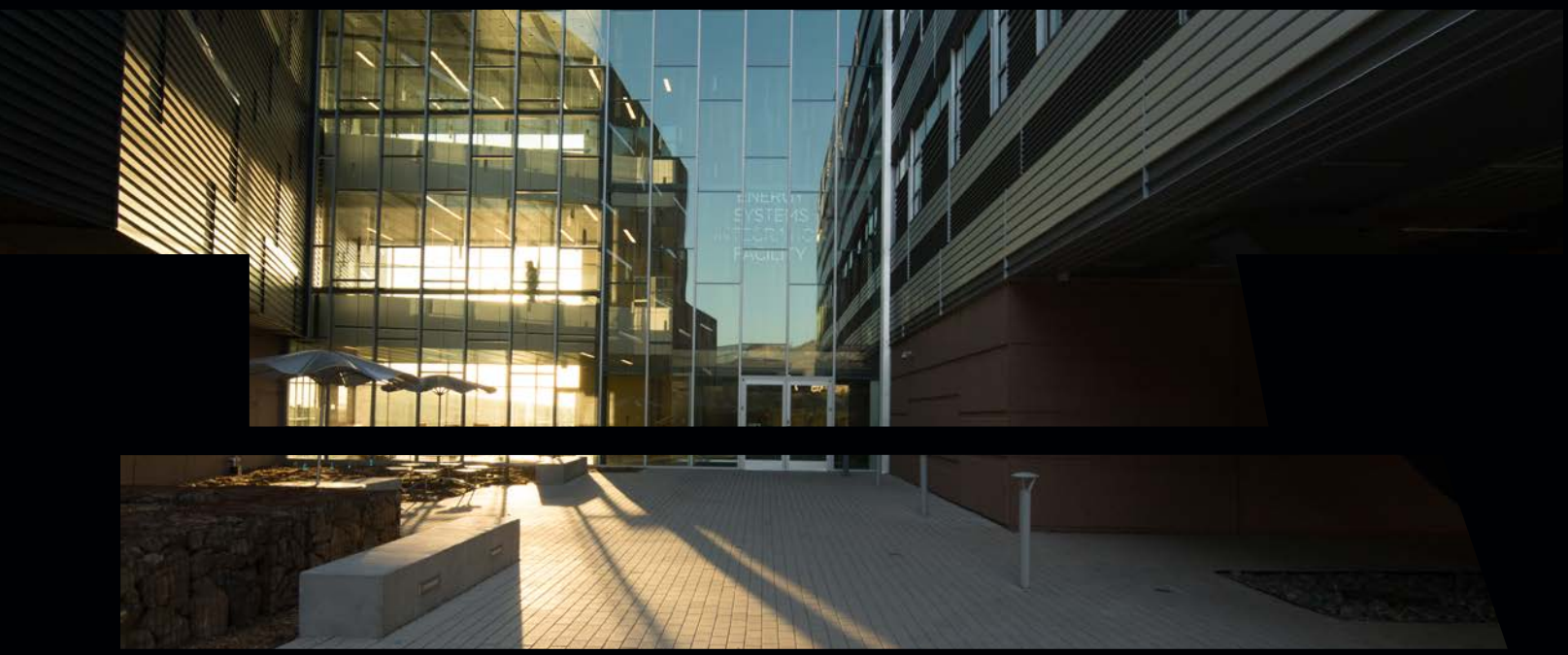
ESIF 2015



Bring us your challenges

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

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.

"Addressing the challenges of creating cleaner, more reliable, and more affordable energy systems will require collaboration on an unprecedented scale. The ESIF was designed to be a connection point where industry, academia, and government could work together on this most complex and important global challenge of our time. So think big, think broadly, and think boldly: bring us your biggest energy challenges, and let's solve them together."

-Bryan Hannegan, Associate Laboratory Director for Energy Systems Integration

BRING US YOUR CHALLENGES

The Energy Systems Integration Facility (ESIF) is the nation's premier facility for research, development, and demonstration of the components and strategies needed to optimize our entire energy system. It was established in 2013 by the U.S. Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy, on the campus of its National Renewable Energy Laboratory (NREL), and is a designated DOE user facility.

Since our inception two years ago, the ESIF team and our more than 100 industry and academic partners have tackled the biggest 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? And how do we fashion new business models, regulatory frameworks, and value propositions for consumers in this changing world?

This second ESIF Annual Report documents the great progress we have made in using the unique capabilities at the ESIF to explore the integration of solar and wind technologies into the electric grid using advanced power electronics. We have also continued to expand the ESIF's capabilities with regard to hydrogen production, storage, and fueling, including the first high-altitude, high-pressure fueling station for fuel cell vehicles installed at the ESIF this year. Our work on microgrids and energy storage is helping military bases, communities, and industrial complexes improve their resilience and increase their sustainability. And, in the last year, we deployed new capabilities at the ESIF to develop and validate advanced distribution management systems, and explore the cyber and physical security issues associated with emerging grid technologies.

In the past year, NREL has not only expanded its capabilities at the ESIF, but has also established a connection to enable joint research activities between the ESIF and the test transmission grid at Idaho National Laboratory, the bulk power system operations center at the Pacific Northwest National Laboratory, and NREL's National Wind Technology Center (NWTC). In particular, the NWTC at NREL offers similar integration capabilities to the ESIF, but at a larger 1–10 MW scale that goes beyond the physical limitations of the ESIF. This combination of national laboratory capabilities is a key element of the Grid Modernization Laboratory Consortium, providing the tools and knowledge needed for our partners to transform their energy systems at a pace and scale that matters for U.S. and global economic growth, environmental quality, and national security objectives.

As the world accelerates its move toward clean energy systems, there is much more work to be done "beyond the grid" with respect to thermal energy, fuels supply, and water and wastewater systems. For example, integrating thermal sources with electric grids can provide new options to make the best use of variable renewable energy sources at times when on-site production exceeds the local demand. Similarly, water technologies for pumping and treatment can serve as controllable loads, adding new flexibility to electric grids impacted by high penetrations of variable renewables. In the coming year, we will expand on our firm foundation in electric grids to address the modernization of the broader energy system.

Addressing the challenges of creating cleaner, more reliable, and more affordable energy systems will require collaboration on an unprecedented scale. The ESIF was designed to be a connection point where industry, academia, and government could work together on this most complex and important global challenge of our time. So think big, think broadly, and think boldly: bring us your biggest energy challenges, and let's solve them together.

Sincerely,

Bryan Hannegan
Associate Laboratory Director for Energy Systems Integration at NREL

TABLE OF CONTENTS

6 FY 2015 Challenges We've Met

- 6 Renewable Energy to Grid Integration: PV, Wind, & Advanced Inverters
- 10 Renewable Fuels & Vehicle to Grid Integration: Hydrogen, Fuel Cells, & Electric Vehicles
- 16 Grid Control & Resilience: Energy Storage & Microgrids
- 22 Grid Modeling, Control, & Cybersecurity
- 28 High Performance Computing & Visualization

35 Partners

38 New Connections

40 DOE Program Research

46 INTEGRATE Projects

51 User Facility Updates

54 Inventions

58 Publications

RENEWABLE ENERGY TO GRID INTEGRATION:

PV, Wind, & Advanced Inverters

Project Spotlight

NREL Teams with SolarCity and HECO to Maximize Solar Power on Hawaiian Electric Grids

Hawaii has some of the highest penetrations of rooftop solar in the country—11% according to the Solar Electric Power Association, compared to a national average of 0.5%. As the number of rooftop solar systems grew in Hawaii, the Hawaiian Electric Company (HECO) became concerned that all of this distributed photovoltaic (PV) energy could create instability or damaging conditions, leading HECO to halt new PV interconnections.

One of HECO's main concerns was spikes in voltage called load rejection overvoltage (LRO) that can occur at the customer site. In theory, the new generation of smart inverters should be able to react quickly to mitigate the harmful effect of LRO. However, no comprehensive LRO test had yet been performed with advanced inverters to prove this.

To better understand the capabilities of advanced PV inverters, HECO partnered with SolarCity and NREL to run a series of tests to measure the magnitude and duration of LRO events and demonstrate the inverters' ability to mitigate their impact. LRO tests were completed at the ESIF on five commercially available advanced inverters ranging in size from 3 kW to 12 kW and included single-phase inverters, three-phase string inverters, and micro inverters.

Continued on page 8

"We know how important the option of solar is for our customers. Solving these issues requires that everyone—utilities, the solar industry, and other leading technical experts like NREL—work together. That's what this work is all about. With the highest amount of solar in the nation, our utilities are facing potential reliability and safety issues before anywhere else."

- Colton Ching, Vice President for Energy Delivery, Hawaiian Electric Company

Project Impact

- **Waiting customers connected.** Based on the results of this work, HECO cleared the queue of some 2,500 customers waiting to connect their PV systems to the grid.
- **Ceiling for solar power in Hawaii raised.** Limits on distributed solar power were more than doubled from 120% of minimum daytime load to 250%.
- **Interconnection standards and codes changed.** NREL researchers helped to update IEEE 1547 and UL 1741 to standardize inverter testing protocols and procedures for advanced inverter functionalities.

Project Spotlight *continued from page 6*

Results of this testing showed that the maximum overvoltage levels and durations did not exceed acceptable limits in any test and were typically well below the maximum. This demonstrated that with advanced inverter technology, overvoltages were not as big of a risk as utilities feared and allowed HECO to start connecting waiting customers' PV systems.

Testing continues at the ESIF to better understand how advanced inverters affect dynamics such as voltage regulation and multi-inverter unintentional islanding. This research is supported by the Office of Energy Efficiency and Renewable Energy's and DOE's Grid Modernization Initiative. Funding was equally shared between SolarCity and DOE's SunShot Initiative.

Project Highlights

Arizona Public Service

Researchers at NREL developed software tool kits and provided training to Arizona Public Service engineers to help them better predict, plan for, and mitigate the effects of high penetrations of PV on their distribution feeders.

Google

Inverter testing at the ESIF has begun for Google's Little Box Challenge, a competition offering $1 million to the team that can build the best kilowatt-scale PV inverter with a power density greater than 50 W/in.^{3}. NREL is supporting Google and the IEEE Power Electronics Society on this project.

New Tools

Rooftop Solar Resource Monitoring System Upgrades

These upgrades add additional measurement capability to existing monitoring stations. New data available include plane-of-array irradiance, latitude-tilt irradiance, back-of-panel PV temperature, ambient temperature, and relative humidity. Data are taken every second with a silicon diode pyranometer.

New Resources

PV Integration Handbook

In collaboration with Southern California Edison, Electrical Distribution Design, and Quanta Technology, NREL researchers have produced a handbook to help distribution engineers facing the challenge of high-penetration PV integration for the first time. Funding for this project was provided by DOE's SunShot initiative. Download the handbook at http://www.nrel.gov/docs/fy16osti/63114.pdf.

Western Wind and Solar Integration Study: Part 3

This report covers the third phase of the Western Wind and Solar Integration Study, one of the largest regional solar and wind studies to date. The study found that with good system planning, sound engineering practices, and commercially available technologies, the Western Interconnection can withstand the crucial first minute after grid disturbances with high penetrations of wind and solar on the grid. Download the study at http://www.nrel.gov/docs/fy16osti/64822.pdf.

National Solar Radiation Database Update

The National Solar Radiation Database (NSRDB) is a serially complete collection of meteorological and solar irradiance data sets. The data are publicly available and provide foundational information to help solar system designers, building architects and engineers, renewable energy analysts, and many others to improve and expand solar energy technologies. In this new update, the NSRDB changed from using mainly empirical modeling and data collected at stations to using a physics-based modeling approach called the Physical Solar Model. Download data at https://nsrdb.nrel.gov/.

RENEWABLE FUELS & VEHICLE TO GRID INTEGRATION:

Hydrogen, Fuel Cells, & Electric Vehicles

Project Spotlight

NREL Launches Integrated Production-to-Dispensing Hydrogen Infrastructure at the ESIF

Commercially available fuel cell electric vehicles (FCEVs) from Toyota, Hyundai, General Motors, Honda, Daimler AG, and others are being sold or leased to early adopters in a few U.S. states—most notably California. To help address the challenges of building a hydrogen refueling infrastructure nationally and accelerate deployment, NREL has added new tools at the ESIF and forged new industry partnerships.

The new tools include an electrolyzer stack test bed (up to 1 MW); multiple hydrogen compression and storage stages; a state-of-the-art hydrogen vehicle fueling station with precooling; two high-pressure, low-temperature (up to 875 bar, down to -40°C) hydrogen component test beds; and a six-axis robot being used for hydrogen fueling hose reliability testing.

All of this equipment is designed to work seamlessly in various test configurations with data monitoring while providing fuel-cell-quality hydrogen to the rest of the ESIF labs for accelerated component-level testing, R&D, and FCEV fueling. This integrated system covers all aspects of a hydrogen economy—from renewable hydrogen

Continued on page 12

"Our new commercial products, developed for mobility and renewable energy applications, require specialized test beds and high electrical energy sources for evaluation. NREL, along with their expert staff, delivered both. NREL assembled the required test bed in a short period of time. The staff was proficient and very capable on conducting the requested test. As a small company, it is difficult to build the required infrastructure needed to evaluate high-energy products. The value provided by NREL was performed at a very justifiable cost."

- Monjid Hamdan, Engineering Director, Giner, Inc.

