U.S. DEPARTMENT OF ENERGY

The U.S. Department of Energy's Ten-Year-Plans for the Office of Science National Laboratories FY 2018

FERMI NATIONAL ACCELERATOR LABORATORY

Lab-at-a-Glance

Location: Batavia, IL
Type: Single-program Laboratory
Contractor: Fermi Research Alliance, LLC
Site Office: Fermi Site Office
Website: www.fnal.gov

- **FY 2017 Lab Operating Costs:** $427.6million
- **FY 2017 DOE/NNSA Costs:** $426.5 million
- **FY 2017 SPP (Non-DOE/Non-DHS) Costs:** $1.1 million
- **FY 2017 SPP as % Total Lab Operating Costs:** 0.3%
- **FY 2017 DHS Costs:** $0 million

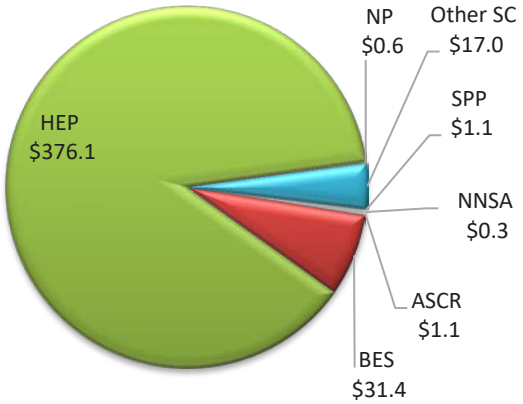
Physical Assets:

- 6,800 acres and 366 buildings
- 2.4 million GSF in buildings
- Replacement Plant Value: $2.2B
- 19k GSF in 9 Excess Facilities
- 20k GSF in Leased Facilities

Human Capital:

- 1,783 Full Time Equivalent Employees (FTEs)
- 13 Joint Faculty
- 88 Postdoctoral Researchers
- 29 Graduate Students
- 65 Undergraduate Students
- 3,472 Facility Users
- 9 Visiting Scientists

FY 2017 Costs by Funding Source ($M)



Mission Overview

Fermi National Accelerator Laboratory is an international hub for particle physics located 40 miles west of Chicago, Illinois. Fermilab's employees and users drive discovery in particle physics by building and operating world-leading accelerator and detector facilities, performing pioneering research with national and global partners, and developing new technologies for science that support U.S. industrial competitiveness. The laboratory's core capabilities include particle physics; large-scale user facilities and advanced instrumentation; accelerator science and technology; and advanced computer science, visualization, and data. Fermilab's science strategy for the future delivers on the U.S. particle physics community's goals as outlined in the Particle Physics Project Prioritization Panel's 2014 report. The strategy's primary ten-year goal is a world-leading neutrino science program anchored by the Long-Baseline Neutrino Facility (LBNF) and Deep Underground Neutrino Experiment (DUNE), powered by megawatt beams from an upgraded and modernized accelerator complex made possible by the Proton Improvement Plan II (PIP-II). The flagship facility comprised of LBNF, DUNE, and PIP-II will be the first international mega-science project based at a Department of Energy national laboratory.

Fermilab's particle accelerator complex is the only one in the world to produce both low- and high-energy neutrino beams for study. Fermilab integrates U.S. universities and national laboratories into the global particle physics enterprise through its Large Hadron Collider (LHC) programs; neutrino science,

accelerator science, and precision science programs; and cosmic frontier experiments. Large-scale computing facilities drive research in particle physics and other fields of science. The laboratory's R&D infrastructure and its engineering and technical expertise advance particle accelerator and detector technology for use in science and society. Fermilab's partnerships and technology transitions programs, including the Illinois Accelerator Research Center, leverage this expertise to apply particle physics technologies to problems of national importance in energy and the environment, national security, and industry.

Fermi Research Alliance, LLC manages Fermilab for the Department of Energy. FRA is an alliance of the University of Chicago and the Universities Research Association, Inc.

Core Capabilities

Fermilab has unique and powerful infrastructure essential to the advancement of discovery in particle physics, including the nation's only accelerator complex dedicated to particle physics and a suite of particle detectors. Scientific research around the world is supported by Fermilab's facilities for design, fabrication, assembly, testing, and operation of particle accelerators and detectors; by its expertise and facilities for computing; and by a talented workforce with globally competitive knowledge, skills, and abilities. The laboratory is thus uniquely positioned to advance the DOE/SC mission in scientific discovery and innovation with a primary focus on high-energy physics (HEP) and capabilities that address mission needs for advanced scientific computing research (ASCR), particle accelerators for light sources (BES), nuclear physics (NP), and workforce development for teachers and scientists (WDTS). Fermilab has four core capabilities: **Particle Physics; Large-Scale User Facilities/Advanced Instrumentation; Accelerator Science and Technology**; and **Advanced Computer Science, Visualization, and Data** and is primarily funded by the DOE Office of High Energy Physics (DOE/HEP).

Particle Physics

Particle physics is the heart of the laboratory's science mission and is defined by four main science themes—neutrino science, collider science, precision science, and cosmic science—supported by theory, facilities and workforce development.

