81,600**	**81,600**	**N/A**
Total, TEC	**92,000**	**92,000**	**N/A**
Contingency, TEC	*18,400*	*18,400*	***N/A***
Other Project Cost (OPC)			
Conceptual Design	1,000	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	**93,000**	**93,000**	**N/A**
Total, Contingency (TEC+OPC)	***18,400***	***18,400***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Fiscal Year	Type	Prior Years	FY 2021	FY 2022	FY 2023	Outyears	Total
FY 2020	TEC	12,000	—	—	—	73,000	85,000
	OPC	800	—	—	—	—	800
	TPC	12,800	—	—	—	73,000	85,800
FY 2021	TEC	20,000	15,000	—	—	57,000	92,000
	OPC	800	—	—	—	—	800
	TPC	20,800	15,000	—	—	57,000	92,800
FY 2022	TEC	20,000	20,000	26,000	—	26,000	92,000
	OPC	410	590	—	—	—	1,000
	TPC	20,410	20,590	26,000	—	26,000	93,000
FY 2023	TEC	20,000	20,000	26,000	13,000	13,000	92,000
	OPC	410	590	—	—	—	1,000
	TPC	20,410	20,590	26,000	13,000	13,000	93,000

Notes:
- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*
- *Other Project Costs (OPC) are funded through laboratory overhead.*

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	4Q FY 2025
Expected Useful Life	Varies by System
Expected Future Start of D&D of this capital asset	4Q FY 2025

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[kkk]
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. 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.

[kkk] 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-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 2023 Request for the Seismic and Safety Modernization (SSM) project is $27,500,000 of Total Estimated Cost (TEC) funding. The 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 2023 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) 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
FY 2023	9/6/18	6/17/19	9/4/19	1Q FY 2023	1Q FY 2023	1Q FY 2023	N/A	1Q FY 2027

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

Fiscal Year	Performance Baseline Validation	CD-3A
FY 2020	4Q FY 2021	N/A
FY 2021	3Q FY 2021	3Q FY 2021
FY 2022	1Q FY 2022	1Q FY 2022
FY 2023	1Q FY 2023	1Q FY 2023

CD-3A – Approve Long-Lead Procurement and Site Preparation Activities

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D	OPC, Total	TPC
FY 2020	10,000	85,400	95,400	2,200	2,200	97,600
FY 2021	10,000	85,400	95,400	2,200	2,200	97,600
FY 2022	9,000	86,400	95,400	2,200	2,200	97,600
FY 2023	9,000	86,400	95,400	2,200	2,200	97,600

Notes:

- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*
- *Other Project Costs (OPC) are funded through laboratory overhead.*

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*.

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	5,000
FY 2023	27,500	27,500	35,000
Outyears	25,400	25,400	46,400
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	6,000
FY 2023	27,500	27,500	35,000
Outyears	25,400	25,400	46,400
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	6,000
FY 2023	27,500	27,500	35,000
Outyears	26,530	26,530	47,530
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	700	**N/A**
Total, Design (TEC)	**9,000**	**9,000**	**N/A**
Construction	71,400	71,400	**N/A**
Construction - Contingency	15,000	15,000	**N/A**
Total, Construction (TEC)	**86,400**	**86,400**	**N/A**
Total, TEC	**95,400**	**95,400**	**N/A**
Contingency, TEC	*15,700*	*15,700*	***N/A***
Other Project Cost (OPC)			
Conceptual Planning	200	200	**N/A**
Conceptual Design	1,800	1,800	**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***	***15,900***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Fiscal Year	Type	Prior Years	FY 2021	FY 2022	FY 2023	Outyears	Total
FY 2020	TEC	5,000	—	—	—	90,400	95,400
	OPC	1,500	—	—	—	700	2,200
	TPC	6,500	—	—	—	91,100	97,600
FY 2021	TEC	10,000	10,000	—	—	75,400	95,400
	OPC	1,600	—	—	—	600	2,200
	TPC	11,600	10,000	—	—	76,000	97,600
FY 2022	TEC	10,000	5,000	27,500	—	52,900	95,400
	OPC	1,070	—	—	—	1,130	2,200
	TPC	11,070	5,000	27,500	—	54,030	97,600
FY 2023	TEC	10,000	5,000	27,500	27,500	25,400	95,400
	OPC	1,070	—	—	—	1,130	2,200
	TPC	11,070	5,000	27,500	27,500	26,530	97,600

Notes:
- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*
- *Other Project Costs (OPC) are funded through laboratory overhead.*

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	1Q 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	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[lll]
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, is performing 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.

[lll] 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 2023 Request for the Continuous Electron Beam Accelerator Facility (CEBAF) Renovation and Expansion (CRE) project is $2,000,000. The preliminary Total Estimated Cost (TEC) range for this project is $47,000,000 to $96,000,000. The preliminary Total Project Cost (TPC) range for this project is $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 131,000 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 2023 funds will support Project Engineering and Design (PED) activities, and 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	1Q FY 2020	4Q FY 2020	3Q FY 2021	4Q FY 2021	N/A	4Q FY 2026
FY 2022	7/20/18	4Q FY 2019	3/18/19	1Q FY 2022	3Q FY 2022	4Q FY 2022	N/A	4Q FY 2029
FY 2023	7/20/18	10/16/19	3/18/19	4Q FY 2022	3Q FY 2022	4Q FY 2023	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	4Q FY 2020	4Q FY 2021
FY 2021	4Q FY 2020	4Q FY 2020	4Q FY 2021
FY 2022	1Q FY 2022	1Q FY 2022	N/A
FY 2023	4Q FY 2022	4Q 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	OPC, Total	TPC
FY 2020	4,200	61,800	66,000	435	435	66,435
FY 2021	5,000	82,000	87,000	2,300	2,300	89,300
FY 2022	8,000	79,000	87,000	3,000	3,000	90,000
FY 2023	5,000	82,000	87,000	3,000	3,000	90,000

Notes:
- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*
- *Other Project Costs (OPC) are funded through laboratory overhead.*

2. Project Scope and Justification

Scope

The scope of the CRE project will include renovating 131,000 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.

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	57,000 gsf
ARC Renovation	65,000 gsf	122,000 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	2,000	2,000	3,233
FY 2023	1,000	1,000	1,728
Total, Design (TEC)	**5,000**	**5,000**	**5,000**
Construction (TEC)			
FY 2022	10,000	10,000	4,000
FY 2023	1,000	1,000	4,000
Outyears	71,000	71,000	74,000
Total, Construction (TEC)	**82,000**	**82,000**	**82,000**
Total Estimated Cost (TEC)			
FY 2020	2,000	2,000	39
FY 2021	2,000	2,000	3,233
FY 2022	10,000	10,000	4,000
FY 2023	2,000	2,000	5,728
Outyears	71,000	71,000	74,000
Total, TEC	**87,000**	**87,000**	**87,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Other Project Cost (OPC)			
FY 2019	878	878	878
FY 2020	589	589	589
FY 2023	600	600	600
Outyears	933	933	933
Total, OPC	**3,000**	**3,000**	**3,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Project Cost (TPC)			
FY 2019	878	878	878
FY 2020	2,589	2,589	628
FY 2021	2,000	2,000	3,233
FY 2022	10,000	10,000	4,000
FY 2023	2,600	2,600	6,328
Outyears	71,933	71,933	74,933
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	3,500	6,500	**N/A**
Design - Contingency	1,500	1,500	**N/A**
Total, Design (TEC)	**5,000**	**8,000**	**N/A**
Construction	65,000	62,000	**N/A**
Construction - Contingency	17,000	17,000	**N/A**
Total, Construction (TEC)	**82,000**	**79,000**	**N/A**
Total, TEC	**87,000**	**87,000**	**N/A**
Contingency, TEC	*18,500*	*18,500*	***N/A***
Other Project Cost (OPC)			
Conceptual Planning	2,400	2,400	**N/A**
Conceptual Design	400	400	**N/A**
OPC - Contingency	200	200	**N/A**
Total, Except D&D (OPC)	**3,000**	**3,000**	**N/A**
Total, OPC	**3,000**	**3,000**	**N/A**
Contingency, OPC	*200*	*200*	***N/A***
Total, TPC	**90,000**	**90,000**	**N/A**
Total, Contingency (TEC+OPC)	***18,700***	***18,700***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Fiscal Year	Type	Prior Years	FY 2021	FY 2022	FY 2023	Outyears	Total
FY 2020	TEC	2,000	—	—	—	64,000	66,000
	OPC	20	—	—	—	415	435
	TPC	2,020	—	—	—	64,415	66,435
FY 2021	TEC	2,000	2,000	—	—	83,000	87,000
	OPC	1,700	—	—	—	600	2,300
	TPC	3,700	2,000	—	—	83,600	89,300
FY 2022	TEC	2,000	2,000	10,000	—	73,000	87,000
	OPC	1,467	—	—	—	1,533	3,000
	TPC	3,467	2,000	10,000	—	74,533	90,000
FY 2023	TEC	2,000	2,000	10,000	2,000	71,000	87,000
	OPC	1,467	—	—	600	933	3,000
	TPC	3,467	2,000	10,000	2,600	71,933	90,000

Notes:
- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*
- *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	4Q FY 2079

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[mmm]
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 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.

[mmm] With the implementation of OMB's Reduce the Footprint initiative, DOE no longer maintains the space bank. Footprint is managed using the Facility Information Management System, with decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

20-SC-75, Large Scale Collaboration Center, SLAC
SLAC National Accelerator Laboratory
Project is for Design and Construction

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

Summary

The FY 2023 Request for the Large Scale Collaboration Center (LSCC) is $30,000,000 of Total Estimated Cost (TEC) funding. The preliminary 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 2023 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	3Q FY 2022	1Q FY 2023	3Q FY 2022	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
FY 2023	7/20/18	8/15/19	11/18/19	3Q FY 2022	1Q FY 2023	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	–
FY 2021	TBD	1Q FY 2020	1Q FY 2023
FY 2022	3Q FY 2022	N/A	N/A
FY 2023	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	OPC, Total	TPC
FY 2020	6,000	54,000	60,000	1,000	1,000	61,000
FY 2021	9,000	55,000	64,000	2,000	2,000	66,000
FY 2022	11,000	53,000	64,000	2,000	2,000	66,000
FY 2023	11,000	53,000	64,000	2,000	2,000	66,000

Notes:
- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*
- *Other Project Costs (OPC) are funded through laboratory overhead.*

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-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 which will enable the lab to improve the ability to co-locate 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
FY 2023	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
FY 2023	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
FY 2023	400	400	400
Outyears	1,096	1,096	1,096
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
FY 2023	30,400	30,400	40,400
Outyears	1,096	1,096	1,096
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	8,800	**N/A**
Design - Contingency	2,200	2,200	**N/A**
Total, Design (TEC)	**11,000**	**11,000**	**N/A**
Construction	42,400	42,400	**N/A**
Construction - Contingency	10,600	10,600	**N/A**
Total, Construction (TEC)	**53,000**	**53,000**	**N/A**
Total, TEC	**64,000**	**64,000**	**N/A**
Contingency, TEC	*12,800*	*12,800*	***N/A***
Other Project Cost (OPC)			
Conceptual Design	2,000	2,000	**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***	*N/A*	***N/A***
Total, TPC	**66,000**	**66,000**	**N/A**
Total, Contingency (TEC+OPC)	***12,800***	***12,800***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Fiscal Year	Type	Prior Years	FY 2021	FY 2022	FY 2023	Outyears	Total
FY 2020	TEC	3,000	—	—	—	57,000	60,000
	OPC	700	—	—	—	300	1,000
	TPC	3,700	—	—	—	57,300	61,000
FY 2021	TEC	11,000	8,000	—	—	45,000	64,000
	OPC	700	1,300	—	—	—	2,000
	TPC	11,700	9,300	—	—	45,000	66,000
FY 2022	TEC	11,000	11,000	12,000	—	30,000	64,000
	OPC	504	—	—	—	1,496	2,000
	TPC	11,504	11,000	12,000	—	31,496	66,000
FY 2023	TEC	11,000	11,000	12,000	30,000	—	64,000
	OPC	504	—	—	400	1,096	2,000
	TPC	11,504	11,000	12,000	30,400	1,096	66,000

Notes:
- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*
- *Other Project Costs (OPC) are funded through laboratory overhead.*

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	4Q FY 2027
Expected Useful Life	50 years
Expected Future Start of D&D of this capital asset	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 Laboratory	34,000-45,000
Area of D&D in this project at SLAC National Laboratory	8,260
Area at SLAC National Laboratory to be transferred, sold, and/or D&D outside the project, including area previously "banked"	None[nnn]
Area of D&D in this project at other sites	None
Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked"	None
Total area eliminated	None

8. Acquisition Approach

The SLAC Management and Operating (M&O) contractor, Stanford University, will perform the acquisition for this project, overseen by the Bay Area Site Office. The M&O contractor is responsible for awarding and managing all subcontracts related to this project. Various acquisition alternatives were considered for this project, such as traditional design-bid-build, design-build, and construction manager/general contractor. After considering these alternatives in relation to the schedule, size, and risk, the design-build approach was selected. The M&O contractor's annual performance evaluation and measurement plan will include project performance metrics on which it will be evaluated.