Project Impact

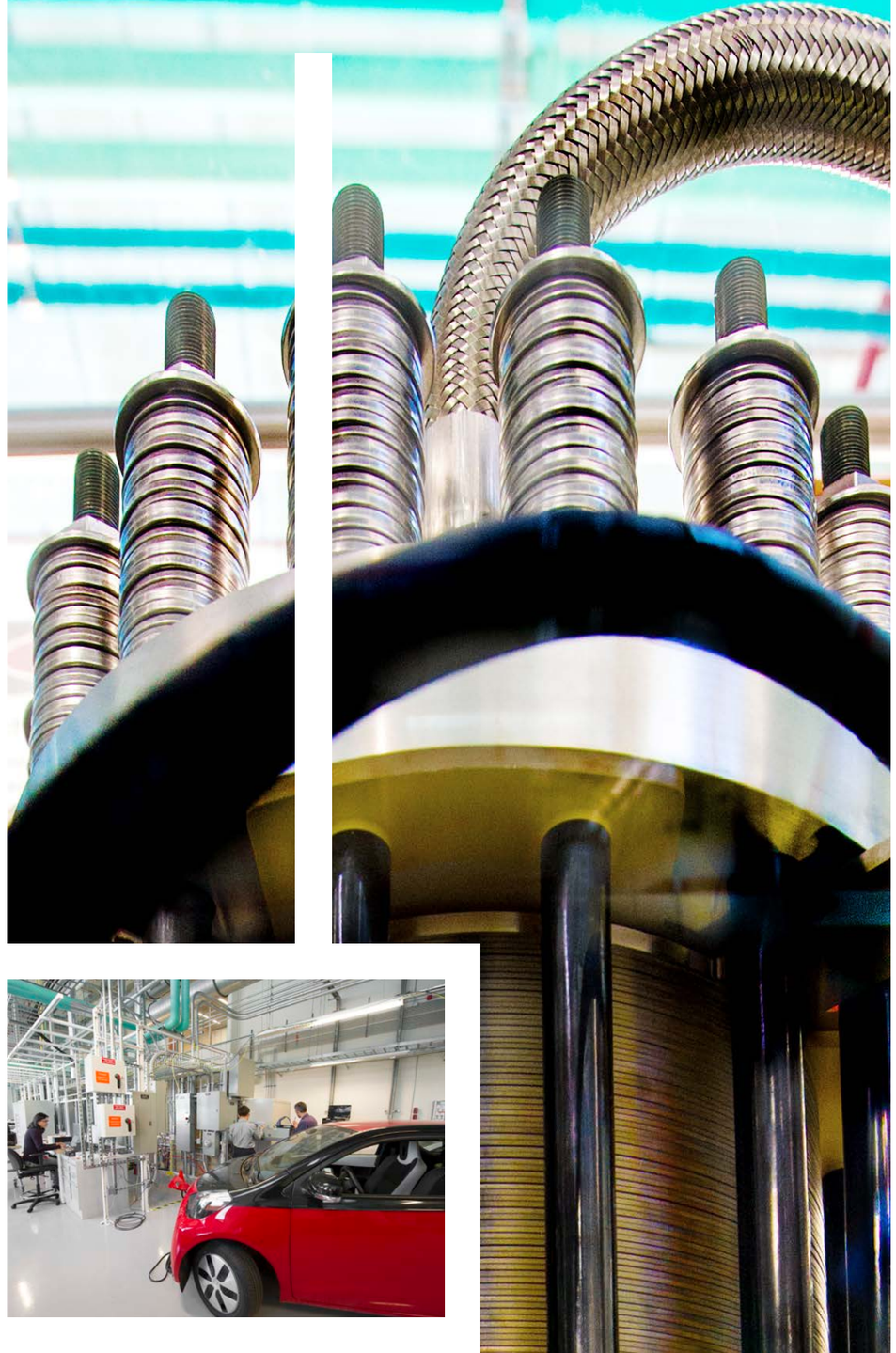
- **H2FIRST-developed HyStEP device to cut station prep time from six weeks to one.** The HyStEP device, developed through H2FIRST, is intended to check the safety of fueling stations to ensure that the amount of heat generated doesn't exceed safe limits. Findings are shared with all car manufacturers instead of each company having to separately certify a station. That's expected to shorten the time it takes for a station to be ready for customers from about six weeks to one.
- **NREL tools positioned to complement, not compete with existing resources.** "NREL (has) capabilities that in a lot of ways are ahead of the curve. As a car manufacturer, I want to concentrate on vehicle engineering and powertrain engineering, and have the ability to do that. But I don't necessarily want to test the hose on a hydrogen station. That's out of my domain." - Tim McGuire, Project Manager, Mercedes-Benz Research and Development North America.

production to its use in fuel cells—making it the most advanced and highly instrumented hydrogen technology testing facility in the world.

FCEV manufacturers are already taking advantage of these advanced new tools. Toyota's Mirai and Highlander, Mercedes-Benz's B-Class F-CELL, and Hyundai's Tucson Fuel Cell currently comprise a fleet of five vehicles used on and around the NREL campus to support infrastructure testing and evaluation at NREL. Research ranges from technical challenges such as testing new hydrogen fueling methods to outreach, education, and improving user experience at hydrogen fueling stations. Materials research on critical fuel cell components such as membrane electrode assembly (MEA) is ongoing with partner General Motors.

On the hydrogen production side, NREL is working with partners Giner, Proton OnSite, and Southern California Gas Company on the concept of power-to-gas. These companies are investigating ways of optimizing hydrogen production with the electric grid to produce natural gas, which would enable greater penetrations of renewable energy.

NREL is also colead with Sandia National Laboratories on H2FIRST—a collaboration among national laboratories and public and private partners. H2FIRST is aimed at making the fueling experience for FCEVs equivalent to or better than that of gasoline cars. Fiscal Year 2015 achievements include the publication of a reference document exploring the pros and cons of different hydrogen station designs, a gap analysis between industry needs and commercial-off-the-shelf detector capabilities for inline hydrogen contaminant detectors, and the development of the Hydrogen Station Equipment Performance (HyStEP) device for the acceleration of commercial hydrogen station acceptance.



Project Highlights

Giner Large-Scale Hydrogen PEM Electrolyzer

Giner collaborated with NREL to test large-scale polymer electrolyte membrane (PEM) electrolyzer stacks designed to maximize renewable energy on the grid by converting it to hydrogen when supply exceeds demand. Researchers validated the electrolyzer stack's performance to demonstrate the capability of this growing technology to provide grid services, energy storage, and emissions-free transportation fuel for FCEVs.

PG&E Plug-in Hybrid Electric Utility Truck

NREL performed testing and analysis on a Pacific Gas and Electric (PG&E) plug-in hybrid electric utility truck developed by Efficient Drivetrains, Inc., that has approximately 30 miles of all-electric range and is capable of exporting up to 120 kW of AC power to the grid. Using the ESIF's drive-in thermal chamber and research utility system, NREL researchers conducted testing and analysis to improve understanding of the truck's export power mode and onboard thermal control under a variety of environmental conditions.

Southern California Gas Company Power-to-Gas Project

NREL is collaborating with Southern California Gas Company, electrolyzer manufacturer Proton OnSite, and the National Fuel Cell Research Center at the University of California, Irvine to demonstrate a power-to-gas energy storage system concept—the first of its kind in the United States. The technology converts electricity into hydrogen and then combines hydrogen with carbon dioxide to produce methane. This approach could provide North America with a large-scale, cost-effective solution for storing excess energy produced from renewable sources.

New Tools

Electrolyzer Stack Test Bed

NREL designed, built, and now operates an electrolyzer stack test bed that provides on-site hydrogen production for fuel cell labs, hydrogen component testing research, and fuel cell electric vehicle refueling. The test bed was designed for hydrogen production in the range of 100 kg per day. It is already operating at approximately half that capacity with a Proton OnSite 120-kW PEM stack.

Hydrogen Vehicle Fueling Station

NREL designed, built, and commissioned a dual-pressure (350/700-bar) hydrogen fueling system. The system compresses and stores hydrogen fed from the electrolyzer stack test bed up to 400 bar (80 kg capacity at 6,000 psig). Another compression stage can then elevate the pressure to 875 bar (60 kg capacity at approximately 13,000 psig), where it is stored for vehicle refueling. The fueling system precools the hydrogen gas to refuel a vehicle in approximately 3–5 minutes.

Hydrogen Component Test Beds

NREL has successfully employed two high-pressure hydrogen test bays for the first time. The test bays can accommodate research and development of hydrogen components at up to approximately 13,000 psig. One of the test beds includes thermal cycling to simulate ambient temperature fluctuations. The other one features low-temperature (-40°C) cooling of the hydrogen gas to simulate real-life component stresses associated with hydrogen refueling.

New Resources

Online Fuel Cell Contaminants Tool

Balance of plant plastic materials can create contamination in fuel cell systems that directly affect FCEV performance. NREL researchers have examined the relevant materials and contaminants and developed an easy-to-use online tool to help system developers choose the cleanest material for their application. The online tool is publicly available at http://www.nrel.gov/hydrogen/system_contaminants_data/.

GRID CONTROL & RESILIENCE:
Energy Storage & Microgrids

Project Spotlight

Raytheon and NREL Demonstrate a Microgrid Powered by Solar Energy and Batteries

Cities, utilities, businesses, universities, and the U.S. military are turning to microgrids for supplemental and backup power. This is because microgrids offer the flexibility, quick response and control, and security that the larger grid can't. They also respond to customers' desire for more local control of their energy and a greater percentage of renewables powering their homes and businesses.

While microgrids offer big advantages in security and emergency power, earlier versions were not always efficient, often relying heavily on diesel generators or other fossil fuels for power. In a first-of-its-kind demonstration, NREL partnered with Raytheon Company, Primus Power, and Advanced Energy to successfully demonstrate an advanced microgrid system that draws 100% of its power from solar energy and batteries. The demonstration will lead to a pilot system to be installed at the Marine Corps Air Station (MCAS) Miramar designed to power one building for at least 72 hours.

To prove the concept, NREL provided a test environment in the ESIF for Raytheon's microgrid power and control system that closely reflected the planned real-world installation at MCAS Miramar. ESIF engineers mimicked the planned microgrid using a grid simulator, DC power supplies to simulate the PV system and the battery storage system, and a "load bank" that can simulate up to 200 kW of electricity use, equal to about 20 U.S. homes.

Continued on page 18

"The results of the work being accomplished in the ESIF laboratory are truly amazing, and representing MCAS Miramar, I can honestly say that it has accomplished a huge amount of risk mitigation for when (the microgrid) gets installed on base. As I said in the lab, seeing a completely renewable energy system, that scale and complexity, island and perform as envisioned was the most fun I've ever had at work. It truly felt like history in the making."

- Mick Wasco, PE, CEM, Installation Energy Manager, Marine Corps Air Station (MCAS) Miramar

Project Impact

- **Microgrid components improved.** Test results led to the refinement of the battery DC power quality, optimization of the use of solar power, and enhancements to the microgrid controller.
- **Risks of deployment reduced.** By testing the microgrid at full power and actual load levels, problems could be identified early, allowing project partners to make adjustments before the microgrid is implemented in the field.
- **100% PV penetration demonstrated on a microgrid.** The demonstration proved that an energy storage system-driven microgrid with conventional PV inverters can achieve 100% PV penetration while retaining the power quality needed to satisfy critical facility loads.

Project Spotlight *continued from page 16*

Using this setup, NREL was able to simulate the battery working at full power, replicate a variable solar energy supply over time, and re-create the loads on the system based on the actual loads measured at MCAS Miramar. The simulated microgrid was tested in both grid-connected and off-grid or "islanded" modes, and the efficacy of the microgrid controller was evaluated in managing PV output power and battery charging and discharging to maximize the use of solar power.

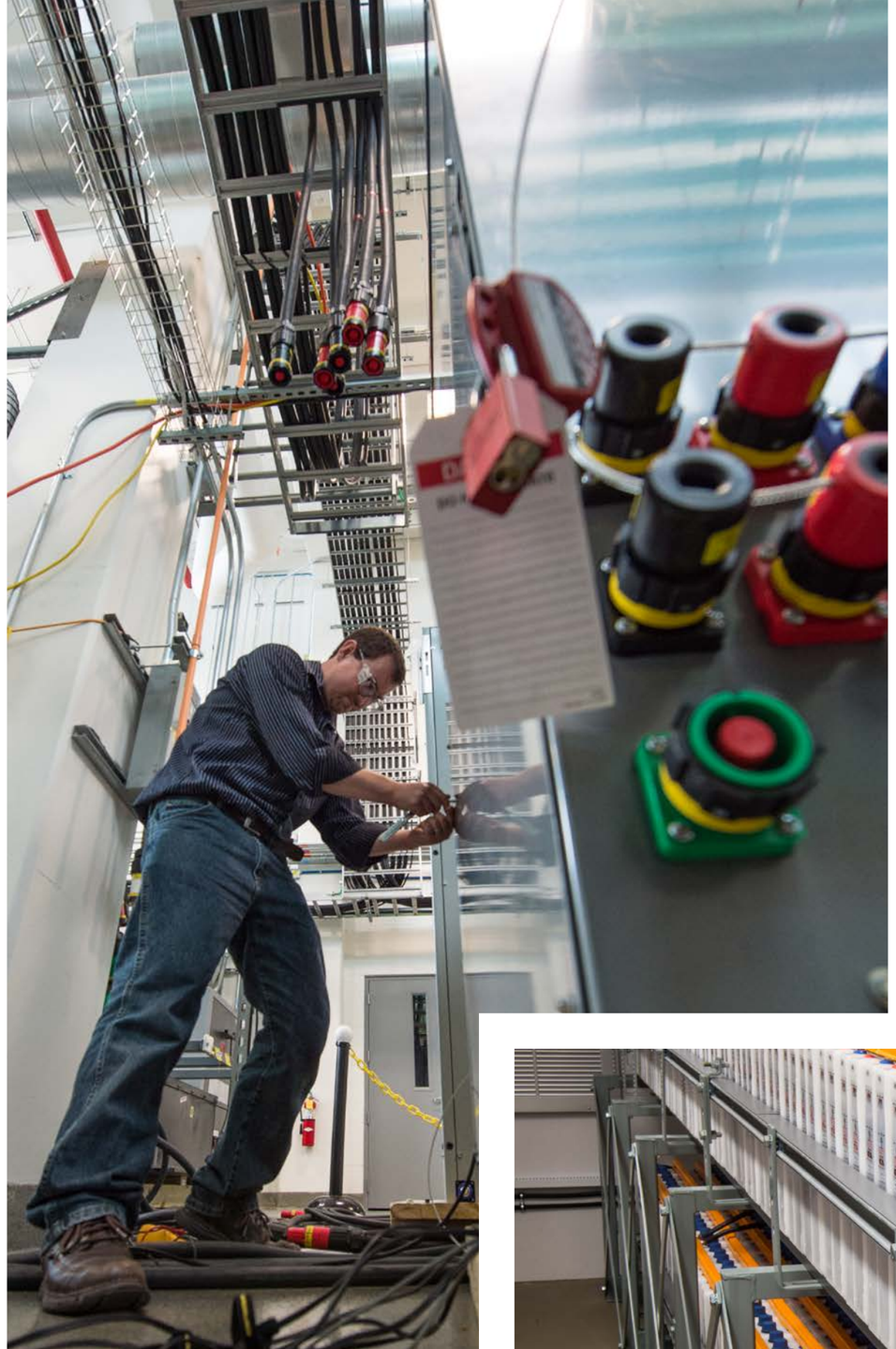
Project Highlights

Erigo and EaglePicher Microgrid Energy Storage System

NREL researchers are helping to test an energy storage system developed by Erigo and EaglePicher and sponsored by U.S. Northern Command that contains three independently controllable energy storage technologies. The system will be integrated into microgrid applications and other scenarios a military base might encounter.