Neutrino science

Fermilab is the only laboratory in the world that operates two accelerator-based neutrino beams simultaneously, the Neutrinos at the Main Injector (NuMI) beamline and the Booster Neutrino Beamline (BNB). These two intense neutrino sources illuminate an important collection of experiments that are studying neutrinos over both short and long distances, allowing the Fermilab neutrino program to address questions such as whether additional (sterile) neutrinos exist and whether neutrinos violate matter-antimatter (CP) symmetry. The NOvA experiment operates on the high-energy NuMI beamline and explores the parameters of neutrino flavor transformation. This exploration will become comprehensive with the operation of the Deep Underground Neutrino Experiment (DUNE) in a new beamline created as part of the Long Baseline Neutrino Facility (LBNF) and powered by the Proton Improvement Plan II (PIP-II) accelerator upgrades. The Short Baseline Neutrino program on the low-energy BNB searches for sterile neutrinos through a suite of three experiments: the MicroBooNE detector that began operating with beam in 2015; the ICARUS detector that will begin operating in 2019; and the Short-Baseline Near Detector (SBND) that will follow in 2020. Experience with these liquid-argon detectors will also inform the future flagship international LBNF/DUNE program. This succession of neutrino experiments is prescribed by the P5 report and is being executed by collaborations of scientists enabled by the capabilities that exist at Fermilab.

Collider science

The Large Hadron Collider (LHC) at CERN, the European center for particle physics, is the world's largest and most powerful particle accelerator. Operating at the center-of-mass-energy of 13-14 TeV, the LHC explores the energy frontier and probes the laws of nature by recreating the conditions of the early universe. Fermilab serves as the host laboratory for more than 800 university-based U.S. scientists and students working on the CMS (Compact Muon Solenoid) experiment, one of two large multipurpose detectors at the LHC. Fermilab is the leading U.S. center for LHC science and second-largest world center after CERN. The laboratory's globally distributed computational capabilities for the CMS experiment are unparalleled. Laboratory scientists are engaged in physics analyses of LHC data including studies of the Higgs boson and searches for new phenomena such as supersymmetry, extra dimensions, and dark matter. A skilled and talented workforce of scientists, engineers, and technicians leverages Fermilab's accelerator and detector R&D programs to contribute essential developments, improvements, and upgrades to the CMS detector and the LHC accelerator. Fermilab is leading the HL-LHC CMS Upgrade Project, the HL-LHC Accelerator Upgrade Project, and US CMS Operations.

Precision science

Fermilab's precision science theme includes experiments that attempt to reveal gaps in the current understanding of the laws of physics by testing predictions to the highest accuracy and searching for phenomena that are either extremely rare or forbidden by current theories. Deviations from expectations are a possible indication of new particles and new interactions. Fermilab has reconfigured accelerator components to create muon beams, which began to deliver beam to first experiment at the Muon Campus—Muon g-2—in 2017. The beams will increase in intensity over time, culminating with delivery of the world's most intense muon beam to the Mu2e experiment in 2021.

The Muon g-2 experiment will precisely measure a property of muons called the anomalous magnetic moment and investigate hints from previous experiments that the muon's magnetic moment may be different from what was predicted by the Standard Model of particle physics. If true, this could be an indication of new physics with far-reaching implications. The Mu2e experiment will search for the spontaneous conversion of muons to electrons. The experiment will be sensitive to new physics manifesting itself in rare processes and corresponding to energies several orders of magnitude higher than those achievable at the LHC, thereby complementing collider experiments' searches for new particles and new interactions.

Cosmic science

Fermilab leads the Dark Energy Survey, is a key partner in several world-leading cosmic science experiments, and contributes to R&D efforts toward new dark energy, dark matter, and cosmic microwave background (CMB) experiments. Fermilab researchers built the camera and are currently leading the science collaboration for the Dark Energy Survey, which finished its fifth, and next-to-final, year of observations in 2018. Fermilab is working with other DOE laboratories to build three new large cosmic surveys (DESI, LSST, CMB-4). The laboratory is engaged in world-leading searches for particle dark matter, taking on major responsibilities for the construction of second-generation experiments (LUX-ZEPLIN and SuperCDMS SNOLAB). Fermilab plays an important role, together with other laboratories, in the design of CMB-S4, which will establish the world's best limit on the sum of neutrino masses and help explore the phenomenon of cosmic inflation.

Theory, Facilities, and Workforce Development

Fermilab's Theory and Theoretical Astrophysics groups perform research at the confluence of these four themes. The laboratory's accelerators and particle detectors, and its fabrication, assembly, testing, and computing facilities provide unique capabilities within DOE and for particle physics research. For example, the Fermilab Test Beam Facility is in high demand for R&D of advanced particle detector technologies. The Office of Education and Public Outreach and the Lederman Science Center support students and faculty in STEM education and the DOE WDTS mission.

Particle Physics is funded primarily by DOE/HEP with additional funding from DOE/BES (and DOE/SLI for infrastructure), and advances DOE's Scientific Discovery and Innovation mission.

Large-Scale User Facilities and Advanced Instrumentation

Fermilab's Large-Scale User Facilities/Advanced Instrumentation core capability encompasses two DOE/SC user facilities: the Fermilab Accelerator Complex and the CMS Center, which together supported more than 3,400 users in FY 2017. The laboratory has the human capital and infrastructure essential to developing, designing, constructing, and operating large-scale user facilities and advanced instrumentation.

Fermilab Accelerator Complex

The Fermilab Accelerator Complex is the nation's only accelerator complex dedicated to particle physics and the second-largest particle physics accelerator complex in the world. Research at this user facility has led to many discoveries over more than 40 years of operation, including the top quark, bottom quark, tau neutrino, determination of the properties of charm- and bottom-quark systems, and numerous precision measurements, including the discovery of new matter-antimatter asymmetries in kaon decays.

