Energy Systems Integration Facility (ESIF)

Facility Stewardship Plan

Revision 2.1

Martha Symko-Davies and Juan Torres
National Renewable Energy Laboratory

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

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Technical Report
NREL/MP-5B00-70567
January 2018

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Abstract

The U.S. Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy (EERE), has established the Energy Systems Integration Facility (ESIF) on the campus of the National Renewable Energy Laboratory (NREL) and has designated it as a DOE user facility. This 182,500-ft^2 research facility provides state-of-the-art laboratory and support infrastructure to optimize the design and performance of electrical, thermal, fuel, and information technologies and systems at scale. This Facility Stewardship Plan provides DOE and other decision makers with information about the existing and expected capabilities of the ESIF and the expected performance metrics to be applied to ESIF operations. This plan is a living document that will be updated and refined throughout the lifetime of the facility.

Revisions Log

Rev. No.	Date	Revision Description	Pages Modified
0.1	11/13/2013	Prepared initial draft	All
0.2	11/15/2013	Added discussion of real property assets as Section 5.1 Clarified changes made to discussion of research asset functional life in new Section 5.2 Added new Section 6.0 to describe User Program Updated Section 7 performance metrics table and definitions	14–20
0.3	12/12/2013	Revised significant content and format throughout	All
0.4	12/20/2013	Added megawatt capacity to description of Research Electrical Distribution Busses (REDB) Added new Section 9: ESIF Steering Committee Revised Section 10: Performance Metrics	4 26 27–29
0.5	12/31/2013	Made minor revisions throughout; submitted to EERE for review	All
1.0	1/24/2014	Made minor revisions throughout per EERE	All
1.1	4/1/2014	Updated Section 2: Research Objectives to conform with User Facility Plan Updated budget tables per FY 2015 request	3–5 21–27
1.2	9/16/14	Updated funding in tables 1–4 Updated Section 8.2 per FY 2015 capital plans Changed users to non-NREL organizations for the first metric in Table 5 and adjusted text in Section 10.1 Revised metrics in Table 5 to state both “committed” funding and “expended” and updated text in Section 10.4 Added conference papers and R&D 100 award to Section 10.3: Technical Output Submitted to DOE for FY 2014 approval (9/16/14)	21,22,23,26 24,25 29,30,31 29 31

Rev. No.	Date	Revision Description	Pages Modified
2.0	8/18/16	Rewrote and expanded Section 2: Research Objectives to conform with Quadrennial Energy Review (QER), Quadrennial Technology Review (QTR), Grid Modernization Initiative, and EERE Strategic Plan (Section 2.0) Changed System Performance Laboratory lab name (Section 4.2) Updated financial tables (Sections 8.0–Section 8.3) Updated REDB build-out plans (Section 8.2) Updated High Performance Computing and Data Center information with expansion/replacement plans (Section 8.3) Added new section describing management and administration costs and functions, including User Program (Section 8.4) Updated performance metrics table with FY 2014 and FY 2015 actuals and new goals for FY 2016 and FY 2017 (Section 10.0) Added new method for calculating facility availability and use in Section 10.2 Defined new performance goals for high-impact projects (Section 10.4) and projects in new mission space (Section 10.5) Defined capability hubs with floor maps (Appendix A)	2–6 9 18–23 20–21 22–23 24 26 27 28–29 30–37
2.1	9/25/17	Removed Appendix A Added research focus areas (Section 2.1) Changed Optimization and Control Laboratory name (Section 5.3) Updated sections on HPC and analysis and visualization equipment and costs (Section 7.0) Updated financial tables (Section 8)	4 17 23–25, 32–33 27–33

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1 Introduction

The U.S. Department of Energy (DOE) has established the Energy Systems Integration Facility (ESIF) on the campus of the National Renewable Energy Laboratory (NREL) in Golden, Colorado. The ESIF is a unique national asset that has the capability to catalyze the public and private sector research and development (R&D) necessary to accelerate the commercialization and adoption of renewable energy and energy-efficiency technologies into today's energy systems where they can operate synergistically with other energy resources and technologies. A focus of this research is to demonstrate how advanced energy systems technologies can improve the overall reliability, resilience, and security of energy systems at an affordable cost. This 182,500-ft.^{2} research facility, along with supporting capabilities across the NREL campus, provides a contained and controlled integrated energy systems platform upon which the research community and commercial partners can develop and evaluate both individual technologies as well as integrated systems approaches.

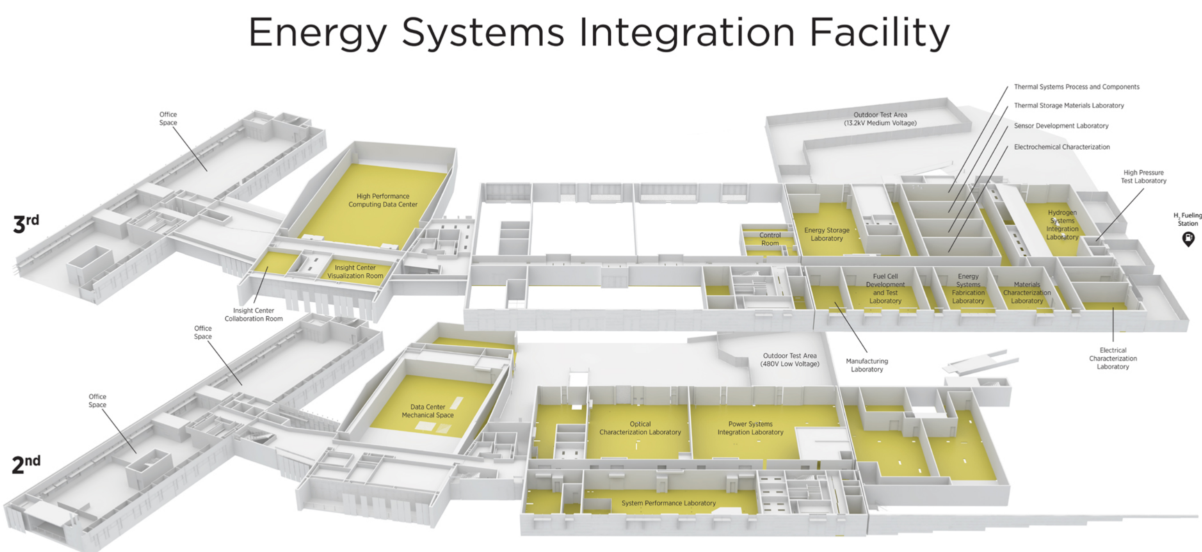

Figure 1. Energy Systems Integration Facility on the National Renewable Energy Laboratory campus

The ESIF is the nation's first research facility that can conduct integrated megawatt-scale research, development, and demonstration (RD&D) of the components and strategies needed to safely and seamlessly integrate clean energy technologies into energy systems infrastructure and utility operations at the speed and scale required to meet national goals. Through a combination of RD&D tools and approaches, the ESIF allows researchers, entrepreneurs, utilities, and other stakeholders the ability to identify and resolve the technical, operational, and financial risks of the large-scale integration of renewable energy and energy-efficiency technologies in today's environment.

Connected by common infrastructure, the ESIF's laboratories offer the following unique capabilities:

- **Hardware-in-the-loop (HIL) at megawatt-scale power:** HIL capabilities allow researchers and manufacturers to conduct integration tests at full power and actual load levels in real-time simulations and evaluate component and system performance before going to market. HIL capabilities can also be extended to much larger simulations of power and energy grids, and they can be connected remotely to capabilities located at other sites.
- **Research Electrical Distribution Bus (REDB):** The REDB is the ultimate power integration circuit, comprising two AC and two DC ring buses, and connecting multiple sources of energy and plug-and-play testing components in key ESIF labs.
- **Supervisory Control and Data Acquisition System (SCADA):** Integrated throughout the ESIF, a SCADA system monitors and controls the REDB operations, safety, and resilience and gathers real-time, high-resolution data for collaboration and visualization.
- **High Performance Computing and Data Center:** Petascale computing using Peregrine, NREL's high-performance computer (HPC), enables unprecedented large-scale numerical modeling, including the simulation of material properties, processes, and fully integrated systems that would otherwise be too expensive, too dangerous, or even impossible to study by direct experimentation.
- **Data analysis and visualization:** Analysis and visualization capabilities at the ESIF go beyond what is found in a typical utility operations center. The ESIF's fully integrated visualization tools allow researchers and NREL partners to see and understand complex systems and operations in a completely virtual environment.

Throughout the design and construction of the facility, more than 250 technical experts and potential users from numerous industries, laboratories, and universities were consulted to identify priority RD&D needs in energy systems integration. The resulting capabilities of the ESIF, both human and equipment, provide these external stakeholders access to high-value assets that one organization (e.g., business, university, utility) alone could not afford to build, maintain, and operate.

The Alliance for Sustainable Energy, LLC (Alliance) operates NREL for DOE. As such, the Alliance is a steward for the ESIF and charged with executing a robust user program to ensure that this national asset is leveraged to the greatest extent possible. This plan documents the stewardship model for the ESIF. It will be updated annually to summarize progress and revise performance metrics as needed. This plan complements the ESIF User Facility Plan, which is a public document that serves as a guide for the ESIF's users and provides the research community with information on how to access the ESIF's capabilities through the ESIF's user program.

2 Research Objectives

As described in the DOE *Quadrennial Energy Review*, the nation's electric grid provides reliable, affordable, and increasingly sustainable electricity to power our growing need for energy services (comfort, function, mobility, health, etc.) and serves as a platform the innovation needed to maintain our competitiveness in a global economy. The structure of this 20th century grid, however, cannot meet all the demands of the 21st century. The architecture of today's grid reflects its origin nearly a century ago as a one-way delivery system connecting large-scale generation remotely located from consumers, hierarchical control structures with minimal feedback, limited energy storage, and passive loads.

