ESIF 2014

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

ENERGY SYSTEMS INTEGRATION FACILITY

U.S. DEPARTMENT OF ENERGY

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

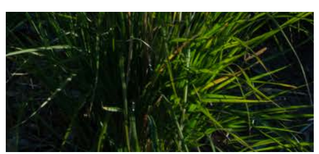
THE ESIF ONE YEAR LATER—A SUCCESS STORY

Our nation's energy systems are going through an important transition: while clean energy technologies continue to be advanced through research and development, they are also reaching deployment levels that are impacting how our energy systems function, particularly with regard to the power grid. To help both new and legacy energy systems work together efficiently, NREL, a Department of Energy National Laboratory focused on energy efficiency and renewable energy technologies, has launched a significant effort to explore energy systems integration.

NREL's Energy Systems Integration Facility (ESIF) opened just over a year ago and has become a focal point for scientists, engineers, equipment manufacturers, utilities, and policymakers to collaborate in transforming our energy systems to meet the demands of the 21st century. Primarily sponsored by the U.S. Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy (EERE), the ESIF is an excellent example of the impact that a federally funded research facility can have on solving national problems beyond the scope of private investment. It also demonstrates the importance of a partnership approach among the federal government, industry, and academia.

A year in, the ESIF is well on its way toward proving its value on both the national and international stages. And in a short amount of time, the facility has already earned accolades: it's a designated LEED Platinum building; it received the Lab of the Year Award from the editors of *R&D Magazine*; and its supercomputer created in partnership with Hewlett-Packard was honored with an R&D 100 Award.

Researchers at the ESIF are working with industry partners such as Advanced Energy, General Motors, Solectria, Toyota, and several electric utilities, as well as government partners like the U.S. Army and Australia's Commonwealth Scientific and Industrial Research Organisation. With our partners, we are tackling challenges like integrating advanced solar inverters onto the grid, operating microgrids that can keep providing power when the main power grid is down, supplying the power needs for the Army's forward operating bases, and improving automotive fuel cells and advanced battery technologies.



NREL also worked with EERE across program offices to develop a holistic approach to grid integration through the Integrated Network Testbed for Energy Grid Research and Technology Experimentation (INTEGRATE) project. Using both DOE-funded research and partnerships with industry, INTEGRATE focuses on characterization of distributed energy technologies at the ESIF, development of open-source interoperability standards, and cross-technology demonstrations showing how EERE technologies can work holistically to provide services to the grid.

Going forward, the ESIF's official designation as a DOE User Facility opens the door to scientists and engineers from industry and academia. And by using concepts such as remote power hardware-in-the-loop, the ESIF's unique capabilities can be linked virtually to other grid integration research facilities throughout the country and the world. Working in partnership with the nation's thought leaders, and with facilities like the ESIF, we can solve the energy systems challenges that we face to ensure a secure, clean, and economically prosperous future.

DAN E. ARVIZU

Director of the National Renewable Energy Laboratory

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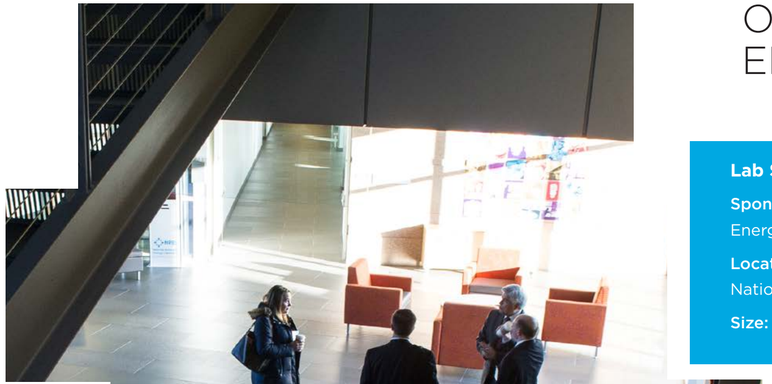
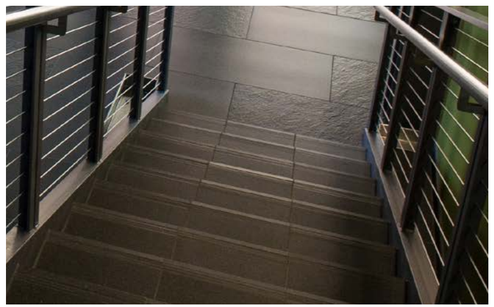




OVERVIEW—
ENERGY SYSTEMS INTEGRATION FACILITY

Lab Stats

Sponsor: U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE)

Location: Golden, Colorado, on the campus of DOE's National Renewable Energy Laboratory (NREL)

Size: 182,500 square feet

The ESIF is a unique new national asset that brings together public- and private-sector research and development efforts to accelerate the integration of renewable energy and energy efficiency technologies into legacy energy systems.

This facility, along with supporting capabilities across the NREL campus, provides a contained and controlled platform for integrated energy systems research. Commercial, governmental, and academic partners use this platform to develop and evaluate both individual technologies as well as integrated systems approaches.