[nnn] 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 2023 Request for the Argonne Utilities Upgrade (AU2) project is $8,000,000 of Total Estimated Cost (TEC) funding. The preliminary TEC range for this project is $172,000,000 to $290,300,000. The preliminary Total Project Cost (TPC) range for this project is $173,000,000 to $291,300,000. 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 2023 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	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	11/30/20	3Q FY 2021	4Q FY 2023	2Q FY 2024	4Q FY 2024	N/A	4Q FY 2033
FY 2023	5/17/19	10/30/20	7/1/21	3Q FY 2024	4Q FY 2025	4Q FY 2025	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	2Q FY 2024	N/A
FY 2023	3Q FY 2024	N/A

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	OPC, Total	TPC
FY 2021	37,500	177,500	215,000	1,000	1,000	216,000
FY 2022	37,500	177,500	215,000	1,000	1,000	216,000
FY 2023	37,500	177,500	215,000	1,000	1,000	216,000

Notes:
- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*
- *Other Project Costs (OPC) are funded through laboratory overhead.*

2. Project Scope and Justification

Scope

The preliminary scope of the AU2 project 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; improving the resilience of this plant would prevent 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

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	500	500	500
FY 2023	8,000	8,000	8,000
Outyears	28,000	28,000	28,500
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	500	500	500
FY 2023	8,000	8,000	8,000
Outyears	205,500	205,500	206,000
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	500	500	500
FY 2023	8,000	8,000	8,000
Outyears	205,500	205,500	206,000
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	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)

Fiscal Year	Type	Prior Years	FY 2021	FY 2022	FY 2023	Outyears	Total
FY 2021	TEC	500	2,000	—	—	212,500	215,000
	OPC	700	300	—	—	—	1,000
	TPC	1,200	2,300	—	—	212,500	216,000
FY 2022	TEC	500	500	10,000	—	204,000	215,000
	OPC	700	300	—	—	—	1,000
	TPC	1,200	800	10,000	—	204,000	216,000
FY 2023	TEC	500	500	500	8,000	205,500	215,000
	OPC	700	300	—	—	—	1,000
	TPC	1,200	800	500	8,000	205,500	216,000

Notes:
- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*
- *Other Project Costs (OPC) are funded through laboratory overhead.*

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	N/A
Expected Useful Life	N/A
Expected Future Start of D&D of this capital asset	N/A

Related Funding Requirements
(dollars in thousands)

	Annual Costs		Life Cycle Costs[ooo]	
	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

[ooo] Life-Cycle costs will be performed as part of CD-1.

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[ppp]
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.

[ppp] 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 2023 Request for the Linear Assets Modernization Project (LAMP) is $23,425,000 of Total Estimated Cost (TEC) funding. The preliminary TEC range for this project is $164,000,000 to $376,000,000. The preliminary Total Project Cost (TPC) range for this project is $170,000,000 to $382,000,000. Currently, these cost ranges encompass the most feasible preliminary alternatives. The preliminary TPC estimate for this project is $242,000,000.

LAMP will upgrade high priority utility systems to increase the reliability, capability, resilience, 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 2023 funds will support Project Engineering and Design (PED) activities and will initiate long-lead procurement activities after the appropriate CD approval. CD-1, Approve Alternative Selection and Cost Range" was scheduled for March 17, 2022, but needed to be rescheduled due to Project Management Executive availability.

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
FY 2023	5/17/19	11/1/21	2Q FY 2022	4Q FY 2025	2Q FY 2024	4Q FY 2025	N/A	1Q 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 2021	4Q FY 2021	1Q FY 2021
FY 2022	1Q FY 2023	3Q FY 2022
FY 2023	4Q FY 2025	3Q FY 2025

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	OPC, Total	TPC
FY 2021	48,000	188,000	236,000	3,700	3,700	239,700
FY 2022	23,500	212,500	236,000	4,000	4,000	240,000
FY 2023	50,000	186,000	236,000	6,000	6,000	242,000

Notes:
- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*
- *Other Project Costs (OPC) are funded through laboratory overhead.*

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 to power the National Energy Research Scientific Computing Center (NERSC) to full capacity. 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, 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 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 sub-project of the LAMP project will enable an optimized NERSC-10 upgrade which will play a central role in breakthrough science in the climate arena.

LAMP will deliver significantly more modern and resilient general-purpose infrastructure. The combination of data collection and artificial intelligent monitoring systems will enable the systems to adjust to trends, predict maintenance requirements, 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, 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.

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 project is currently pre-CD-1 so 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.

<table>
<tr><th>Performance Measure</th><th>Threshold</th><th>Objective</th></tr>
<tr><td rowspan="2">Storm Drainage System, Hydrauger/ Slope Stability</td><td rowspan="2">Install 1,000 Linear Feet of hydraugers.</td><td>Install up to 2,500 Linear Feet of hydraugers. (Lawrence Corridor)</td></tr>
<tr><td>Install up to 3,000 Linear Feet of hydraugers. (East Canyon/McMillan Corridor)</td></tr>
<tr><td rowspan="3">Sanitary Sewer</td><td rowspan="3">Install 150 Linear Feet of pipe.</td><td>Install up to 2,500 Linear Feet of pipe. (Lawrence Corridor)</td></tr>
<tr><td>Install up to 3,500 Linear Feet of pipe. (McMillan Corridor)</td></tr>
<tr><td>Install up to 1,000 Linear Feet of pipe along the electrical distribution loop corridors. (McMillan Corridor)</td></tr>
<tr><td rowspan="2">High Pressure City Water</td><td rowspan="2">Install 1,500 Linear Feet of pipe.</td><td>Install up to 3,500 Linear Feet of pipe. (East Canyon Corridor)</td></tr>
<tr><td>Install up to 2,000 Linear Feet of pipe along the electrical distribution loop corridors. (McMillan Corridor)</td></tr>
</table>

Performance Measure	Threshold	Objective
Communications & Data	Install 2,600 Linear Feet of ductbank.	Install up to 4,000 Linear Feet of ductbank with manholes and cables. (Lawrence Corridor)
		Install up to 2,500 Linear Feet of ductbank with manholes and cables. (East Canyon Corridor)
		Install up to 1,500 Linear Feet of ductbank with manholes and cables along the electrical distribution loop corridors. (East Canyon Corridor)
		Install up to 1,500 Linear Feet of ductbank with manholes and cables. (McMillan Corridor)
		Install up to 5,000 Linear Feet of ductbank with manholes and cables along the electrical distribution loop corridors. (McMillan Corridor)
Electrical Distribution/Grizzly Substation	Expand the Grizzly Substation to 70 MW capacity.	Expand the Grizzly Substation up to 150 MW capacity with two redundant lines with SCADA for new equipment.
		Provide a new SCADA Control Building.
		Provide two remote SCADA Control Rooms.
		Provide SCADA remote control and monitoring of existing and new circuit breakers.
		Install up to 400 Linear Feet of electrical feeders segregating lines 1 and 2 for SW-A1.
		Install SCADA for existing 115kV equipment.
	Install 1,500 Linear Feet of electrical feeders segregating lines 1 and 2. (Lawrence Corridor)	Install up to 3,500 Linear Feet of electrical feeders segregating lines 1 and 2.
		Feed B59 (NERSC) with up to 80 MW of electrical power with 3,500 Linear Feet of redundant and segregated lines.
		Install up to 2,000 Linear Feet of electrical feeders and Pad Mounted Switches for electrical distribution loops, segregating lines 1 and 2.
		Provide SCADA remote control and monitoring of existing and new circuit breakers.
	Install 1,200 Linear Feet of electrical feeders segregating lines 1 and 2. (East Canyon/McMillan Corridor) (Con't)	Install up to 2,600 Linear Feet of electrical feeders segregating lines 1 and 2. (East Canyon Corridor)
		Install up to 5,700 Linear Feet of electrical feeders and Pad Mounted Switches for electrical distribution loops, segregating lines 1 and 2. (East Canyon Corridor)
		Provide SCADA remote control and monitoring of existing and new circuit breakers. (East Canyon Corridor)

Performance Measure	Threshold	Objective
Electrical Distribution/Grizzly Substation (Con't)	Install 1,200 Linear Feet of electrical feeders segregating lines 1 and 2. (East Canyon/McMillan Corridor) (Con't)	Install up to 2,200 Linear Feet of electrical feeders segregating lines 1 and 2. (McMillan Corridor)
		Install up to 6,300 Linear Feet of electrical feeders and Pad Mounted Switches for electrical distribution loops, segregating lines 1 and 2. (McMillan Corridor)
		Provide SCADA remote control and monitoring of existing and new circuit breakers. (McMillan Corridor)
Natural Gas	Install 200 Linear Feet of pipe.	Install up to 1,000 Linear Feet of pipe. (Lawrence Corridor)
		Install up to 2,500 Linear Feet of pipe. (McMillan Corridor)
		Install up to 2,000 Linear Feet of pipe along the electrical distribution loop corridors. (McMillan Corridor)
Compressed Air	*Not Applicable*	Install up to 3,500 Linear Feet of pipe. (Lawrence Corridor)
		Install up to 3,500 Linear Feet of pipe. (East Canyon Corridor)
		Install up to 2,500 Linear Feet of pipe. (McMillan Corridor)
		Install up to 1,500 Linear Feet of pipe along the electrical distribution loop corridors. (McMillan Corridor)