Energy Storage Evaluation Tools for SDG&E

NREL is building research and testing tools to support evaluating energy storage installations in San Diego Gas & Electric (SDG&E) territory. The tools are developed to identify an optimal dispatch strategy to operate energy storage, analyze the technical impact on the feeders, and calculate the associated cost-benefit of energy storage on SDG&E distribution feeders. A cost-benefit/alternatives analysis and a cost-benefit tool were developed to evaluate existing and future battery energy storage systems on SDG&E's distribution feeders. NREL also developed a hardware-in-the-loop test bed for energy storage testing at the ESIF and tested use cases, developed a standard procedure for battery storage performance testing, and is establishing a virtual connection between the Real Time Digital Simulator (RTDS) at NREL's ESIF facility and the RTDS at SDG&E's Integrated Test Facility, enabling integrated experiments for future SDG&E needs.



New Tools

Cyber-Physical Microgrid Testing Platform

As part of a Laboratory Directed Research and Development project, researchers at NREL have demonstrated a cyber-physical microgrid testing platform. Real-time communications are essential to microgrid operations and can affect the performance of microgrid hardware. The ESIF is able to add an important communications layer that connects real computers and virtual hosts to the hardware or technology under test. This makes it possible to test not only factors such as microgrid power quality, system stability, and load management but also communications protocols, latency and bandwidth requirements, and data management to obtain a complete picture of the microgrid's performance.

New Resources

PV-Coupled Energy Storage Modeling

Modeling the behavior of PV-coupled energy storage can be complex given the interplay among short- and long-term battery performance and degradation, solar generation, complex utility tariff structures, incentives, and costs. NREL's System Advisor Model (SAM) team, in conjunction with energy storage experts in the ESIF, developed a detailed PV-coupled battery energy storage model that can accurately predict the voltage, capacity, thermal, and long-term degradation behavior of lead acid and lithium-ion battery systems. Leveraging SAM's built-in detailed PV models and comprehensive financial models, with the addition of a feature to run the model at 1-minute time steps throughout the 30-year potential lifetime of a system, users can now evaluate both performance issues as well as the resulting economic viability of behind-the-meter energy storage. Complex issues such as battery replacement costs incurred due to heavy cycling are fully captured in the model at a level of detail not previously possible with other optimization tools. Technical reports are available at http://www.nrel.gov/docs/fy15osti/64641.pdf and http://www.nrel.gov/docs/fy16osti/64987.pdf. SAM can be downloaded for free at https://sam.nrel.gov/.

Microgrid Controls and Management Systems Workshop

NREL's Energy Systems Integration (ESI) team held a workshop on microgrid controls and management systems on July 9 that included speakers and attendees from utilities, manufacturers, academia, and other national labs. The workshop was part of an Advanced Grid Control Technologies Workshop Series and featured perspectives from microgrid owners on implementing and operating microgrids and perspectives from microgrid vendors on advancements in microgrid controls and management system technology. More than 35 people attended the event, with many attendees participating in a tour of the ESIF on July 8. Presentations from this workshop are available at http://www.nrel.gov/esi/agct_workshops.html.

GRID MODELING, CONTROL, & CYBERSECURITY

Project Spotlight

Duke Energy, GE, and NREL Test the Voltage Control of Smart Inverters Using Modeled North Carolina Distribution Feeder and Alstom DMS as a Testing Tool

Solar is booming in North Carolina. The state currently ranks fourth in the country in installed solar capacity, outpacing states several times its size. What makes North Carolina different from other leading solar states such as Hawaii is that this new solar capacity isn't on rooftops. According to the Solar Energy Industries Association, more than 98% of the solar electric capacity installed in North Carolina in 2014 was utility scale.

Integrating such high penetrations of utility-scale solar into distribution grids can present voltage regulation challenges for utilities. Duke Energy, the primary utility for North Carolina, wanted to compare how the advanced inverters working autonomously or in conjunction with their existing distribution management system (DMS) could help. Duke Energy partnered with NREL and DMS vendor General Electric (GE) Grid Solutions (formerly Alstom Grid) to better understand these voltage interactions through simulation, visualization, and hardware testing.

For this research, Duke Energy provided data for a rural distribution circuit that already has a 5-MW solar PV system located two miles from the substation. The data included the technical details of the network along with one year of power, voltage, and current measurements taken every minute from the substation and PV system. With this information, NREL and GE modeled the Duke Energy feeder and simulated future

Continued on page 24

"Utilities cannot afford to build all the equipment and infrastructure needed to test emerging grid technologies. Using a facility like the ESIF not only makes this research financially feasible, but the collaboration between partners helps all of us learn."

- Leslie Ponder, Technology Evaluation Manager, Duke Energy

Project Impact

- **A commercial DMS is used as a simulation and research tool.**
  Until recently, a DMS controlled only utility equipment, not assets such as solar PV and inverters that the utility may or may not own. Smart inverters' two-way communications capabilities changed that dynamic, and new DMS features allow for both control and testing within the operations platform. This project is one of the first of its kind to explore PV voltage control questions using a commercial DMS as a research tool.
- **DMS linked with power-hardware-in-the-loop.**
  Using the commercial DMS package for simulation also paved the way for linking the DMS to power hardware-in-the-loop (PHIL) testing at the ESIF of both a utility-scale PV inverter and medium-voltage capacitor bank. This co-simulation setup allows the hardware to interact in real time with larger grid conditions simulated by the DMS package and for the DMS to send SCADA control signals to the actual hardware, providing a test bed for advanced DMS functions.
- **Partnership among utility, vendor, and NREL proves to be model for effective collaboration.**
  By bringing together insights, data, and tools from all parties, the research impact is broader. This work is helping to gain a complete understanding of how the grid functions under high PV penetrations.

operations on the same GE DMS used by Duke Energy for daily operations run in testing mode at faster-than-real-time speeds.

These simulations are allowing the team to compare and contrast three classes of operating modes: with a conventional inverter (for a baseline), with a smart inverter providing local voltage control, and with smart inverters coordinated by the DMS to optimize voltage control using a combination of existing utility resources and advanced PV inverters.

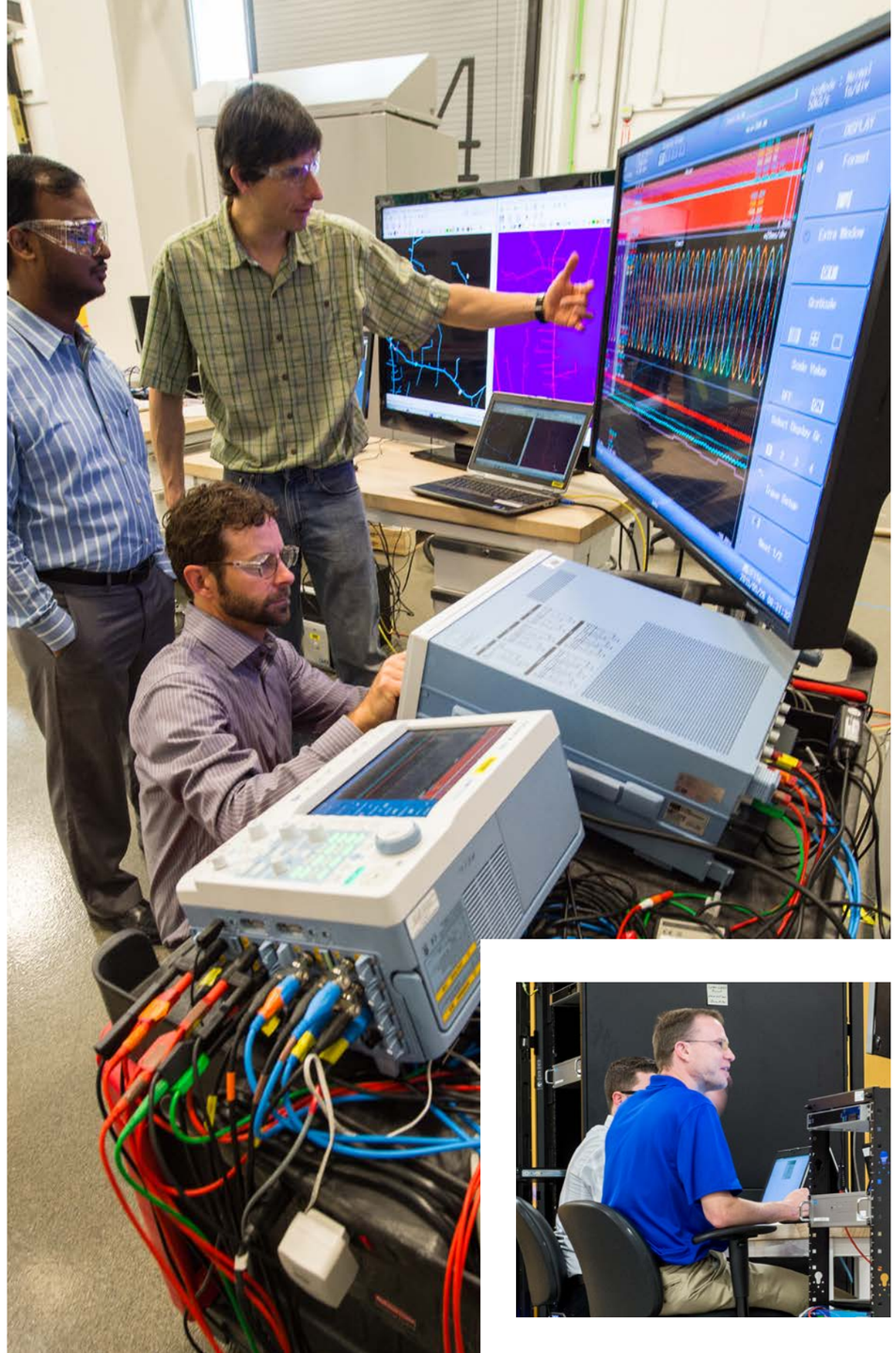
Project Highlights

Distributed Energy Resource Management System

NREL partnered with the Electric Power Research Institute (EPRI) to develop a distributed energy resource management system that would allow distributed energy resources (DER) to "talk" to other systems or entities, providing information about demand, supply, and use of electricity. The research and development effort was the culmination of several years of coordinated work with numerous industry stakeholders and builds on the original development of smart inverter standards.

Integrated Energy System Model

NREL researchers have developed the integrated energy system model (IESM) co-simulation platform—a tool that simulates residential power use, distributed generation, energy management systems, distribution feeders, and the impacts of retail electricity tariffs on them. Using the ESIF's high-performance computing (HPC) capability, the model was used to simulate a distribution feeder with 500 simulated homes equipped with home energy management systems (HEMS) under time-of-use rates. Using the ESIF's hardware-in-the-loop capability, the performance of a house and air-conditioning system was validated. This model opens up new testing opportunities that would allow utilities to refine rate structures to understand the impacts of energy management systems on loads. It would also provide customer-use insights for HEMS manufacturers to optimize the performance of these devices around energy pricing.



Cybersecurity Test Bed

A new initiative underway at NREL is helping to prevent hackers from gaining control of parts of the nation's power grid. A team of NREL researchers and leading cybersecurity vendors designed and built the Test Bed for Secure Distributed Management—a hardware and software system that mimics the communications, power systems, and cybersecurity layers for a utility's distribution system. The team then attacked the test bed to figure out what cybersecurity protection methods worked or didn't work. The project has successfully completed five distribution grid management use cases involving the test bed: auto-sectionalizing and restoration, volt-VAR optimization, direct response with elecric vehicles (EVs), PV smoothing with storage, and frequency regulation with storage. While the cybersecurity test bed was designed for power distribution grids, it can also be applied to other online energy devices, such as electric vehicles, wind turbines, home energy networks, thermostats, and demand response systems.

New Tools

AMETEK AC/DC High Power Source

NREL has acquired a second AC/DC regenerative power source from AMETEK. When installed in parallel with existing California Instruments RS Series units at the ESIF, the new system is the largest known AC grid simulator in the world with the bandwidth and modularity of the RS system. The AMETEK grid simulator is used as the power amplifier for megawatt-scale PHIL testing at the ESIF, which allows researchers and manufacturers to test new energy technologies at full power in real-time simulations—safely evaluating component and system performance and reliability before going to market.

Medium-Voltage Utility Poles

Two new medium-voltage utility poles have been installed in the ESIF's medium-voltage outdoor test area. The new poles will allow the connection of pole-mounted utility hardware, such as medium-voltage capacitor banks and transformers. The poles include built-in data acquisition and can be connected to the Research Electrical Distribution Bus for real-time hardware-in-the-loop experiments.

New Resources

Advanced Distribution Management Systems Workshop

NREL's ESI team held a workshop on Advanced Distribution Management Systems (ADMS) on July 7 that included speakers and attendees from utilities, manufacturers, academia, and other national labs. The workshop was part of an Advanced Grid Control Technologies Workshop Series and featured presentations from early ADMS adopters and leading utilities on how they use and calculate return on investment for advanced applications on their DMS. More than 35 people attended the event, with many attendees participating in a tour of the ESIF on July 8. Presentations from this workshop are available at http://www.nrel.gov/esi/agct_workshops.html.