The ESIF is the nation's first research facility that can conduct megawatt-scale research, development, and demonstration (RD&D) of the components and strategies needed to safely integrate clean energy technologies into the electrical grid 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 large-scale integration of renewable energy and energy efficiency technologies.

The ESIF is also home to Peregrine—the largest high performance computer (HPC) in the world exclusively dedicated to advancing renewable energy and energy efficiency technologies. On an annual basis, the HPC system can deliver approximately 12 million node-hours of computational capacity that can be used for EERE-funded programs or mission-related work, or for collaborative projects with a growing user community.

In this document, you'll find highlights of the research conducted at the ESIF in fiscal year 2014.

AWARDS & RECOGNITIONS

Lab of the Year Award from *R&D Magazine*

The editors of *R&D Magazine* named the ESIF the 2014 Laboratory of the Year. The ESIF was lauded with this prestigious international award for being a first-of-its-kind research user facility that uniquely merges three specialized components: an ultra-energy-efficient workplace that consumes 74% less energy than the national average for office buildings; one of the world's most energy-efficient HPC data centers; and sophisticated high-bay laboratory spaces with outdoor test areas.

The award also recognized the research at the ESIF for its importance in helping transform how the nation generates, delivers, and uses energy by modernizing the interplay between energy sources, infrastructure, and data.

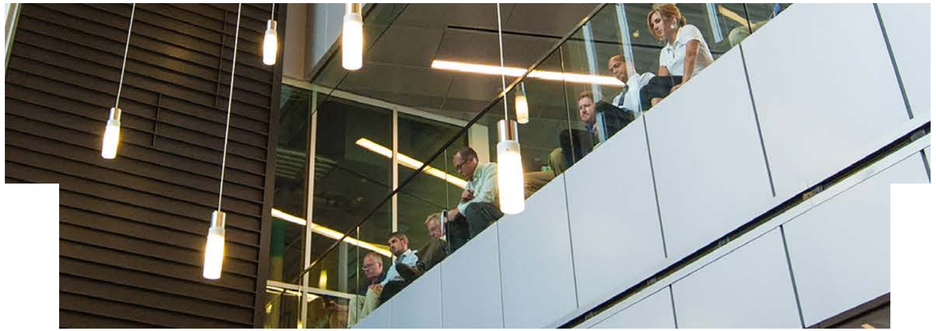
Supercomputing Platform Wins R&D 100 Award

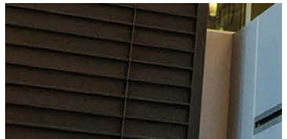
Peregrine—the ultraefficient HPC platform used at the ESIF—was named one of the top 100 technology breakthroughs of 2014 by *R&D Magazine*. Hewlett-Packard (HP) in collaboration with NREL won the award for the HP Apollo 8000 liquid-cooled supercomputing platform. This innovative system uses component-level warm-water cooling to dissipate heat generated by the supercomputer, thus eliminating the need for expensive and inefficient chillers in the data center. Peregrine was also selected as one of three Editor's Choice Awards.

Platinum Designation from the U.S. Green Building Council for Leadership in Energy and Environmental Design (LEED)

ESIF achieved all 56 LEED points applied for, and the facility was rated 40% more energy efficient than the baseline, per ASHRAE/IESNA Standard 90.1-2004. Now that a 720 kW solar photovoltaic array has been installed on nearby South Table Mountain, the efficiency has increased to 46.2% above baseline.

Additionally, NREL projects $1 million in annual operating cost savings from the energy-efficient HPC data center, compared to the cost of operating a traditional data center. The cost savings are due to an estimated $800,000 electrical energy savings and a $200,000 thermal energy savings from reusing waste heat from the data center to heat the ESIF.





Additional Awards

2013 Excellence in Construction Awards: 1st Place Mechanical, more than $10 million; Construction Pyramid Award: 2nd Place Mechanical, more than $10 million—Associated Builders and Contractors, Rocky Mountain Chapter

2013 HPCwire Award: Editor's Choice: Best Application of "Green Computing" in HPC—*HPCwire*

2013 InfoWorld Green 15 IT Award—*InfoWorld*

2014 Metal Architecture Design Awards: Sustainable Design Award—*Metal Architecture*

2014 PMI Project of the Year Award Finalist—Project Management Institute

ACE Awards: Best Building Project—General Contractor (More than $70 million), Bronze Award, and People's Choice Award—Associated General Contractors of Colorado

Arizona Public Service Energy Award—American Institute of Architects, Arizona Chapter

Design-Build Project Awards: Industrial/Process/Research Award and Best Overall Project Award—Design Build Institute Rocky Mountain Region

Excellence Awards: Award of Excellence for Pre-Cast Concrete—American Concrete Institute, Rocky Mountain Chapter

Mountain States Best Projects: Government/Public Building Merit Award—*Engineering News Record*

PRIDE Awards: Award of Merit, Sustainability—International Interior Design Association, Southwest Chapter

Salt River Pima Sustainable Building Award—American Institute of Architects, Arizona Chapter

Secretary's Achievement Award—U.S. Department of Energy

Summit Award: Energy Efficiency and Green Construction Project of the Year—Independent Electrical Contractors Rocky Mountain

DOE PROGRAM RESEARCH

The ESIF supported more than $13 million in DOE research in the laboratories, including the following projects.