Five key factors challenge this existing architecture:

- Changing mix of types and characteristics of electric generation (e.g., distributed and clean energy)
- Growing demands for a more resilient and reliable grid (especially because of weather impacts, cyber attacks, and physical attacks)
- Growing supply-side and demand-side opportunities for customers to participate in electricity markets
- Interdependencies with other energy infrastructures (e.g., natural gas, water, communications networks) along with the emergence of interconnected electricity information and control systems
- Aging electricity infrastructure.

A modernized grid will be essential for the prosperity, competitiveness, and innovation of a U.S. economy that increasingly relies on high quality power, and the grid's transformation to lower carbon power and more efficiency will be a critical part of enabling a global clean energy economy. It must deliver reliable, affordable, and clean electricity to consumers where they want it, when they want it, and how they want it, while maintaining flexibility for change and providing a platform for innovation. Additionally, a modernized grid must integrate customers and their end-use decisions into grid operations. The DOE *Quadrennial Technology Review* outlined in further detail the technology challenges and R&D opportunities that exist to transform the grid and enable a cleaner energy future.

To deliver on this vision for the future grid, DOE has developed the Grid Modernization Initiative (GMI) and an associated Grid Modernization Multi-Year Program Plan (MYPP) to guide future investments in RD&D projects to accelerate the transformation of the nation's electric grid. The MYPP envisions R&D in six Technical Areas:

- **Devices and Integrated Systems Testing:** enabling new grid services from emerging distributed energy resources (DERs) (e.g., distributed generation, buildings, vehicles, fuel cells, storage)
- **Sensing and Measurements:** reducing the cost and increasing the performance of sensing technologies at all levels of the grid (device, distribution, and transmission) and better extracting useful information from the data collected

- *System Operations, Power Flow, and Control*: developing new methods for real-time control of the electric grid, taking into account the proliferation of emerging technologies and DERs
- *Design and Planning Tools*: advancing and accelerating tools for planning distribution systems with large numbers of DERs while taking into account inherent uncertainties in where and how DERs will be connected to the grid
- *Security and Resilience*: more capably detecting threats to the reliable and secure operation of the grid while developing standards for device-level and system-level resilience
- *Institutional Support*: providing analysis and technical assistance to support stakeholders in changing their policies, regulations, and markets as needed to support modernizing the grid.

In parallel, EERE has incorporated the following grid integration objectives into its Strategic Plan via its Goal 5: Enable the Integration of Clean Electricity into a Reliable, Resilient, and Efficient Grid:

- By 2020, enable DERs to supply up to 50% of the electricity, on average, across a safe, reliable, and cost-effective distribution system.
- By 2025, enable up to 35% of the nation's electricity to come from variable generation resources while also achieving a safe, reliable, and cost-effective power system.
- By 2035, develop the technologies and tools for active devices (including smart buildings, electric vehicles, and distributed generation) to provide 10% of grid flexibility needs.
- On an ongoing basis, provide to regulators, policymakers, and other stakeholders the technologies, tools, and technical assistance needed to modify policies, markets, and other institutions as needed to achieve these goals.

The ESIF provides the technical capabilities and research infrastructure needed to address all of the above grid modernization research challenges needed for a more rapid transition of the Nation's electric grid and related energy infrastructure into a cleaner, more intelligent and modernized energy system. Already since its opening in September 2013, the ESIF has been home to more than 100 industry and academic partners who have used ESIF capabilities and facilities to conduct critical R&D in these areas. As the flagship facility for DOE's GMI and related programmatic research programs, the stewardship and operation of the ESIF must therefore be directly aligned with the department's mission, the QER, the QTR, the MYPP, the EERE Strategic Plan, and program-specific research objectives. With the advice and oversight of an ESIF Steering Committee, these plans and priorities will be used to allocate ESIF resources as well as to set the future direction for development of further ESIF capabilities.

2.1 Research Focus Areas

Researchers in the ESIF are tackling the major challenges facing the nation's energy system. How do we incorporate new technologies into our existing energy infrastructure? How do we operate a system with higher levels of variable supply and demand? How do we keep the lights on and the fuel flowing in a world of extreme weather events, cyber threats, and aging infrastructure?

Our research efforts focus on developing, evaluating, and demonstrating innovative technologies and strategies to ensure that our energy sources, demand response programs, and delivery systems can work together optimally as a system. Our research focus areas include:

- **Renewable electricity-to-grid integration:** At the ESIF, we can test out renewable technologies at actual power before interconnection with the grid. This helps manufacturers learn how to design these technologies to seamlessly integrate with the system, and it raises the confidence of utilities and investors to support their integration.
- **Vehicle-to-grid integration:** Our work focuses on building the infrastructure and integration needed for vehicles—primarily electric vehicles and hydrogen fuel cell vehicles—and the grid to work together and benefit each other.
- **Renewable fuels-to-grid integration:** NREL is researching how hydrogen and other renewable fuels offer new ways to integrate our energy systems. Renewable fuels can serve as potential storage mediums for electric power that can either be used to fuel vehicles or converted back into electricity. Electrolyzer technologies also offer ancillary grid services to utilities.
- **Building-to-grid integration:** This work focuses on how buildings, which are the largest use of electricity in the United States, can provide a range of grid services to enhance energy efficiency and reliability of the grid. It covers research from homes to commercial-scale buildings and how to integrate smart functionalities to better manage energy.
- **Battery and thermal energy storage:** NREL examines how best to integrate these energy storage technologies into the electric grid and potentially into other energy systems, such as building heating supplies and electric vehicles. NREL is also creating better materials for batteries and thermal storage devices to improve their performance and lower costs.
- **Microgrids:** The megawatt-scale capabilities of the ESIF allow manufacturers and integrators to test out their technology or configuration at actual power before implementation—something that is possible at only a handful of facilities in the world.
- **Autonomous energy grids:** This research focuses on developing advanced nonlinear control and optimization theory for energy grid operations and how to best used new big data analytics and machine learning techniques to make better decisions for real-time grid control.
- **Cybersecurity and resilience:** NREL's Cyber-Physical Systems Security and Resilience Center is located in the ESIF and serves as an independent resource for utilities and energy-sector companies to evaluate the security of new technologies and get objective insights on organizational cybersecurity efforts from experts in the field.
- **Smart home and building systems:** The ESIF is a one-of-a-kind testing space that connects appliances, a home, or even a community to an end-to-end energy ecosystem.

By incorporating power generation, energy storage, and end loads into the facility, researchers can simulate real-world conditions in a controlled laboratory environment.

- **Energy-water nexus and energy systems integration:** The ESIF enables researchers to consider the relationships among electricity, thermal, water, and fuel systems and data and information networks to ensure optimal integration and interoperability across the entire energy system spectrum.
- **HPC and visualization:** Peregrine, the largest HPC system in the world exclusively dedicated to advancing renewable energy and energy-efficiency technologies, is located in the ESIF. The HPC system enables unprecedented large-scale numerical models for studying and simulating material properties, processes, and fully integrated systems that would otherwise be too expensive, too dangerous, or even impossible to study by direct experimentation.

3 Research Infrastructure

The ESIF incorporates extensive electrical, thermal, fuels, and data acquisition research infrastructure throughout the facility. These research buses tie all of the individual laboratories together and allows interconnection of equipment between laboratories, as well as rapid reconfiguration of systems under test. These research infrastructures and the equipment needed for connection to them have a continuing demand for routine maintenance and replacement. This aspect of ESIF operations demands planned funds, staffing, and time on the buses for effective maintenance. These costs are detailed further in Section 8.

3.1 Research Electrical Distribution Bus

The Research Electrical Bus (REDB) is the heart of the ESIF's electrical system testing capability, facilitating power flow between fixed equipment, as well as equipment under test located throughout the testing laboratories. Research activities conducted on the REDB will support the DOE Core Competency in Power Systems and Electrical Engineering. The research community will be able to use this asset to advance its understanding of electromagnetic phenomena and enable the design and engineering of circuitry, electrical and electronic devices and equipment, sensors, instruments and control systems to address the efficiency and reliability of power transmission systems and grid interface of variable generation.

The REDB includes AC and DC buses and related switchgear, and has been designed to maximize flexibility while minimizing the associated risks. Each REDB bus consists of a centralized ring-bus connected through feeders to each of the individual labs. Electrically operated switches are used to control connections to the ring-bus. These switches can also isolate portions of the ring-bus allowing multiple experiments to be performed simultaneously on the same bus. This capability is a unique approach to configuring electrical systems and the approach of operating more than one experiment on a bus demands exceptional understanding of the architecture and safety systems. As the use of ESIF expands, there will be a demand to train and qualify more engineers and safety staff to assure maximum effectiveness while maintaining absolute control of the configurations for personnel protection.

Currently there are two AC and two DC buses, with the capacity to expand to four buses each. The AC buses are four-wire and rated at 600 V and can support variable frequencies from 16 2/3–400 Hz. Currently the AC buses are rated at 250A (200-kW capacity) and 1,600 A (1-MW capacity). Configuring these systems to interconnect and support control with data collection requires high-voltage connection units and special carts that are designed and built on-site. The AC buses, or isolated portions thereof, may be operated with the neutral grounded or floating. The DC buses are three-wire and rated at +/- 500 V from pole to common or 1,000 V from negative to positive pole. Currently the DC buses are rated at 250 A and 1,600 A. Future build-outs should consider increasing capacity up to 2,500 A (2-MW capacity). The DC buses, or isolated portions thereof, may be operated with the common grounded or floating.

3.2 Thermal Distribution System

The ESIF's integrated thermal distribution system consists of a thermal water loop connected to a research boiler and chiller that provide precise and efficient control of the input water temperature delivered to laboratories within the ESIF. Research activities conducted on the thermal distribution system will support the DOE Core Competency in Mechanical Design and Engineering by allowing study and testing of heating, ventilating, and air-conditioning (HVAC) systems as well as combined heat and power applications that require controlling input water temperature or capturing waste heat.

The 750,000 Btu-hour condensing type boiler heats water with a high efficiency (> 90% higher heating value) by using the waste heat in the flue gases to preheat the cold water entering the boiler. The boiler has a modulating gas valve to control the output of the burner to match the load, with a minimum turndown ratio of 10 (e.g., allowing operation as low as 10% of its full load level).