> "NREL's ESI team provided the coordination and facilities to perform meaningful cybersecurity tests in a live distributed grid environment. This was all accomplished working with multiple vendors, integrators, and a very condensed schedule. The experience and exposure has been invaluable to BlackRidge Technology. The lessons we learned, along with the other cybersecurity vendors, will provide a blueprint for others in the industry, saving testing time and costs, and will allow us all to better protect the nation's distribution grid infrastructure."
>
> - John Thuotte, Project Manager, BlackRidge Technology

HIGH PERFORMANCE COMPUTING & VISUALIZATION

Project Spotlight

NREL Uses HPC to Model World's Largest Power System

Just how big is the North American power grid's Eastern Interconnection? The network spans the eastern half of the continent, serving the energy needs of 70% of all U.S. load, more than 240 million people. The system includes more than 7,000 generators connected to more than 50,000 transmissions lines. In short, it's huge, and simulating the entire system at high resolution for an entire year had never been attempted.

The need for a reliable model, however, was growing increasingly important. With renewable energy generation ramping up across the United States, answering the "how" and "how much" questions around integrating higher penetrations of renewables was dependent on a model to examine scenarios. To start to answer these questions, NREL convened a technical review committee of experts to work on the Eastern Renewable Generation Integration Study (ERGIS).

ERGIS is a multiyear, multiprogram-funded project aimed at understanding the operational impacts of high penetrations of wind and solar generation on the Eastern Interconnection by providing the highest temporal and spatial resolution modeling and analysis of the interconnection ever done. Even with NREL's HPC to shoulder the computational burden, the mathematical challenges associated with a model this complex required new tools and solutions.

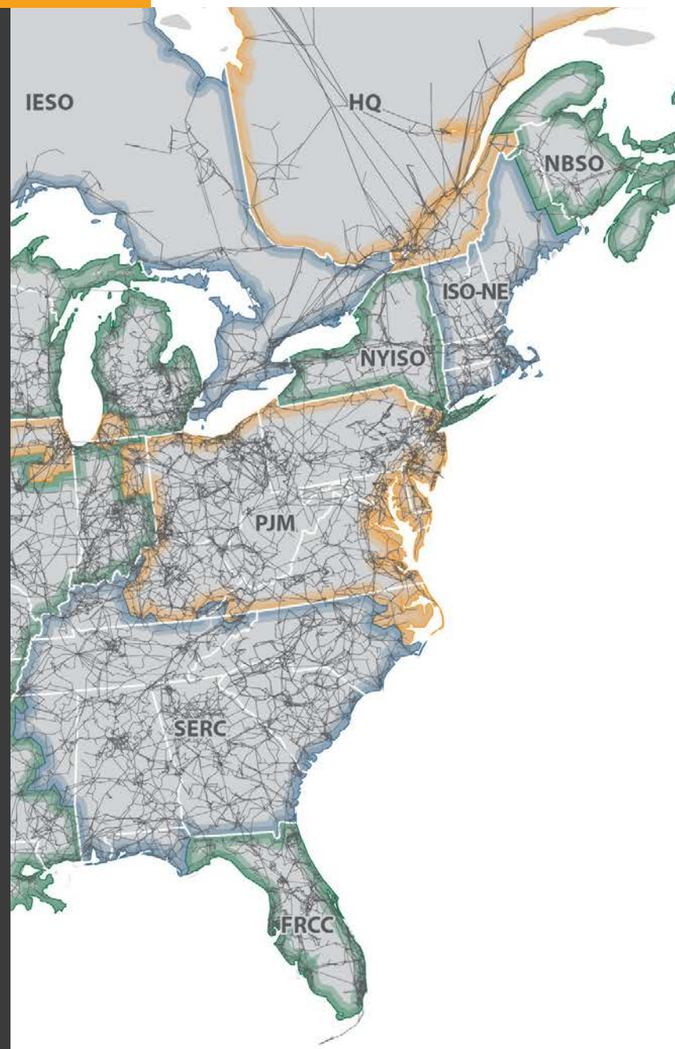
Continued on page 30

"The ESIF's computational and visualization facilities made it possible for NREL to conduct the most advanced wind and solar integration study in the world. These facilities were used to run numerical weather models, simulate power system operations, and analyze and communicate findings. Without access to these facilities, it would not have been feasible to conduct rigorous analyses of the 5-minute operation of the largest power system in the world in the presence of hundreds of gigawatts of wind and solar generation."

- Aaron Bloom, Senior Project Manager, NREL

Project Impact

- **Data sets, models, and computational solutions developed by NREL for ERGIS provide springboard for future research.** Completing this complex integration study has produced innovative tools and knowledge that can be leveraged on future projects.
- **Results show that integrating large amounts of renewable energy into the Eastern Interconnection is technically feasible while meeting system demands.** A full report and analysis will be available in the summer of 2016. For more information on this project, visit http://www.nrel.gov/electricity/transmission/eastern_renewable.html.
- **ERGIS report begins to answer "how" and "how much" questions for integrating high penetrations of renewables.** The report not only demonstrates that the grid can handle high penetrations of renewables but also identifies the pathways to make it happen and challenges associated with each pathway.

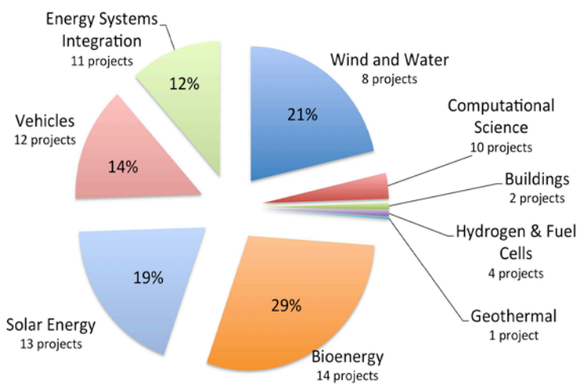


Project Spotlight *continued from page 28*

One of the bigger challenges to creating this model was to make the solve time manageable without compromising resolution. The complexity of the model run at the required resolution put initial solve-time estimates to simulate one year of operations at more than 500 days. Because one day's solution depended on the solution for the previous day or days, there was no obvious way to solve for multiple time intervals in parallel.

The novel solution that NREL researchers developed was to break the simulation into 73 intervals and overlap the first two days between each time period (the amount of overlap required to minimize the error introduced by partitioning). This allowed researchers to capture sufficient information to establish operational history and made it possible to run the simulations in parallel on separate nodes while retaining accuracy. Using this approach reduced the solve time to only 19 days.

FY15 Allocated Node Hours



During FY15, Peregrine supported 51 research and development projects involving modeling and simulation across nine Office of Energy Efficiency and Renewable Energy offices and programs. Peregrine sustained an average use of 83%.

Awards

ESIF Data Center Garners 2014 DOE Sustainability Award

Peregrine—the ultraefficient HPC in the ESIF—was recognized by DOE with a 2014 Sustainability Award for its novel approach to energy reduction. The ESIF HPC developed by Hewlett-Packard features a chiller-less design, warm-water liquid cooling, an annual average power usage effectiveness (PUE) of 1.06, and waste heat capture and reuse—making it the world's most energy-efficient data center.

Top Honors Go to NREL Supercomputing Achievements

NREL and Texas Advanced Computing Center at the University of Texas at Austin received the HPCwire 2014 Editors' Choice Award for Top Supercomputing Achievement for groundbreaking research in converting biomass to biofuels. This is significant because although NREL's new facility and HPC system have been recognized for their advances in energy efficiency, this HPCwire award recognizes how these HPC resources are being used to advance important areas of science and technology.

"Use of NREL's HPC system Peregrine has been important to our efforts to develop high power laser tools as we iterate designs with both field test and computing simulation data."

- Dr. Joel Moxley, Founder and EVP Business Development, Foro Energy

Project Highlights

Abengoa Optimizes a New Assembly Method for Concentrating Solar Power Parabolic Troughs at the ESIF's Insight Center

NREL is collaborating with Abengoa at the ESIF to develop a new, more cost-effective manufacturing process for critical components of concentrating solar power systems. Abengoa researchers were able to model their assembly method design in the ESIF's Insight Center using three-dimensional visualization to allow engineers to see and interact with their CAD models at a 1:1 scale. With an immersive virtual environment like the Insight Center, engineers are able to work within their design at full scale before the prototype stage, which allows them to identify and eliminate design flaws earlier.

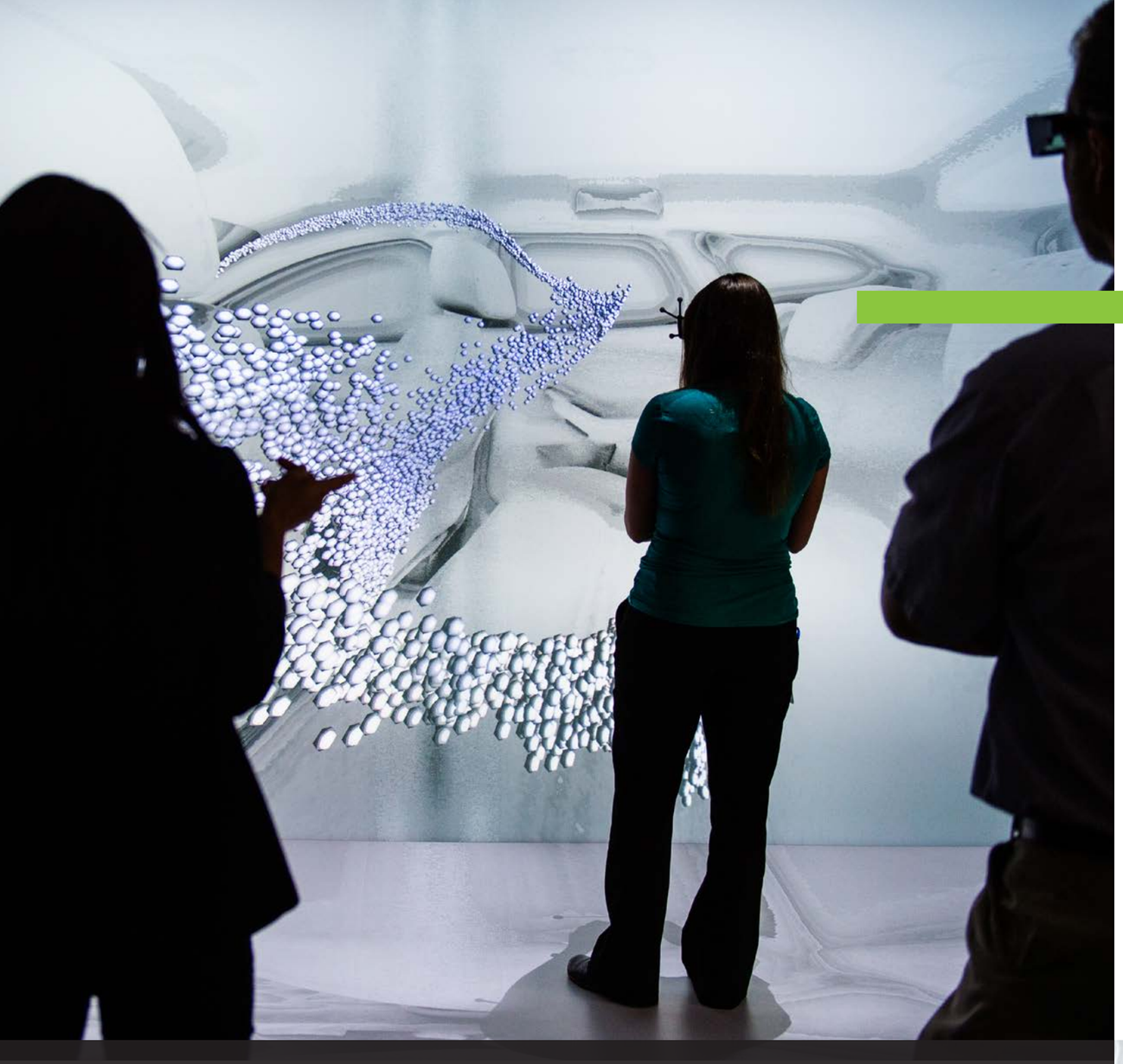
New Tools

Peregrine Doubles in Size

In response to continued high demand for computational resources, Peregrine has expanded to have an additional 1,152 nodes, each of which will have two of the new Intel E5-2670v3 Xeon "Haswell-EP" processor chips and 64 GB of memory. These new nodes will bring the aggregate peak performance of Peregrine to 2.2 PetaFLOPS. The new nodes have been integrated into the system's high-speed Inifiniband network as two 576-node "scalable units," which increased the maximum number of CPU cores that a single job can use from 6,912 cores to 13,824 cores. This expansion nearly doubles the number of node hours available for project allocations.

ESIF Research Data Service Comes Online

The new ESIF Research Data Service, designed and implemented in FY 2015, is an integrated collection of scalable data management clusters, databases, and applications that make it possible to seamlessly access ESIF experimental data, modeling, and simulation data; the HPC; and the Insight Center. Recent accomplishments include real-time data services for hardware-in-the-loop experiments and a Big Data Time Series cluster that collects and provides fast access to billions of metering data points.



PARTNERS

NREL continues to forge new partnerships across industry, academia, and government to leverage the expert staff and exceptional resources that the ESIF offers. Below are partners with active agreements in FY 2015.

3M*

Abengoa Solar

ACCIONA Solar

AccuFlux

Advanced Energy Industries

AirGenerate

Albeado

American Vanadium

Aquahydrex Pty Ltd.

Arizona Public Service

Asetek

AutoPort

BlackRidge

Bonneville Power Administration

Boreas Group

Bosch

California Energy Commission

Case Western Reserve University

CellEra

ClipperCreek

Clemson University

Colorado School of Mines*

CPS Energy

CSIRO*

DC Systems

Denver Water

Duke Energy*

EaglePicher Technologies

ElementOne, Inc.

EPRI*

Electric Reliability Council of Texas

Emerson

Energy Exemplar

Enphase Energy

Erigo

FireEye

Florida Power & Light

Fronius

GE*

General Motors

Giner, Inc.*

Google*

Hawaiian Electric Company

HOUZE*

Ingersoll Rand

Intwine

Irradiance

KPA

Lake Benton Power Partners

Leclanché

Mercedes-Benz USA

MidAmerican Energy Company

N-Dimension

NanoSonic

Nebland Software

Netherlands Enterprise Agency (RVO)

New Jersey Institute of Technology

NRG Energy

Ohio Fuel Cell Coalition

Omnetric Group

Pacific Gas and Electric

Parker Hannifin Corp.*

PDC Machines, Inc.