EERE Fuel Cell Technologies Office

- Codes and Standards R&D Roadmap Implementation
- Enlarging Potential National Penetration for Stationary Fuel Cells through System Design and Optimization
- Fuel Cell Manufacturing Quality Control R&D
- Fuel Cell Technology Status Analysis
- GSE Validation
- Hydrogen Dispenser Hose Reliability Improvement
- INTEGRATE Project
- MDV Hybrid Truck Tech Validation
- Market Transformation Assistance
- Renewable Electrolysis: Integrated Systems Development and Testing
- Rotating Disc Electrode Studies
- Tech-econ Evaluation of Combined Heat and Power with SMR
- Technology Validation Data Collection and Analysis
- Web Portal Tool Development

EERE Solar Energy Technologies Office

- Degradation Mechanisms and Development of Protective Coatings for Thermal Energy Storage and Heat Transfer
- Fluid Containment Materials
- Distributed Grid Integration
- Emerging Technology Characterization
- INTEGRATE CRADA Projects

Buildings Technologies Office

- Differential Thermal Cycling Unit
- INTGRATE Project—Characterizing Building Loads for Grid Services

EERE Vehicle Technologies Office

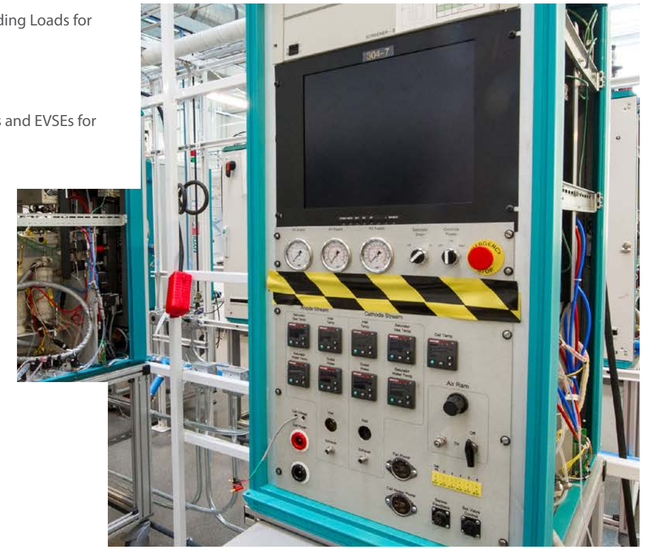
- INTEGRATE Project—Characterizing EVs and EVSEs for Grid Services

EERE Wind and Water Power Office

- INTEGRATE Project—Characterizing Wind Turbines for Grid Services

Office of Electricity

- Interconnection and Interoperability Standards Testing



DOE PROGRAM RESEARCH HIGHLIGHTS

Fuel Cell Performance Advances

NREL supported DOE's Fuel Cell Technologies Office with research and testing in several ESIF laboratories that demonstrated fuel cell performance at state-of-the-art levels. Novel electrocatalysts based on PtNi or PtCo nanowires were fabricated in the Energy Systems Fabrication Laboratory and characterized for performance, durability, and composition in the Electrochemical Characterization Laboratory and Materials Characterization Laboratory.

The highest performing materials demonstrated improvement in mass activity that was five times DOE's 2020 targets for oxygen reduction. At the ESIF's labs, scientists have scaled up these high-performing materials, incorporated them into membrane electrode assemblies, and tested them for performance and durability. They have shown improvements in state-of-the-art fuel cell performance at rated power.

NREL Hosts NFCTEC to Analyze Real-World Applications of Fuel Cell Technology

The National Fuel Cell Technology Evaluation Center (NFCTEC) at the ESIF plays a crucial role in NREL's independent, third-party analysis of hydrogen fuel cell technologies in real-world operation. NREL analyzes detailed data and reports from industry on fuel cell technology status, progress, and technical challenges. The NFCTEC is designed to securely manage, store, and process these proprietary data.

NREL partners submit data to the NFCTEC on a regular basis. NREL analysts use the NFCTEC's internal network to efficiently process and analyze the data. NFCTEC analysts generate results for durability, reliability, maintenance, costs, operation, utilization, range, efficiency, safety, and end-user trends using the NREL Fleet Analysis Toolkit.

While the raw data always remain confidential, individualized analysis results are provided to the partners that supplied the data. Results are then aggregated into publically available composite data showing the status and progress of the technology without identifying individual companies or revealing proprietary information.

NREL Researchers Develop Hydrogen Fueling Hose Reliability Test Setup

NREL researchers developed a unique test setup in the ESIF to assess the durability of hydrogen fueling hoses. Hoses are a largely untested—and currently costly—component of hydrogen fueling stations. At the ESIF, NREL is using a robot to mimic the repetitive stress of a human bending and twisting the hose to refuel a vehicle—all under the high-pressure and low-temperature conditions required in the hose to deliver hydrogen to a fuel cell vehicle's onboard storage tank. The hose reliability project will begin repetitive fueling motions in FY15 to assess whether the hose material can withstand these stresses over time.