Performance Measure	Threshold	Objective
Controls/Artificial Intelligence	*Not Applicable*	Install up to 40 Smart Meters for new wet utility construction. (Lawrence Corridor)
		Provide integration with SCADA. (Lawrence Corridor)
		Provide integration with Microgrid enhancement. (Lawrence Corridor)
		Install up to 60 Smart Meters for new wet utility construction. (East Canyon Corridor)
		Install up to 50 Smart Meters for new wet utility construction. (McMillan Corridor)
		Provide integration with SCADA. (East Canyon/McMillan Corridors)
		Provide integration with Microgrid enhancement. (East Canyon/McMillan 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	500	500	1,000
FY 2023	23,425	23,425	15,000
Outyears	25,075	25,075	34,000
Total, Design (TEC)	**50,000**	**50,000**	**50,000**
Construction (TEC)			
Outyears	186,000	186,000	186,000
Total, Construction (TEC)	**186,000**	**186,000**	**186,000**
Total Estimated Cost (TEC)			
FY 2020	500	500	–
FY 2021	500	500	–
FY 2022	500	500	1,000
FY 2023	23,425	23,425	15,000
Outyears	211,075	211,075	220,000
Total, TEC	**236,000**	**236,000**	**236,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Other Project Cost (OPC)			
FY 2019	173	173	173
FY 2020	500	500	500
FY 2021	1,750	1,750	1,750
FY 2022	1,000	1,000	1,000
Outyears	2,577	2,577	2,577
Total, OPC	**6,000**	**6,000**	**6,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Project Cost (TPC)			
FY 2019	173	173	173
FY 2020	1,000	1,000	500
FY 2021	2,250	2,250	1,750
FY 2022	1,500	1,500	2,000
FY 2023	23,425	23,425	15,000
Outyears	213,652	213,652	222,577
Total, TPC	**242,000**	**242,000**	**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	49,000	19,500	**N/A**
Design - Contingency	1,000	4,000	**N/A**
Total, Design (TEC)	**50,000**	**23,500**	**N/A**
Construction	135,000	162,500	**N/A**
Construction - Contingency	51,000	50,000	**N/A**
Total, Construction (TEC)	**186,000**	**212,500**	**N/A**
Total, TEC	**236,000**	**236,000**	**N/A**
Contingency, TEC	*52,000*	*54,000*	***N/A***
Other Project Cost (OPC)			
Conceptual Design	3,600	2,200	**N/A**
Start-up	1,200	1,000	**N/A**
OPC - Contingency	1,200	800	**N/A**
Total, Except D&D (OPC)	**6,000**	**4,000**	**N/A**
Total, OPC	**6,000**	**4,000**	**N/A**
Contingency, OPC	*1,200*	*800*	***N/A***
Total, TPC	**242,000**	**240,000**	**N/A**
Total, Contingency (TEC+OPC)	***53,200***	***54,800***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Fiscal Year	Type	Prior Years	FY 2021	FY 2022	FY 2023	Outyears	Total
FY 2021	TEC	500	2,000	—	—	233,500	236,000
	OPC	1,700	—	—	—	2,000	3,700
	TPC	2,200	2,000	—	—	235,500	239,700
FY 2022	TEC	500	500	12,850	—	222,150	236,000
	OPC	570	1,230	500	—	1,700	4,000
	TPC	1,070	1,730	13,350	—	223,850	240,000
FY 2023	TEC	500	500	500	23,425	211,075	236,000
	OPC	673	1,750	1,000	—	2,577	6,000
	TPC	1,173	2,250	1,500	23,425	213,652	242,000

Notes:
- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*
- *Other Project Costs (OPC) are funded through laboratory overhead.*

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

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	1,200	75,000	60,000
Utilities	12	12	600	600
Maintenance and Repair	4,200	3,000	210,000	150,000
Total, Operations and Maintenance	5,712	4,212	285,600	210,600

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[qqq]
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.

[qqq] 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 2023 Request for the Critical Utilities Infrastructure Revitalization (CUIR) project is $25,425,000 of Total Estimated Cost (TEC) funding. The preliminary Total Estimated Cost (TEC) range for this project is $160,000,000 to $306,000,000. The preliminary Total Project Cost (TPC) range for this project is $164,500,000 to $310,500,000. Currently, these cost ranges encompass the most feasible preliminary alternatives. The preliminary TPC estimate for this project is $208,500,000.

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-1, Approve Alternatives Selection and Cost Range, which was approved January 21, 2022. FY 2023 funds will support Project Engineering and Design (PED) activities, initiate long-lead procurement and early construction activities after the appropriate CD approvals.

A Federal Project Director with the appropriate certification level (Level II: TPC greater than $50,000,000 and equal to or less than $100,000,000) has been assigned to this project.

Critical Milestone History

Fiscal Year	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 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	4Q FY 2020	4Q FY 2021	1Q FY 2024	4Q FY 2026	1Q FY 2024	N/A	4Q FY 2032
FY 2023	5/17/19	4/15/21	1/21/22	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	4Q FY 2021	4Q FY 2021
FY 2023	1Q FY 2024	2Q FY 2023

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	OPC, Total	TPC
FY 2021	38,500	147,500	186,000	3,000	3,000	189,000
FY 2022	20,000	166,000	186,000	3,000	3,000	189,000
FY 2023	15,000	189,000	204,000	4,500	4,500	208,500

Notes:
- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*
- *Other Project Costs (OPC) are funded through laboratory overhead.*

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, resilient, 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.

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. The Objective KPPs are shown adjacent to the applicable Threshold KPPs in the following charts. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion.

Performance Measure	Threshold	Objective
Subproject 1: Critical Electrical Work		
	Install and test three (3) 12kV circuits	Install and test (5) 12kV circuits along the 3 km linac to allow independent utility operation of each segment.
	Install and test 12 kV Sub-station to provide 3.5MVA power.	Install and test 12 kV Sub-station to provide 5MVA power.
	Install and test one new 60MVA (or larger) 230/12kV transformer.	Install and test two new 60MVA (or larger) 230/12kV transformer.
	Provide redundant N+1 (N active and one spare) electrical feeder circuits. Install and test Switchgear to allow feeder cable selection.	
	Replace monitoring equipment to provide AI/ML input at 9 substation relay doors with 1 integration hub.	Replace monitoring equipment to provide AI/ML input at 12 substation relay doors with 1 integration hub. Also integrate data from the substation, backup generator and transformer into the data-analytics platform.
	Install and test 1.5MVA backup generator.	

Performance Measure	Threshold	Objective
Subproject 2: Linac Utilities and Equipment		
	Replace and reconfigure medium-voltage equipment for 4 Variable Voltage Substations (VVS).	
	Replace low voltage sections for 10 K-subs, 10 VVS and 16 Motor Control Centers (MCC).	
	Replace 4 klystron water heat exchangers, 4 controls, and 4 pumps.	
	Replace 12,000 linear feet of domestic/fire water piping. Install submeters, flow and pressure sensors at 2 domestic water main branches.	Replace 18,000 linear feet of domestic/fire water piping. Install submeters, flow and pressure sensors at 4 domestic water main branches.
	Replace 2,700 linear feet of water main, laterals, and valves. Install 5 backflow preventors and 5 fire hydrants. Install submeter flow and pressure sensors at 1 domestic water key node.	
	Replace 1,000 linear feet of sanitary sewer piping. Install sensors to measure sewage flow, Total Dissolved Solids (TDS) at 2 effluent stations.	Install sensors to measure sewage flow, Total Dissolved Solids (TDS) at 5 existing effluent stations.
	Replace or re-line 5,000 linear feet of storm drain piping.	Replace or re-line 10,000 linear feet of storm drain piping.
		Integrate substation and water-cooling system monitor output into data-analytics platform.

Performance Measure	Threshold	Objective
Subproject 3: Sitewide Utilities		
	Replace 11 waveguide water heat exchangers, controls, and pumps.	
	Replace 3 klystron water heat exchangers, controls, and pumps.	
	Replace 11 accelerator, klystron, and waveguide monitoring devices.	
	Install 2 natural gas main meters, replace 6 existing BTU energy meter, and integrate each into data analytics platform.	Install 4 main gas meters and 8 gas submeters, replace 12 energy BTU meters and integrate each into the data analytics platform.
		Replace 10 programmable logic controller (PLC) to provide AI/ML input.
		Integrate substation and water-cooling system monitor output into data-analytics platform.

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	500	500	500
FY 2023	1,000	1,000	1,000
Outyears	12,500	12,500	13,000
Total, Design (TEC)	**15,000**	**15,000**	**15,000**
Construction (TEC)			
FY 2023	24,425	24,425	15,000
Outyears	164,575	164,575	174,000
Total, Construction (TEC)	**189,000**	**189,000**	**189,000**
Total Estimated Cost (TEC)			
FY 2020	500	500	–
FY 2021	500	500	500
FY 2022	500	500	500
FY 2023	25,425	25,425	16,000
Outyears	177,075	177,075	187,000
Total, TEC	**204,000**	**204,000**	**204,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Other Project Cost (OPC)			
FY 2020	323	323	323
FY 2021	1,572	1,572	1,572
Outyears	2,605	2,605	2,605
Total, OPC	**4,500**	**4,500**	**4,500**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Project Cost (TPC)			
FY 2020	823	823	323
FY 2021	2,072	2,072	2,072
FY 2022	500	500	500
FY 2023	25,425	25,425	16,000
Outyears	179,680	179,680	189,605
Total, TPC	**208,500**	**208,500**	**208,500**

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design	12,000	16,000	**N/A**
Design - Contingency	3,000	4,000	**N/A**
Total, Design (TEC)	**15,000**	**20,000**	**N/A**
Construction	150,000	132,000	**N/A**
Construction - Contingency	39,000	34,000	**N/A**
Total, Construction (TEC)	**189,000**	**166,000**	**N/A**
Total, TEC	**204,000**	**186,000**	**N/A**
Contingency, TEC	*42,000*	*38,000*	***N/A***
Other Project Cost (OPC)			
Conceptual Planning	2,700	2,200	**N/A**
Conceptual Design	1,800	800	**N/A**
Total, Except D&D (OPC)	**4,500**	**3,000**	**N/A**
Total, OPC	**4,500**	**3,000**	**N/A**
Contingency, OPC	***N/A***	*N/A*	***N/A***
Total, TPC	**208,500**	**189,000**	**N/A**
Total, Contingency (TEC+OPC)	***42,000***	***38,000***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Fiscal Year	Type	Prior Years	FY 2021	FY 2022	FY 2023	Outyears	Total
FY 2021	TEC	500	2,000	—	—	183,500	186,000
	OPC	1,000	1,000	—	—	1,000	3,000
	TPC	1,500	3,000	—	—	184,500	189,000
FY 2022	TEC	500	500	10,000	—	175,000	186,000
	OPC	323	1,000	—	—	1,677	3,000
	TPC	823	1,500	10,000	—	176,677	189,000
FY 2023	TEC	500	500	500	25,425	177,075	204,000
	OPC	323	1,572	—	—	2,605	4,500
	TPC	823	2,072	500	25,425	179,680	208,500

Notes:
- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*
- *Other Project Costs (OPC) are funded through laboratory overhead.*

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	4Q FY 2032
Expected Useful Life	30 years
Expected Future Start of D&D of this capital asset	4Q 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	TBD	7,805	TBD	885,000
Utilities	TBD	14,940	TBD	158,930
Maintenance and Repair	TBD	5,700	TBD	702,000
Total, Operations and Maintenance	TBD	28,445	TBD	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[rrr]
Area of D&D in this project at other sites	None
Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked"	None
Total area eliminated	None

8. Acquisition Approach

The SLAC Management and Operating (M&O) contractor, Stanford University, will perform the acquisition for this project, overseen by the Bay Area Site Office. The M&O contractor is responsible for awarding and managing all subcontracts related to this project. The M&O contractor will evaluate various acquisition alternatives and project delivery methods prior to achieving CD-1. Potential acquisition and project delivery methods include, but are not limited to, firm-fixed-price contracts for design-bid-build, construction management, and design-build subcontracts. The M&O contractor will also evaluate potential benefits of using 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.

[rrr] With the implementation of OMB's Reduce the Footprint initiative, DOE no longer maintains the space bank. Footprint is managed using the Facility Information Management System, with decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

20-SC-80, Utilities Infrastructure Project, FNAL
Fermi National Accelerator Laboratory
Project is for Design and Construction

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

Summary

The FY 2023 Request for the Utilities Infrastructure Project (UIP) is $20,000,000 of Total Estimated Cost (TEC) funding. The preliminary Total TEC range for this project is $248,000,000 to $403,000,000. The preliminary Total Project Cost (TPC) range for this project is $252,000,000 to $407,000,000. 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-1, Approve Alternative Selection and Cost Range, which was approved on February 23, 2022. FY 2023 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
FY 2023	5/17/19	10/2/2021	2/23/22	2Q FY 2024	2Q FY 2024	2Q FY 2024	N/A	4Q FY 2034

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
FY 2023	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	OPC, Total	TPC
FY 2021	73,000	237,000	310,000	4,000	4,000	314,000
FY 2022	28,300	281,700	310,000	4,000	4,000	314,000
FY 2023	43,800	266,200	310,000	4,000	4,000	314,000

Notes:

- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*
- *Other Project Costs (OPC) are funded through laboratory overhead.*

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, inefficient boilers will be replaced and electrical metering equipment will be improved in order 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.