Pecan Street Research Institute

Pentair

PowerHub Systems

Proton OnSite

Raytheon*

Sandia National Laboratories

San Diego Gas & Electric*

Schneider Electric

Scitor

SecLab

Smarter Grid Solutions

SolarCity

Solectria Renewables*

Southern California Edison

Southern California Gas Company

Spectrum Automation Controls*

Strategic Analysis, Inc.

SunPower

Synopsys

Technical University of Denmark

Tendril

The Babcock and Wilcox Company

Toyota North America*

TransPower

U.S. Navy

University of Arizona

University of California, Irvine

University of Central Florida

University of Colorado, Boulder*

University of Delaware

University of Denver

University of Oregon

University of Texas at San Antonio

University of Wisconsin

ViaSat

WEB Aruba N.V.

Whisker Labs

Wyle

* These partners have more than one project.

NEW CONNECTIONS

Real-time links were established between the ESIF and other testing facilities within the DOE's national lab complex, multiplying research power and optimizing the use of equipment and resources. These achievements open the door for software and equipment anywhere in the world to establish a real-time connection to the unique facilities and capabilities available within the national laboratory complex.

Pacific Northwest National Laboratory

- GridLAB-D distribution system models
- Research hardware and software

Idaho National Laboratory

- Multiple real-time digital simulator (RTDS) racks
- Utility-scale transmission system
- Research hardware and software

National Wind Technology Center

- Controllable Grid Interface (CGI) to emulate grid disturbance and test how renewable energy technologies perform before deployment
- Dynamometers that test up to 5 MW
- Utility-scale solar generators and high-power energy storage

DOE PROGRAM RESEARCH

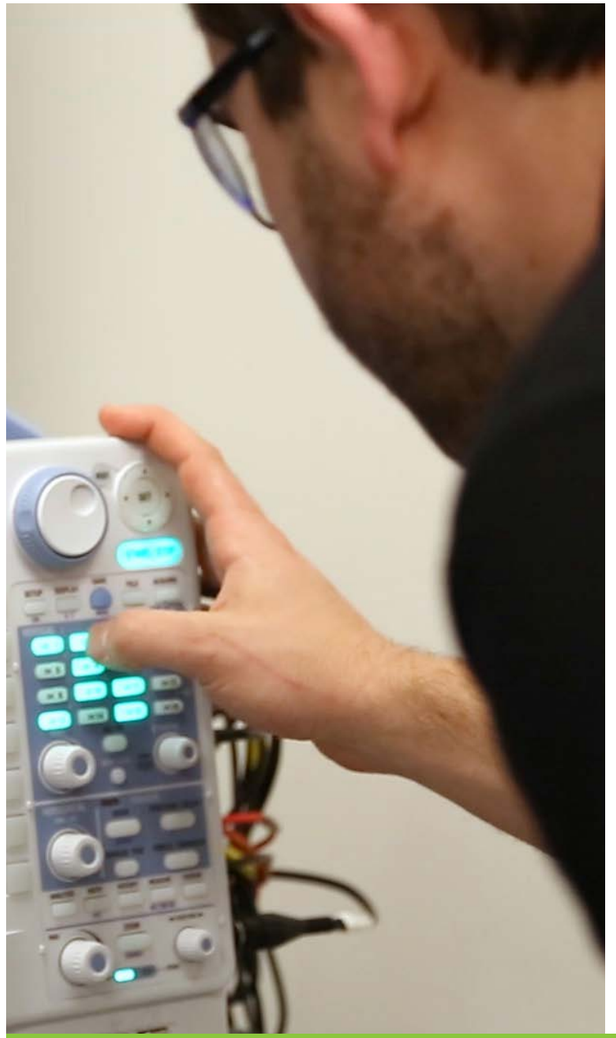
In FY 2015, NREL performed DOE program research with a total value of more than $14.4 million in the ESIF laboratories, including these projects:

Bioenergy Technologies Office

- Biological Studies of Energy Systems
- Biomass Scenario Model
- Chemistry and Computational Fluid Dynamics Studies of Energy Systems
- Process-scale Mechanistic Modeling for the Biochemical Conversion of Biomass to Transportation Fuels

Building Technology Office

- Advanced Fenestration Durability Testing
- Commercial Buildings Research
- Consulting to Zero-Energy Community Developer
- Cost-Optimal New Construction Practices
- National Residential Energy-Efficiency Economic Potential Impact Analysis VOLTTRON Installation and Testing



Computing

- Algorithm Characterization to Assess Application Performance on Future Architectures
- Application Energy Consumption for Various Node States and Configurations
- Framework for Comparison of Spatiotemporal and Time Series Datasets
- High-Performance Interactive System Dynamics Visualization
- High-Fidelity Computational Fluid Dynamics
- Tools for Design and Scale-up of Solar Thermochemical Reactors
- Visualization and Simulation of Manufacturing Line

Energy Systems Integration (Multiple DOE Program Offices)

- Eastern Renewable Generation Integration Study (ERGIS)
- High-Resolution Rapid Refresh with National Oceanic and Atmospheric Administration
- Integrated Energy System Model Development
- Multi-Scale Grid Management Framework and System Prototype
- PLEXOS Modeling
- Resource Planning Model Development
- Western Interconnection Generation Reliability and Flexibility Adequacy Analysis

INTEGRATE Projects (Collaborative)

EPRI: Cohesive Application of Standards-Based Connected Devices to Enable Clean Energy

EPRI: End-to-End Communications and Control System to Support Clean Energy Technologies

Omnetric: Open Field Message Bus Reference Architecture Demonstration

Smarter Grid Solutions: Demonstrating Active Network Management INTEGRATion

University of Delaware: Open V2X at ESIF

Fuel Cell Technologies Office

Advanced Ionomers & MEAs for Alkaline Membrane Fuel Cells

Analysis of Optimal Stationary Fuel Cells for Buildings

Demonstrating Hydrogen as a Storage Mechanism for Renewable Electricity

Electrolysis System, Stack, and Component Performance

Fuel Cell Manufacturing Quality Control R&D

Fuel Cell R&D, Including Catalysts and Electrodes

Fuel Cell Vehicle Demonstration

High-Efficiency Tandem Absorbers for Economical Solar Hydrogen Production

Hydrogen Dispenser Hose Reliability Improvement

Hydrogen Fueling Infrastructure Component and System Testing at the Hydrogen Infrastructure

Test and Research Facility

Hydrogen Sensor Development and Evaluation

Hydroxide Conductors for Energy Conversion Devices

Scenario Evaluation and Regionalization Analysis

Technology Validation Performed in the National Fuel Cell Technology Evaluation Center

Geothermal Technologies Office

High Power Laser Tool and System for Unique Geothermal Well Completions

Office of Electricity Delivery and Energy Reliability

GE Microgrid Plant Control Design and Development

Grid Interactive Microgrid Controller for Resilient Communities

Pre-standards Research—Updating Interconnection Conformance Tests

Smart Grid Pre-Standard Testing Support: Testing of Multiple Inverter Interactions Using PHIL

Solar Energy Technologies Office

California Solar Initiative—Distribution System Integration Modeling

Charge-Transport in Nanostructured Quantum-Dot 3D Arrays

Codes & Standards Development for PV Interconnection and Interoperability

Combinatorial Materials Discovery for Organic Photovoltaics

Computational Materials Science for Advancing Photovoltaic Technologies

Degradation Mechanisms and Development of Protective Coatings for Thermal Energy Storage and Heat Transfer Fluid Containment Materials

Design and Discovery of Semiconducting Energy Materials

Eastern Renewable Generation Integration Study (ERGIS)

Emerging Technology Characterization

Integrated Grid Modeling System (IGMS)

Near-Blackbody Enclosed Particle Receiver Testing

NREL Materials Database

Outside California Distribution System Integration Modeling

PLEXOS Modeling

Predicting Morphologies of Organic Photovoltaic Polymers

Solar Resource Assessment from Geostationary Satellites

Sub-Hour Irradiance National Database

Tetrahedrally Bonded Conductors as Competing Phases in PV

Theoretical Materials Science

Tools for Design and Scale-up of Solar Thermochemical Reactors

Western Interconnection Generation Reliability and Flexibility Adequacy Analysis

New Industry Partnerships

SolarCity: address interconnection challenges of the high-penetration utility-interconnected PV in electrical distribution systems

Advanced Energy: high-penetration PV power electronics and energy management technology research, development, and demonstration

SDG&E: support SDG&E grid and storage efforts

Southern California Gas Company: enable higher penetrations of solar power generation using the natural gas pipeline for energy storage

Duke Energy: identify the operational impacts of high penetrations of PV with smart inverters on a representative distribution feeder in Duke Energy's territory

Google: innovation in PV inverter power density

SunPower: residential PV-energy storage testing

Vehicle Technologies Office

Charge Transport in Organic Radical Batteries

Electric Drive Vehicle Climate Control Load Reduction

Evaluation of Electric Trucks

Fleet DNA Project

High Energy, Long Life Organic Battery with Quick Charge Capability

Integrated Computational Materials Engineering Development of Advanced Steel for Lightweight Vehicles

Internal Combustion Engine Energy Retention

Multiscale Multiphysics Lithium-ion Battery Modeling

Performance of High-Temperature Bonded Interfaces

Thermomechanical Modeling of a Power Electronics Module

Validation and Development of Coupled Computational Fluid Dynamics and Ignition Kinetics Models for Transportation Fuels

Wind and Water Power Technologies Office

Computational Fluid Dynamics Simulations of the Hydrodynamics of Offshore Floating Platforms for Wind Turbines

ERGIS

High-Fidelity Computational Fluid Dynamics

Industry Support Projects on Wave Energy System Computational Fluid Dynamics Modeling

Integrating ESIF and NWTC Hardware-in-the-Loop Testing Capabilities

Offshore Technology Demonstration

PLEXOS Modeling

Simulator for Offshore Wind Farm Applications + Super Controller

Wave Energy System Computational Fluid Dynamics Modeling for Extreme Conditions

Western Interconnection Generation Reliability and Flexibility Adequacy Analysis

Wind Flow Modeling—Atmospheric Science

Wind Plant Optimization & Systems Engineering

INTEGRATE PROJECTS

Project Spotlight

Smarter Grid Solutions INTEGRATE Team Tests Active Network Management Platform to Control DER in Real Time

From PV on rooftops to utility-scale wind power plants, renewable energy generation is increasing at all scales. This expansion has created the need for new tools and technologies that enable the grid to handle high penetrations of these variable DER more efficiently.

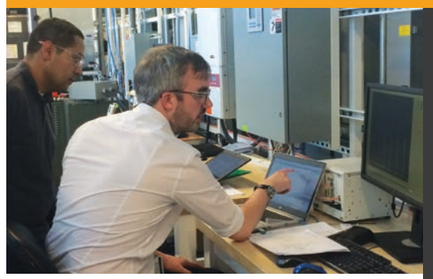
DOE's Integrated Network Testbed for Energy Grid Research and Technology Experimentation (INTEGRATE) project provides RD&D support to advance innovative solutions in this area. INTEGRATE aims to enable the development and validation of open-source, interoperable technologies that help the grid host more renewable energy.

Five research teams were chosen through the INTEGRATE request for proposal to test their ideas at the ESIF. Smarter Grid Solutions was one of those teams and has already begun testing its Active Network Management (ANM) integrated distribution grid management solution.

ANM is designed to coordinate control of DER with associated grid constraints in real time. It offers a quick (second-to-second), local, repeatable, and time-bounded management platform that pushes real-time intelligence to the grid edge. The platform has been deployed in Europe, and testing at the ESIF is focused on proving the concept for the North American grid.

The Smarter Grid Solutions team has completed a Smart Home use case—the first of three use cases it will test. This first use case evaluated how ANM can be used to manage power flow and voltage constraints on a radial network. The second and third use cases will scale up the testing to a campus and then to a distribution grid.

Continued on page 48



"We have been very pleased with the power hardware-in-the-loop testing at the ESIF and the ability to use this demonstration opportunity to benchmark ANM technologies for North American utilities while also demonstrating that real-time hosting capacity for clean energy is significantly higher compared to traditional static grid hosting capacity approaches. The NREL team has been great to work with, and we are looking forward to the Smart Campus and Smart Distribution use cases over the next 12 months."

- Jeremiah Miller, Senior Smart Grid Analyst, Smarter Grid Solutions

Project Impact

- **The Smart Home use case demonstrated coordinated control of residential-scale PV system generation, EV charging, and battery storage with uncontrolled home loads.** This first demonstration achieved ANM control response as designed under three different constraint scenarios: reverse power flow constraints where export of excess PV generation was restricted, import constraints where ANM was used to control a group of DER to provide grid demand response, and voltage rise management at the point of common coupling.
- **With this first proof of concept successfully completed on a small scale, the Smart Campus use case demonstration is now underway.** The Smart Campus demonstration will use a modified IEEE 13-node feeder model for PHIL testing and will incorporate the following DER on a spot network: generator (as emulated combined heat and power), PV array emulator with 500-kW PV inverter, energy storage, EVs, and controllable loads.

INTEGRATE Projects Overview

The INTEGRATE teams are focused on three areas: connected devices, communications and control systems, and integrated systems. Testing at the ESIF is underway for three of the five projects. These demonstrations will continue throughout FY 2016; results and conclusions will be available at the end of 2016.