NREL Tests Advanced Functions of Utility-Scale PV Inverters

Inverters developed by Advanced Energy and Solectria, in collaboration with DOE's Solar Energy Technologies Office (SETO), were tested by ESIF researchers for performance. Using modified test protocols from Sandia National Laboratories, researchers tested the advanced functionality capabilities of 500 kW, 750 kW, and 1,000 kW PV inverters.

With these results, NREL also developed, tested, and published a preliminary test procedure for inverters with advanced grid support features. This test plan and the test results it produced have provided valuable guidance to various national standards-development efforts aimed at easing the integration of high penetrations of distributed resources, including the IEEE 1547 amendment and update, the UL 1741 update, and the CPUC Rule 21 process.

NREL Scientists Develop Protective Coatings for Thermal Energy Storage and Heat Transfer Fluid Containment Materials

In order to meet the efficiency goals established by the DOE SunShot Initiative, concentrating solar power (CSP) plants must operate at elevated temperatures (600°C to 900°C). To operate at temperatures this high, CSP plants need new heat transfer fluids and storage media such as molten salts (i.e., chlorides and carbonates). While they are effective under high heat, these salts are potentially corrosive to the wall and piping materials that contain them.

To combat this corrosion, NREL scientists at the ESIF's Thermal Storage Laboratories are investigating and developing ways to protect the materials that contain the heated salts. In recent tests, NREL scientists worked to characterize the thermal properties of candidate molten salts, and study the high-temperature degradation of the containment materials (i.e., ceramics and metals). Tests results showed these materials were severely corroded by molten chlorides and carbonates at temperatures over 600°C.

With these findings, NREL scientists worked to develop and evaluate protective coatings for the containment materials. Electrochemical corrosion tests and analysis were used to select the optimal coatings. Testing demonstrated a low corrosion rate of 192 μm/year in an aggressive chloride mixture at 700°C for a Ni-based coating oxidized in air at 900°C in which protective oxides are formed. After applying this coating to substrate AISI 310 stainless steel (4.589 mm/year), its corrosion was reduced by 96%.

Research Leads to Higher-Performance, Lower-Cost Solar Receiver

Research performed at the ESIF on NREL's SETO-funded Near-Blackbody Enclosed Particle Receiver is improving the design of a new CSP receiver for lower-cost solar power delivery.

Several fundamental studies, including material development and characterization, and multiphase flow and heat transfer testing, were performed in the ESIF's Thermal Storage Process and Components test laboratory. The goal of this testing and development is to design a receiver that achieves more than 90% thermal efficiency, with particle exit temperatures of 800°C, which will achieve a working fluid temperature greater than 650°C.

Additionally, the materials selected for the receiver will need to withstand these high temperatures while yielding a total receiver cost of less than $150 per kilowatt-hour thermal. The development of this particle receiver will enable a lower-cost, higher-performance CSP system for cost-competitive solar power generation.

Research Advances on Thin-Film PV Performance

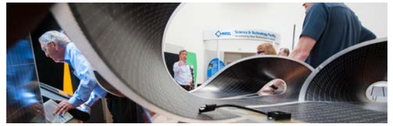
NREL researchers used ESIF laboratories to advance a major course of research on reversible light-induced changes in the performance of thin-film PV modules. This work explored ways to stabilize PV module performance without light exposure, provided new insight on the performance state achieved outdoors, and developed best practices for making repeatable performance measurements on CIGS and CdTe PV modules.

This work allows a better understanding of the changes that can happen with thin-film technologies and how to accurately measure their performance. NREL researchers worked with the United States Technical Advisory Group to integrate lessons learned during this research into the international standards used by the entire PV industry.

Window Durability Test Accelerates Energy Efficiency Improvements

Supporting DOE's Building Technologies Office, NREL has partnered with the Insulating Glass Manufacturers Alliance (IGMA) to develop a hyper accelerated lifetime test for insulated windows.

This speeded-up test will provide IGMA with estimates of an insulated window's durability in only two weeks. Such a short turnaround on performance data greatly accelerates the development cycle of new improvements in the glass's energy efficiency.



To develop this test, researchers used the Differential Thermal Cycling Unit in the ESIF's Optical Characterization and Thermal Systems Laboratory. This unit made it possible to independently control the temperature and humidity on both sides of the tested materials and achieve realistic conditions for the accelerated testing of transparent fenestrations (i.e., windows).

INTEGRATE Project Targets a Smarter Energy Grid

In a first-of-its-kind research project, ESIF is supporting EERE's Solar Energy, Wind, Vehicles, Buildings, and Fuel Cell Technologies Offices to develop a holistic approach to grid integration.

The Integrated Network Testbed for Energy Grid Research and Technology Experimentation (INTEGRATE) project focuses on developing new ways to support the reliability and performance of the electric grid under increasing deployment of clean energy technologies.

At the ESIF, NREL researchers and industry partners will work to characterize distributed energy technologies, develop open-source interoperability standards, and initiate cross-technology demonstrations showing how EERE technologies can work together to improve the reliability and efficiency of the grid.

PARTNERSHIP HIGHLIGHTS

When NREL researchers and scientists support industry innovators, the achievements can have a broad and lasting impact. Here are some highlights of the great work performed with industry partners at the ESIF in FY14.