The Fermilab Accelerator Complex comprises seven particle accelerators and storage rings with particle-beam capabilities found nowhere else in the world. Future upgrades of the accelerator complex enabled by the Proton Improvement Plan II (PIP-II) project will provide megawatts of beam power to the Long-Baseline Neutrino Facility (LBNF) and Deep Underground Neutrino Experiment (DUNE). Currently, Fermilab uniquely supplies two very intense neutrino sources (the low-energy Booster neutrino beam and the high-energy NuMI beam) that enable the physics programs of the NOvA, MicroBooNE, and MINERvA experiments. By 2020, the Booster neutrino beam will deliver neutrinos to all three detectors of the Short-Baseline Neutrino program: MicroBooNE (already operating), ICARUS (starting 2019) and the Short-Baseline Near Detector (SBND, starting 2020). Beams of muons are being delivered to the Muon g-2 experiment following successful reconfiguration and upgrades of the accelerator complex. Fermilab will the world center for the study of muons when high-intensity muon beams are delivered to the Mu2e experiment starting in 2019. The Fermilab Test Beam Facility is the only U.S. location that enables detector R&D tests with high-energy hadron beams and is used by more than 200 international researchers annually.

CMS Center

For almost two decades Fermilab has served as the host laboratory for the more than 800 scientists and students from about 50 U.S. universities who work on the CMS experiment at the Large Hadron Collider (LHC) in Geneva, Switzerland. Fermilab also leads the HL-LHC CMS Upgrades, the HL-LHC Accelerator Upgrade Project, and US CMS Operations. Researchers using

Fermilab's CMS facilities played leading roles in the 2012 Higgs boson discovery, and ongoing research promises to further revolutionize our understanding of the universe.

The CMS Center consists of the LHC Physics Center (LPC), CMS Remote Operations Center, and the U.S. CMS Computing Facility at Fermilab. The LPC is designed to engage members of U.S. CMS institutions distributed across the country in physics analyses of LHC data and in upgrades to the CMS detector. The LPC creates a thriving environment for collaboration among participating institutions by facilitating remote participation, conferences, classes, and other opportunities. Through the Distinguished Researcher and Guest and Visitor programs, collaborators are supported to spend significant time at the LPC, and the CMS Data Analysis School draws 100 participants each year. The Remote Operations Center enables physicist participation in remote operations and monitoring of the CMS detector and keeps scientists, students, and technicians connected to operations activities at CERN without the time and expense of European travel. The U.S. CMS Computing Facility at Fermilab is the largest and most reliable Tier-1 computing facility worldwide (after the CERN Tier-0 center). As part of a worldwide grid computing capability, this facility is available to qualified CMS researchers around the world. A proposal to make the CMS Center a national user facility is currently under review by DOE/SC.

Advanced Instrumentation

An experienced and talented workforce at Fermilab conceives and develops state-of-the-art particle detector technologies and uses them to construct detector systems. Achievements include the development of very-low-mass silicon detectors for particle physics collider experiments, CCD detectors for the Dark Energy Camera, scintillator detectors used for a wide variety of particle physics experiments, and liquid-argon time-projection chambers used by current neutrino experiments and the future flagship experiment, DUNE. Fermilab's advanced instrumentation capability is used to develop and construct upgrades for the CMS detector at the LHC, including innovative silicon trackers, a silicon-based calorimeter, readout electronics, and R&D for precision timing detectors.

Large-Scale User Facilities/Advanced Instrumentation is funded primarily by DOE/HEP (and DOE/SLI for infrastructure), and advances DOE's Scientific Discovery and Innovation mission.

Accelerator Science and Technology

Fermilab's Accelerator Science and Technology core capability includes five core competencies, strategically aligned with recommendations of the 2015 HEPAP Accelerator R&D sub-panel: high-intensity particle beams; high-power target stations; high-field superconducting magnets; high-gradient and high-quality-factor superconducting radio-frequency (SRF) cavities; and accelerator science and technology training. These core competencies are enabled by unique accelerator and beam test facilities and world-leading expertise that sustain Fermilab's leadership role in high-intensity and high-energy accelerator applications. Fermilab has established strategic partnerships in accelerator science and technology with leading universities including Northern Illinois University, Illinois Institute of Technology, Northwestern University, Cornell University, and the University of Chicago. Fermilab's Illinois Accelerator Research Center (IARC) is uniquely positioned to cement partnerships with industry and universities to increase strategic partnership projects and to advance DOE's accelerator stewardship program.

High-intensity particle beams

Fermilab operates the world's most advanced high-intensity proton accelerator complex dedicated to particle physics. The ongoing Proton Improvement Plan (PIP), an intermediate step

of AIPs toward 1 MW of beam power, and a subsequent upgrade project (PIP-II) will maintain Fermilab's international leadership and support the next generation of neutrino and precision science experiments. PIP-II leverages laboratory capabilities in accelerating and transporting high-intensity beams in circular and linear accelerators and is needed as the next step to achieving a beam power of more than 2 MW for LBNF/DUNE and beyond. Results from accelerator R&D at Fermilab support the flagship neutrino science program and influence how U.S. and international accelerators are designed, constructed, and operated. Fermilab has achieved more than 700 kW beam power to the NOvA experiment through PIP, and is running around $2x10^{17}$ protons per hour from the proton source to support the Short-Baseline Neutrino program and the Muon g-2 experiment.