Performance Measure	Threshold	Objective
Chilled Water Plant and CUB Upgrades	▪ Construct a new building for chilled water production (6,000 tons cooling capacity)	▪ Add additional 25 percent square footage to new chilled water plant for future growth.
	▪ Refurbish the existing Central Utility Building envelope ▪ Replace mechanical infrastructure in the CUB to support the Wilson Hall footprint area	▪ Upgrade existing CUB envelope and roof with environmentally sustainable improvements.
Kautz Road Substation	▪ Replace/ Upgrade the KRS to improve arc flash safety requirements	▪ Upgrade existing CUB envelope and roof with environmentally sustainable improvements.
Linear Utilities Replacement	▪ Revitalize 5 miles of the Industrial Cooling Water (ICW) system	▪ Revitalize 16 miles of the Industrial Cooling Water (ICW) system
	▪ Replace 5 miles of the Domestic Water System (DWS)	▪ Replace 19 miles of the Domestic Water System (DWS)
	▪ Replace 3.5 miles of the Sanitary Sewer systems	▪ Replace 11 miles of the Sanitary Sewer System
	▪ Replace 2 miles of underground Natural Gas lines	▪ Replace 22 miles of underground Natural Gas lines
	▪ Replace 2 miles of electrical distribution feeders and associated unit substations, transformers, etc.	▪ Replace 65 miles of electrical distribution feeders and associated unit substations, transformers, etc. ▪ Provide Electrical Code upgrades to Master Substation ▪ Replace 100 percent of the High-Pressure Sodium exterior lights along sidewalks, roads, and parking lots with LED.

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	500	500	1,000
FY 2023	20,000	20,000	19,500
Outyears	22,300	22,300	23,300
Total, Design (TEC)	**43,800**	**43,800**	**43,800**
Construction (TEC)			
Outyears	266,200	266,200	266,200
Total, Construction (TEC)	**266,200**	**266,200**	**266,200**
Total Estimated Cost (TEC)			
FY 2020	500	500	–
FY 2021	500	500	–
FY 2022	500	500	1,000
FY 2023	20,000	20,000	19,500
Outyears	288,500	288,500	289,500
Total, TEC	**310,000**	**310,000**	**310,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Other Project Cost (OPC)			
FY 2020	1,500	1,500	1,500
FY 2021	600	600	600
FY 2022	500	500	500
Outyears	1,400	1,400	1,400
Total, OPC	**4,000**	**4,000**	**4,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Project Cost (TPC)			
FY 2020	2,000	2,000	1,500
FY 2021	1,100	1,100	600
FY 2022	1,000	1,000	1,500
FY 2023	20,000	20,000	19,500
Outyears	289,900	289,900	290,900
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	33,300	24,000	**N/A**
Design - Contingency	10,500	4,300	**N/A**
Total, Design (TEC)	**43,800**	**28,300**	**N/A**
Construction	192,700	220,000	**N/A**
Construction - Contingency	73,500	61,700	**N/A**
Total, Construction (TEC)	**266,200**	**281,700**	**N/A**
Total, TEC	**310,000**	**310,000**	**N/A**
Contingency, TEC	*84,000*	*66,000*	***N/A***
Other Project Cost (OPC)			
Conceptual Planning	2,300	2,300	**N/A**
Conceptual Design	700	700	**N/A**
OPC - Contingency	1,000	1,000	**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*	*1,000*	***N/A***
Total, TPC	**314,000**	**314,000**	**N/A**
Total, Contingency (TEC+OPC)	***85,000***	***67,000***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Fiscal Year	Type	Prior Years	FY 2021	FY 2022	FY 2023	Outyears	Total
FY 2021	TEC	500	2,000	—	—	307,500	310,000
	OPC	2,000	—	—	—	2,000	4,000
	TPC	2,500	2,000	—	—	309,500	314,000
FY 2022	TEC	500	500	13,300	—	295,700	310,000
	OPC	—	1,530	500	—	1,970	4,000
	TPC	500	2,030	13,800	—	297,670	314,000
FY 2023	TEC	500	500	500	20,000	288,500	310,000
	OPC	1,500	600	500	—	1,400	4,000
	TPC	2,000	1,100	1,000	20,000	289,900	314,000

Notes:
- *This project has not received CD-2 approval; therefore, funding estimates are preliminary.*
- *Other Project Costs (OPC) are funded through laboratory overhead.*

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	4Q FY 2034
Expected Useful Life	30 years
Expected Future Start of D&D of this capital asset	4Q FY 2064

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	287	TBD	8,600
Utilities	TBD	577	TBD	17,300
Maintenance and Repair	TBD	287	TBD	8,600
Total, Operations and Maintenance	TBD	1,151	TBD	34,500

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....................	10,000 – 30,000
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[sss]
Area of D&D in this project at other sites	None
Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked"	None
Total area eliminated	TBD

8. Acquisition Approach

The FNAL Management and Operating (M&O) contractor, Fermi Research Alliance LLC, will perform the acquisition for this project. The M&O contractor is responsible for awarding and managing all subcontracts related to this project and will evaluate various acquisition alternatives and project delivery methods prior to achieving CD-1. The M&O will also evaluate potential benefits of using a single or multiple contracts to procure materials, equipment, construction, commissioning, and other project scope elements. Its annual performance and evaluation measurement plan will include project performance metrics for FNAL on which will be evaluated.

[sss] 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 2023 Request for the Biological and Environmental Program Integration Center (BioEPIC) project is $45,000,000 of Total Estimated Cost (TEC) funding. The Total Estimated Cost (TEC) for this project is $165,000,000. The Total Project Cost (TPC) for the project is $167,200,000.

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 co-located 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-2/3, Approve Baseline and Start of Construction, which was approved on September 22, 2021. FY 2023 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
FY 2023	3/13/18	5/9/19	5/9/19	9/22/21	2/22/21	9/22/21	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
FY 2023	9/22/21

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D	OPC, Total	TPC
FY 2020	13,000	127,000	140,000	2,200	2,200	142,200
FY 2021	13,000	127,000	140,000	2,200	2,200	142,200
FY 2022	13,000	127,000	140,000	2,200	2,200	142,200
FY 2023	15,000	150,000	165,000	2,200	2,200	167,200

Note:
- *Other Project Costs (OPC) are funded through laboratory overhead.*

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 gaps by providing a state-of-the-art facility that will collocate biosciences research and other programs.

The BioEPIC building will bring together important SC 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. The current facilities 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 resilient 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.*

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
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	1,858
FY 2020	10,000	10,000	6,919
FY 2021	–	–	5,024
FY 2022	–	–	1,199
Total, Design (TEC)	**15,000**	**15,000**	**15,000**
Construction (TEC)			
FY 2020	5,000	5,000	–
FY 2021	20,000	20,000	2,740
FY 2022	35,000	35,000	30,000
FY 2023	45,000	45,000	34,000
Outyears	45,000	45,000	83,260
Total, Construction (TEC)	**150,000**	**150,000**	**150,000**
Total Estimated Cost (TEC)			
FY 2019	5,000	5,000	1,858
FY 2020	15,000	15,000	6,919
FY 2021	20,000	20,000	7,764
FY 2022	35,000	35,000	31,199
FY 2023	45,000	45,000	34,000
Outyears	45,000	45,000	83,260
Total, TEC	**165,000**	**165,000**	**165,000**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Other Project Cost (OPC)			
FY 2018	767	767	767
FY 2019	748	748	748
FY 2020	21	21	21
Outyears	664	664	664
Total, OPC	**2,200**	**2,200**	**2,200**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Project Cost (TPC)			
FY 2018	767	767	767
FY 2019	5,748	5,748	2,606
FY 2020	15,021	15,021	6,940
FY 2021	20,000	20,000	7,764
FY 2022	35,000	35,000	31,199
FY 2023	45,000	45,000	34,000
Outyears	45,664	45,664	83,924
Total, TPC	**167,200**	**167,200**	**167,200**

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design	15,000	10,600	15,000
Design - Contingency	N/A	2,400	**N/A**
Total, Design (TEC)	**15,000**	**13,000**	**15,000**
Construction	125,000	105,000	125,000
Construction - Contingency	25,000	22,000	25,000
Total, Construction (TEC)	**150,000**	**127,000**	**150,000**
Total, TEC	**165,000**	**140,000**	**165,000**
Contingency, TEC	*25,000*	*24,400*	*25,000*
Other Project Cost (OPC)			
Conceptual Planning	1,500	1,500	**N/A**
Conceptual Design	600	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	**167,200**	**142,200**	**165,000**
Total, Contingency (TEC+OPC)	***25,100***	***24,500***	***25,000***

5. Schedule of Appropriations Requests

(dollars in thousands)

Fiscal Year	Type	Prior Years	FY 2021	FY 2022	FY 2023	Outyears	Total
FY 2020	TEC	11,000	—	—	—	129,000	140,000
	OPC	1,500	—	—	—	700	2,200
	TPC	12,500	—	—	—	129,700	142,200
FY 2021	TEC	20,000	6,000	—	—	114,000	140,000
	OPC	1,500	—	—	—	700	2,200
	TPC	21,500	6,000	—	—	114,700	142,200
FY 2022	TEC	20,000	20,000	35,000	—	65,000	140,000
	OPC	1,521	—	—	—	679	2,200
	TPC	21,521	20,000	35,000	—	65,679	142,200
FY 2023	TEC	20,000	20,000	35,000	45,000	45,000	165,000
	OPC	1,536	—	—	—	664	2,200
	TPC	21,536	20,000	35,000	45,000	45,664	167,200

Note:

- *Other Project Costs (OPC) are funded through laboratory overhead.*

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	4Q FY 2027
Expected Useful Life	50 years
Expected Future Start of D&D of this capital asset	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	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[ttt]
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, is performing 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.

[ttt] 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 and cyber controls that will mitigate possible risks to the laboratories' employees, nuclear and special materials, classified and sensitive information, hazardous materials, mission essential functions (e.g., DOE Isotope Program), 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 2023 Request

The FY 2023 Request for S&S is $189.5 million. The FY 2023 Request supports sustained levels of operations in S&S program elements including Protective Forces, Security Systems, Information Security, Cybersecurity, Personnel Security, Material Control and Accountability, and Program Management.

The FY 2023 Request also includes $81.26 million in Cybersecurity 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. Funding in this Request supports the implementation of Executive Order 14028 requirements for Maximum MFA, Maximum Encryption, Cloud Strategy/Security, Improved Logging and Supply Chain Management, and Zero Trust Infrastructure.

The FY 2023 Request supports the S&S program's highest priority, which is to provide adequate security for the Category I quantity of special nuclear material housed in Building 3019 at the Oak Ridge National Laboratory (ORNL).

The FY 2023 Request ensures the implementation of key and mandatory National and Departmental security policies. Funding supports the first stages of implementation of Homeland Security Presidential Directive-12 (HSPD-12); thereby providing the standardized Federal credential for not only cleared contractor employees and sub-contractors, but also for long-term uncleared employees and contractors. SC has approximately 50,000 long-term uncleared contractor personnel that require the credential and the associated Tier 1 background investigation. In future requests SC will need to consider the annual influx of new long-term uncleared contractor personnel that require the credentials and the associated Tier 1 background investigations. The funding includes the HSPD-12 associated modernization of physical access control systems at site entry points, buildings, and select internal facility locations. These systems mitigate threats to a range of national security interests, to include protection of employees (e.g., active shooter), high-consequence hazardous materials, classified matter, and intellectual property as outlined in the Department's Design Basis Threat policy. The FY 2023 Request provides the resources to implement the administration's policies associated with foreign national collaborations that assure the protection of U.S. science and technology. These new security mandates include the review of curriculum vitae to determine what intellectual capital to permit access to and rigorous validation of immigration documentation.