Ametek Partnership Improves Grid Simulators

In addition to being a testbed for the latest renewable energy technologies, the ESIF is also a place where the manufacturers of test equipment can go to improve their products.

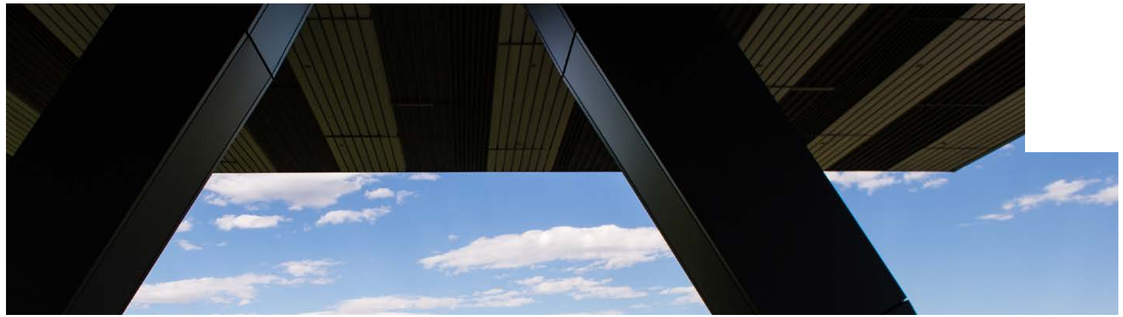
Ametek is the leading supplier of grid simulators for PV inverter testing, with more than 100 of their RS90 units out in the field. It's also the manufacturer of the ESIF's 1 MVA grid simulator, which is made up of 12 of Ametek's RS90 units that have been paralleled. This first-of-its-kind system is still working through operational challenges and suffered some reliability issues during FY14.

At the ESIF, NREL research operations staff worked with Ametek to identify the root cause of the failures and resolve the issues. The system improvements that Ametek made were carried forward into its product line to ensure a much more reliable system going forward.

R&D Partnership with GM Focuses on Lowering Cost, Improving Performance of Automotive Fuel Cells

NREL and General Motors (GM) partnered on a multiyear, multimillion-dollar joint R&D effort to lower the cost of automotive fuel cell stacks through improvements in materials and manufacturing.

To accomplish this, NREL and GM will focus on critical next-generation fuel cell electric vehicle challenges. These include reducing platinum loading, achieving higher power densities, understanding the implication of contaminants on fuel cell performance and durability, and accelerating manufacturing processes to attain greater economies of scale. Several fuel cell test stands from GM have been installed in the ESIF and will be used by both NREL and GM researchers for fuel cell development efforts.



CSIRO Joins Forces with NREL to Develop Solar Microgrid Controller

NREL partnered with Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) to develop a solar microgrid controller that will recognize when new solar power is introduced to the grid. This plug-and-play technology will allow newly connected solar generation to be automatically "discovered" and configured by the main generation control system.

To develop this technology, NREL researchers performed an assessment of communications protocols and determined compatibility requirements for the controller. They also created an interconnected microgrid system at the ESIF to test the hardware's ability to manage the output power of a diesel generator in the presence of a load bank and solar simulator.

CSIRO is now working with multinational engineering firm ABB to execute the project.

NREL Works with American Vanadium to Test CellCube Energy Storage System

NREL collaborated with American Vanadium to test and develop CellCube, a powerful energy storage system that provides an uninterrupted supply of power from solar and wind power stations, no matter the outdoor conditions. This technology will allow renewables to integrate more effectively with the power grid.

The first CellCube vanadium redox flow energy storage system has been installed at the ESIF, and testing of the battery will begin in FY15. This 20 kW battery—which can deliver 100 kWh—will be tested for applicability for renewable integration, microgrid, and utility-scale applications. To accommodate the CellCube, which holds more than 1,300 gallons of electrolytes, NREL upgraded its building occupancy rating for the ESIF's Electrical Characterization Laboratory.

NREL and Toyota Test High-Penetration PHEV Effect on Power Grid

NREL continued its collaboration with Toyota Motor Engineering & Manufacturing North America to find new and better ways to integrate plug-in hybrid electric vehicles (PHEVs) into the power grid.

Using 12 Toyota Prius PHEVs, NREL researchers tested the impact of high-penetration PHEV deployment on residential systems at the ESIF's Medium Voltage Outdoor Test Area (MVOTA). Results from the testing have provided confirmation on the levels at which vehicle loads begin to affect distribution grid power quality. These findings will lead to better strategies for the monitoring and control of power distribution throughout the grid.

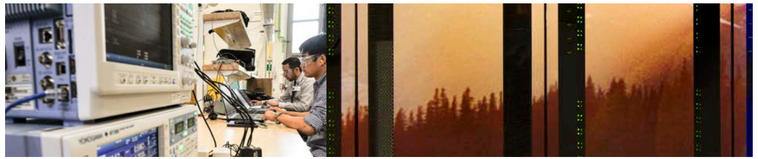
Toyota and NREL have developed plans for the next phase of testing, which will incorporate real residential loads using the ESIF's Smart Power Laboratory.