High-power target stations

Fermilab operates three high-power target stations: the 700 kW NuMI beam (to be upgraded to 1 MW); the Booster Neutrino Beam; and the particle production target station for the Muon g-2 experiment. A fourth target station is under construction for the Mu2e experiment. A fifth target station is under design for the LBNF/DUNE project. Each of these stations include specialized targets with capabilities up to 1.2 MW of beam power, as well as specialized focusing devices (magnetic horns, lithium lenses, graded solenoids), shielding, instrumentation, beam windows, remote handling, and other systems. Fermilab maintains this core competency through the development of these facilities and continuous improvement. Fermilab also executes a high-power targetry (HPT) R&D program directed at the challenges of future multi-MW target facilities. The laboratory leads the international RaDIATE collaboration researching new radiation- and thermal-shock-compatible materials and technologies.

High-field superconducting magnets

Fermilab has a long history of developing, fabricating, and delivering advanced superconducting magnets, such as the world's first superconducting dipole magnets deployed in a circular collider (the Tevatron). The laboratory's core competency in high-field superconducting magnets, including novel superconducting materials and magnetic components, electromechanical magnetic designs, and technologies, is essential to the luminosity upgrades of CERN's LHC accelerator. This core competency is also critical to enable upgrades of the LHC for operations at higher energies, which would require further increases in the maximum magnetic field achievable in accelerator-quality magnets. Infrastructure supporting Fermilab's magnet work includes a superconducting strand and cable testing facility, cable making and coil winding machines, collaring and yoking presses, reaction ovens, a cryogenic vertical magnet test facility for cold masses, a cryogenic horizontal magnet test facility for magnets in cryostats, and cryogenic infrastructure.

High-gradient and high-quality-factor SRF cavities

Fermilab's SRF expertise and infrastructure comprise a globally renowned core competency in the fabrication and testing of SRF technology. Laboratory staff members play an important role in the design and planning of linear and circular accelerators around the world that depend on SRF technology. This core competency enables Fermilab to be a key partner in the construction of the superconducting linear accelerator for SLAC's LCLS-II free electron laser, the highest-priority construction project in the DOE Office of Science. Fermilab's experienced staff and extensive infrastructure led the way in the design of SRF cryomodules and cryogenic infrastructure for LCLS-II and extended the state of the art for SRF cavity performance. By working with SLAC National Accelerator Laboratory and Thomas Jefferson National Accelerator Laboratory to establish LCLS-II as a world-leading facility, Fermilab is contributing its unique infrastructure and expertise to the broader scientific endeavor while simultaneously enhancing

in-house capabilities for future projects such as PIP-II. This infrastructure and expertise also position the laboratory to contribute to potential future accelerators and colliders. SRF infrastructure includes chemical processing and high-pressure rinsing of cavities, processing and brazing furnaces, cleanroom assembly facilities, inspection and testing capabilities for both bare and dressed cavities, cryomodule assembly stations, and a complete cryomodule test facility. The laboratory's core competency in SRF technology, including design and production of non-elliptical cavities such as those needed for PIP-II, is also essential to the luminosity upgrades of CERN's LHC accelerator through the application of crab cavities for luminosity control and levelling.

Beam test facilities

The Fermilab Accelerator Science and Technology (FAST) facility hosts a unique program of advanced accelerator R&D at the Integrable Optics Test Accelerator (IOTA) ring. The research promises to advance accelerator science and enable high-intensity accelerator technologies for multi-megawatt proton beams. An electron injector to the IOTA ring provides an additional platform for accelerator science and technology.

Accelerator science and technology training

Fermilab is making significant contributions to the nation's accelerator science and technology workforce training. The laboratory hosts the United States Particle Accelerator School (USPAS), which has trained over 4,500 students since its inception in 1981 and has undergone a restructuring that re-establishes the USPAS as a Fermilab program. Fermilab also maintains a renowned joint university/laboratory doctoral program in accelerator physics and technology, as well as several undergraduate summer internship programs in collaboration with Argonne National Laboratory.

Accelerator Science is funded by DOE/HEP with additional funding from DOE/BES (and DOE/SLI for infrastructure), and advances DOE's Scientific Discovery and Innovation mission.

Advanced Computer Science, Visualization, and Data

Fermilab's expertise in Advanced Computer Science, Visualization, and Data enables scientific discovery. This core capability complements theory and experiments to increase scientific knowledge through data collection, storage, reconstruction, and analysis, as well as through scientific simulations. Fermilab has a remarkable history of developing, delivering, and deploying computing technologies for the scientific community.

Fermilab scientists and engineers are internationally recognized as experts in high-performance computing algorithms, scientific workflow systems and analysis frameworks, sophisticated scientific simulations, machine intelligence, and data analytics toolkits. A prominent and successful example is a community software framework and scientific workflow engine (the "art" framework) that is adopted by the U.S.-based neutrino and muon experimental communities and by some of the direct-detection dark matter experiments. Furthermore, aspects of machine intelligence such as deep learning, are becoming more prominent in scientific analyses.

Fermilab is recognized for expertise in designing, developing, and operating distributed computing infrastructures and facilities, petascale scientific data management, and scientific workflows for data recording, processing, and analysis. The laboratory provides access to large-scale computational and data-management facilities for the CMS experiment at CERN, the LHC Physics Center, neutrino science and precision science experiments, the Dark Energy Survey, computational cosmology, lattice QCD, and accelerator simulations.