The 60-ton chiller cools water with continuous thermal control using hot gas bypass in one stage to divert hot, high-pressure refrigerant vapor from the discharge line directly to the low-pressure side of the system. This allows for variable loads on the evaporator, keeps the compressor more fully loaded and allows for efficient operation over a wide range of expected varying demands for chilled water.

3.3 Fuel Distribution Systems

The ESIF's integrated fuel distribution systems provide natural gas, diesel fuels, and hydrogen throughout the laboratory space for a variety of potential applications. Standard, laboratory-grade natural gas supply is provided to ESIF labs through a utility connection. Diesel fuel is available in two ESIF laboratories: the Power Systems Integration Lab (PSIL) and the Energy Storage Lab (ESL). Each of these labs is equipped with a 50-gallon "day tank" for diesel fuel and supply lines throughout their lab space.

Utility-connected electrolyzers located in the Energy Systems Integration Laboratory (ESIL) deliver semiconductor-grade hydrogen (99.999+% purity) for use in the ESIF's laboratories. Oxygen produced during electrolysis is directly vented to atmosphere. The hydrogen is stored at 450 psi (the electrolyzer operating pressure), regulated down, and provided for general use at 200 psi through ¼-in. diameter distribution lines. An outdoor test pad next to the ESIL is designed to house equipment enabling hydrogen compression (for use in high pressure test cells) and storage (for supply to a vehicle dispensing pad) to 750 bar pressure. Supply lines to the compressors are ¼ in. in size.

3.4 Supervisory Control and Data Acquisition System

Integrated throughout the ESIF, a SCADA system monitors and controls the safety systems within the building and also gathers real-time, time-synchronized, high-resolution data for collaboration and visualization. Extensive measures have been built into the system to ensure reliable data capture and protection. Secure, segregated accounts are created to allow users to access the data collected from their own experiments, while ensuring the integrity of proprietary and sensitive information. Experimental data (voltage and current) can be taken at points on each portion of the REDB at 128 samples/cycle to ensure valid waveform measurements.

3.5 Control Room

The ESIF Control Room allows system engineers to configure and monitor experiments across the ESIF's laboratories and research infrastructure. It also serves as the monitoring point for the ESIF's integrated safety and control systems. The Control Room hosts an array of 18-in. by 55-

in. monitors that can be configured as needed for operational needs or experiment control, connection to the ESIF's SCADA system, secure connections to partner networks, researcher workstations and standalone computer connections.

3.6 Fixed Equipment

The ESIF also hosts a wide array of fixed equipment to support component and system testing. At present, these include grid simulators, load banks, photovoltaic (PV) simulators, DC power supplies, real-time digital simulators, and other hardware that will be required to provide dynamic simulation of emerging future energy systems.

3.7 Common Utilities

Most ESIF laboratories are equipped with the following:

- Power: Three-phase 480/277 V_{AC}, 208/120 V_{AC}, 240 split-phase V_{AC} and 120 single-phase V_{AC}
- Water: process heating and cooling, and research cooling (chilled water)
- Dedicated exhaust
- Natural gas
- Compressed air
- Nitrogen
- House hydrogen.

3.8 Office Space

The ESIF's office area consists of two floors with space for 200 research staff (100 spaces per floor), with designated space set-aside for commercial partners and users of the ESIF. All offices are modular and designed to benefit from 100% daylighting much of the year. Each floor has five hard-walled huddle rooms, a kitchen unit, and a central copy/printer/mail room. Natural light enters deep into the ESIF through 15-ft long skylights and large expanses of clerestory glazing, allowing electrical lights to be shut off between 10 a.m. and 2 p.m. daily in the office and laboratory buildings.

The Office Area heating and cooling systems consist of an air-handling unit that delivers the conditioned ventilation air thru the under-floor air distribution system and an active beam system. The office air-handling unit has a design capacity of 24,000 cubic feet per minute (with a minimum outside air of 6,500 cubic feet per minute) and consists of a prefilter, heating coil, fan section, cooling coil, and a final filter. The office space also has supplemental natural ventilation that consists of operable windows at the perimeter, return fans, and a set of relief air louvers at the center of the office space. This enables natural cooling and ventilation throughout the building, and solar powered fans aid in extracting heat from offices.

The active-beam system also provides both heating and cooling within the space. The active-beam system consists of pipes that are passed through a "beam" and a transfer fan that supplies air to the beam. The active beams are located along the perimeter and can changeover from heating to cooling and vice versa.

4 Electrical Systems Laboratories

Each of ESIF's electrical systems laboratories are designed and equipped for RD&D projects involving key electrical components of emerging integrated future energy systems. These laboratories each offer potential for single large experiments designed to apply several components in a closed loop or connected to external hardware or simulations.

The highly flexible design of these laboratories allows them to be safely divided into multiple test stand locations ("capability hubs") to enable work on independent equipment development and experimentation by multiple users. This design also allows maintenance to occur in one or more sections of a lab while work continues elsewhere, ensuring maximum availability and function to the user community.

These laboratories can be connected through the various Research Infrastructures (Section 3) to create a flexible and self-contained "energy system" that allows integration tests at full power involving multiple sources of energy and load. This unique feature of the ESIF allows researchers and engineers to tackle major renewable energy integration challenges, such as:

- **Link renewables to dynamic load control:** Demonstrate technology to control loads dynamically without affecting occupant comfort on various scales (including single building, campus and multisite) to smooth solar PV variability. Integrate with real-time predictive models of PV and wind energy generation and loads.
- **Link renewables to energy storage:** Demonstrate the same concept as dynamic load control with energy storage (such as battery vehicle-to-grid, natural gas through compressed air energy storage, and large-scale hydrogen). Validate the performance of local energy storage to reduce the variability of solar at the distribution level. Integrate at test using power HIL to evaluate storage at various distribution locations and feeder types or in larger transmission systems.
- **Link renewables to natural gas:** Demonstrate the ability to have renewable energy work synergistically with natural gas generators at both the local level where waste heat can be collected and used, and at the larger system level to reduce system variability.
- **Distributed control architectures:** Develop new grid architectures that enable cell controllers to allow microgrids for improved reliability and security. Link power system controls that integrate combined heat and power applications for wind and solar energy systems to demand controls.
- **Enable grid-compatible and transactive building energy use:** Use advanced sensors and control technologies to modify high energy, low energy building use and campus load shapes. High penetrations of these distributed buildings might be able to provide new services to utilities based on new load models.
- **Sustainable transportation:** Develop and apply large-scale transportation system simulation scenarios highlighting options for charging, fuel flexibility, and response to events affecting availability and cost. Support modeling and simulation through demonstrations of vehicles that can be recharged or refueled in a variety of ways, including through response to signals driven by changes in the availability of renewable energy or changes in grid condition.

The capabilities and key research equipment in each of the ESIF's electrical systems laboratories is described in the following subsections. Research activities conducted in these laboratories support the DOE Core Competency in Systems Engineering and Integration by allowing users to develop and design new controls, models and feedback loops that communicate among individual electrical, thermal, fuel and water components of emerging future energy systems to enable interoperability and overall system performance.

4.1 Power Systems Integration Laboratory

The Power Systems Integration Laboratory is designed for developing and testing large-scale distributed energy system components for grid-connected, stand-alone, and microgrid applications. The laboratory can accommodate large power system components such as inverters for PV and wind systems, diesel and natural gas generators, battery packs, microgrid controllers, interconnection switchgear, and vehicles. Closely coupled with the REDB, the Power Systems Integration Laboratory will offer power testing capability of megawatt-scale DC and AC power systems, as well as advanced HIL and model-in-the-loop simulation capabilities. Thermal heating and cooling loops and fuel supply systems also allow testing of combined heating/cooling and power systems.

In addition to common utilities, the Power Systems Integration Laboratory features:

- 8,600-ft^2 working space (enough for three 40-ft and three 20-ft shipping containers)
- 30-ft high ceilings
- 30-ft high overhead roll-up doors
- In-floor carbon monoxide exhaust systems
- Diesel storage tank
- AC and DC power sources.

Types of research that can be done in the Power Systems Integration Lab might include:

- Development of control algorithms for power electronics to enhance grid stability and reliability with DR including variable renewables imparting bidirectional flow on distribution feeders.
- Simulation of grid conditions for development and evaluation of advanced power system components and systems that can provide new grid services
- Development and evaluation of optimal dispatch algorithms and communication interfaces
- Electrical interconnection testing (i.e., IEEE 1547, UL 1741 types of tests).

4.2 System Performance Laboratory

The System Performance Laboratory is designed for the development and integration of smart residential energy technologies including the integration of DERs and renewable energy resources through power electronics and smart energy management for building applications. The laboratory is designed to be highly flexible and configurable, capable of supporting a variety of typical household appliances. The System Performance Laboratory can be used for a variety of smart power applications that range from developing advanced inverters and power converters to testing residential and commercial scale meters and control technologies. Through connections to the REDB and SCADA system, the laboratory can also serve as the residential node for any integrated system experiments involving building-to-grid interactions.

In addition to common utilities, the System Performance Laboratory features

- 5,300-ft^2 working space
- Three residential home test bays fitted with appliances and other typical loads
- Connections in each test bay for 120/240-V electric service, water, and natural gas
- Individual breaker panels and residential advanced metering infrastructure for each test bay
- Environmental chambers that can incorporate location-specific HVAC loads
- Distribution transformers and associated monitoring equipment for each test bay
- Cybersecurity test bed.

Types of research that can be done in the System Performance Laboratory might include:

- Testing of advanced appliances, home automation, HVAC, and energy management systems in collaboration with industry, academia, and other research stakeholders
- HIL modeling involving household loads and distributed generation
- Innovation in advanced metering, residential batteries, and home energy management systems
- High-resolution study of interactions between the distribution system and residential loads
- Development of effective building control architectures, sensors, and interoperation platforms
- Optimal strategies for building resilience during extreme weather events.