Mobile Microgrid Developed by NREL and Wyle Provides Electricity for U.S. Army's Forward Operating Bases

Under a research agreement with Wyle Labs, NREL continued its work with the U.S. Army to develop the Consolidated Utility Base Energy (CUBE) System. CUBE is a solar, battery, and generator hybrid power system that provides electricity to forward operating bases.

NREL scientists were tasked with completing a prototype CUBE system and validating its performance, reliability, and projected fuel savings through a series of tests at the ESIF. NREL scientists performed 24-hour testing and were able to demonstrate a 31% fuel savings when operating the CUBE in peak shaving mode. In 2015, NREL researchers will work to enhance the CUBE's capabilities even further, including adding a grid connection capability.

The goal of this research and development project is to create a more resilient and reliable microgrid, designed to protect against extended power outages caused by natural disasters, accidents, or attacks.



PARTNERS

The ESIF supported more than $5 million of new funds-in research through cooperative research agreements, work-for-others agreements, and technical service agreements, in partnerships with the following organizations.

- 3M*
- Abengoa Solar*
- Advanced Energy Industries
- American Vanadium
- Ametek
- Asetek
- California Department of Food and Agriculture
- CellEra
- Colorado School of Mines*
- Colorado State University
- CSIRO*
- Duke Energy
- ElementOne, Inc.
- General Electric
- General Motors
- Giner, Inc.*
- Houze
- Idaho National Laboratory
- Insulating Glass Manufacturers Alliance
- KPA
- Netherlands Enterprise Agency (RVO)
- New Jersey Institute of Technology
- Pacific Northwest National Laboratory
- Parker Hannifin Corp.
- PDC Machines, Inc.
- Proton OnSite
- Raytheon
- Sandia National Laboratories
- San Diego Gas & Electric
- SineWatts
- SolarCity
- Solar Power Inc.
- Solectria Renewables*
- Southern California Edison
- Southern California Gas
- Spectrum Automation Controls
- SunPower
- Technical University of Denmark
- The Babcock and Wilcox Company
- Toyota North America*
- University of California, Irvine
- University of Colorado, Boulder
- University of Delaware
- University of Wisconsin
- Wyle*
- YTC America Inc.

* These partners have more than one project.

NEW PARTNERSHIPS FOR FY15 HIGHLIGHTS

Big things are ahead for the ESIF in FY15. New partnerships and projects are just getting underway that will have significant effects on the deployment of clean energy technologies. Below are just a few of the partners that will be collaborating with NREL at the ESIF in FY15.

Duke Energy and Alstom Grid

NREL is collaborating with Alstom Grid to implement a comprehensive modeling, analysis, visualization, and hardware study using a representation of Duke Energy's utility feeder. This testing will make it easier for utilities to adopt smart inverters by addressing the challenges of modeling them in GIS, DMS, OMS, and SCADA.

Google

NREL researchers will evaluate inverters submitted to Google's Little Box Challenge for efficiency and performance under typical operating conditions. Shrinking the current inverter and making it cheaper to produce and install would enable more solar-powered homes and more efficient distribution grids and help bring electricity to remote areas.

San Diego Gas & Electric

San Diego Gas & Electric (SDG&E) is working with NREL to develop a real microgrid scenario with high penetrations of PV—using conditions that exist in SDG&E's territory. This scenario will be tested in the ESIF, and NREL scientists will investigate control cases for firming PV using energy storage in the microgrid. The results of this project will give SDG&E insight on how to effectively use high-penetration PV in islanded microgrids through proper energy storage sizing and placement.

Solar City and the Hawaiian Electric Companies

Working with SolarCity and the Hawaiian Electric Companies, NREL researchers will conduct tests to analyze high-penetration solar scenarios using advanced modeling. This will include load rejection overvoltage and ground fault overvoltage testing. With the results of these tests, the Hawaiian Electric Companies will be able to approve PV deployments for customers who have been waiting to connect to high-penetration solar circuits.

CAPABILITY UPGRADES

High Performance Computing

After extensive testing, NREL began using a new 1.2 petaflop HPC system named Peregrine in early 2014. This new system is the largest HPC system in the world exclusively dedicated to advancing renewable energy and energy efficiency technologies.

Developed in partnership with HP and Intel, Peregrine is a first-of-its-kind liquid-cooled supercomputer. It's also a living example of energy systems integration. Instead of using inefficient and expensive-to-run chillers, Peregrine's warm-water cooling system captures at least 90% of the data center's waste heat and reuses it as the primary heat source for the ESIF offices and labs. Peregrine helps to make the ESIF data center the world's most energy efficient, with a power usage effectiveness rating of 1.06.

Peregrine had immediate impact in FY14, providing more than 7 million compute node hours during the nine months it was used. It supported 46 modeling and simulation projects, advancing the mission across the spectrum of energy efficiency and renewable energy technologies.

Power Hardware-in-the-Loop Demonstrated at Megawatt Scale

Using Advanced Energy's 500 kW and 1 MW inverter, NREL researchers and operations staff successfully demonstrated the power hardware-in-the-loop (PHIL) testing capability in the ESIF at the megawatt scale.