The laboratory is a leader in grid computing, which originally evolved to satisfy the rapidly expanding data needs of LHC experiments and is now in use by other areas of science, industry, government, and commerce. Fermilab scientific computing facilities use grid technology to share resources for data processing, storage, and analysis. Fermilab is a leader in providing grid computing resources to scientific organizations outside DOE/HEP through the Open Science Grid, a consortium dedicated to providing secure access to distributed high-throughput computing for scientific research. HEPCloud capabilities provide Fermilab computing users access to commercial cloud resources and DOE/ASCR HPC resources. Experiments such as CMS, Mu2e, and NOvA are exploiting Fermilab's HEPCloud capabilities.

Due to the collaborative nature of particle physics research, Fermilab does not develop scientific software or computing capabilities in isolation. The laboratory partners with all DOE/SC laboratories and international laboratories such as CERN, DESY in Germany, and KISTI, the Korean Institute of Science and Technology Information, to work on projects that include the Open Science Grid, accelerator modeling, computational cosmology, and particle physics simulations. Fermilab's strategy is to leverage DOE/ASCR expertise where appropriate to respond to computational challenges presented by the DOE/HEP program through the judicious use of partnership programs such as DOE's Scientific Discovery through Advanced Computing (SciDAC) program, as well as periodic DOE/ASCR calls for proposals.

Fermilab's data center is the single largest U.S. HEP computing center with 80,000 processing cores, 40 petabytes of disk storage, and nearly an exabyte of data storage on robotic tape systems. State-of-the-art computational facilities enable the laboratory to develop new capabilities to support the DOE scientific mission. Fermilab plays an essential role in developing software and hosting scientific computing projects and three major computing facilities for the science community: a CMS Tier-1 Center; Lattice QCD Computing; and FermiGrid.

CMS Tier-1 Center: The CMS experiment uses a distributed computing model in which data distribution, processing, and delivery is handled by seven international Tier-1 centers together with university- and laboratory-based Tier-2 computing and storage facilities. This computing model satisfies the needs of particle physicists by providing data storage and processing power on an extreme scale, interconnected by the strongest networks. The CMS Tier-1 Center at Fermilab is the most powerful worldwide (after CERN's Tier-0 center) for the 3,000-member, 41-country CMS experiment.

Lattice QCD Computing: Quantum chromodynamics (QCD) is the theory that describes how quarks and gluons interact via the strong force and predicts the properties of hadrons such as the proton, neutron, and pion. QCD calculations involve numerical simulations performed on a lattice of space-time points (known as Lattice QCD) that can be extremely computationally intensive. Fermilab operates large computer clusters for such calculations as part of DOE's national Lattice QCD computational infrastructure.

FermiGrid: Fermilab is the host laboratory for several neutrino and precision science experiments and provides computing facilities for these experiments, including reliable resources for data recording and processing (the equivalent of the CERN LHC "Tier 0" for neutrino and precision science). FermiGrid is the primary HEP facility for non-LHC computing and provides computing and storage resources that are shared among these experiments.

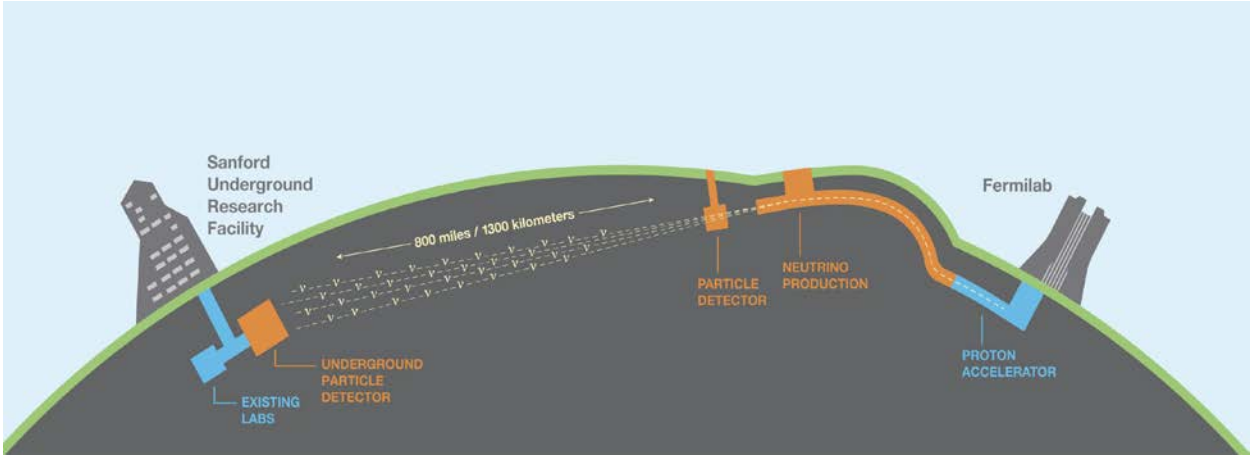
Advanced Computer Science, Visualization, and Data is funded primarily by DOE/HEP with additional funding from DOE/ASCR (and DOE/SLI for infrastructure), and advances DOE's Scientific Discovery and Innovation mission.

Science Strategy for the Future

Fermilab's primary ten-year goal is to establish a world-leading neutrino science program led by the Long-Baseline Neutrino Facility and Deep Underground Neutrino Experiment (LBNF/DUNE) and powered

by megawatt beams from an upgraded and modernized accelerator complex made possible by the Proton Improvement Plan II (PIP-II) project. Identified by the U.S. particle physics community in its consensus Particle Physics Prioritization Panel (P5) report as the highest-priority domestic construction project in its timeframe, LBNF/DUNE is attracting global partners willing to invest significant financial, technical, and scientific resources. A five-year program that includes current and near-term neutrino experiments, an R&D platform that serves the wider neutrino physics community, and prototype detectors (ProtoDUNEs) at the European laboratory CERN is driving the development of capabilities and infrastructure planning and bringing together the international community needed for LBNF/DUNE.