4.3 Energy Storage Laboratory

The Energy Storage Laboratory is designed for the integration of energy storage systems (both stationary and vehicle-mounted) and interconnection with the utility grid. Focusing on battery technologies, but also hosting ultracapacitors and other electrical energy storage technologies, the laboratory provides all resources necessary to develop, test, and prove out stationary or mobile energy storage system performance and compatibility with distributed energy systems. The Energy Storage Laboratory is designed to ensure personnel and equipment safety when testing hazardous battery systems or other energy storage technologies. Through connection to the REDB and SCADA systems, the Energy Storage Laboratory can provide megawatt-scale power testing capability as well as advanced HIL and model-in-the-loop simulation capabilities.

In addition to common utilities, the Energy Storage Laboratory features 9,600-ft^2 of space, which can accommodate:

- Up to two 20-ft. shipping containers
- Large commercial vehicles up to city-bus size
- Large battery systems, power electronics packages, and integrated system tests
- Housing for a planned large drive-in environmental chamber (-40ºC to 140ºC with humidity control) for testing commercial-sized hybrid, electric, biofuel, compressed natural gas, and hydrogen vehicles
- Robust safety design to handle any kind of battery or energy storage system.

Types of research that can be done in the Energy Storage Laboratory might include:

- Performance assessments of batteries, power conversion equipment, capacitor systems, or DC systems such as commercial microgrids
- Long-duration reliability and safety tests of battery or energy storage system components
- Development of economic models for energy storage systems via HIL tests driven by market signals and grid conditions requiring multiple services from energy storage.

4.4 Electrical Characterization Laboratory

The Electrical Characterization Laboratory supports detailed testing of electrical components and systems. This laboratory allows researchers to test the ability of electrical equipment to withstand high-voltage surges and high current faults, including equipment using standard and advanced fuels such as hydrogen. It is designed as a safe and secure environment that can survive destructive testing of electrical equipment. A separate control room provides a safe location for researchers with video links into the main test area.

In addition to common utilities, the Electrical Characterization Laboratory features:

- 1,500-ft^2 with a separate control room and exterior entrance
- Integrated safety programmable logic controller systems
- Separate ventilation system
- Electrical service and testing area designed to be Class 1, Division 2 approved
- High-current surge tester
- High-voltage surge tester
- High-speed data acquisition and secure data storage.

Types of research that can be done in the Electrical Characterization Laboratory might include:

- Testing of electrical equipment to meet specific surge capabilities (e.g., lightning strikes)

- Testing new, unproven, or potentially hazardous equipment for robust safety assessment prior to use in other labs at the ESIF
- Evaluation of proprietary or sensitive equipment in a controlled and secure environment.

4.5 Energy Systems Integration Laboratory

The ESIL provides a flexible, renewable-ready platform for research, development, and testing of state-of-the-art hydrogen-based and other energy storage systems. The main focus of the laboratory is assessment of the technical readiness, performance characterization, and research to help industry move these systems towards optimal renewable-based production and efficient use of hydrogen. Research conducted in the ESIL will advance engineering knowledge and market deployment of hydrogen technologies to support a growing need for versatile distributed electricity generation, applications in microgrids, energy storage for renewables integration, and home and station-based hydrogen vehicle fueling.

In addition to common utilities, the ESIL features:

- More than 3,000-ft^2 of monitored Class I, Division 2 approved test space
- Large test bays to accommodate various sized electrolyzers, fuel cells, and related systems
- Two high-pressure testing bays fully rated for testing systems to 15,000 psig
- A large adjacent outdoor testing area for hydrogen storage, compression, or other large equipment
- A 600-ft^2 control room
- An electrical room
- Combustible gas monitoring
- Automated monitoring and control systems.

Types of research that can be done in the ESIL might include:

- Close- and direct-coupling of renewable energy sources (PV and wind) to electrolyzers
- Performance and efficiency validation of electrolyzers, fuel cells, and compressors
- Reliability and durability tracking and prediction
- Equipment modeling and validation testing
- Internal combustion or turbine technology for electricity production
- Safety and code compliance.

4.6 Outdoor Testing Areas

ESIF's outdoor testing areas allow utilities and researchers to evaluate electrical distribution-level equipment. The Low Voltage Outdoor Test Area (LVOTA) is designed for the testing and integration of 480-V class systems. In addition to its test bays, the LVOTA features three diesel generator sets (80 kW, 120 kW, and 300 kW) and two 30-kW Capstone natural gas micro-turbines that can be used for experiments, to include complex microgrids and hybrid diesel/natural gas/renewable energy systems. The ESIF's 1-MW load bank is also housed in LVOTA. This highly unique and specialized load bank contains resistive, inductive, and captive elements that allow it to create any power factor in load step size of 50 W. LVOTA test areas are connected via the REDB, allowing tremendous flexibility for testing at megawatt levels.

The Medium-Voltage Outdoor Testing Area (MVOTA) is designed to support systems up to 13.2 kV. The MVOTA is arranged with reclosing breakers to simulate two utility distribution feeders at the medium voltage range (4-kV to 34-kV is the "typical" range for medium voltage, while MVOTA is 13.2 kV). The MVOTA has been designed to accommodate a wide variety of other fixed equipment in the future including 1,000-kVA network protectors, utility reclosers, additional 200-A switch cabinets, additional transformers, load banks, and line impedance simulators. The MVOTA contains two 20-ft by 40-ft and three 10-ft by10-ft test pads that facilitate easy configuration and connection of a test article to the REDB at either 13.2 kV or 480 V.

The Rooftop Test Area is a planned area for future testing of experimental equipment that requires unshaded solar access. Examples include PV arrays, concentrating solar power (CSP) systems, solar hot water systems, and HVAC units. The Rooftop Test Area's original design included an elevated metal test platform with connection to the REDB, as well as connections to house power. At present, the roof top test area consists only of platform supports (no utilities) and will require extensive future development and construction for larger projects.

5 Thermal Systems Laboratories

The ESIF's thermal systems laboratories are designed and equipped for RD&D projects involving key thermal components of emerging integrated future energy systems. Several of these feature capabilities particularly suited for R&D of high-temperature working fluids and thermal materials typical of CSP applications.

The highly flexible design of these laboratories allows them to be safely divided into multiple test stand locations to enable work on independent equipment development and experimentation by multiple users. This design also allows maintenance to occur in one or more sections of a lab while work continues elsewhere, ensuring maximum availability and function to the user community.

The capabilities and key research equipment in each of the ESIF's thermal systems laboratories is described in the following subsections. Research activities conducted in the ESIF's thermal systems laboratories support the DOE Core Competency in Applied Materials Science and Engineering by allowing users to better understand and characterize the performance of materials in hostile thermal environments. This knowledge will lead to improved efficiency, economy, cost-effectiveness, environmental acceptability, and safety in thermal energy generation technologies and systems.

5.1 Thermal Storage Materials Laboratory

The Thermal Storage Materials Laboratory investigates materials that can be used as high-temperature heat transfer fluids or thermal energy storage media in CSP plants. Research objectives include the discovery and evaluation of candidate fluids and phase change materials to serve as working fluids or thermal energy storage media in the temperature range from 300°–800°C. Experiments conducted in this laboratory work to enable higher temperature operation of CSP systems, leading to higher efficiency and lower cost.

In addition to common utilities, the Thermal Systems Process and Components Laboratory features:

- 950-ft^2 of laboratory space
- Differential scanning calorimeter (to 1,200°C)
- Thermal gravimetric analyzer (to 1,100°C)
- High-temperature rheometer (to 1,100°C)
- Controlled atmosphere furnace (to 1,100°C)
- Densitometer
- Glovebox with HEPA filtration
- Analytical balances and general chemistry supplies.

Types of research that can be done in the Thermal Storage Materials Laboratory might include:

- Preparation of thermal storage materials that are sensitive to moisture, oxygen or trace gases
- Evaluation of thermo-physical properties such as melting point, heat of fusion, density, viscosity, and thermal stability of candidate materials.

5.2 Thermal Systems Process and Components Laboratory

The focus of the Thermal Systems Process and Components Laboratory is to support R&D, testing, and evaluation of new thermal energy storage systems that are relevant to utility-scale CSP plants. The laboratory holds test systems that can provide heat transfer fluids for the evaluation of heat exchangers and thermal energy storage devices. These test systems have the capacity to handle molten salt rated to 800°C, nitrate salt rated to 600°C, or other heat transfer fluid compositions such as hot air, carbon dioxide, steam systems, or other working fluids that might have been characterized previously in the Thermal Storage Materials Laboratory next door or at other laboratories.

In addition to common utilities, the Thermal Systems Process and Components Laboratory features:

- 950-ft^2 of laboratory space
- Four 10-ft. by 10-ft. test bays for evaluation of 30-kW thermal systems
- Custom test system to provide hot salt or molten metal heat transfer fluid to the test device
- Thermal energy storage process test loops
- Outdoor air feed and exhaust for system cooling
- HEPA-rated enclosure for testing systems containing nanomaterial.

Types of research that can be done in the Electrical Characterization Laboratory might include:

- Thermal energy storage system testing through multiple charge and discharge cycles
- Evaluation of heat exchanger performance and storage efficiency
- Testing of instrument and sensor compatibility with hot heat transfer fluids
- Evaluation of supercritical heat transfer fluids such as steam or carbon dioxide.

5.3 Optimization and Control Laboratory

The Optimization and Control Laboratory (OCL) is designed to be highly flexible and configurable, capable of supporting a variety of research. In addition to providing state-of-the-art characterization and testing capabilities for assessing large test articles including optical performance for various PV and CSP technologies, the OCL uses HIL research capabilities to integrate and optimize building technology. The laboratory features large, open test bays with high ceilings to accommodate large test articles.

In addition to common utilities, the Optimization and Control Laboratory features:

- Large environmental chamber
- REDB (AC & DC)
- Upgraded electrical house power
- Domestic water tap.

Types of research that can be done in the Laboratory might include:

- Integrated residential and commercial buildings testing
- Large inverter testing
- Integrated environmental testing of inverter and power systems components
- Structural analysis and testing to support detailed CSP system design
- Testing of advanced materials and geometries for receiver tubes
- HIL testing of advanced power blocks and/or thermal storage units.