Description

The S&S program is organized into seven program elements:

1. Protective Forces
2. Security Systems
3. Information Security
4. Cybersecurity
5. Personnel Security
6. Material Control and Accountability
7. Program Management

Protective Forces

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 the backbone of the physical protection of Departmental personnel, material, equipment, property, and facilities through the deployment of HSPD-12 and local credentials, entry control points, fences, barriers, lighting, sensors, surveillance 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.

Cybersecurity

The Cybersecurity program develops and maintains a comprehensive cybersecurity program for ten national laboratories and five dedicated offices. There are numerous adversaries with the goals of disrupting vital DOE Office of Science missions and stealing critical research intellectual property. The cyber goals for the Cybersecurity program are to empower mission and science, align cyber funding to opportunities for risk reduction, strengthen Cybersecurity security posture by embracing new security designs, and offer unified guidance and cybersecurity procedures. The Cybersecurity program responds to cyber incidents by supporting the activities needed to for incident management, prosecution, and investigation of cyber intrusions. The program supports both disaster recovery and incident recovery, as well as notifications within the cybersecurity community. Based on DOE directives, the DOE cybersecurity program management, site cybersecurity initiatives, and cybersecurity infrastructure management comprise the final component of the cybersecurity program.

Personnel Security

The Personnel Security program element encompasses the processes for employee suitability and security clearance determinations at each site to ensure that individuals are trustworthy and eligible for access to classified information or matter. This element also includes the management of security clearance programs, adjudications, security education, awareness programs for Federal and contractor employees, and processing and hosting approved foreign visitors.

Material Control and Accountability (MC&A)

The MC&A program element provides assurance that Departmental materials are properly controlled and accounted for at all times. This element supports administration, including testing performance and assessing the levels of protection, control, and accountability required for the types and quantities of materials at each facility; documenting facility plans for materials control and accountability; assigning authorities and responsibilities for MC&A functions; and establishing programs to detect and report occurrences such as material theft, the loss of control or inability to account for materials, or evidence of malevolent acts.

Program Management

The Program Management program element coordinates the management of Protective Forces, Security Systems, Information Security, Personnel Security, and MC&A to achieve and ensure appropriate levels of protections are in place through the conduct of security and/or vulnerability assessments, local threat assessments, and performance assurance activities.

Safeguards and Security
Funding

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Safeguards and Security				
Protective Forces	44,200	44,200	50,000	+5,800
Security Systems	20,180	20,180	34,260	+14,080
Information Security	4,420	4,420	5,010	+590
Cybersecurity	37,520	37,520	81,260	+43,740
Personnel Security	5,500	5,500	8,480	+2,980
Material Control and Accountability	2,465	2,465	2,800	+335
Program Management	6,715	6,715	7,700	+985
Total, Safeguards and Security	**121,000**	**121,000**	**189,510**	**+68,510**

Safeguards and Security
Explanation of Major Changes

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Safeguards and Security	**$121,000**	**$189,510**	**+$68,510**
Protective Forces	$44,200	$50,000	+$5,800
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, inflation, and contractually obligated Cost of Living Adjustments for Protective Forces.
Security Systems	$20,180	$34,260	+$14,080
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 support the first stages of implementation of HSPD-12 for uncleared long-term contractor personnel and the associated modernization of personnel access control systems. These systems also mitigate active shooter and workplace violence, as well as providing control and compartmentalization of classified matter, intellectual property, sensitive information, and hazardous materials. Funding increases also address sustained levels of operations at increased overhead and inflation rates.
Information Security	$4,420	$5,010	+$590
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 inflation rates.

(dollars in thousands)

FY 2021 Enacted	FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Cybersecurity $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 continue implementation of Executive Order 14028 requirements at both federal and Management & Operating sites to build out Maximum MFA, Maximum Encryption, Cloud Strategy/Security, Improved Logging and Supply Chain Management, Zero Trust Infrastructure, Secure Critical Software, Controlled Unclassified Information protections, participate in the DHS Continuous Diagnostics and Monitoring program, build out Industrial Control Systems protections, and protect Government Furnished Equipment on foreign travel.	The budget remains flat from FY 2022 to FY 2023. For outyears, continual investments would be applied towards cyber infrastructure to support Zero Trust Infrastructure.
Personnel Security $5,500	$8,480	+$2,980
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 additional FTEs to support the increased (approximately 50,000 employees across 13 laboratories and operating facilities) HSPD-12 access authorization functions and the increased functions for the increased processing and vetting of foreign nationals. Funding will also provide sustained support for personnel security activities at increased overhead and inflation rates.

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Material Control and Accountability	$2,465	$2,800	+$335
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 inflation rates.
Program Management	$6,715	$7,700	+$985
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 provides integration of all security elements and security procedures protecting SC Research missions.	Funding will provide sustained support for Program Management activities at increased overhead and inflation rates.

Safeguards and Security
Funding Summary

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Other	121,000	121,000	189,510	+68,510
Total, Safeguards and Security	**121,000**	**121,000**	**189,510**	**+68,510**

Program Direction

Overview

The Office of Science (SC) Program Direction (PD) budget supports a highly skilled federal workforce to develop and oversee SC investments and Administration priorities in basic research on climate change and clean energy, advanced computing, cybersecurity, fundamental science to transform manufacturing, quantum information sciences, artificial intelligence and machine learning, biopreparedness, critical materials, 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 continues to increase investments in 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 29,000 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 nearly 34,000 users per year. SC oversees ten of DOE's 17 national laboratories. SC also continues to update its business processes for awards management and research related activities to advance diversity, equity, and inclusion in its extramural research programs.

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:

- Conducts 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.
- Establishes and maintains competitive research portfolios, which include high-risk, high-reward research, to achieve mission goals and objectives.
- Conducts 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.
- Organizes, participates in, or lead committees composed of agency and/or interagency personnel.
- Provides safety, security, and infrastructure oversight and management of all SC user facilities and other current research investments.
- Provides oversight and management of all line item construction projects and other capital asset projects.
- Provides oversight and management of the maintenance and operational integrity of the ten SC-stewarded national laboratories.
- Provides policy, strategy, and resource management in the areas of laboratory oversight, information management, 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 management. As part of this, the CSC:

- Provides necessary IT equipment and systems to ensure connectivity between Headquarters and field sites to successfully support the mission of the Office of Science.

- 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 2023 Request
The FY 2023 Request is $211.211 million and will support a total level of approximately 820 FTEs. The Request supports a pay raise of 4.6 percent. 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[uuu]. 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 2023 Request supports:
- Three-hundred and fourteen (314) 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 Counsel.
- Two (2) FTEs in the DOE Congressional and Intergovernmental Affairs to support Regional Offices.
- Two (2) FTEs supporting the President's Council of Advisors on Science and Technology (PCAST).[vvv]
- Three hundred and ninety-five (395) CSC and site office federal staff.
- Forty-three (43) OSTI federal staff to manage SC's public access program.

[uuu] OMB Memo M-17-22
[vvv] PCAST is required by Executive Order 13539, as amended by Executive Order 13596.

Program Direction
Funding

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Program Direction				
Salaries and Benefits	142,245	142,245	156,086	+13,841
Travel	1,500	1,500	2,100	+600
Support Services	27,341	27,341	29,800	+2,459
Other Related Expenses	12,687	12,687	14,900	+2,213
Working Capital Fund	8,227	8,227	8,325	+98
Total, Program Direction	**192,000**	**192,000**	**211,211**	**+19,211**
Federal FTE	778	778	820	+42

Program Direction

Activities and Explanation of Changes

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 Request vs FY 2021 Enacted
Program Direction	**$192,000**	**$211,211**	**+$19,211**
Salaries and Benefits	$142,245	$156,086	+$13,841
Funding supports 778 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 820 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 4.6 percent pay raise and the projected salary and benefit requirements for the requested FTE levels.
Travel	$1,500	$2,100	+$600
Funding supports facility visits where the use of electronic telecommunications is not practical for mandated on-site inspections and facility operations reviews. Ensuring scientific management, compliance, safety oversight, and external review of research funding across all SC programs requires staff to travel, since SC senior program managers are not co-located with grantees or at national laboratories.		The Request will support facility visits where the use of electronic telecommunications is not practical for mandated on-site inspections and facility operations reviews. Ensuring scientific management, compliance, safety oversight, and external review of research funding across all SC programs requires staff to travel, since SC senior program managers are not co-located with grantees or at national laboratories.	The increase in travel reflects the return to work with travel to conferences and site visits while still continuing videoconferencing instead of travel, where possible.

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 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	$29,800	+$2,459
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 2023.

(dollars in thousands)

FY 2021 Enacted		FY 2023 Request	Explanation of Changes FY 2023 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	$14,900	+$2,213
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 2023.
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 Working Capital Fund requirements for FY 2023.

Program Direction
Funding

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Program Direction				
HQ Salaries and Benefits	70,993	70,993	75,578	+4,585
HQ Travel	1,068	1,068	1,250	+182
HQ Support Services	20,529	20,529	22,500	+1,971
HQ Other Related Expenses	5,015	5,015	6,535	+1,520
HQ Working Capital Fund	8,227	8,227	8,325	+98
Total, Headquarters	**105,832**	**105,832**	**114,188**	**+8,356**
Field Offices Salaries and Benefits	64,611	64,611	72,802	+8,191
Field Offices Travel	417	417	750	+333
Field Offices Support Services	4,037	4,037	4,192	+155
Field Offices Other Related Expenses	6,626	6,626	6,898	+272
Total, Field Offices	**75,691**	**75,691**	**84,642**	**+8,951**
OSTI Salaries and Benefits	6,641	6,641	7,706	+1,065
OSTI Travel	15	15	100	+85
OSTI Support Services	2,775	2,775	3,108	+333
OSTI Other Related Expenses	1,046	1,046	1,467	+421
Total, Office of Scientific and Technical Information	**10,477**	**10,477**	**12,381**	**+1,904**
Total, Program Direction	**192,000**	**192,000**	**211,211**	**+19,211**
Program Direction Summary				
Salaries and Benefits	142,245	142,245	156,086	+13,841
Travel	1,500	1,500	2,100	+600
Support Services	27,341	27,341	29,800	+2,459
Other Related Expenses	12,687	12,687	14,900	+2,213
Working Capital Fund	8,227	8,227	8,325	+98
Total, Program Direction	**192,000**	**192,000**	**211,211**	**+19,211**
Federal FTE	778	778	820	+42

Program Direction
Funding Detail

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Technical Support				
System review and reliability analyses	1,373	1,373	1,485	+112
Management Support				
Automated data processing	10,850	10,850	12,161	+1,311
Training and education	577	577	737	+160
Reports and analyses, management, and general administrative services	14,541	14,541	15,417	+876
Total, Management Support	**25,968**	**25,968**	**28,315**	**+2,347**
Total, Support Services	**27,341**	**27,341**	**29,800**	**+2,459**
Other Related Expenses				
Rent to GSA	775	775	880	+105
Rent to others	2,162	2,162	2,306	+144
Communications, utilities, and miscellaneous	2,622	2,622	3,674	+1,052
Other services	551	551	963	+412
Operation and maintenance of facilities	1,340	1,340	1,443	+103
Supplies and materials	491	491	676	+185
Equipment	4,746	4,746	4,958	+212
Total, Other Related Expenses	**12,687**	**12,687**	**14,900**	**+2,213**
Working Capital Fund	**8,227**	**8,227**	**8,325**	**+98**

Program Direction
Funding Summary

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted
Other	192,000	192,000	211,211	+19,211
Total, Program Direction	**192,000**	**192,000**	**211,211**	**+19,211**

Public Access[www]

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 Office of Science and Technology 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.