As the country's particle physics and accelerator laboratory, Fermilab is moving forward with new experiments, new international and national partnerships, and R&D programs that support all the science drivers identified in the Particle Physics Prioritization Panel (P5) report. Serving as an effective



Artist's rendering of the Long-Baseline Neutrino Facility (LBNF) that will send a very intense beam of neutrinos 1300 km (800 miles) to a massive liquid-argon detector located deep underground in the Sanford Underground Research Facility in South

host lab for LBNF/DUNE and solidifying existing and attracting new partnerships are the laboratory's highest priorities in the coming years. Refocusing the Accelerator Science and Technology thrust and becoming a major force in the Office of Science's Quantum Information Science (QIS) initiative round out Fermilab's major initiatives.

Infrastructure

Overview of Site Facilities and Infrastructure

Fermilab's 6,800 acre site and extensive infrastructure supports the laboratory's current particle physics research program, including the experiments at the Fermilab Accelerator Complex user facility and others located around the world. The laboratory's infrastructure is also evolving to support the significant requirements of the international LBNF/DUNE and PIP-II projects.

Operating the Fermilab Accelerator Complex user facility for science requires the use of buildings, real property trailers, and tunnels as well as hundreds of miles of utility infrastructure. The total real property Replacement Plant Value (RPV) for conventional facilities is $997M, and when including the laboratory's programmatic accelerator and tunnel assets (OSF 3000) the total RPV is $2.15B. All of the laboratory's real property is used and owned by DOE. Property usage is predominately divided among research and development space and administrative areas. Unoccupied land is maintained as restored prairie, tilled agriculture, or woodland and is preserved for future science needs.

In addition to modernized facilities and infrastructure at Fermilab to support the fast-approaching LBNF/DUNE era, DOE has a 19,771 GSF real-property lease with the South Dakota Science and

Technology Authority (SDSTA) at the Sanford Underground Research Facility (SURF). Real-property improvements will be necessary at SURF in both leased space and non-leased space in support of the DOE science mission. The most immediate needs are additional project office space within the leased area of an existing building and improvements to SDSTA-owned infrastructure in order to mitigate vulnerabilities to LBNF/DUNE. These activities have line-item congressional budget authorization and the DOE Senior Realty Officer has approved this work as necessary to the DOE mission. Other elements of this approved work will construct new utility systems, underground detectors, and support systems for LBNF/DUNE. In addition to this work within the leased space and associated temporary construction easements, there is expected to be incremental investment (some funded by DOE) in related SDSTA infrastructure to better meet life safety requirements and increase the reliability of general infrastructure systems needed to conduct the DOE mission. Future requirements development by Fermilab as the LBNF/DUNE host laboratory is underway and will likely result in additional DOE investments for office space, warehousing, and operational activities at SURF.

The Fermilab Campus Master Plan[2] supports the implementation of the laboratory's strategic plan and major initiatives. Executing the plan and continuing an ongoing demolition program will reduce the number of buildings, trailers, and overall gross square footage. In FY 2017, overhead funds were used to complete demolitions totaling 11,497 GSF. The goal for FY 2018 is to complete demolitions totaling 6,709 GSF. During FY 2017, Fermilab added six buildings and three entries under Other Structures and Facilities (OSF) to the DOE's Facilities Information Management System (FIMS) inventory. In past years, the OSF category was used to report two substandard assets: electrical substations and the industrial cooling water system. These two assets are now reported as adequate due to the success of the SLI-funded Utilities Upgrade Project that mitigated the lab's highest infrastructure vulnerability.

Types and Conditions of Facilities

Types of Facilities	Number of Facilities			Gross Square Footage of Facilities		
	Adequate	Substandard	Inadequate	Adequate	Substandard	Inadequate
Other Structures and Facilities	53	0	0	--	--	--
Mission Unique Facilities	99	0	0	408,261	0	0
Non-Mission Unique Facilities	216	23	62	1,828,790	28,274	191,141

Fermilab completed the Laboratory Operations Board (LOB) infrastructure assessment in FY 2014. This provided an opportunity to extend the effort that began with the development of the Campus Master Plan by working with the scientific user community to validate the results of the plan and establish the campus strategy. Lab space accounts for 48% of the substandard and inadequate non-mission unique facility square footage, and two-thirds of the lab space is in light industrial-frame buildings constructed in the Fermilab Village shortly after the laboratory was founded. This space is planned for demolition in the future. The remaining 52% consists of real property trailers or residential houses constructed before the Fermilab land acquisition and is used for housing, office, and storage space. The trailers are planned for demolition as well.

In non-excess facilities with overall utilization less than 75%, there are 139,383 GSF identified as underutilized in FIMS, based on the space type utilization level. This includes space with utilization ranging from 0% to 70% within those facilities. There are eight assets currently identified as excess facilities in FIMS, totaling 8,181 GSF. While these facilities are planned for near-term demolition, they are still occupied and in use. Accordingly, the FY 2017 carrying costs for these facilities included annual actual maintenance and operating costs totaling $10,366. A pilot project to demolish two accelerator

[2] http://fess.fnal.gov/master_plan/index.html

service buildings, while preserving utilities necessary to serve underground experimental areas, has been completed, and 36 accelerator service buildings will be added to the excess facilities list and scheduled for demolition in the future. In total there are 83 buildings, some of which are currently occupied, identified for future excess. These include the accelerator service buildings, Fermilab Village lab buildings, and office trailers. Demolition estimates have been refined based on the pilot project, and an excess facilities project has been submitted for this SLI-GPP category. Excess characterization and priority data for these assets has been populated in FIMS, concurrent with submittal of the FY 2018 Annual Laboratory Plan. Full implementation of the master plan will relocate additional functions and personnel from geographically remote locations to the Central and Technical Campuses, thereby vacating legacy facilities that will also be slated for demolition.