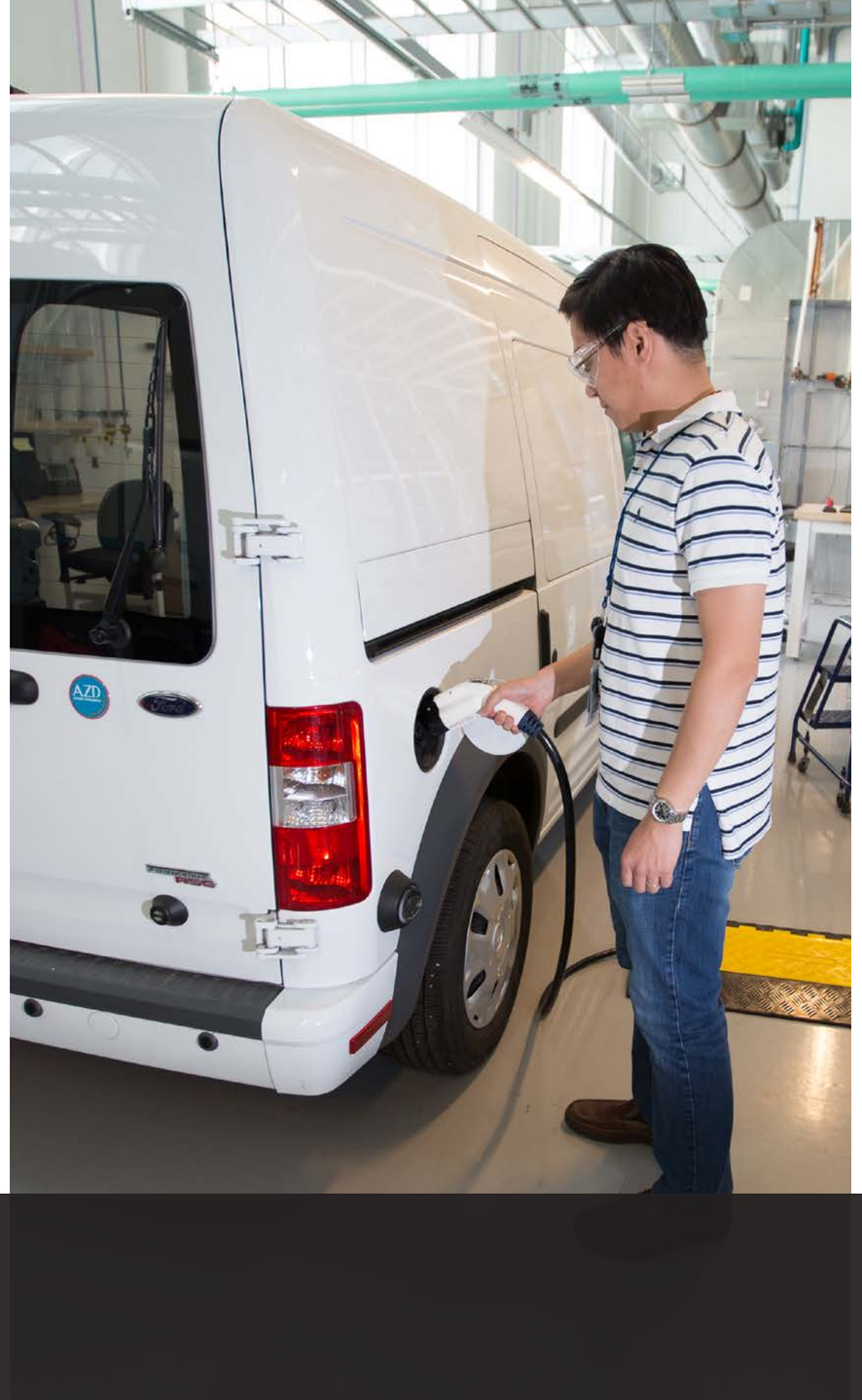
Connected Devices

Project 1: EPRI and five device manufacturers are testing the ability of a set of connected devices to provide grid services. A primary focus of this research is standardizing device services for various clean energy technology types and developing communication interfaces.

Project 2: The University of Delaware is evaluating the ability of vehicle-to-grid capable bidirectional EVs to provide grid services and testing open protocols for coordinating those services.

Communications & Control Systems

Project 3: EPRI, Schneider Electric, and other energy management system providers aim to demonstrate an end-to-end framework of communications, information, and computation technologies, integrating the operation of different domains within distribution systems (DMS, demand response service, residential appliance scheduling) through open-source software tools.



Integrated Systems

Project 4: The Omnetric Group, a joint venture between Siemens and Accenture, along with partners Duke Energy, CPS Energy, and the University of Texas at San Antonio will demonstrate an Open Field Message Bus platform. The platform is designed to help the grid to effectively support large-scale complex operations such as distribution systems at electric utilities, allowing for a higher penetration of clean energy resources.

Project 5: Smarter Grid Solutions is demonstrating a distribution grid management solution using ANM to enhance grid capacity and services by providing real-time coordinated control of DER. The project leverages a smart energy platform that has been deployed in the United Kingdom. The objective is to use network assets to coordinate renewable energy generators and DER to enhance grid capacity for renewable energy.

USER FACILITY UPDATES

Awards and Certifications

ESIF Achieves International Quality Management Standard

The ESIF was certified to international standard ISO 9001:2008 for quality management. This standard is established by the International Organization for Standardization (ISO), the world's largest developer of voluntary international standards. The ISO 9001:2008 standard is globally recognized and defines the structure of a facility's quality management system to ensure continuous improvement. The ESIF is also certified to ISO 14001:2004, a standard that defines the structure of a facility's environmental management system to improve its environmental performance, and OHSAS 18001, an occupational health and safety management system standard. These international certifications further the ESIF's position as a world-class research, development, and demonstration facility.

ESIF Is a Finalist for PMI Award

The ESIF was honored by the Project Management Institute (PMI) as one of three international finalists for PMI's Project of the Year Award. This award recognizes projects from any industry in the public and private sectors that have demonstrated superior use of project management techniques.

Facility and Process Improvements

Enhancements Incorporated into ESIF Online User Support System

Leveraging software developed by Pacific Northwest National Laboratory for their Wiley Environmental and Molecular Sciences Laboratory user facility, NREL has

adapted and improved its online user support system to provide greater functionality and a better user experience. The system is currently being used to process requests for shared equipment and work space. The goal is to have all ESIF users, including NREL staff, submit and manage their resource requests through this system.

Streamlined Onboarding Process Gets Partners into Labs Faster and More Efficiently

The ESIF User Program team and NREL's Office of the Chief Information Officer have integrated the ESIF online user support system with Workday. Partners can now electronically sign onboarding forms and take initial ESIF-specific training through the Learning Management System prior to their arrival at NREL. This means that partners can walk through the doors, receive a badge, and begin work in the labs more quickly. More than 60 external ESIF lab users have been electronically onboarded, with an expectation of that number doubling in FY 2016.

NREL Publishes ESIF User Guide

The ESIF User Program team has developed and published an ESIF User Guide. This booklet is designed to be a quick reference for new users of the ESIF and provides essential information about working safely in the ESIF labs, required trainings, campus policies and procedures, and what to do in case of an emergency.

Capability Hub Configuration

To accommodate new projects, NREL defined 26 purpose-built spaces throughout the ESIF's laboratories. These "capability hubs" will allow greater flexibility in the use of lab space and a more efficient distribution of the lab's testing resources. Each hub is connected to equipment for a specific testing purpose and can be interconnected with other equipment and areas of the lab to create an integrated system.

> "We more than doubled the number of external partners that were able to use the ESIF in FY 2015 compared to FY 2014, thanks to a streamlined onboarding process and a new and more flexible lab configuration. Our team is committed to growing collaboration opportunities by ensuring that the user experience is a positive and productive one."
>
> - Steve Bonde, ESIF User Facility Support Manager, NREL

INVENTIONS

Patents Filed

ESIF Capability/ Resource Used	Title	Primary NREL Center	NREL Number	Inventor Name
Lab	Platinum Nickel Nanowires as Oxygen Reducing Electrocatalysts and Methods of Making the Same	5900 - Chemistry & Nanoscience	PROV/14-41	Alia, Shaun; Pivovar, Bryan
Lab	Batch and Continuous Methods for Evaluating the Physical and Thermal Properties of Thin Films	5J00 - Materials Applications & Performance	PROV/14-68	Penev, Michael; Sopori, Bhushan; Ulsh, Michael; Rupnowski, Przemyslaw; Bender, Guido
Other	Model Predictive Control For Heat Transfer To Fluids	5500 - Buildings & Thermal Systems	13-77	Jin, Xin; Maguire, Jeff; Christensen, Dane
Lab	Systems and Methods For Direct Thermal Receivers Using Near Blackbody Configuration	5500 - Buildings & Thermal Systems	13-51	Wagner, Michael; Ma, Zhiwen; Martinek, Janna; Neises, Ty; Turchi, Craig

Licenses

ESIF Capability/ Resource Used	Title	Primary NREL Center	NREL Number	Contributor Name
HPC	ED-SVM, Fluent CAEBAT API	2C00 - Computational Sciences	SWR-15-04	Graf, Peter; Kim, Gi-Heon; Smith, Kandler
HPC	Acceptor-Donor-Acceptor Type Polymers as Electron Donors in Organic Photovoltaic Bulk Heterojunctions	2C00 - Computational Sciences	ROI-15-48	Olson, Dana; Larsen, Ross; Owczarczyk, Zbyslaw
HPC	STREAMM (Simulation Toolkit for Renewable Energy Advanced Materials Modeling)	2C00 - Computational Sciences	SWR-15-29	Graf, Peter; Larson, Ross
Lab	Method and apparatus for rapid measurement of solar simulator uniformity	5200 - National Center for Photovoltaics	ROI-15-05	Silverman, Timothy
Other	H2 FAST (Hydrogen Station Financial Analysis Scenario Tool)	5400 - Transportation & Hydrogen Systems	SWR-15-06	Bush, Brian; Penev, Michael; Melaina, Marc
Other	Grid-friendly System for Implementing High Penetration Distributed PV with Storage	5400 - Transportation & Hydrogen Systems	ROI-15-10	Neubauer, Jeremy
Lab	Hydrogen Removal from Solar Thermal Power Plants	5500 - Buildings & Thermal Systems	ROI-15-28	Glatzmaier, Greg
Other	Zoned, modular, combination HVAC heat pump and heat pump water heater system	5500 - Buildings & Thermal Systems	ROI-15-19	Booten, Chuck; Christensen, Dane
Lab	U-Cavity Receiver Design and Operation for Solid-Particle-Based Concentrating Solar Power Plant",	5500 - Buildings & Thermal Systems	ROI-15-27	Ma, Zhiwen; Martinek, Janna
Other	Smartphone- and Wearables-based Building Energy Management	5500 - Buildings & Thermal Systems	ROI-15-52	Jin, Xin; Earle, Lieko; Sha, Mo; Sparn, Bethany
Lab	High-Temperature, High-Efficiency Fluid Bed Particle Receiver	5500 - Buildings & Thermal Systems	ROI-15-61	Ma, Zhiwen; Martinek, Janna; Mehos, Mark; Netter, Judy; Turchi, Craig; Wendelin, Timothy
Other	Immersible Computation Module For Electric Water Heating	5500 - Buildings & Thermal Systems	ROI-15-82	Christensen, Dane
Other	Embedded Computation Module for Air Heating	5500 - Buildings & Thermal Systems	ROI-15-83	Christensen, Dane

ESIF Capability/ Resource Used	Title	Primary NREL Center	NREL Number	Contributor Name
Other	Embedded Computation Module for Space Heating	5500 - Buildings & Thermal Systems	ROI-15-84	Christensen, Dane
Other	Foam-in-Place Insulation for Retrofit of Window Openings	5500 - Buildings & Thermal Systems	ROI-15-91	Christensen, Craig; Booten, Chuck
Other	Modular Split HVAC System Driven from a Single Motor	5500 - Buildings & Thermal Systems	ROI-15-94	Roberts, Dave; Winkler, Jon; Booten, Chuck
Other	Integrated Personalized Comfort System	5500 - Buildings & Thermal Systems	ROI-15-99	Christensen, Dane; Carmichael, Scott; Arent, Doug; Macmillan, Stuart
Other	Thermal Storage For Modular Split HVAC System	5500 - Buildings & Thermal Systems	ROI-15-103	Winkler, Jon; Booten, Chuck
Other	SWR-15-30 Ingersoll-Rand Connected Thermostat Database Development and Analysis	5500 - Buildings & Thermal Systems	SWR 15-30	Booten, Chuck; Robertson, Joseph
Lab	Lockout/Tagout Device Design For 2-Way Valve	5900 - Chemistry & Nanosci-ence	ROI-15-95	Bender, Guido; Clark, Phil
Other	Radiometer Calibration & Characterization (RCC)—Windows Version	5D00 - Power Systems Engineering	SWR-15-02	Wells, Chet (RETIRED); Andreas, Afshin; Reda, Ibrahim; Wilcox, Stephen (RETIRED); Stoffel, Thomas (RETIRED); Myers, Daryl (RETIRED); Maxwell, Gene (RETIRED)
Other	Integrated Grid Modeling System (IGMS)	5D00 - Power Systems Engineering	SWR-15-08	Hale, Elaine; Palmintier, Bryan; Hansen, Timothy; Jones, Wesley; Sorensen, Harry; Biagioni, David
Other	Home Energy Management System (HEMS)	5D00 - Power Systems Engineering	SWR-15-12	Pratt, Annabelle; Wu, Hongyu; Chakraborty, Sudipta
Other	Bus.py	5D00 - Power Systems Engineering	SWR-15-14	Hale, Elaine; Palmintier, Bryan; Hansen, Timothy; Jones, Wesley
Lab	JSON-link Library	5D00 - Power Systems Engineering	SWR-15-25	Palmintier, Bryan; Lundstrom, Blake

ESIF Capability/ Resource Used	Title	Primary NREL Center	NREL Number	Contributor Name
Lab	JSON-link for Hardware-in-the-Loop	5D00 - Power Systems Engineering	SWR-15-26	Palmintier, Bryan; Lundstrom, Blake
Lab	Communication Whiteboard for Real-time Co-simulation	5D00 - Power Systems Engineering	SWR-15-27	Palmintier, Bryan; Lundstrom, Blake
Lab	Connectors for Whiteboard Real-time Co-simulation	5D00 - Power Systems Engineering	SWR-15-28	Palmintier, Bryan; Lundstrom, Blake
Other	glmgen	6A20 - Strategic Energy Analysis	SWR-15-01	Hale, Elaine; Palmintier, Bryan; Hansen, Timothy
Lab	Integrated Energy System Model (IESM)	6A20 - Strategic Energy Analysis	SWR-15-07	Pratt, Annabelle; Jones, Wesley; Lunacek, Monte; Ruth, Mark; Wu, Hongyu; Mittal, Saurabh
Lab	PV DC-DC Converter LabVIEW FPGA Control	5B00 - Energy Systems Integration Facility	SWR-15-18	Shirazi, Mariko; Martin, Gregory; Kramer, William
Lab	Battery and PV DC-DC Converter Lab-VIEW FPGA Control Code	5B00 - Energy Systems Integration Facility	SWR-15-19	Shirazi, Mariko; Martin, Gregory; Kramer, William
Other	Handheld Solar Radiation/Inverter Energy Comparator Meter	5B00 - Energy Systems Integration Facility	ROI-15-109	McNutt, Peter; Sekulic, Bill; Walker, Andy

PUBLICATIONS

ESIF Laboratory Publications

Conference Papers (Preprints)

Deceglie, M.G., T.J. Silverman, B. Marion, and S.R. Kurtz. 2015. "Robust Measurement of Thin-Film Photovoltaic Modules Exhibiting Light-Induced Transients: Preprint." Presented at SPIE Optics+Photonics, San Diego, California, August 9–13, 2015. NREL/CP-5J00-64769.