[www] Responds to the reporting requirement specified by the FY 2022 House Energy and Water Development Appropriations Committee Report 117-98 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 2021 Planned Cost	**FY 2021 Actual Cost**	**FY 2022 Planned Cost**	**FY 2023 Planned Cost**
Brookhaven National Laboratory	4,917	5,678	5,578	4,876
Lawrence Berkeley National Laboratory	3,900	4,263	19,089	19,400
Notre Dame Radiation Laboratory	125	—	127	—
Oak Ridge Institute for Science and Education	—	213	—	—
Oak Ridge National Laboratory	19,564	33,255	28,886	30,349
Oak Ridge Office	6,673	4,755	6,410	4,188
Office of Scientific and Technical Information	421	522	397	427
SLAC National Accelerator Laboratory	3,407	6,028	3,934	4,003
Thomas Jefferson National Accelerator Facility	198	76	133	110
Total, Direct-Funded Maintenance and Repair	**39,205**	**54,790**	**64,554**	**63,353**

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 2021 Planned Cost	**FY 2021 Actual Cost**	**FY 2022 Planned Cost**	**FY 2023 Planned Cost**
Ames Laboratory	2,400	2,800	2,400	2,700
Argonne National Laboratory	46,768	46,862	51,237	49,231
Brookhaven National Laboratory	30,211	37,812	33,352	33,308
Fermi National Accelerator Laboratory	21,704	19,890	23,183	17,636
Lawrence Berkeley National Laboratory	29,749	39,833	31,051	27,886
Oak Ridge Institute for Science and Education	480	511	656	901
Oak Ridge National Laboratory and Y-12	73,830	66,402	55,925	65,419
Oak Ridge Office	1,537	1,603	2,236	2,474
Pacific Northwest National Laboratory	10,322	11,837	11,270	12,686
Princeton Plasma Physics Laboratory	6,843	6,994	6,280	7,200
SLAC National Accelerator Laboratory	14,195	19,467	14,089	18,409
Thomas Jefferson National Accelerator Facility	10,188	9,985	7,634	7,481
Total, Indirect-Funded Maintenance and Repair	**248,227**	**263,996**	**239,313**	**245,331**

Report on FY 2021 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 2021 to the amount planned for FY 2021, including Congressionally directed changes.

Science
Total Costs for Maintenance and Repair

	(dollars in thousands)	
	FY 2021 Planned Cost	**FY 2021 Actual Cost**
Ames Laboratory	2,400	2,800
Argonne National Laboratory	46,768	46,862
Brookhaven National Laboratory	35,128	43,490
Fermi National Accelerator Laboratory	21,704	19,890
Lawrence Berkeley National Laboratory	33,649	44,096
Notre Dame Radiation Laboratory	125	—
Oak Ridge Institute for Science and Education	480	724
Oak Ridge National Laboratory and Y-12	93,394	99,657
Oak Ridge Office	8,210	6,358
Office of Scientific and Technical Information	421	522
Pacific Northwest National Laboratory	10,322	11,837
Princeton Plasma Physics Laboratory	6,843	6,994
SLAC National Accelerator Laboratory	17,602	25,495
Thomas Jefferson National Accelerator Facility	10,386	10,061
Total, Maintenance and Repair	**287,432**	**318,786**

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 2021 Planned Cost	**FY 2021 Actual Cost**	**FY 2022 Planned Cost**	**FY 2023 Planned Cost**
Argonne National Laboratory	400	9,652	400	550
Brookhaven National Laboratory	978	690	619	500
Fermi National Accelerator Laboratory	20	—	20	—
Lawrence Berkeley National Laboratory	16	—	2	400
Oak Ridge National Laboratory	500	2,049	250	1,250
SLAC National Accelerator Laboratory	56	—	—	158
Total, Indirect-Funded Excess Facilities	**1,970**	**12,391**	**1,291**	**2,858**

Science
Research and Development

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2022 Annualized CR
Basic	5,362,845	5,472,305	6,124,959	+652,654
Applied	–	–	–	–
Subtotal, R&D	5,362,845	5,472,305	6,124,959	+652,654
Equipment	238,706	239,739	248,988	+9,249
Construction	1,343,109	1,187,956	1,221,513	+33,557
Total, R&D	**6,944,660**	**6,900,000**	**7,595,460**	**+695,460**

Science
Small Business Innovative Research/Small Business Technology Transfer (SBIR/STTR)

(dollars in thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request vs FY 2021 Enacted	
Office of Science					
Advanced Scientific Computing Research					
SBIR	25,736	27,495	30,775	+5,039	+19.58%
STTR	3,620	3,869	4,327	+707	+19.53%
Basic Energy Sciences					
SBIR	56,592	59,161	63,747	+7,155	+12.64%
STTR	7,963	8,328	8,965	+1,002	+12.58%
Biological and Environmental Research					
SBIR	23,850	23,738	28,054	+4,204	+17.63%
STTR	3,352	3,339	3,945	+593	+17.69%
Fusion Energy Sciences					
SBIR	12,352	13,216	14,487	+2,135	+17.28%
STTR	1,740	1,863	2,036	+296	+17.01%
High Energy Physics					
SBIR	22,325	21,080	22,769	+444	+1.99%
STTR	3,140	2,964	3,202	+62	+1.97%
Nuclear Physics					
SBIR	18,685	19,564	21,450	+2,765	+14.80%
STTR	2,625	2,748	3,015	+390	+14.86%
Accelerator R&D and Production					
SBIR	–	542	878	+878	–
STTR	–	75	124	+124	–
Total, Office of Science SBIR	**159,540**	**164,796**	**182,160**	**+22,620**	**+14.18%**
Total, Office of Science STTR	**22,440**	**23,186**	**25,614**	**+3,174**	**+14.14%**

Note:
- *The other DOE programs SBIR/STTR funding amounts are listed in the other DOE budget volumes.*

DEPARTMENT OF ENERGY
Funding by Site
Science FY 2023
(Dollars in Thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request Detail
Ames Laboratory			
Research - Basic Energy Sciences	16,782	16,782	16,782
Basic Energy Sciences	16,782	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	275	275	0
Fusion Energy Sciences	275	275	0
Research - High Energy Physics	1,618	1,600	2,000
High Energy Physics	1,618	1,600	2,000
21-SC-73, Ames Infrastructure Modernization	150	0	0
Construction - Science Laboratories Infrastructure	150	0	0
Science Laboratories Infrastructure	150	0	0
Safeguards and Security - SC	1,231	1,231	2,671
Total Ames Laboratory	**21,306**	**21,138**	**21,453**
Ames Site Office			
Program Direction - SC	664	664	768
Total Ames Site Office	**664**	**664**	**768**
Argonne National Laboratory			
Research - Advanced Scientific Computing Research	161,432	161,104	167,746
Advanced Scientific Computing Research	161,432	161,104	167,746
Research - Basic Energy Sciences	223,706	238,314	222,150
18-SC-10, Advanced Photon Source Upgrade (APS-U), ANL	160,000	101,000	9,200
Construction - Basic Energy Sciences	160,000	101,000	9,200
Basic Energy Sciences	383,706	339,314	231,350
Research - Biological & Environmental Research	33,868	33,868	41,007
Biological and Environmental Research	33,868	33,868	41,007
Research - Fusion Energy Sciences	389	200	330
Fusion Energy Sciences	389	200	330
Research - High Energy Physics	16,795	13,818	16,061
High Energy Physics	16,795	13,818	16,061
Operations and Maintenance - Nuclear Physics	30,552	31,235	34,321
Nuclear Physics	30,552	31,235	34,321
20-SC-77, Argonne Utilities Upgrade, ANL (20-SC-79)	500	500	8,000
Construction - Science Laboratories Infrastructure	500	500	8,000
Science Laboratories Infrastructure	500	500	8,000
Safeguards and Security - SC	10,469	10,469	18,985
Total Argonne National Laboratory	**637,711**	**590,508**	**517,800**
Argonne Site Office			
Program Direction - SC	3,997	3,997	4,879
Total Argonne Site Office	**3,997**	**3,997**	**4,879**
Bay Area Site Office			
Program Direction - SC	6,027	0	0
Total Bay Area Site Office	**6,027**	**0**	**0**
Berkeley Site Office			
Program Direction - SC	0	3,616	3,923
Total Berkeley Site Office	**0**	**3,616**	**3,923**
Brookhaven National Laboratory			
Research - Advanced Scientific Computing Research	2,313	1,580	2,643

DEPARTMENT OF ENERGY
Funding by Site
Science FY 2023
(Dollars in Thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request Detail
Advanced Scientific Computing Research	2,313	1,580	2,643
Research - Basic Energy Sciences	167,542	183,954	211,501
Basic Energy Sciences	167,542	183,954	211,501
Research - Biological & Environmental Research	17,353	17,353	18,900
Biological and Environmental Research	17,353	17,353	18,900
Research - Fusion Energy Sciences	2,409	0	2,409
Fusion Energy Sciences	2,409	0	2,409
Research - High Energy Physics	75,692	69,273	75,568
11-SC-40, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment	3,516	6,000	10,000
Construction - High Energy Physics	3,516	6,000	10,000
High Energy Physics	79,208	75,273	85,568
Operations and Maintenance - Nuclear Physics	220,175	212,345	213,056
20-SC-52, Electron Ion Collider, BNL	5,000	3,750	20,000
Construction - Nuclear Physics	5,000	3,750	20,000
Nuclear Physics	225,175	216,095	233,056
Research - Accelerator R&D and Production	0	5,367	6,176
Accelerator R&D and Production	0	5,367	6,176
Facilities and Infrastructure (SLI)	0	0	4,000
20-SC-71, Critical Utilities Rehabilitation Project, BNL	20,000	26,000	13,000
19-SC-71, Science User Support Center, BNL	20,000	38,000	0
Construction - Science Laboratories Infrastructure	40,000	64,000	13,000
Science Laboratories Infrastructure	40,000	64,000	17,000
Safeguards and Security - SC	14,233	14,233	21,275
Total Brookhaven National Laboratory	**548,233**	**577,855**	**598,528**
Brookhaven Site Office			
Program Direction - SC	4,444	4,444	5,343
Total Brookhaven Site Office	**4,444**	**4,444**	**5,343**
Chicago Operations Office			
Research - Basic Energy Sciences	217,479	0	0
Basic Energy Sciences	217,479	0	0
Research - Biological & Environmental Research	23,772	0	0
Biological and Environmental Research	23,772	0	0
Research - Fusion Energy Sciences	41,878	0	0
Fusion Energy Sciences	41,878	0	0
Operations and Maintenance - Nuclear Physics	140,954	0	0
Nuclear Physics	140,954	0	0
Payment In Lieu of Taxes	1,650	0	0
Science Laboratories Infrastructure	1,650	0	0
Total Chicago Operations Office	**425,733**	**0**	**0**
Consolidated Business Center			
Payment In Lieu of Taxes	3,000	4,820	4,891
Oak Ridge Landlord	5,860	6,430	6,559
Science Laboratories Infrastructure	8,860	11,250	11,450
Safeguards and Security - SC	4,397	4,397	5,635
Program Direction - SC	43,481	43,481	45,799
Total Consolidated Business Center	**56,738**	**59,128**	**62,884**
Fermi National Accelerator Laboratory			
Research - Advanced Scientific Computing Research	874	700	1,778
Advanced Scientific Computing Research	874	700	1,778
Research - High Energy Physics	326,113	301,673	318,163
18-SC-42, Proton Improvement Plan II (PIP-II), FNAL	79,000	90,000	120,000