Campus Strategy

Fermilab's strategy and major initiatives, as described in Section 4, are the principal factors driving site facilities and infrastructure planning. Science and technology mission needs are synchronized with site planning by flowing down laboratory strategy through the Campus Master Plan, which guides the actions of the Campus and Facility Planning Board that ensures coordination, communication, and prioritization for facilities projects. In addition to reducing inefficiencies associated with functional obsolescence and geographically dispersed facilities, the campus strategy represents a comprehensive approach to the development of Fermilab's future infrastructure. The Facilities Engineering Services Section works closely with the Chief Research Officer, experimental planning groups, project teams, the laboratory's Campus and Facility Planning Board, and the Office of Campus Strategy and Readiness to efficiently use existing facilities or develop plans to expand facilities. Infrastructure gaps are prioritized according to mission need.

The Campus Master Plan encompasses three design themes: modernization of facilities; consolidation and centralization of dispersed and inefficient support facilities; and preservation of the laboratory's unique character and identity. Three SLI-funded projects support the themes of the plan. Urgent needs to centralize, consolidate, and modernize scientific, technical, and engineering facilities will begin to be solved by the Integrated Engineering Research Center (IERC), with start of construction expected in FY 2019. The Utilities Upgrade Project is nearing completion with CD-4 expected in FY 2018. This project represents the type of investment needed for utilities modernization across the site. The Wilson Hall revitalization project will improve efficiencies and density in the lab's largest administrative building and includes enhancements that address Fermilab's role as host laboratory for LBNF/DUNE and PIP-II.

The campus strategy has four goals:

- Construct sustainable infrastructure that will attract international investment and the brightest minds to the world's leading laboratory for accelerator-based neutrino science
- Maximize productivity by establishing an atmosphere of *"eat-sleep-work to drive discovery"* that efficiently meets the needs of the scientific community
- Integrate into one geographic area the entire life cycle of research, engineering, fabrication, and operations expertise for accelerators and detectors
- Consolidate, centralize, and modernize to optimize operational resources, maximize efficiency, enhance communication, and foster succession planning

These goals address the laboratory's strategic plan and major initiatives by providing facilities and infrastructure to close identified infrastructure gaps that include:

- Sufficient space for project teams and international users to support Fermilab's role as host laboratory for LBNF/DUNE and PIP-II
- Centralized office and collaborative space for more efficient resource utilization

- Increased high-bay space for production facilities
- Modernized facilities with modular walls and furniture for efficient reconfiguration
- Short-term accommodations for a growing number of collaborating visitors and users
- State-of-the-art computing facilities

The Infrastructure Investment Table (sent under separate cover as Enclosure 4) provides a roadmap for planned investments for specific projects that are needed to close these gaps. The SLI-funded IERC project [see Section 4.2] is the highest priority infrastructure project for the laboratory in that it signifies to international partners that Fermilab is prepared to serve as host laboratory for LBNF/DUNE, and will be prepared to coordinate substantial in-kind contributions from international partners contributing to the project's construction. The IERC will bring scientific and technical resources that are currently

Artist's rendering of the Integrated Engineering Research Center adjacent to Fermilab's Wilson Hall.

scattered across the site into closer proximity to foster a more effective and efficient work environment. For scientific and technical personnel who will have both project and operational responsibilities, the IERC will enable them to perform both functions more effectively and shift more easily between activities. The IERC project received CD-1 ESAAB approval in April 2017. The project team has started the preliminary design phase, and expects a construction start in FY 2019. The construction of this building

begins to satisfy the most urgent needs to relocate resources to the Central Campus in accordance with the Campus Master Plan.

The master plan defines a Central Campus that is centered on Wilson Hall and includes a new scientific hostel (guesthouse) that fulfills the "sleep" portion of the *"eat-sleep-work to drive discovery"* theme. The hostel will meet the growing needs of short-term visitors, thereby supplementing the longer-term housing in the Fermilab Village. A schematic design and preliminary site selection has been completed. At the request of DOE/HEP, an alternatives analysis has been started to determine funding options for the scientific hostel. One funding option is SLI GPP due to the increase in the GPP limit to $20M. The Central Campus also includes the future site of the superconducting linear accelerator to be constructed through the PIP-II project, which replaces a major aging component of the existing accelerator complex and provides the beam power needed to support LBNF/DUNE. The Neutrino Campus is located west of the Central Campus, and construction of two new detector halls for the Short Baseline Neutrino program has been completed.

Artist's rendering of the scientific hostel located near the existing Lederman Science Center. Wilson Hall is shown in the background.

The laboratory is nearing completion of the first phase of the Wilson Hall 2.0 modernization that began in FY 2016 with $9M from SLI's GPP program. This project increases density through standardized floor plans and implements a standard for reconfigurable walls and furniture. This project will also establish better connectivity with the IERC. Other proposed projects that are candidates for GPP funding include expansion of the Central Utility Plant and Excess Facilities Removal projects.