Deceglie, M.G., T.J. Silverman, B. Marion, S. Kurtz, and R. Sarah. 2015. "Temperature-Dependent Light-Stabilized States in Thin-Film PV Modules: Preprint." Presented at the 42nd IEEE Photovoltaic Specialists Conference, New Orleans, Louisiana, June 14–19, 2015. NREL/CP-5J00-64417.

Silverman, T.J., M. Deceglie, C. Deline, and S. Kurtz. 2015. "Partial Shade Stress Test for Thin-Film Photovoltaic Modules: Preprint." Presented at SPIE Optics + Photonics, San Diego, California, August 9–13, 2015. NREL/CP-5J00-64456.

Silverman, T.J., M.G. Deceglie, X. Sun, R.L. Garris, M.A. Alam, C. Deline, and S. Kurtz. "Thermal and Electrical Effects of Partial Shade in Monolithic Thin-Film Photovoltaic Modules: Preprint." Presented at the 42nd IEEE Photovoltaic Specialists Conference, New Orleans, Louisiana, June 14–19, 2015. NREL/CP-5J00-64448.

Conference Papers (Published Proceedings)

Marion, B., A. Anderberg, C. Deline, J. del Cueto, M. Muller, G. Perrin, J. Rodriguez, S. Rummel, T.J. Silverman, F. Vignola, R. Kessler, J. Peterson, S. Barkaszi, M. Jacobs, N. Riedel, L. Pratt, and B. King. 2014. "New Data Set for Validating PV Module Performance Models." In *Proceedings of the 2014 IEEE 40th Photovoltaic Specialist Conference (PVSC)*: 1,362–1,366. Piscataway, NJ: Institute of Electrical and Electronics Engineers. NREL/CP-5J00-61179.

Panwar, M., S. Suryanarayanan, and S. Chakraborty. 2014. "Steady-State Modeling and Simulation of a Distribution Feeder with Distributed Energy Resources in a Real-Time Digital Simulation Environment." In *Proceedings of the 2014 North American Power Symposium (NAPS)*: 1–6. Piscataway, NJ: Institute of Electrical and Electronics Engineers. NREL/CP-5D00-62381.

Silverman, T.J., M.C. Deceglie, B. Marion, and S.R. Kurtz. 2015. "Performance Stabilization of CdTe PV Modules Using Bias and Light." In *Proceedings of the 2014 IEEE 40th Photovoltaic Specialist Conference (PVSC)*: 344–349. Piscataway, NJ: Institute of Electrical and Electronics Engineers. NREL/CP-5J00-63144.

Fact Sheets

"Microgrid-Ready Solar PV." NREL/FS-7A40-64582.

"NREL Develops High-Speed Scanner to Monitor Fuel Cell Material Defects." NREL/FS-5900-64828.

"NREL's Controllable Grid Interface Saves Time and Resources, Improves Reliability of Renewable Energy Technologies." NREL/FS-5000-63837.

"Stationary Fuel Cell Systems Analysis Project: Partnership Opportunities." NREL/FS-5400-64370.

Journal Articles

Alia, S.M., S. Pylypenko, K.C. Neyerlin, S.S. Kocha, and B.S. Pivovar. 2014. "Nickel Nanowire Oxidation and Its Effect on Platinum Galvanic Displacement and Methanol Oxidation." *ECS Transactions* 64(3): 89–95. NREL/JA-5900-63856.

Buttner, W.J., R. Burgess, C. Rivkin, M.B. Post, L. Boon-Brett, V. Palmisano, and P. Moretto. 2014. "An Assessment on the Quantification of Hydrogen Releases through Oxygen Displacement Using Oxygen Sensors." *International Journal of Hydrogen Energy* 39(35) December: 20,484– 20,490. NREL/JA-5400-61075.

Chlistunoff, J., and B. Pivovar. 2015. "Effects of Ionomer Morphology on Oxygen Reduction on Pt." *Journal of the Electrochemical Society* 162(8): F890–F900. NREL/JA-5900-63733.

Cho, H.S., M. Das, H. Wang, N.H. Dinh, and J.W. Van Zee. (2015). "Contamination Mechanism and Behavior of Amide Bond Containing Organic Contaminant on PEMFC." *Journal of the Electrochemical Society* 162(4): F427–aF435. NREL/JA-5900-62537.

Christ, J.M., K.C. Neyerlin, H. Wang, R. Richards, and N.H. Dinh. 2014. "Impact of Polymer Electrolyte Membrane Degradation Products on Oxygen Reduction Reaction Activity for Platinum Electrocatalysts." *Journal of the Electrochemical Society* 161(14): F1481–F1488. NREL/JA-5900-62449.

Christ, J.M., K.C. Neyerlin, R. Richards, and N.H. Dinh. 2014. "Concentration Effects of Polymer Electrolyte Membrane Degradation Products on Oxygen Reduction Activity for Three Platinum Catalysts." *Journal of the Electrochemical Society* 161(14): F1360–F1365. NREL/JA-5900-62445.

Decegelie, M.G., T.J. Silverman, K. Emery, D. Dirnberger, A. Schmid, S. Barkaszi, N. Riedel, L. Pratt, S. Doshi, G. Tamizhmani, B. Marion, and S.R. Kurtz. 2015. "Validated Method for Repeatable Power Measurement of CIGS Modules Exhibiting Light-Induced Metastabilities." *IEEE Journal of Photovoltaics* 5(2) March: 607-612. NREL/JA-5J00-63237.

Long, H., and B.S. Pivovar. 2015. "Hydroxide Degradation Pathways for Substituted Benzyltrimethyl Ammonium: A DFT Study." *ECS Electrochemistry Letters* 4(1): F13–F16. NREL/JA-2C00-62672.

Ma, Z., A. Pesaran, V. Gevorgian, D. Gwinner, and W. Kramer. 2015. "Energy Storage, Renewable Power Generation, and the Grid: NREL Capabilities Help to Develop and Test Energy-Storage Technologies." *IEEE Electrification Magazine* 3(3): 30–40. NREL/JA-5500-64373.

Opu, M., G. Bender, C.S. Macomber, J.W. Van Zee, and H.N. Dinh. 2015. "Understanding the Effects of PEMFC Contamination from Balance of Plant Assembly Aids Materials: In Situ Studies." *Journal of the Electrochemical Society* 50(2): 619–634. NREL/JA-5900-64088.

Palmisano, V., E. Weidner, L. Boon-Brett, C. Bonato, F. Harskamp, P. Moretto, M.B. Post, R. Burgess, C. Rivkin, and W.J. Buttner. 2015. "Selectivity and Resistance to Poisons of Commercial Hydrogen Sensors." *International Journal of Hydrogen Energy* 40(35): 11,740–11,747. NREL/JA-5400-63929.

Palmisano, V., L. Boon-Brett, C. Bonato, F. Harskamp, W.J. Buttner, M.B. Post, R. Burgess, and C. Rivken. 2014. "Evaluation of Selectivity of Commercial Hydrogen Sensors." International *Journal of Hydrogen Energy* 39(35) December: 20,491–20,496. NREL/JA-5400-61200.

Sturgeon, M.R., C.S. Macomber, C. Engtrakul, H. Long, and B.S. Pivovar. 2015. "Hydroxide Based Benzyltrimethylammonium Degradation: Quantification of Rates and Degradation Technique Development." *Journal of the Electrochemical Society* 162(4): F366–F372. NREL/JA-5900-63275.

Posters

Ruth, M., A. Pratt, M. Lunacek, S. Mittal, H. Wu, and W. Jones. 2015. "Effects of Home Energy Management Systems on Distribution Utilities and Feeders Under Various Market Structures." NREL/PO-6A20-64413.

Presentations

Ainscough, C., and J. Kurtz. 2015. "ARRA Material Handling Equipment Composite Data Products: Data through Quarter 3 of 2014." NREL/PR-5400-64362.

Bloom, A., A. Townsend, and D. Palchak. 2015. "The Eastern Renewable Generation Integration Study: Flexibility and High Penetrations of Wind and Solar." Presented at the IEEE Power and Energy Society General Meeting, Denver, Colorado, July 26–30, 2015. NREL/PR-6A20-64795.

Hunter, B., and T. Markel. 2015. "Integrated Network Testbed for Energy Grid Research and Technology Experimentation (INTEGRATE)." NREL/PR-5B00-64062.

Kurtz, J., S. Sprik, C. Ainscough, and G. Saur. 2015. "Fuel Cell Electric Vehicle Evaluation." NREL/PR-5400-64221.

Neubauer, J., E. Wood, E. Burton, K. Smith, and A. Pesaran. 2015. "Impact of Fast Charging on Life of EV Batteries." NREL/PR-5400-63700.

Pesaran, A., C. Zhang, G.-H. Kim, and S. Santhanagopalan. 2015. "Coupled Mechanical-Electrochemical-Thermal Modeling for Accelerated Design of EV Batteries." NREL/PR-5400-63701.

Ruth, M. 2015. "Industrial Scale Energy Systems Integration." NREL/PR-6A20-64651.

Ruth, M., A. Pratt, M. Lunacek, S. Mittal, H. Wu, and W. Jones. 2015. "Effects of Home Energy Management Systems on Distribution Utilities and Feeders Under Various Market Structure." NREL/PR-6A20-64365.

Saur, G., J. Kurtz, C. Ainscough, S. Sprik, and M. Post. 2015. "Stationary Fuel Cell System Composite Data Products: Data through Quarter 4 of 2014." NREL/PR-5400-64234.

Sprik, S., J. Kurtz, C. Ainscough, and M. Peters. 2015. "Next Generation Hydrogen Station Composite Data Products: Data through Quarter 4 of 2014." NREL/PR-5400-64317.

Technical Reports

DiOrio, N., A. Dobos, S. Janzou, A. Nelson, and B. Lundstrom. 2015. *Technoeconomic Modeling of Battery Energy Storage in SAM*. (Technical Report) NREL/TP-6A20-64641. Golden, CO: National Reenable Energy Laboratory.

Jimenez, A., and R. Robichaud. 2015. *Winnebago Resource Study: Cooperative Research and Development Final Report, CRADA Number CRD-09-329*. (Technical Report) NREL/TP-7A40-63933. Golden, CO: National Renewable Energy Laboratory.

Pesaran, A., C. Ban, E. Burton, J. Gonder, P. Grad, M. Jun, M. Keyser, G.H. Kim, J. Neubauer, S. Santhanagopalan, A. Saxon, Y. Shi, K. Smith, M. Sprague, R. Tenent, E. Wood, C. Yang, C. Zhang et al. 2015. *NREL Energy Storage Projects: FY2014 Annual Report*. (Technical Report) NREL/TP-5400-63420. Golden, CO: National Renewable Energy Laboratory.

Pratt, J., D. Terlip, C. Ainscough, J. Kurtz, and A. Elgowainy. 2015. *H2FIRST Reference Station Design Task: Project Deliverable 2-2*. (Technical Report) NREL/TP-5400-64107. Golden, CO: National Renewable Energy Laboratory.

Terlip, D., C. Ainscough, W. Buttner, and S. McWhorter. 2015. H2FIRST *Hydrogen Contaminant Detector Task: Requirements Document and Market Survey*. (Technical Report) NREL/TP-5400-64063. Golden, CO: National Renewable Energy Laboratory.

ESIF High Performance Computing Publications

Brochure

"Analysis Insights, August 2015: Sustainable Transportation—Moving People and Goods in Ways that are Cleaner, Greener, Smarter." NREL/BR-6A20-64046.

Conference Papers (Preprint)

Churchfield, M.J., Z. Wang, and S. Schmitz. 2015. "Modeling Wind Turbine Tower and Nacelle Effects within an Actuator Line Model." Presented at the American Institute of Aeronautics and Astronautics SciTech Forum and Exposition, Kissimmee, Florida, January 5–9, 2015.

Grout, R.W.S. 2015. "Mixed-Precision Spectral Deferred Correction: Preprint." Presented at the 27th International Conference on Parallel Computational Fluid Dynamics, Montreal, Canada, May 17–20, 2015. NREL/CP-2C00-64959.

Conference Papers (Published Proceedings)

Barrows, C., T. Mai, E. Hale, A. Lopez, and K. Eurek. 2015. "Considering Renewables in Capacity Expansion Models: Capturing Flexibility with Hourly Dispatch." In *Proceedings of the 2015 IEEE Power and Energy Society General Meeting*. Piscataway, NJ: Institute of Electrical and Electronics Engineers.

Chakraborty, S., A. Hoke, and B. Lundstrom. 2015. "Evaluation of Multiple Inverter Volt-VAR Control Interactions with Realistic Grid Impedances." In *Proceedings of the 2015 IEEE Power and Energy Society General Meeting*: 1–5. Piscataway, NJ: Institute of Electrical and Electronics Engineers.

Gebraad, P.M.O., P.A. Fleming, and J.W. van Wingerden. 2015. "Comparison of Actuation Methods for Wake Control in Wind Plants." Presented at the American Control Conference, Chicago, Illinois, July 1–3, 2015. NREL/CP-5000-63794.