6 Fuel Systems Laboratories

ESIF's fuel systems laboratories are designed and equipped for RD&D projects involving key transportation fuel components of emerging integrated future energy systems. ESIF's laboratory capabilities are particularly well suited for R&D of advanced fuel cell and electrochemical cell technologies, providing a complete suite of capabilities to help users move novel hydrogen and fuel cell concepts from ideas to market.

The highly flexible design of these laboratories allows them to be safely divided into multiple test stand locations to enable work on independent equipment development and experimentation by multiple users. This design also allows maintenance to occur in one or more sections of a lab while work continues elsewhere, ensuring maximum availability and function to the user community.

The capabilities and key research equipment in each of the ESIF's fuel systems laboratories are described in the following subsections. Research activities conducted in the ESIF's fuel systems laboratories support the DOE Core Competency in Systems Engineering and Integration by allowing users to develop and design new fuel system controls, models and feedback loops that communicate with electrical and thermal components of emerging future energy systems to enable interoperability and overall system performance.

6.1 Manufacturing Laboratory

The Manufacturing Laboratory focuses on developing methods and technologies that will assist manufacturers of hydrogen and fuel cell technologies, as well as other renewable energy technologies, to scale up their manufacturing capabilities to volumes that meet DOE and industry targets. The laboratory's diagnostic capabilities can address a wide range of materials, including polymer films, carbon and catalyst coatings, carbon fiber papers and wovens, and multilayer assemblies of these materials, as well as ceramic-based materials in pre- or post-fired forms.

In addition to common utilities, the Manufacturing Laboratory features:

- A continuous roll-to-roll processing line suitable for 6-in.–18-in.-wide webs
- Benchtop roller prototype
- Infrared camera detector with various optics and excitation strategies
- Dual laser thickness instrumentation
- Ultralow force pneumatic caliper.

Types of research that can be done in the Manufacturing Laboratory might include:

- Coating, casting, deposition of functional layers, drying or curing of novel fuel cell materials
- Nondestructive techniques for measurement of critical fuel cell material properties
- In-line validation of quality control techniques for manufacturers
- Application to organic and thin film PV and battery technologies.

6.2 Energy Systems Fabrication Laboratory

The Energy Systems Fabrication Laboratory is designed for manufacturing and testing components for fuel cells and electrochemical cells using a variety of manufacturing techniques. Fabricated components include catalysts, thin-film and gas diffusion electrodes, and membrane electrode assemblies (MEAs). The main focus of the laboratory is to provide support for fuel cell research that is performed in adjacent laboratories. The laboratory enables NREL to manufacture fuel cells in-house using, for example, experimental catalyst developed at NREL. It further enables the creation of MEAs containing artificial defects required for the systematic study of performance and lifetime effects and the evaluation of in-house and externally developed quality control diagnostics for high-volume production of fuel cell. Experiments performed in the laboratory focus mainly on the development of alternative fuel cell manufacturing methods.

6.3 Materials Characterization Laboratory

The Materials Characterization lab supports the physical and photo-electrochemical characterization of novel materials. In this laboratory, a suite of analytical instrumentation and techniques enables the characterization of unknown material samples. This laboratory is currently transitioning its utility to better serve energy systems integration basic science including energy storage and biofuels analysis. Laboratory services include dedicated gas supplies, gas detection, chemical fume hoods, a ventilated enclosure, and standard chemical laboratory services: house air, nitrogen, and hydrogen supply.

6.4 Electrochemical Characterization Laboratory

The Electrochemical Characterization Laboratory is designed for evaluating the electrochemical properties of novel materials synthesized by various techniques and understanding and delineating the reaction mechanisms within electrochemical fuel cells. These activities can provide practical solutions to issues of cost, performance, and durability facing proton exchange membrane fuel cells.

Example activities that could be conducted here include:

- Determination and benchmarking of novel electrocatalyst activity
- Determination of electrochemical surface area
- Determination of electrocatalyst and support corrosion resistance and durability
- Synthesis and characterization of novel electrocatalyst
- Determination of fundamental electrochemical parameters
- Estimation of electrocatalyst use.

6.5 Energy Systems Sensor Laboratory

The Energy Systems Sensor Laboratory is designed to support the research, development, testing, and evaluation of advanced hydrogen sensor technologies to support the needs of the emerging hydrogen infrastructure. Information gained from the sensor testing can aid sensor technology development, selection and deployment, and development of codes and standards.

The laboratory also provides support to end-users, including assessment of technologies to be used in applications and deployment.

The laboratory contains a sophisticated sensor testing apparatus specially developed at NREL. The system is fully automated for around-the-clock operation with remote control and monitoring capabilities via the internet. This allows for testing and analysis of sensors over a wide range of controlled and monitored environmental conditions. Capabilities also exist to support:

- Testing the impact of interferants and poisons
- Evaluating the life span of sensors with separate dedicated life test fixtures
- Testing of sensors for process applications, including responses under high hydrogen concentrations.

6.6 Fuel Cell Development and Test Lab

The Fuel Cell Development and Test Laboratory supports fuel cell R&D projects through in-situ fuel cell testing. Applications include catalyst development, contaminant studies, and durability testing. The laboratory can support single and full stack testing capabilities for a variety of fuel cell types, including Proton Exchange Membrane, Direct Methanol, Phosphoric Acid, Anion Exchange Membrane, and Solid Oxide fuel cells. More than 10 test stands offer testing in the 25-250 Ampere range.

The laboratory also features:

- A full-size fuel cell stack test station
- Multiple single-cell fuel cell testing stations
- Spatial testing capability using 121-channel segmented cell system or multichannel potentiostat
- Calibration equipment, using standards in accordance with or exceeding USFCC standards.

6.7 Energy Systems High-Pressure Test Laboratory

The High-Pressure Test Lab provides space where high-pressure hydrogen components can be safely tested. The laboratory is colocated with energy storage activities such as ultracapacitors, super conducting magnetic flywheel and mechanical energy storage systems for an integrated approach to energy storage system development and demonstration. The walls of the Energy Systems High Pressure Test Laboratory are built from concrete, capable of sustaining an overpressure condition or in the case of a component failure during test, and can act as secondary containment. Remote data and remote cameras are used for test observation, providing the added safety mechanisms needed. A critical understanding of component failure modes is essential in developing protocols for accelerated life testing to accurately scale to real world conditions is essential for developing regulations, codes and standards required for safe operation.

The following types of tests can be performed:

- Component and system level performance and efficiency
- Strength of materials and hydrogen compatibility
- Safety demonstration
- Model validation
- Life cycle reliability.

7 High Performance Computing, Analysis and Visualization

High-performance computing (HPC) at the ESIF enables unprecedented large-scale numerical models for study and simulation of material properties, processes, and fully integrated systems that would otherwise be too expensive, too dangerous, or even impossible to study by direct experimentation. With state-of-the-art computational modeling and predictive simulation capabilities, the HPC will reduce the risks and uncertainty that are often barriers to industry adopting new and innovative technologies, thereby accelerating the transformation of our nation's energy system.

The state-of-the-art multiprogram facility at the ESIF advances DOE Core Competencies in several mission areas:

- **Applied mathematics** (through development of the mathematical models, computational algorithms and analytical techniques needed to enable science and engineering-based solutions of energy systems integration challenges)
- **Advanced computer science, visualization, and data** (through development and testing of new tools, libraries, languages, data management, and visualization techniques for energy systems integration)
- **Computational science** (through connecting applied mathematics and computer science with the engineering research conducted elsewhere in the ESIF; e.g., using hardware experiments conducted at the ESIF or elsewhere to drive computational simulations of future energy systems).

7.1 High-Performance Computing

NREL is home to Peregrine, the largest HPC system in the world exclusively dedicated to advancing renewable energy and energy-efficiency technologies. Peregrine comprises of 2,592 interconnected "compute nodes" with a total of 58,752 of the latest Intel Xeon processors. Another 288 accelerated compute nodes use Intel Phi Many Integrated Core (MIC) coprocessors that provide faster computation. The compute nodes in Peregrine are interconnected using a very high-speed (56 Gb/s) InfiniBand network. Peregrine runs the Linux Operating System and has a dedicated high performance parallel Lustre file system with approximately 1 petabyte (10^{15} bytes or characters) of online file storage.

The peak performance of Peregrine is approximately 2.24 petaflops, or 2.24 million billion floating point (mathematical) operations per second, making Peregrine the 30th fastest computer in the world. On an annual basis, the HPC system can deliver approximately 20 million node-hours of computational capacity that can be used directly for EERE-funded programs or mission-related work, or for collaborative projects with a growing user community.

HPC systems such as Peregrine have a lifespan of approximately 4 years. It takes approximately 2.5 years to gather requirements, develop specifications, procure, and implement a replacement system. A replacement for Peregrine is needed by January 2019 to ensure continued reliable delivery of computational capacity for EERE mission-related work. As of September 14, 2017, the project to procure and implement a new system for Peregrine with two to five times more capacity within the planned ESIF Facilities and Infrastructure recapitalization budget is on schedule for summer 2018 delivery and January 2019 production operation.

NREL's Mass Storage System provides an additional 5 petabytes long-term data storage capacity for the HPC. It is designed to keep the most-used data quickly accessible and to economically store data that is accessed less often. This is achieved by employing high-performance disks for the newest working data, and by moving older data to economical tape storage with the help of software algorithms, a large robotic tape library, and a series of high-performance tape drives. Data are fully protected without external backups, and the system provides robust performance for both ingest and retrieval.

Data Storage systems such as the Mass Storage System typically have long lifespans exceeding 10 years. The servers and disk drives within the Mass Storage System have a lifespan of approximately 5 years. Other portions like the tape library, tape drives, and tapes still have longer service life. As of September 14, 2017, a project to replace the server and disk components of Mass Storage System is underway with completion planned for December 2017.