A challenge for the Technical Campus is to provide the needed capability for production capacity given the limited availability of production space. The Technical Campus houses fabrication, production, and testing facilities for LCLS-II and PIP-II cryomodules, high-field magnets for CERN's LHC accelerator upgrade, and solenoids for the Mu2e project. The first step towards satisfying this infrastructure gap is to construct the Industrial Center Building High Bay Addition. This project will soon begin under the GPP program and will provide another critical element to fulfilling future science requirements.

The Utilities Upgrade Project will eliminate the lab's largest infrastructure vulnerability. However, the laboratory's utility infrastructure will continue to require further investment to accommodate ongoing operations and future mission needs. The laboratory's utility infrastructure currently comprises 71% of the site's total FY 2017 deferred maintenance backlog, or $22.3M of a total $31.6M. It is important to note that the Utilities Upgrade Project reduced deferred maintenance at the end of FY 2016 by $8.3M. The investment funding profile through FY 2029 (see Enclosure 4) includes investments in utility systems and building improvements that will eliminate more of the deferred maintenance backlog. While utility GPP projects identified in the lab's investment plan are an important part of controlling deferred maintenance growth, the investment via the SLI Modernization Initiative proved critical for improved utility reliability for existing and future science needs. The goal for a combination of ongoing maintenance at 2% of Fermilab's conventional replacement plant value, laboratory and Office of Science

GPP projects, SLI investment, and substantial demolition of facilities is expected to control the deferred maintenance backlog to an acceptable level.

Fermilab's core capabilities are subject to risks from deferred maintenance and infrastructure gaps. Previously, the highest ranked infrastructure risk was a potential failure of Fermilab's Master Substation. This risk has been mitigated now that the new substation is fully operational. Other significant infrastructure risks are associated with continued inefficiency in operations due to functionally obsolete buildings, geographically dispersed locations, utility failures due to aging systems, isolated downtimes due to localized failures, and resources consumed by excess facilities. Several legacy buildings in the Fermilab Village are still used for lab space and manufacturing facilities despite being classified as inadequate or substandard under the LOB assessment. A candidate for an FY 2018/2019 GPP crosscut is funding for the Excess Facilities Removal project. This project as well as other projects in the updated Campus Master Plan are part of the plan to relocate laboratory functions to modern facilities in the Central Campus.

In addition to planning associated with the 2018 update of the Fermilab Campus Master Plan, a second strategic planning effort is underway to identify opportunities to modernize facilities, increase efficiency, and reduce costs associated with operations of the Fermilab Accelerator Complex. In recent years, the accelerator complex has undergone a significant transition from colliding high-energy beams to producing high-intensity proton beams for neutrino and precision science. Even with the successful transition to a new operating mode, parts of the complex are more than 50 years old and DOE plans to run the complex well beyond 2040. While Fermilab's accelerator complex has transitioned, the laboratory's accelerator scientists and technical teams are developing transformational accelerator technologies for use across the DOE/SC complex and around the globe. These transitions, combined with the condition and age of Fermilab's accelerator facilities, drive the need to consolidate core research and operations functions and modernize key support facilities. This is the primary motivation for developing a strategic plan for the Fermilab Accelerator Complex for the LBNF/DUNE/PIP-II era.

A preliminary outcome from the strategic planning effort validates previously identified conclusions, namely that an Accelerator Science and Technology Center is needed to sustain the national and international accelerator science community with modernized R&D and operations capabilities. The current lack of a modern, efficient, centralized space for accelerator scientists and key mission support staff reflects an infrastructure gap. To address this gap and align future construction activities associated with the PIP-II upgrade to the accelerator complex, a beneficial occupancy date of 2025 has been established for this new building. This building will upgrade working conditions for more than 25% of the laboratory staff and will provide a modern workspace for visiting and collaborating national and international accelerator scientists. Co-locating accelerator scientists and their technical teams will allow better integration of the accelerator science, operations, and technology functions of the laboratory. Modernizing the control of the accelerator complex with state-of-the-art space for people to work in also presents an opportunity to rethink traditional approaches to the operation of large-scale user facilities. A tightly integrated modern approach will bring the expertise for accelerator operations, cryogenic operations, operations for R&D facilities, and experiment operations into a centralized location for improved efficiency across all of the laboratory's operations areas. Moreover, a new building will make it possible to decommission existing laboratory facilities that will be replaced by the modernized facilities needed in the LBNF/DUNE/PIP-II era and beyond. The goal is to achieve CD-0 approval for this building in FY 2018.

Site Sustainability Plan Summary

In FY 2017, Fermilab recommitted to an environmentally sound and sustainable future. The following notable sustainability accomplishments support Fermilab's ability to deliver on its mission.

- Used a state-funded program to identify 9,124 MWh and 94K therms of energy conservation measures
- Installed the first two electric vehicle charging stations for both fleet and personal charging
- Awarded a 7th annual Energy Star status for superior energy performance at the Grid Computing Center
- Completed a vulnerabilities screening to identify assets most vulnerable to likely climate impacts

Fermilab certified four new High Performance Sustainable Buildings (HPSB) in FY 2017 bringing the lab's status to 6% of total campus gross square footage (FY 2017 target is 15%). Fermilab continues to design new facilities to meet HPSB goals and has begun an initiative to develop net zero facility design standards. Fermilab traditionally funds projects with sustainability outcomes from conventional sources.

Fermilab maintains a sustainable fleet of vehicles. The lab manages 168 DOE owned and 27 GSA leased vehicles. From FY 2018 through FY 2020 the lab expects to replace 8 vehicles/year (no fleet additions planned).