DEPARTMENT OF ENERGY
Funding by Site
Science FY 2023
(Dollars in Thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request Detail
11-SC-40, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment	167,484	170,000	166,000
11-SC-41, Muon to Electron Conversion Experiment, FNAL	2,000	13,000	2,000
Construction - High Energy Physics	248,484	273,000	288,000
High Energy Physics	574,597	574,673	606,163
Research - Accelerator R&D and Production	0	0	23
Accelerator R&D and Production	0	0	23
Facilities and Infrastructure (SLI)	0	11,500	0
20-SC-80, Utilities Infrastructure Project, FNAL (20-SC-82)	500	500	20,000
17-SC-71, Integrated Engineering Research Center, FNAL	10,250	10,250	0
Construction - Science Laboratories Infrastructure	10,750	10,750	20,000
Science Laboratories Infrastructure	10,750	22,250	20,000
Safeguards and Security - SC	8,480	8,480	14,215
Total Fermi National Accelerator Laboratory	**594,701**	**606,103**	**642,179**
Fermi Site Office			
Program Direction - SC	3,452	3,452	3,651
Total Fermi Site Office	**3,452**	**3,452**	**3,651**
Idaho National Laboratory			
Research - Advanced Scientific Computing Research	70	0	0
Advanced Scientific Computing Research	70	0	0
Research - Basic Energy Sciences	570	570	570
Basic Energy Sciences	570	570	570
Research - Fusion Energy Sciences	1,646	1,646	2,800
Fusion Energy Sciences	1,646	1,646	2,800
Total Idaho National Laboratory	**2,286**	**2,216**	**3,370**
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	238,816	220,112	218,226
Advanced Scientific Computing Research	238,816	220,112	218,226
Research - Basic Energy Sciences	147,285	157,516	149,283
18-SC-12, Advanced Light Source Upgrade (ALS-U), LBNL	62,000	75,100	135,000
Construction - Basic Energy Sciences	62,000	75,100	135,000
Basic Energy Sciences	209,285	232,616	284,283
Research - Biological & Environmental Research	166,693	171,224	176,405
Biological and Environmental Research	166,693	171,224	176,405
Research - Fusion Energy Sciences	1,200	1,200	0
Fusion Energy Sciences	1,200	1,200	0
Research - High Energy Physics	71,772	63,450	67,945
High Energy Physics	71,772	63,450	67,945
Operations and Maintenance - Nuclear Physics	23,069	25,591	34,817
Nuclear Physics	23,069	25,591	34,817
Research - Accelerator R&D and Production	0	1,282	430
Accelerator R&D and Production	0	1,282	430
Facilities and Infrastructure (SLI)	0	0	5,500
20-SC-72, Seismic and Safety Modernization, LBNL	5,000	27,500	27,500
20-SC-78, Linear Assets Modernization Project, LBNL (20-SC-80)	500	500	23,425
19-SC-74, Biological & Environmental Program Integration Center (BioEPIC), LBNL	20,000	35,000	45,000
Construction - Science Laboratories Infrastructure	25,500	63,000	95,925
Science Laboratories Infrastructure	25,500	63,000	101,425

DEPARTMENT OF ENERGY
Funding by Site
Science FY 2023
(Dollars in Thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request Detail
Safeguards and Security - SC	7,675	7,675	13,450
Total Lawrence Berkeley National Laboratory	**744,010**	**786,150**	**896,981**
Lawrence Livermore National Laboratory			
Research - Advanced Scientific Computing Research	5,254	3,490	6,722
Advanced Scientific Computing Research	5,254	3,490	6,722
Research - Basic Energy Sciences	2,091	2,091	2,091
Basic Energy Sciences	2,091	2,091	2,091
Research - Biological & Environmental Research	28,095	28,095	31,082
Biological and Environmental Research	28,095	28,095	31,082
Research - Fusion Energy Sciences	9,765	9,201	6,482
Fusion Energy Sciences	9,765	9,201	6,482
Research - High Energy Physics	3,665	2,271	2,275
High Energy Physics	3,665	2,271	2,275
Operations and Maintenance - Nuclear Physics	1,607	1,807	1,784
Nuclear Physics	1,607	1,807	1,784
Research - Accelerator R&D and Production	0	258	93
Accelerator R&D and Production	0	258	93
Total Lawrence Livermore National Laboratory	**50,477**	**47,213**	**50,529**
Los Alamos National Laboratory			
Research - Advanced Scientific Computing Research	4,096	1,469	1,782
Advanced Scientific Computing Research	4,096	1,469	1,782
Research - Basic Energy Sciences	20,646	22,787	21,320
Basic Energy Sciences	20,646	22,787	21,320
Research - Biological & Environmental Research	32,230	32,230	34,667
Biological and Environmental Research	32,230	32,230	34,667
Research - Fusion Energy Sciences	1,700	1,700	300
Fusion Energy Sciences	1,700	1,700	300
Research - High Energy Physics	3,177	1,650	1,890
High Energy Physics	3,177	1,650	1,890
Operations and Maintenance - Nuclear Physics	8,259	8,752	9,039
Nuclear Physics	8,259	8,752	9,039
Research - Accelerator R&D and Production	0	50	0
Accelerator R&D and Production	0	50	0
Safeguards and Security - SC	248	248	0
Total Los Alamos National Laboratory	**70,356**	**68,886**	**68,998**
National Renewable Energy Laboratory			
Research - Basic Energy Sciences	5,742	5,742	5,742
Basic Energy Sciences	5,742	5,742	5,742
Research - Biological & Environmental Research	3,877	3,877	3,760
Biological and Environmental Research	3,877	3,877	3,760
Total National Renewable Energy Laboratory	**9,619**	**9,619**	**9,502**
Oak Ridge Institute for Science & Education			
Research - Advanced Scientific Computing Research	500	0	0
Advanced Scientific Computing Research	500	0	0
Research - Basic Energy Sciences	28	0	0
Basic Energy Sciences	28	0	0
Research - Biological & Environmental Research	778	778	1,348
Biological and Environmental Research	778	778	1,348
Research - High Energy Physics	170	0	0
High Energy Physics	170	0	0
Operations and Maintenance - Nuclear Physics	0	0	896
Nuclear Physics	0	0	896

DEPARTMENT OF ENERGY
Funding by Site
Science FY 2023
(Dollars in Thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request Detail
Safeguards and Security - SC	2,425	2,425	3,663
Total Oak Ridge Institute for Science & Education	**3,901**	**3,203**	**5,907**
Oak Ridge National Laboratory			
Research - Advanced Scientific Computing Research	251,854	247,946	251,831
17-SC-20, SC Exascale Computing Project (ECP)	168,945	129,000	77,000
Advanced Scientific Computing Research	420,799	376,946	328,831
Research - Basic Energy Sciences	350,012	341,571	332,791
19-SC-14, Second Target Station (STS), ORNL	29,000	32,000	32,000
18-SC-11, Spallation Neutron Source Proton Power Upgrade (PPU), ORNL	52,000	17,000	17,000
Construction - Basic Energy Sciences	81,000	49,000	49,000
Basic Energy Sciences	431,012	390,571	381,791
Research - Biological & Environmental Research	86,641	86,341	86,682
Biological and Environmental Research	86,641	86,341	86,682
Research - Fusion Energy Sciences	27,947	31,947	23,258
14-SC-60, U.S. Contributions to ITER (U.S. ITER)	242,000	221,000	240,000
Construction - Fusion Energy Sciences	242,000	221,000	240,000
Fusion Energy Sciences	269,947	252,947	263,258
Research - High Energy Physics	1,253	990	1,410
High Energy Physics	1,253	990	1,410
Operations and Maintenance - Nuclear Physics	15,436	14,832	17,580
Nuclear Physics	15,436	14,832	17,580
20-SC-51, U.S. Stable Isotope Production and Research Center, ORNL	12,000	0	0
Construction - Isotope R&D and Production	12,000	0	0
Isotope R&D and Production	12,000	0	0
Research - Accelerator R&D and Production	0	57	0
Accelerator R&D and Production	0	57	0
Oak Ridge Nuclear Operations	26,000	20,000	20,000
20-SC-74, Craft Resources Support Facility, ORNL (19-SC-74)	25,000	0	0
19-SC-73, Translational Research Capability, ORNL	22,000	21,500	0
Construction - Science Laboratories Infrastructure	47,000	21,500	0
Science Laboratories Infrastructure	73,000	41,500	20,000
Safeguards and Security - SC	30,166	30,166	38,100
Total Oak Ridge National Laboratory	**1,340,254**	**1,194,350**	**1,137,652**
Oak Ridge National Laboratory Site Office			
Program Direction - SC	4,757	4,757	6,955
Total Oak Ridge National Laboratory Site Office	**4,757**	**4,757**	**6,955**
Office of Scientific & Technical Information			
Research - Basic Energy Sciences	161	0	0
Basic Energy Sciences	161	0	0
Research - Biological & Environmental Research	285	285	0
Biological and Environmental Research	285	285	0
Operations and Maintenance - Nuclear Physics	0	143	141
Nuclear Physics	0	143	141
Facilities and Infrastructure (SLI)	200	200	200
Science Laboratories Infrastructure	200	200	200
Safeguards and Security - SC	759	759	2,201
Program Direction - SC	10,477	10,477	12,381
Total Office of Scientific & Technical Information	**11,882**	**11,864**	**14,923**
Pacific Northwest National Laboratory			
Research - Advanced Scientific Computing Research	4,635	600	3,664
Advanced Scientific Computing Research	4,635	600	3,664
Research - Basic Energy Sciences	23,694	23,694	23,694

DEPARTMENT OF ENERGY
Funding by Site
Science FY 2023
(Dollars in Thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request Detail
Basic Energy Sciences	23,694	23,694	23,694
Research - Biological & Environmental Research	113,325	121,325	137,632
Biological and Environmental Research	113,325	121,325	137,632
Research - Fusion Energy Sciences	723	723	1,200
Fusion Energy Sciences	723	723	1,200
Research - High Energy Physics	1,995	1,300	1,550
High Energy Physics	1,995	1,300	1,550
Operations and Maintenance - Nuclear Physics	0	818	861
Nuclear Physics	0	818	861
Facilities and Infrastructure (SLI)	0	1,600	5,400
18-SC-71, Energy Sciences Capability, PNNL	23,000	0	0
Construction - Science Laboratories Infrastructure	23,000	0	0
Science Laboratories Infrastructure	23,000	1,600	5,400
Safeguards and Security - SC	13,512	13,512	19,958
Total Pacific Northwest National Laboratory	**180,884**	**163,572**	**193,959**
Pacific Northwest Site Office			
Program Direction - SC	5,066	5,066	6,058
Total Pacific Northwest Site Office	**5,066**	**5,066**	**6,058**
Princeton Plasma Physics Laboratory			
Research - Advanced Scientific Computing Research	400	0	0
Advanced Scientific Computing Research	400	0	0
Research - Fusion Energy Sciences	65,015	65,015	55,337
Fusion Energy Sciences	65,015	65,015	55,337
21-SC-71, Princeton Plasma Innovation Center, PPPL	150	900	10,000
21-SC-72, Critical Infrastructure Recovery & Renewal, PPPL	150	2,000	4,000
20-SC-76, Tritium System Demolition and Disposal, PPPL (20-SC-78)	13,000	6,400	0
Construction - Science Laboratories Infrastructure	13,300	9,300	14,000
Science Laboratories Infrastructure	13,300	9,300	14,000
Safeguards and Security - SC	3,358	3,358	6,405
Total Princeton Plasma Physics Laboratory	**82,073**	**77,673**	**75,742**
Princeton Site Office			
Program Direction - SC	1,991	1,991	2,190
Total Princeton Site Office	**1,991**	**1,991**	**2,190**
Sandia National Laboratories			
Research - Advanced Scientific Computing Research	18,509	14,862	16,171
Advanced Scientific Computing Research	18,509	14,862	16,171
Research - Basic Energy Sciences	24,264	25,122	24,240
Basic Energy Sciences	24,264	25,122	24,240
Research - Biological & Environmental Research	15,928	15,928	12,122
Biological and Environmental Research	15,928	15,928	12,122
Research - Fusion Energy Sciences	2,100	2,534	500
Fusion Energy Sciences	2,100	2,534	500
Research - High Energy Physics	50	500	100
High Energy Physics	50	500	100
Total Sandia National Laboratories	**60,851**	**58,946**	**53,133**
Savannah River National Laboratory			
Research - Biological & Environmental Research	150	150	0
Biological and Environmental Research	150	150	0
Research - Fusion Energy Sciences	75	75	0
Fusion Energy Sciences	75	75	0
Total Savannah River National Laboratory	**225**	**225**	**0**