NREL's HPC data center requires just under 1 megawatt of power to operate, and creates a considerable amount of waste heat requiring dissipation to maintain peak performance. Ten additional "cooling" racks provide the connection to the facility cooling system necessary to cool the HPC processors using an innovative warm-water direct component-level liquid cooling system designed by HPE with collaboration from NREL. Water has approximately 1,000 times the cooling capacity of air, making it more energy efficient to pump in a cooling system versus the energy needed to run a fan to move cooling air, which is the typical for data centers. In this case, water is supplied to the servers at approximately 75°F and returns from the HPC will be in excess of 95°F. This hot water is integrated directly into the main thermal system of the building, providing the primary source of heat for the ESIF's office and lab spaces and reducing ESIF utility costs. NREL estimates that leveraging the energy-efficient HPC data center will save approximately $1 million in annual operating costs compared to a traditional data center. The cost savings are the results of a potential $800,000 electrical energy savings and $200,000 thermal energy savings from reusing the waste heat to heat the ESIF.

For the year ending August 2017, the HPC data center operated with an average power use effectiveness (PUE) of 1.032 against a design goal of an annualized average PUE of 1.06 or better. The PUE is defined as the ratio of total power to run the data center facility (IT equipment, lighting, HVAC, uninterruptible power supply systems, etc.) to the total power drawn by all IT equipment. The ESIF Building Automation System calculates PUE based on 15-minute interval energy measurements taken at 27 different points on the system. An ideal PUE is 1.0 (i.e., all energy is delivered directly to computing equipment). Typical data centers achieve a PUE rating of approximately 1.80. Compared to its peers, the ESIF data center is one of the most energy=efficient HPC data centers in the world.

7.2 Data Analysis and Visualization

The Insight Center at NREL combines state-of-the-art visualization and collaboration tools to promote knowledge discovery in energy systems integration. Located adjacent to NREL's High-Performance Computing (HPC) Data Center, the Insight Center uses advanced visualization technology to provide on-site and remote viewing of experimental data; high-resolution visual imagery; and large-scale simulation data. The Insight Center comprises two spaces: the Visualization room and the Collaboration room.

The Visualization room provides meeting space that features a large, rear-projected, 14 megapixel image display. Large-scale, high-resolution visual imagery can be used to effectively convey information and illustrate research findings to stakeholders and visitors. The Visualization room also boosts the exchange of ideas among NREL researchers and their collaborating partners. Using the high-resolution, large-scale display, researchers and others now have the visual “real estate” that will enable them to analyze large-scale simulations, ensembles of simulations, and highly detailed visual analytics displays.

The Collaboration Room provides multiple workspaces in which researchers and partners from all disciplines of science and engineering can interactively visualize highly complex, large-scale data, systems, and operations. In this area, researchers can view in real time the testing and simulation of equipment and technologies. The main workspace is a stereoscopic immersive virtual environment composed of six projectors that illuminate two surfaces—a wall and the floor. The projected space can be used in conjunction with an optical tracker and the visualizations respond in relation to the movement of the user. This allows users to physically explore and interact with their complex data in new ways that promote and accelerate understanding and innovation.

7.3 Secure Data Center and Visualization Room

The ESIF’s Secure Data Center provides secure management, storage, processing, and visualization of industry proprietary data. NREL industrial partners can submit highly sensitive operational, maintenance, safety, and cost data for a particular technology to the Secure Data Center on a regular basis, typically once every three months. At present, the Secure Data Center houses the National Fuel Cell Technology Evaluation Center, which uses the Secure Data Center’s internal network of servers, storage, computers, backup systems and software to efficiently process raw data, digest large amounts of time series data for visualization, and create composite data products that show the status and progress of fuel cell technologies without identifying individual companies or revealing proprietary information. This approach can be applied to any technology class of interest using the resources available at the Secure Data Center.

8 Facilities and Infrastructure Budget

As described in sections 3–7, the ESIF's research infrastructure, equipment, and spaces represent a highly integrated set of capabilities that can be used to advance energy systems RD&D and deployment; however, to maintain the capabilities that these assets provide, they will need to be continually updated and replaced as technologies improve and the existing assets become obsolete. In addition, the ESIF will need to maintain the necessary staff expertise and equipment capabilities in a constant state of readiness to facilitate access to ESIF capabilities and assets by all types of users and to conduct many different types of experiments.

To attract a diverse user community and deliver outcomes that enable clean energy to be implemented and operated at scale, DOE will support the base operating costs of the ESIF, consistent with the model at other DOE user facilities. This will ensure that the facility is kept operationally ready, equipment is maintained to be state-of-the-art, and operations are conducted safely. By operating in this manner, the facility will attract funding and intellectual assets from external users that leverage the federal government's investment. Without this model, the availability and value of the capabilities could erode, leading to user attrition, a loss of intellectual value, and a decrease in leveraged funding from external users.

In Fiscal Year 2014, EERE began to directly fund NREL site-wide facility support costs as part of the new stewardship model for the campus. Previously, these costs were a significant portion of NREL's indirect pool. The stewardship model removed these relatively fixed costs from the indirect pool, allowing NREL's labor rate multiplier to be reduced. This approach provided for greater stability in the operation and maintenance of DOE's assets on the NREL campus and also resulted in a much more competitive labor rate that benefits all DOE programs, other federal agencies, and the private sector entities that fund work at NREL. Overall, this has enabled greater diversity in funding sources for NREL, allowing greater leverage of the asset investments that have been made on the campus.

A similar stewardship model is used for the ESIF, enabling the ESIF to be EERE and NREL's first official DOE Technology User Facility dedicated to applied research. The DOE's FY 2014 budget included a separate line item for $20 million in initial funding for the first year of ESIF operations. This ESIF Facilities and Infrastructure line item grew in FY 2015 (to $30 million) and FY 2016 (to $36 million) to provide sufficient funding for full, steady-state operations of the ESIF, and to ensure that the ESIF's capital and equipment assets are maintained.

This section describes the planned expenditure of ESIF Facilities and Infrastructure funds in three areas: (1) Facility Maintenance and Services ("Sitewide Costs"); (2) Research Operations; and (3) High Performance Computing. Table 1 provides a summary of expenditures by area for FY 2014 through FY 2017.

Table 1. FY 2014–FY 2017 Summary of ESIF Operations Costs

	FY 2014 ($ million)	FY 2015 ($ million)	FY 2016 ($ million)	FY 2017 ($ million)
Facility Maintenance and Services	$4.5	$5.0	$4.9	$5.0
Research Operations	$5.3	$15.1	$12.1	$10.3
High Performance Computing	$4.3	$9.6	$16.5	$15.7
Management and Administration	$0.2	$0.6	$1.7	$3.7
Total ESIF Operations	*$14.3*	*$30.3*	*$35.2*	*$34.7*

8.1 Facility Maintenance and Services

ESIF Facility Maintenance and Services activities provide for basic building maintenance and engineering support; fire, emergency and custodial services; and general utilities (electricity, natural gas, water, etc.). These activities provide a basic level of facility services to the ESIF's high-bay labs, high-performance computer and data center, and office wing for 200 researchers and partners.

Many of these costs are incurred on the basis of NREL campus-wide contracts, so they have been assessed to the ESIF on a pro rata share based on physical footprint (square feet) of the facility compared to total NREL facility footprint. Other costs, e.g., utilities, are easier to clearly identify with the ESIF and are therefore fully assessed. Table 2 provides a breakdown of actual costs for FY 2015 through FY 2017.

Table 2. FY 2015–FY 2017 Breakdown of ESIF Facility Maintenance and Services Costs

	FY 2015 ($ million)	FY 2016 ($ million)	FY 2017 ($ million)
Maintenance and Engineering	$3.0	$3.0	$2.8
Fire, Emergency, Custodial, etc.	$1.3	$1.3	$1.2
General Utilities	$0.7	$0.6	$1.0
Total Facility Maintenance & Services	*$5.0*	*$4.9*	*$5.0*

8.2 Research Operations

The ESIF's Research Operations staff is responsible for assuring that the objectives of the ESIF are accomplished within the policies, DOE prime contract, and legal environment within which NREL operates. ESIF Research Operations staff works closely with NREL's designated Facility Manager for the ESIF and NREL's designated Environment, Health and Safety Points of Contact for the ESIF through a direct matrixed model to provide overall operational stewardship of the ESIF, ensuring a high level of availability and reliability. This staff comprises:

- An **ESIF operations manager** who ensures that ESIF laboratories and capabilities are operated and maintained within an approved safety envelope defined by hazard assessment, configuration management, maintenance management, and work control. The ESIF operations manager is also responsible for establishing a safety culture that recognizes the ESIF's unique and complex hazards, evaluation of risk, design for safety, and operation by trained and qualified personnel within established operating limits.
- **Area work supervisors** ensure all activities in their assigned area(s) of the ESIF are authorized and within the facility safety envelope that defines risks; and they maintain situational awareness of all activities occurring in their designated ESIF laboratory area, both routine and nonroutine. Area work supervisors also assist users with planning and implementation of their activities, providing input on ESIF capabilities, capacities, rules, requirements, and controls credited with preventing/mitigating hazardous conditions that might be present or arise as a result of a change in activity. Area work supervisors are anticipated for the following areas:
    - Electrical systems laboratories
    - Thermal systems laboratories
    - Fuel systems laboratories
    - High Performance Computing Data Center and office space
    - Outdoor test areas and large equipment.
- **System engineers** who serve as the design authority, subject matter expert (SME), and system owner for one or more assigned systems (REDB, SCADA, thermal loop, etc.) in the ESIF. CSEs assist users in the development of their safe operating procedures, test activity plans, and safe work permits for using the ESIF's system(s) and ensure any such use is within the system and facility safety envelopes. CSEs also ensure the system is operated and maintained according to operation and maintenance manuals, maintenance procedures, or other such documents, and identify needed replacements, improvements and upgrades to keep the system performance at optimum. In addition, Research Operations activities also enable the unique operations and maintenance of the ESIF's complex systems and research infrastructures, such as:
    - The REDB that will demand maintenance and capital expenditures to expand capacity and support multiple users (see below)
    - The SCADA system that will have ongoing demands for configuration to support expanding R&D activities
    - The Thermal Energy Distribution Bus, an extensive heat plumbing system with expected operation and maintenance
    - The Fuel Generation, Distribution and Fueling infrastructure at the ESIF that includes delivery, inventory, and distribution activities that will experience wear and require operation and maintenance
    - The ESIF's HIL approach that connects computer simulations with ESIF hardware testing and field devices, requiring new programs, control systems, and physical connections through high-speed networks

- Complex data and communications systems throughout the ESIF with central controls and acquisition for storage and analysis. These are complex systems with development and operations cost.