To make this capability possible, NREL staff had to integrate new control capability into the ESIF's programmable grid, load, and PV simulators, and then demonstrate that the simulators could be operated in real time, to match the exact conditions of the modeled electrical grid. The ability to have real-time control over these simulators establishes a megawatt-scale capability, and makes it possible to connect simulated electrical grids to physical devices.

PHIL allows researchers to test advanced device controls and functionality at full power, and determine how their integration changes the landscape of the grid. This is critical to reducing risk prior to deploying new technologies in real-world applications.

Remote Real-Time Distributed Energy Resource (DER) Testbed

NREL and Pacific Northwest National Laboratory (PNNL) partnered to develop a new testbed that combines the PHIL capability of the ESIF with the remote distribution circuit software model at PNNL.

This approach to at-power, real-time simulation is new in that it's able to use existing distribution system modeling software (e.g., GridLAB-D), instead of converting the grid models to PHIL-specific simulation tools. It also allows for the distribution system model and hardware under test to be hosted at different geographic locations, yet still be linked together in a real-time simulation.

3D Visualization Center

Located adjacent to NREL's HPC data center, the ESIF Insight Center combines state-of-the-art visualization and collaboration tools to promote knowledge discovery in energy systems integration. The Insight Center uses advanced technology to provide on-site and remote viewing of experimental data, high-resolution 3D visual imagery, and large-scale simulation data.

This space 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.

The centerpiece of this room is a custom-designed immersive virtual environment composed of six active stereo 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 to the movement of the user. This allows users to physically explore and interact with their data.

CSP Equipment Test Stand

A receiver test station was installed at the ESIF that provides a valuable testing service to companies that develop and use CSP technology. The test station measures the thermal capture efficiency of parabolic trough receivers—key components that determine the overall operational efficiency of parabolic trough CSP plants.

NREL has completed measurement of the thermal efficiency of a new prototype receiver supplied by Solar Power Inc. NREL is also negotiating work agreements with other companies to measure the thermal efficiencies of receivers in the field, to help predict long-term performance.

Continuous and Pulsed Solar Simulator Equipment

A continuous solar simulator and a long-pulse solar simulator at the ESIF allow researchers to measure performance on PV devices at the module scale.

The continuous simulator enables research on changes in PV module performance due to long-term light exposure, and the long-pulse simulator allows for instantaneous, room-temperature performance measurements. The close proximity of the two instruments makes it possible to transition quickly from one testbed to the other, leading to improved characterization of time-sensitive phenomena.

Smart Power Lab

The 5,300-square-foot Smart Power Laboratory at the ESIF is designed to be a highly flexible and configurable space. This flexibility is essential for smart power applications that can range from developing advanced inverters and power converters to testing residential and commercial-scale meters and control technologies.

Research at the Smart Power Laboratory focuses on the development and integration of smart technologies. This includes the integration of distributed and renewable energy resources into power electronics, and smart energy management for buildings.

Inside the laboratory, researchers are designing models to replicate smart homes with a variety of appliances, HVAC systems, smart meters, PV systems, and electric vehicle chargers. These test models will evaluate the ability of residential and light commercial-scale equipment to provide grid services and participate in transactional energy markets where price and control signals are sent between grid equipment.

1.5 MW PV Simulator and Bi-Directional Power Supply

An additional 500 kW of programmable direct-current (DC) power supply was installed at the ESIF, expanding its PV emulation capabilities to a full 1.5 MW. This increased capacity will support full-power testing of commercial-scale PV inverters, as well as improve the ESIF's ability to support simultaneous testing of multiple devices as part of stand-alone or integrated experiments.

A 660 kW bi-directional DC power supply capable of operating as a PV simulator, battery simulator, or generic DC voltage or current supply was also installed. The supply was used as a PV simulator for the CSIRO microgrid test.

Environmental Chamber

A walk-in environmental chamber capable of operating from -65°C to +85°C and from 10% to 95% relative humidity was added to the ESIF. The environmental chamber was immediately used by NREL researchers to test a piece of electrical equipment for the Department of Defense.

Researchers used a new 300 kW diesel generator to power the equipment in the environmental chamber. The generator was also used to power critical loads during several scheduled power outages at NREL.

USER FACILITY UPDATES

NREL Issued RFP for Connected Devices and Integrated Systems

NREL completed a request for proposals (RFP) for up to $6.5 million in funding for high-impact research, development, and demonstration (RD&D) in the ESIF under the INTEGRATE Project. Awards through this RFP will focus on increasing the hosting capacity of the grid. Hosting capacity relates to the amount of renewable energy that a portion of the grid can "host" without requiring system upgrades. Clean energy technologies will be evaluated for their ability to provide grid services in a holistic manner using an open-source, interoperable platform that allows all the technologies to interchange information and optimize system-level performance. This RFP also represents the first launch of an external user program at the ESIF.

User Support System and Framework

NREL developed a user support system for the ESIF that is open for users to make FY15 resource requests. Working in partnership with PNNL—which developed a similar system for its Environmental Molecular Sciences Laboratory—NREL adopted and modified PNNL's system to take advantage of PNNL's experience and investments. Through this approach, NREL was able to launch the ESIF user support system within a matter of months, avoiding what could have been years of development time and hundreds of thousands of dollars of investment.