DEPARTMENT OF ENERGY
Funding by Site
Science FY 2023
(Dollars in Thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request Detail
SLAC National Accelerator Laboratory			
Research - Advanced Scientific Computing Research	670	450	450
Advanced Scientific Computing Research	670	450	450
Research - Basic Energy Sciences	215,455	231,156	211,456
21-SC-10, Cryomodule Repair and Maintenance Facility, SLAC	1,000	1,000	10,000
18-SC-13, Linac Coherent Light Source-II-High Energy (LCLS-II-HE), SLAC	52,000	50,000	90,000
13-SC-10, Linac Coherent Light Source-II (LCLS-II), SLAC	33,000	28,100	0
Construction - Basic Energy Sciences	86,000	79,100	100,000
Basic Energy Sciences	301,455	310,256	311,456
Research - Biological & Environmental Research	4,100	4,100	4,520
Biological and Environmental Research	4,100	4,100	4,520
Research - Fusion Energy Sciences	5,495	3,545	5,500
20-SC-61, Matter in Extreme Conditions (MEC) Petawatt Upgrade, SLAC	15,000	5,000	1,000
Construction - Fusion Energy Sciences	15,000	5,000	1,000
Fusion Energy Sciences	20,495	8,545	6,500
Research - High Energy Physics	81,678	76,607	81,434
High Energy Physics	81,678	76,607	81,434
Operations and Maintenance - Nuclear Physics	1,166	1,166	1,321
Nuclear Physics	1,166	1,166	1,321
Research - Accelerator R&D and Production	0	1,320	100
Accelerator R&D and Production	0	1,320	100
20-SC-75, Large Scale Collaboration Center, SLAC (19-SC-75)	11,000	12,000	30,000
20-SC-79, Critical Utilities Infrastructure Revitalization, SLAC (20-SC-81)	500	500	25,425
Construction - Science Laboratories Infrastructure	11,500	12,500	55,425
Science Laboratories Infrastructure	11,500	12,500	55,425
Safeguards and Security - SC	3,914	3,914	8,890
Total SLAC National Accelerator Laboratory	**424,978**	**418,858**	**470,096**
Thomas Jefferson National Accelerator Facility			
Research - Advanced Scientific Computing Research	360	0	0
Advanced Scientific Computing Research	360	0	0
Research - High Energy Physics	420	0	0
High Energy Physics	420	0	0
Operations and Maintenance - Nuclear Physics	129,353	134,480	153,899
20-SC-52, Electron Ion Collider, BNL	0	1,250	0
Construction - Nuclear Physics	0	1,250	0
Nuclear Physics	129,353	135,730	153,899
Research - Accelerator R&D and Production	0	350	427
Accelerator R&D and Production	0	350	427
Facilities and Infrastructure (SLI)	0	3,900	0
20-SC-73, CEBAF Renovation and Expansion, TJNAF (19-SC-73)	2,000	10,000	2,000
Construction - Science Laboratories Infrastructure	2,000	10,000	2,000
Science Laboratories Infrastructure	2,000	13,900	2,000
Safeguards and Security - SC	3,037	3,037	5,633
Total Thomas Jefferson National Accelerator Facility	**135,170**	**153,017**	**161,959**
Thomas Jefferson Site Office			
Program Direction - SC	1,812	1,812	2,461
Total Thomas Jefferson Site Office	**1,812**	**1,812**	**2,461**
Undesignated Lab/Plant/Installation			
Research - Advanced Scientific Computing Research	49,552	113,293	85,078
Advanced Scientific Computing Research	49,552	113,293	85,078
Research - Basic Energy Sciences	0	320,459	487,170
Basic Energy Sciences	0	320,459	487,170

DEPARTMENT OF ENERGY
Funding by Site
Science FY 2023
(Dollars in Thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request Detail
Research - Biological & Environmental Research	106,090	94,152	136,433
Biological and Environmental Research	106,090	94,152	136,433
Research - Fusion Energy Sciences	42,456	42,456	71,320
Fusion Energy Sciences	42,456	42,456	71,320
Research - High Energy Physics	28,708	32,810	56,655
High Energy Physics	28,708	32,810	56,655
Operations and Maintenance - Nuclear Physics	52,345	29,732	40,208
Nuclear Physics	52,345	29,732	40,208
Research - Accelerator R&D and Production	0	2,128	6,916
Accelerator R&D and Production	0	2,128	6,916
Workforce Development for Teachers & Scientists	29,000	29,000	41,300
Facilities and Infrastructure (SLI)	0	0	100
Science Laboratories Infrastructure	0	0	100
Safeguards and Security - SC	0	17,096	28,429
Total Undesignated Lab/Plant/Installation	**308,151**	**681,126**	**953,609**
Washington Headquarters			
Research - Advanced Scientific Computing Research	88,623	0	0
Advanced Scientific Computing Research	88,623	0	0
Research - Basic Energy Sciences	439,674	0	0
Basic Energy Sciences	439,674	0	0
Research - Biological & Environmental Research	6,170	0	0
Biological and Environmental Research	6,170	0	0
Research - Fusion Energy Sciences	124,899	0	0
Fusion Energy Sciences	124,899	0	0
Research - High Energy Physics	68,224	0	0
High Energy Physics	68,224	0	0
Operations and Maintenance - Nuclear Physics	67,784	0	0
20-SC-51, U.S. Stable Isotope Production and Research Center, (SIPRC)	0	12,000	12,000
Construction - Nuclear Physics	0	12,000	12,000
Nuclear Physics	67,784	12,000	12,000
Research - Isotope R&D and Production	0	72,000	85,451
Isotope R&D and Production	0	72,000	85,451
Facilities and Infrastructure (SLI)	29,590	0	0
Science Laboratories Infrastructure	29,590	0	0
Safeguards and Security - SC	17,096	0	0
Program Direction - SC	105,832	105,832	114,188
Total Washington Headquarters	**947,892**	**189,832**	**211,639**
Grants			
Research - Advanced Scientific Computing Research	18,097	120,394	235,650
Advanced Scientific Computing Research	18,097	120,394	235,650
Research - Basic Energy Sciences	500	370,673	418,080
Basic Energy Sciences	500	370,673	418,080
Research - Biological & Environmental Research	112,395	142,044	219,127
Biological and Environmental Research	112,395	142,044	219,127
Research - Fusion Energy Sciences	87,028	285,483	312,786
Fusion Energy Sciences	87,028	285,483	312,786
Research - High Energy Physics	112,670	184,123	198,969
High Energy Physics	112,670	184,123	198,969
Operations and Maintenance - Nuclear Physics	0	163,099	211,273
14-SC-50, Facility for Rare Isotope Beams, MSU	5,300	0	0
Construction - Nuclear Physics	5,300	0	0
Nuclear Physics	5,300	163,099	211,273
Research - Accelerator R&D and Production	0	6,123	13,271
Accelerator R&D and Production	0	6,123	13,271
Total Grants	**335,990**	**1,271,939**	**1,609,156**

DEPARTMENT OF ENERGY
Funding by Site
Science FY 2023
(Dollars in Thousands)

	FY 2021 Enacted	FY 2022 Annualized CR	FY 2023 Request Detail
Total Funding by Site for TAS_0222 - Science	**7,026,000**	**7,026,000**	**7,799,211**

GENERAL PROVISIONS—DEPARTMENT OF ENERGY

SEC. 301.

(a) No appropriation, funds, or authority made available by this title for the Department of Energy shall be used to initiate or resume any program, project, or activity or to prepare or initiate Requests For Proposals or similar arrangements (including Requests for Quotations, Requests for Information, and Funding Opportunity Announcements) for a program, project, or activity if the program, project, or activity has not been funded by Congress.

(b)

(1) Unless the Secretary of Energy notifies the Committees on Appropriations of both Houses of Congress at least 3 full business days in advance, none of the funds made available in this title may be used to—

(A) make a grant allocation or discretionary grant award totaling $1,000,000 or more;
(B) make a discretionary contract award or Other Transaction Agreement totaling $1,000,000 or more, including a contract covered by the Federal Acquisition Regulation;
(C) issue a letter of intent to make an allocation, award, or Agreement in excess of the limits in subparagraph (A) or (B); or
(D) announce publicly the intention to make an allocation, award, or Agreement in excess of the limits in subparagraph (A) or (B).

(2) The Secretary of Energy shall submit to the Committees on Appropriations of both Houses of Congress within 15 days of the conclusion of each quarter a report detailing each grant allocation or discretionary grant award totaling less than $1,000,000 provided during the previous quarter.

(3) The notification required by paragraph (1) and the report required by paragraph (2) shall include the recipient of the award, the amount of the award, the fiscal year for which the funds for the award were appropriated, the account and program, project, or activity from which the funds are being drawn, the title of the award, and a brief description of the activity for which the award is made.

(c) The Department of Energy may not, with respect to any program, project, or activity that uses budget authority made available in this title under the heading "Department of Energy—Energy Programs", enter into a multiyear contract, award a multiyear grant, or enter into a multiyear cooperative agreement unless—

(1) the contract, grant, or cooperative agreement is funded for the full period of performance as anticipated at the time of award; or

(2) the contract, grant, or cooperative agreement includes a clause conditioning the Federal Government's obligation on the availability of future year budget authority and the Secretary notifies the Committees on Appropriations of both Houses of Congress at least 3 days in advance.

(d) The amounts made available by this title may be reprogrammed for any program, project, or activity, and the Department shall notify the Committees on Appropriations of both Houses of Congress at least 30 days prior to the use of any proposed reprogramming that would cause any program, project, or activity funding level to increase or decrease by more than $5,000,000 or 10 percent, whichever is less, during the time period covered by this Act.

(e) 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.

(f)

(1) The Secretary of Energy may waive any requirement or restriction in this section that applies to the use of funds made available for the Department of Energy if compliance with such requirement or restriction would pose a substantial risk to human health, the environment, welfare, or national security.

(2) The Secretary of Energy shall notify the Committees on Appropriations of both Houses of Congress of any waiver under paragraph (1) as soon as practicable, but not later than 3 days after the date of the activity to which a requirement or restriction would otherwise have applied. Such notice shall include an explanation of the substantial risk under paragraph (1) that permitted such waiver.

(g) 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 2023 until the enactment of the Intelligence Authorization Act for fiscal year 2023.

SEC. 303. None of the funds made available in this title shall be used for the construction of facilities classified as high-hazard nuclear facilities under 10 CFR Part 830 unless independent oversight is conducted by the Office of Enterprise Assessments to ensure the project is in compliance with nuclear safety requirements.

SEC. 304. None of the funds made available in this title may be used to approve critical decision–2 or critical decision–3 under Department of Energy Order 413.3B, or any successive departmental guidance, for construction projects where the total project cost exceeds $100,000,000, until a separate independent cost estimate has been developed for the project for that critical decision.

SEC. 305. 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. Subparagraphs (B) and (C) of section 40401(a)(2) of Public Law 117–58, paragraph (3) of section 16512(r) of title 42, United States Code, and section (l) of section 17013 of title 42, United States Code, shall not apply for fiscal year 2023.

✦

TITLE V—GENERAL PROVISIONS

(INCLUDING TRANSFER OF FUNDS)

SEC. 501. None of the funds appropriated by this Act may be used in any way, directly or indirectly, to influence congressional action on any legislation or appropriation matters pending before Congress, other than to communicate to Members of Congress as described in 18 U.S.C. 1913.

SEC. 502. 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. 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. 504. Of the unavailable collections currently in the United States Enrichment Corporation Fund, $405,421,000 shall be transferred to and merged with the Uranium Enrichment Decontamination and Decommissioning Fund and shall be available only to the extent provided in advance in appropriations Acts.