See the ESIF's Operations Manual for information about the ESIF's Administrative Group.

Table 3 provides a breakdown of FY 2014–FY 2017 expenditures for Research Operations.

Table 3. FY 2014–FY 2017 Breakdown of ESIF Research Operations Costs

	FY 2014 ($ million)	FY 2015 ($ million)	FY 2016 ($ million)	FY 2017 ($ million)
Staff Labor	$2.6	$5.0	$6.2	$5.5
Operations and Maintenance	$1.6	$2.9	$2.4	$1.7
Software, Materials, Supplies	$1.1	$5.2	$1.5	$1.2
Capital Equipment	$0.0	$2.0	$2.0	$1.9
Total Research Operations	*$5.3*	*$15.1*	*$12.1*	*$10.3*

Starting in FY 2015, the Research Operations budget also includes $2 million for additional acquisitions to the ESIF's physical research infrastructures, e.g., the assets described Sections 3 through 6 of this Stewardship Plan. NREL has applied a nominal average 10-year functional lifetime to these assets (see Appendix B for a complete list) to estimate an annual average recapitalization need of approximately $4 million. In future years, this funding will be applied to recapitalization.

A key limiting research infrastructure is the REDB, Section 3.1). At present, a single, large (~1 MW) experiment involving the REDB effectively precludes others from using it elsewhere at the ESIF, significantly limiting the capability of the ESIF to support future user experiments at the megawatt scale.

A full build-out of originally planned REDB infrastructure is projected to cost $30 million, and would include:

- A second 250-A AC and DC bus, providing additional capacity for users to conduct integrated system experiments at the <500 kW-scale;
- Construction of "B laterals" sections for the existing 250A and 1600A busses, extending access to the REDB into additional ESIF labs for additional use capability;
- A new 2,500-A AC and DC bus, providing a new capability for the ESIF to host integrated systems experiments as large as 2 MW
- Acquisition and connection of necessary fixed equipment (grid simulator, load bank, DC power supplies, etc.) in ESIF labs to enable additional and higher-power testing on these new laterals and busses.

The cost of constructing the 2,500-A AC and DC busses alone is estimated to be approximately $7 million, not including the additional grid simulator and load bank capacity needed to support user research activities on it.

In the first few years of the ESIF's operation, the actual need for recapitalization of existing research infrastructures (many of which are newly installed) will be far less than the expected approximate $4 million steady-state replacement level calculated above. NREL proposes to use the majority of these funds in FY 2016–FY 2018 to build-out the originally planned REDB infrastructure using a phased approach based on user priorities and available funding, as follows:

- FY 2015:
  - Begin power upgrade for fix equipment and start build-out of three additional REDB laterals.
  - Add 500 kW of grid simulation capability.
- FY 2016:
  - Begin build-out of the 2,500 A AC and DC "race tracks" required to support future construction of the 2,500 A AC and DC busses
    - OCL 250 A AC and 250 A DC A laterals
    - OCL House Power Upgrade.
  - Thermal test equipment
  - Opal-RT supplemental systems (3).
- FY 2017:
  - Complete installation of the 2,500 A AC and DC "race tracks" and install the "A Laterals" of the 2,500 A AC and DC busses in priority areas (e.g., the integrated system laboratories described in Section 3)
    - ESIL 1,600-A DC B lateral.
  - Grid simulator installation (FY 2016)
  - RTDS supplemental system (1)
  - Environmental chamber completion (out-year; not in plan)
  - Water pumps, motors, and treatment systems as needed.
- FY 2018:
  - Install B laterals for 2,500-A AC and DC busses to complete installation
    - MVOTA 1,600-A DC and AC 250-A REDB A laterals
    - ECL 1,600-A DC A lateral.
- FY 2019:
  - OCL 1,600-A AC A Lateral
  - Anderson 660-kW bidirectional DC power supply installation.

- FY 2020:
    - LVOTA 1,600-A DC A lateral, 250-A AC and 1,600-A AC B lateral
    - System Performance Laboratory 250-A AC A lateral
    - Magna Power Connection FESB and PVE REDB Connection
    - DC Mobile Smart Switch.

Further new infrastructure build-out would occur only on the basis of future increases in the ESIF's Operations budget or in NREL's General Plant Projects account. Funding for infrastructure outlined in FY 2017–FY 2020 above is contingent upon funding from Congress and approval through the ESIF's Steering Committee.

8.3 High Performance Computing

The ESIF's Computational Sciences staff maintains and makes available NREL's high-performance computing capability to interested users, and supports the work of those users in modeling and simulation of complex energy systems integration problems. This staff includes:

- A **computational sciences director** that leads NREL's laboratory-wide efforts in computational science. The Director is responsible for facility management, system procurement and operation, and long-term archival and data management systems. The Director also initiates and oversees innovative research programs in relevant areas of computer science, mathematics, and scientific computing.
- An **HPC Operations and Systems Group** that maintains and manages the HPC system facilities integration, hardware, network and cyber security to ensure usability, use, and reliability. This group also provides support to users of the HPC resources—e.g., creating accounts, providing training, granting access—and assists them when problems arise in their use of the facilities.
- A **Data Analysis and Visualization Group** that enables knowledge discovery and improved understanding of large-scale, complex scientific data using advanced techniques in visualization, scientific data management, computational statistics, and data science. This group maintains and extends capabilities of the Insight Center, the HPC DAV resources, and distributed data analysis systems and assists users in gaining scientific and engineering insights from the modeling and simulation they conduct on the HPC.
- A **Complex Systems Simulation and Optimization Group** that develops advanced computational approaches and tools that can be applied to mission goals, including in support of energy systems integration. This group is available to partner with users wishing to develop new research-grade tools useful in studying new and complex science and engineering problems.
- A **High-Performance Algorithms and Complex Fluids Group** that uses HPC to predict and understand the behavior challenges rooted in complex fluid dynamics. This group primarily pursues basic and early-stage applied research motivated by reacting, multiphase, and traditional internal and external flows; such flows arise in many areas such as vehicle or power generation combustion and in wind power plants. To use HPC

in this way this group is heavily engaged in developing software and algorithms for solution of partial differential equations using a variety of numerical methods targeting future computational architectures.

In addition, funding for the ESIF's Operations also covers the costs of ongoing operation and maintenance support for NREL's high-performance computing assets, including:

- Contract maintenance on the HPC itself to ensure optimal performance
- Contract maintenance on the Mass Storage system to ensure data integrity and availability
- General operations and maintenance costs for servers, power units, etc.
- Software licenses and support for libraries, compilers, operating systems, backup and storage
- Maintenance of hardware required for HPC and Data Center space conditioning
- Maintenance of plumbing, moving parts and fluids that flow through Data Center server housings.

Table 4 provides a breakdown of FY 2014–FY 2017 expenditures for High Performance Computing.

Table 4. FY 2014–FY 2017 Breakdown of ESIF High-Performance Computing Costs

	FY 2014 ($ million)	FY 2015 ($ million)	FY 2016 ($ million)	FY 2017 ($ million)
Staff Labor	$2.3	$2.6	$5.2	$5.2
Operations and Maintenance	$0.7	$2.0	$3.8	$3.7
Software, Materials, Supplies	$1.3	$4.0	$0.9	$1.0
Capital Equipment	$0.0	$0.0	$6.6	$5.8
Total High Performance Computing	*$4.3*	*$9.6*	*$16.5*	*$15.7*

The Capital Equipment budget will support an estimated ongoing $6–7 million annual need to maintain and upgrade NREL's HPC system, the long-term and archival storage capability, the Insight Center, and the facility infrastructure (pumps, fans plumbing, cooling towers, electrical panels, etc.) that supports them within the ESIF.

NREL has developed the following capitalization plan for its HPC and related assets in FY 2015–FY 2018:

- FY 2015:
  - Added 1 petaflop of additional computational capability to Peregrine, four scalable units composed of two compute racks and one CDU in each scalable unit.

- Initiate planning and acquisition of the second-generation HPC system, to provide overlap with the expected phase out of Peregrine in late FY 2018
- Support expected needs for annual growth in the Mass Storage System.

- FY 2016:
  - Put expanded system into production use by November 1, the start of the FY 2016 user program allocation period.
  - Start lease-to-own payments on the additional four scalable units.
  - Prepare facility space, commission vendor build, and implement second-generation HPC system.
  - Support expected needs for annual growth in the Mass Storage System.
  - Collaborate with Johnson Controls and Sandia National Lab to install and operate thermosyphon dry cooler to reject data center waste heat with dramatically reduce water demand.
  - Continue planning and acquisition of the second-generation HPC system, to provide overlap with the expected phase out of Peregrine in late FY 2018.
- FY 2017:
  - Continue production operations with Peregrine.
  - Continue facility prep for Peregrine replacement (mechanical/electrical build-out to support power and cooling for 5-MW load).
  - Conclude payments on the four additional scalable units.
  - Conduct a major upgrade of Insight Center visualization capabilities and tools.
  - Continue planning and acquisition of the second-generation HPC system, to provide overlap with the expected phase out of Peregrine in late FY 2018.
  - Support expected needs for annual growth in the Mass Storage System.
- FY 2018:
  - Continue production operations with Peregrine.
  - Complete facility prep for Peregrine replacement (mechanical build-out to support power and cooling for 5-MW load).
  - Continue planning and acquisition of the second-generation HPC system, to provide overlap with the expected phase out of Peregrine in mid FY 2019. Hardware delivery is planned late FY 2018. Production Operation is planned January 2019.
  - Replace Mass Storage System servers and disks that have reached their 5-year service life.
  - Support expected needs for annual growth in the Mass Storage System.