ESIF Operations Serves as Model for Safety Enhancement Programs

The ESIF Operations team completed the revision of the ESIF Hazard Analysis Report (HAR). As part of this effort, a new format and content guide and a process hazards analysis tool were developed and will serve as a framework for HAR development for NREL's other facilities. The ESIF Operations team also launched its new Configuration Management, Quality, and Work Control programs.

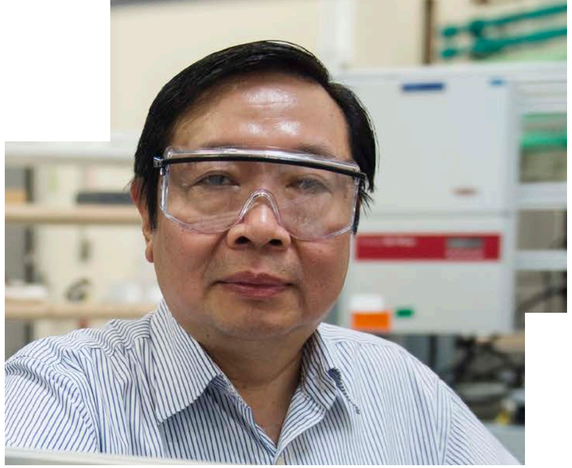
NREL Develops Streamlined Approach for Onboarding ESIF Users

A joint effort between the ESIF Operations team; Human Resources; Security and Emergency Preparedness; and the Environment, Health, and Safety offices resulted in a new, streamlined onboarding process for ESIF users. Now, instead of having to go through the multiday onboarding process that NREL employees go through to have badge access to the site, ESIF's users and project partners are able to complete online training.

INVENTIONS

Licenses

NREL Software Record No.	Title	NREL Contributors	License Type	Licensed To
SWR-12-11	PV Inverter Maximum Power Point Tracking and IEEE 1547 Standard Compliance Control Code	Mari Shirazi, Blake Lundstrom, and Sudipta Chakraborty	Royalty-Bearing License	U.S. Hybrid
SWR-14-11	FESTIV (Flexible Energy Scheduling Tool for Integrating of Variable generation)	Erik Ela and Ibrahim Krad	Non-Fee-Bearing License	Electric Reliability Council of Texas
SWR-14-18	REPRA (Renewable Energy Probabilistic Resource Adequacy Tool)	Eduardo Ibanez	Open-Source Software	N/A
SWR-14-06	GLD2OCT	Peter Gotseff and Alicia Allen	Open-Source Software	N/A
SWR-14-02	IHT (Monte Carlo method for radiative heat transfer between particles)	Ray Grout	Open-Source Software	N/A
SWR-14-05	NREL WISDEM (NREL Wind-Plant Integrated System Design and Engineering Model)	Katherine Dykes, Peter Graf, George Scott, and Andrew Ning	Open-Source Software	N/A
SWR-14-12	SOWFA (Simulator for Wind Farm Applications)	Sang Lee, Matthew Churchfield, and Paul Fleming	Open-Source Software	N/A
SWR-14-20	FLORIS (FLOw Redirection and Induction in Steady-State)	Paul Fleming and Andrew Ning	Open-Source Software	N/A



Records of Invention and Patents

ESIF Capability/Resource Used	Title	NREL Number
Lab	Evaluation of Porosity and Thermal Parameters of Fuel Cell and Battery Membranes: Static and On-Line Monitoring	ROI-14-68
Lab	Closed-Loop Image-Based Tracking Approach for Heliostats	ROI-14-19
Lab	Embedded-Cavity and Cooled-Flare Particle Receiver Design	ROI-14-72
Lab	Particle Receiver Design and Module Fabrication Methods	ROI-14-52
Lab	The Process Design Model of a High-Temperature Solid Oxide Co-Electrolysis System Coupled with Fischer-Tropsch Synthesis and Syncrude Refining Processes	ROI-14-46
Lab	Inverse Templating of Carbon-Supported Catalysts	ROI-14-08
Lab	Platinum-Coated Nickel Nanowires as Oxygen-Reducing Electrocatalysts	ROI-14-41
HPC	IHT (Monte Carlo method for radiative heat transfer between particles)	SWR-14-02
HPC	NREL WISDEM (NREL Wind-Plant Integrated System Design and Engineering Model)	SWR-14-05
HPC	SOWFA (Simulator for Wind Farm Applications)	SWR-14-12
HPC	Combining Independent Blade Pitch Control with Wake Redirection for Wind Turbines	ROI-14-82
HPC	Particle Filters for Tracking Wind Turbine Wakes	ROI-14-83
HPC	FLORIS (FLOw Redirection and Induction in Steady-State)	SWR-14-20
HPC	A Two-Dimensional Thermal-Electrochemical Model for Prismatic Lithium Ion Cells	SWR-14-04
HPC	Strategy to Access Low Band Gap Organic Donor Materials for Organic Photovoltaics that Possess Increased Stability Toward Degradation via Fluorination of Traditional Donor Monomer Frameworks	ROI-14-56

PUBLICATIONS

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