8.4 Management and Administration

The ESIF's Management and Administration budget includes support for the following:

- An ESI/ESIF program manager, who provides technical leadership, oversees program development (annual and multiyear) and guides NREL's ESIF and Grid Integration program direction. The program manager ensures high-quality technical output from NREL's grid integration R&D activities and effective and efficient stewardship of the ESIF and other key research facilities at NREL. The program manager also actively oversees NREL's portfolio of Grid Integration projects and investments to maximize NREL's value and impact to DOE's mission priorities, including proactively proposing changes in the portfolio in partnership with the Office of Electricity Delivery and Energy Reliability and EERE leadership at DOE and engaging in efforts to develop impactful industry partnerships that align with DOE priorities and leverage DOE's investments at NREL, including the ESIF.
- Communications, outreach, and stakeholder engagement to include planning and hosting of visits/meetings at NREL by the Office of Electricity Delivery and Energy Reliability /EERE staff or leaders, industry and/or associations, and universities to strengthen relationships and enhance NREL's Grid Integration program. Workshops on specific topics of importance to DOE to foster industry collaboration and partnership opportunities at the ESIF. The ESIF's administration budget also provides resources for ESIF staff partnerships in industry and academic outreach opportunities that highlight the ESIF and its capabilities to potential partners and users. A regular monthly electronic newsletter, press releases, social media and website presence, and an annual report detail the accomplishments at and capabilities of the ESIF to a broad audience.
- Partnerships and Users Program staff to support industry and academic partners in their use of the ESIF through user calls. Activities include but are not limited to:
    - Annual User Call, June annually as well as other possible calls such as High Impact Projects.
    - Promotion of the ESIF's capabilities to potential partners and users
    - Hosting of tours and visits to the ESIF for prospective partners and users
    - Facilitation of partnership and user agreements and associated statements of work
    - On-boarding of new partners and users
    - Off-boarding of partners to include surveys
    - Metrics tracking and reporting, including space use to support proprietary charges pursuant to DOE O 522.1
    - Administration of the ESIF User Program (anticipated to begin in FY 2017) including preparing calls for proposals, managing peer review and selection, assisting with project management and closeout, and other tasks as necessary.

The ESIF's User Program will provide access to the ESIF's expertise, equipment, and facilities through a regular Annual Call for Proposals each year, as well as specific targeted Open User calls to increase use of specific ESIF research capabilities not fully obligated elsewhere. Users will apply through a formal process that includes peer review of proposals by a panel of independent experts. The ESIF will also sponsor special efforts to engage the academic research community, including visiting faculty programs, postdoctoral exchanges, and graduate/undergraduate student summer programs.

9 Steering Committee

The responsibility for management, operation, and stewardship of the ESIF is vested in the ESI Program Manager and the ESIF management team. An independent ESIF Steering Committee provides guidance and oversight to ensure that the ESIF's assets and capabilities (as described in sections 3–7) are appropriately maintained, operated, and protected and that these national assets are made broadly available to the user community to deliver the value for which the facility was constructed.

9.1 Membership

The ESIF's Steering Committee shall comprise representatives from:

- NREL's executive management team
- DOE Office of Energy Efficiency and Renewable Energy (EERE)
- DOE Office of Electricity Delivery and Energy Reliability
- Other DOE offices as appropriate.

At DOE's discretion, the Steering Committee membership might also include experts from industry, academia, other state or federal agencies, other DOE national laboratories, or other nonfederal research organizations.[1]

9.2 Function

The ESIF's Steering Committee shall provide advice and recommendations to the ESI Program Manager and the ESIF's management team on:

- Research priorities
- User program administration
- Safety and security of operations
- Facility and asset management
- Capital expenditures
- Performance metrics.

Other topics might be addressed as the Committee sees fit. External input is provided to the Steering Committee through an ESIF Users' Committee (described in the ESIF User Facility Plan) and NREL's external advisory committees for Energy Systems Integration, Power Systems Engineering, and Computational Science.

9.3 Meetings

The Steering Committee shall meet at least once per calendar quarter (three months). During each scheduled meeting, the Committee shall review and discuss reports by the ESI Program

[1] In such a case, the requirements of the Federal Advisory Committee Act (5 U.S.C. 1) may apply and may supersede the provisions in the Section where there may be a conflict.

Manager on the performance of the ESIF, its plans and prospects, as well as immediate issues facing the ESIF.

The committee may conduct business when a quorum of its members is present; such quorum shall consist of at least 50% of its members, provided members are present from both DOE and NREL.

10 Performance Metrics

To ensure that the taxpayer investment in the ESIF yields the maximum possible benefit to the nation, several ESIF performance metrics will be continuously tracked and reported on a quarterly basis. These metrics are substantially similar to metrics being tracked by the Alliance for other key NREL "Partnering Facilities" in an effort to understand the impact that each facility has on the delivery of the NREL mission, as well as to understand the overall cost and impact of these capabilities.

In the first three years of ESIF operations, both the Alliance and DOE sought to increase the availability of the ESIF and its use by both DOE programs and external partners. Initial performance metrics for the ESIF were developed that attempted to specifically quantify these aims, as shown in Table 5 below.[2]

Table 5. FY 2015–2017 ESIF Performance Metrics, Goals, and Outcomes[a]

Metric	FY 2014 Actual	FY 2015 Actual	FY 2016 Actual	FY 2017 YTD	FY 2017 Goal
Number of Users	46	57	85	**85**	100
Lab Availability	83%	97%	95%	**95%**	95%
Lab Utilization	50%	57%	61%	**70%**	65%
HPC Availability (FY-July)	88%	88%	90%	**90%**	90%
HPC Utilization (FY-July)	76%	82%	58%	**90%**	75%
DOE Funds Costed	$13.0 million	$13.9 million	$17.5 million	**$18.6** million	-
Partner Funds In Costed	$1.2 million	$2.8 million	$3.5 million	**$2.4** million	-
Partner Funds In Commitments	$2.6 million	$3.5 million	$5.8 million	**$5.9** million	-
Partner Cost Share Commitments	$1.0 million	$8.9 million	$3.1 million	**$2.9** million	-
Technical Outputs (FY-July)	56	267	255	**215**	275

[a] Tracked; not performance

In May and June 2016, the Alliance and DOE held two general meetings to determine how to better measure and improve the performance of the ESIF, taking into account the first three years of operational experience. Both the Alliance and DOE recognize that to be truly successful, the ESIF must meet the needs of each individual program using the facility from both the EERE and the Office of Electricity Delivery and Energy Reliability, as well as other DOE programs and

[2] Alliance and DOE have not agreed to the partner direct funding expenditures, commitments and cost share goals shown in brackets for FY 2016.

offices. At the same time, the ESIF should also enable large, integrated projects use multiple technologies and have national impact.

Thus, the ESIF's performance metrics should measure both aspects: value to individual DOE programs as well as value across DOE programs. As a result, for FY 2017 and beyond, the following performance metrics are proposed:

- DOE project management
- Facility availability and use
- Technical output
- High-impact integrated projects
- Projects in new mission space.

A detailed description of each proposed ESIF performance metric is provided below. In addition to these performance metrics, NREL and DOE might track additional indicators of facility use and mission impact.

10.1 DOE Project Management

Projects are conducted in the ESIF with sponsorship from multiple DOE programs (e.g., Building Technologies Office, Vehicle Technologies Office, smart grid activities, etc.), either as part of program annual operating plans, or awards made under Lab Calls or funding opportunity announcements. As a performance metric, DOE will provide an aggregate grade (A–F) to NREL for the ESIF based on NREL's performance on DOE-sponsored projects using the following criteria:

- The project team met its objectives and milestones on time;
- The project team stayed within its proposed budget;
- The project team engaged and managed external partners effectively (as applicable)
- The project team effectively communicated with DOE.

Successful performance against the above criteria for all projects will be considered to meet expectations, e.g., an aggregate grade of at least "B+."

10.2 Facility Availability and Utilization

The availability and use are reported in the above Table 5. These include DOE and non-DOE projects. This information is separately detailed in the ESIF's Operations Plan.

10.3 Technical Output

This metric shall be defined as the number of products and publications provided to industry partners and/or the public as a result of work conducted at the ESIF. To ensure that ESIF activities demonstrate success in many different ways, a weighting will be applied to different types of products and publications as follows:

- NREL technical report = 0

- Conference paper = 1
- Peer-reviewed literature = 2
- Record of invention or patent = 3
- License of NREL intellectual property created at the ESIF = 5
- R&D 100 Award = 5.

NREL technical reports are developed as a normal part of the project. NREL will keep a count of the number of technical reports, but these will have a weighted score of 0. Conference papers have a weighted score of 1 because they are given to an external audience and can be accessed by the public. Peer-reviewed literature is given a score of 2 because these articles go through a more rigorous peer-review process for publication and are made available to the public in archival journals.

Multiple technical reports or peer-reviewed literature papers associated with the same project shall be counted only as one deliverable. NREL will work with DOE to determine measures of technical output that are applicable to proprietary work, for which usual measures of technical output (e.g., publications) do not apply.

10.4 High Impact Integrated Projects

Each year, subject to available funding, NREL will solicit and implement an agreed-upon number of integrated projects that will have the potential for national impact in the area of grid modernization and/or energy systems integration. To meet this requirement, projects must:

- Use multiple technologies available from multiple program offices.
- Solve challenges outlined in the MYPP.
- Have demonstrable impact of the companies and regions it supports.
- Be nationally scalable.
- Develop lessons learned that could be implemented nationwide.

In addition to projects to be conducted within a single year, NREL may present a significant single-year phase of a multiyear project to meet this requirement. Projects must be presented by NREL in advance to DOE for preapproval. Projects must present to DOE notable outcomes to demonstrate success of projects.

10.5 Projects in New Mission Space

Each year, subject to available funding, NREL will solicit and implement an agreed-upon number of projects outside its traditional scope to help DOE recognize potentially new and important mission spaces. Projects in these work areas should have the potential for national impact and be preapproved by DOE.

Examples might include:

- Energy-water nexus

- Smart cities
- Gas-electricity nexus
- Electrification
- Hydrogen at scale.