Hanson, T., B. Palmintier, S. Suryanarayanan, A. Maciejewski, and H. Jay Siegel. 2015. "Bus.py: A GridLAB-D Communication Interface for Smart Distribution Grid Simulations." In *Proceedings of the 2015 IEEE Power and Energy Society General Meeting*. Piscataway, NJ: Institute of Electrical and Electronics Engineers. (Best paper award)

Journal Articles

Barai, P., K. Smith, C.-F. Chen, G.-H. Kim, and P.P. Mukherjee. 2014. "Reduced Order Modeling of Mechanical Degradation Induced Performance Decay in Lithium-Ion Battery Porous Electrodes." *Journal of the Electrochemical Society* 162(9): A1751–A1771.

Bobela, D.C., B.K. Hughes, W.A. Braunecker, T.W. Kemper, R.E. Larsen, and T. Gennett. 2015. "Close Packing of Nitroxide Radicals in Stable Organic Radical Polymeric Materials." *Journal of Physical Chemistry Letters* 6(8): 1,414–1,419.

Bu, L., M.E. Himmel, and M.F. Crowley. 2015. "The Molecular Origins of Twist in Cellulose I-beta." *Carbohydrate Polymers* 125: 146–152.

Caskey, C.M., J.A. Seabold, V. Stevanovic, M. Ma, W.A. Smith, D.S. Ginley, N.R. Neale, R.M. Richards, S. Lany, and A. Zakutayev. 2015. "Semiconducting Properties of Spinel Tin Nitride and Other IV3N4 Polymorphs." *Journal of Materials Chemistry C* 3: 1,389–1,396.

Ciesielski, P. N., M.F. Crowley, M.R. Nimlos, A.W. Sanders, G.M. Wiggins, D. Robichaud, B.S. Donohoe, and T.D. Foust. 2015. "Biomass Particle Models with Realistic Morphology and Resolved Microstructure for Simulations of Intraparticle Transport Phenomena." *Energy and Fuels* 29(1): 242–254.

Diercks, D.R., M. Musselman, A. Morgenstern, T. Wilson, M. Kumar, K. Smith, M. Kawase, B.P. Gorman, M. Eberhart, and C.E. Packard. 2014. "Evidence for Anisotropic Mechanical Behavior and Nanoscale Chemical Heterogeneity in Cycled LiCoO2." *Journal of the Electrochemical Society* 161(11): F3039–F3045.

Hughes, B.K., W.A. Braunecker, A.J. Ferguson, T.W. Kemper, R.E. Larsen, and T. Gennett. 2014. "Quenching of the Perylene Fluorophore by Stable Nitroxide Radical-Containing Macromolecules." *Journal of Physical Chemistry B* 118(43): 12,541–12,548.

Jeffers, M.A., L.J. Chaney, and J.P. Rugh. 2015. "Climate Control Load Reduction Strategies for Electric Drive Vehicles in Warm Weather." *SAE Technical Papers* 2015-01-0355.

Jun, M., K. Smith, and P. Graf. 2015. "State-Space Representation of Li-Ion Battery Porous Electrode Impedance Model with Balanced Model Order Reduction." *Journal of Power Sources* 273(1): 1,226–1,236.

Kemper, T.W., R.E. Larsen, and T. Gennett. 2015. "Density of States and the Role of Energetic Disorder in Charge Transport in an Organic Radical Polymer in the Solid State." *Journal of Physical Chemistry C* 119(37): 21,369–21,375. NREL/JA-2C00-64650.

Lany, S. 2015. "Semiconducting Transition Metal Oxides." 2015. *Journal of Physics: Condensed Matter* 27(28): 283203.

Long, H., and B. Pivovar. 2014. "Computational Modeling of Degradation of Substituted Benzyltrimethyl Ammonium." *ECS Transactions* 64(3): 1,211–1,219.

Long, H., and B. Pivovar. 2014. "Hydroxide Degradation Pathways for Substituted Benzyltrimethyl Ammonium: A DFT Study." *ECS Electrochemistry Letters* 4(1): F13–F16.

Peng, H., P. Ndione, D.S. Ginley, A. Zakutayev, and S. Lany. 2015. "Design of Semiconducting Tetrahedral Mn1-xZnxO Alloys and Their Application to Solar Water Splitting." *Physical Review X* 5: 021016.

Ortiz, B.R., H. Peng, A. Lopez, P.A. Parilla, S. Lany, and E.S. Toberer. 2015. "Effect of Extended Strain Fields on Point Defect Phonon Scattering in Thermoelectric Materials." *Physical Chemistry Chemical Physics* 17: 19,410–19,423.

Park, J.-S., et al. 2015. 2015. "Stability and Electronic Structure of the Low-Σ Grain Boundaries in CdTe: A Density Functional Study." *New Journal of Physics* 17: 013027.

Park, J-S., et al. 2014. "Defect Properties of Sb- and Bi-Doped CuInSe2: The Effect of the Deep Lone-Pair s States." *Applied Physics Letters* 105: 243901.

Park, J-S., et al. 2015. "Ordering-Induced Direct to Indirect Band Gap Transition in Multi-Cation Semiconductor Compounds." *Physical Review B* 91: 075204.

Peng, H., A. Zakutayev, and S. Lany. 2015. "Tuning Optical Absorption of SnO by Isoelectronic Alloying for PV Absorber." *Condensed Matter: Materials Science.*

Seonah K., D.J. Robichaud, G.T. Beckham, R.S. Paton, and M.R. Nimlos. 2015. "Ethanol Dehydration in HZSM-5 Studied by Density Functional Theory: Evidence for Concerted Process." *Journal of Physical Chemistry A* 119(15): 3,604–3614.

Sprague, M.A., and A. Purkayastha. 2015. "Legendre Spectral Finite Elements for Reissner-Mindlin Composite Plates." *Finite Elements in Analysis and Design* 105: 33–43.

Sprague, M.A., and A. Purkayastha. 2015. "Legendre Spectral Finite Elements for Reissner-Mindlin Composite Plates." *Finite Elements in Analysis and Design* 105: 33–43. NREL/JA-2C00-64523.

Sturgeon, M.R., C.S. Macomber, C. Engtrakul, H. Long, and B. Pivovar. 2015. "Hydroxide Based Benzyltrimethylammonium Degradation: Quantification of Rates and Degradation Technique Development." *Journal of the Electrochemical Society* 162(4): F366–F372.

Trendewicz, A., R. Braun, A. Dutta, and J. Ziegler. 2014. "One Dimensional Steady-State Circulating Fluidized-Bed Reactor Model for Biomass Fast Pyrolysis." *Fuel* 133: 253–262.

Trendewicz, A., R. Braun, A. Dutta, S. Pannala, and J. Ziegler. 2015. "Nonreactive Riser Simulations of Biomass Pyrolysis: Development of 1-D Steady-State Models though 3-D Simulation and Experimental Comparisons." *Fuel*.

Weidman, P.D., and M. Sprague. 2015. "Steady and Unsteady Modeling of the Float Height of an Air Hockey Disk." *Journal of Fluid Mechanics* 778: 39–59.

Welch, A.W., LL. Baranowski, P.P. Zawadzki, S. Lany, C.A. Wolden, and A. Zakutayev. 2015. "CuSbSe2 Photovoltaic Devices with 3% Efficiency." *Applied Physics Express* 8(8): 082301.

Yang, J.-H., et al. 2015. "Enhanced p-type Dopability of P and As in CdTe Using Non-equilibrium Thermal Processing." *Journal of Applied Physics* 118: 025102.

Zawadzki, P.P., A. Zakutayev, and S. Lany. 2015. "Entropy-Driven Clustering in Tetrahedrally Bonded Multinary Materials." *Physical Review Applied* 3: 034007.

Zhang, C., S. Santhanagopalan, M.A. Sprague, and A.A. Pesaran. 2015. "Coupled Mechanical-Electrical-Thermal Modeling for Short-Circuit Prediction in a Lithium-ion Cell under Mechanical Abuse." *Journal of Power Sources* 290: 102–113.

Zhang, C., S. Santhanagopalan, M.A. Sprague, and A.A Pesaran. 2015. "Representative-Sandwich Model for Simultaneously Coupled Mechanical-Electrical-Thermal Simulation of a Lithium-Ion Cell under Quasi-Static Indentation Tests." *Journal of Power Sources* 298: 309–321. NREL/JA-2C00-64882.

Posters

Berstis, L., M. Crowley, and G.T. Beckham. 2015. "Theoretical Models of Electron Transfer Processes in Peptides." Presented at the American Chemical Society National Meeting and Exposition, Denver, Colorado, March 23, 2015.

Bush, B., R. Elmore, D. Getman, D. Inman, and E. Kalendra. 2015. "Automated Analysis of Renewable Energy Datasets." NREL/PO-6A20-64976.

Freed, E.F., M.T. Guarnieri, C.A. Henard, M.F. Crowley, G.T. Beckham, and S. Kim. 2015. "Fatty Acid Decarboxylase Engineering for Continuous Hydrocarbon Fuel Production." Presented at the Society for Industrial Microbiology and Biotechnology Annual Meeting and Exhibition, Philadelphia, Pennsylvania, August 2–6 , 2015.

Kemper, T.W., R. Larsen, P. Graf, S. Sides, and D. Olson. 2015. "Computational Materials Design of Co-Polymers for Organic Electronics." Presented at the Materials Research Society Spring Meeting, San Francisco, California, April 6–10, 2015.

Presentations

Ciesielski, P.N., M.F. Crowley, D. Robichaud, A. Sanders, B.S. Donohoe, M.R. Nimlos, and T.D. Foust. 2014. "3D Biomass Particle Models with Realistic Morphology and Resolved Microstructure for Finite Element Simulations of Intra-Particle Transport Phenomena." Presented at Frontiers in Biorefining, Prince Edward Island, Georgia, October 2014.

Ciesielski, P.N., M.F. Crowley, D. Robichaud, B.S. Donohoe, M.E. Himmel, T.D. Foust, and M.R. Nimlos. 2015. "Understanding the Performance of Biomass Feedstocks in Conversion Processes through Quantitative Microscopy and Computational Analysis." Presented to Forest Products Lab, Madison, Wisconsin, May 2015.

Ciesielski, P.N., M.F. Crowley, D. Robichaud, B.S. Donohoe, M.R. Nimlos, and T.D. Foust. 2014. "Simulations of Heat and Mass Transport during Biomass Conversion Processes using 3D Biomass Particle Models with Resolved Microstructure." Presented at the Comsol Conference, Boston, Massachusetts, October 2014.

Clark, J.M., H.M. Pilath, A. Mittal, L. Moens, M.R. Nimlos, D.J. Robichaud, and D.K. Johnson. 2014. "Production of Propylene from the Thermolysis of Poly(β-hydroxybutyrate) (PHB). An Experimental and Density Functional Theory (DFT) Investigation." Presented at the Symposium on Thermal and Catalytic Sciences, Denver, Colorado, 2014.

Habte, A. 2015. "Developing the Next Generation of Gridded TMYs." Presented at the American Society of Heating, Refrigerating, and Air-Conditioning (ASHRAE) Engineers Annual Conference, Atlanta, Georgia, June 27–July 1.

Hanrieder, N., M. Sengupta, Y. Xie, S. Wilbert, and R. Pitz-Paal. 2015. "Modelling Beam Attenuation in Solar Tower Plants Using Common DNI Measurements." Presented at the 3rd International Conference on Energy and Meteorology, Boulder, Colorado, June 22–26, 2015.

Kemper, T., R.E. Larsen, W. Braunecker, B.K. Hughes, D. Bobela, A. Ferguson, and T. Gennett. 2015. "Computational Analysis of Solvent Effects on Electron Transfer in Organic Radical Battery Cathode Materials." Presented at the American Chemical Society National Meeting and Exposition, Denver, Colorado, March 22–26, 2015.

Kemper, T., R.E. Larsen, W. Braunecker, B.K. Hughes, D. Bobela, A. Ferguson, and T. Gennett. 2015. "Computational Analysis of Solvent Effects on Electron Transfer in Organic Radical Battery Cathode Materials." Presented at the Materials Research Society Spring Meeting, San Francisco, California, April 6–10, 2015.

Kim, G.H., C. Yang, K. Smith, and A. Pesaran. 2015. "Integrated Multiscale Multiphysics Modeling of Safety Response in Lithium-Ion Batteries." Presented at the Advanced Automotive Battery Conference, Detroit, Michigan, June 15–19, 2015.

Kim, S., D. Robichaud, C. Mukarakate, L. Bu, T. Evans, G. Beckham, and M.R. Nimlos. 2015. "Mechanistic Study of Dehydration in HZSM-5 Using Density Functional Theory." Presented at the 37th Symposium on Biotechnology for Fuels and Chemicals, San Diego, California, April 27–30, 2015.

Kim, S., D. Robichaud, C. Mukarakate, L. Bu, T. Evans, G.T. Beckham, R.S. Paton, and M.R. Nimlos. 2015. "Mechanistic Study of Furan Formation in H-ZSM-5 Using Quantum Mechanical Modeling." Presented at the 249th ACS National Meeting and Exposition, Denver, Colorado, March 22–26, 2015.

King, R., P. Hamlington, K. Dykes, and P. Graf, 2015. "Adjoint Optimization of Wind Farm Layouts." Presented at the 2015 North American Wind Energy Academy Symposium, Blackburg, Virginia, June 8, 2015.

Larsen, R., T. Kemper, and D.C. Olson. 2015. "Atomistic Simulations of Donor-Acceptor Polymer Morphologies for High-Efficiency Organic Photovoltaic." Presented at the American Chemical Society National Meeting and Exposition, Denver, Colorado, March 22–26, 2015.

Lee, S., M. Churchfield. S. Sirnivas, P. Moriarty, F.G. Nielsen, B. Skarre, and E. Byklum. 2015. "Coalescing Wind Turbine Wakes." Presented at the Wake Conference, Visby, Sweden, June 9–11, 2015.

Liu, Y., et al. 2015. "Improve Si Solar Cell Efficiency by Defects Incorporation." Presented at the Materials Research Society Spring Meeting, San Francisco, California, April 6–10, 2015.

Long, H., and B. Pivovar. 2015. "Hydroxide Degradation Mechanism for Cations in Anion Exchange Membranes: A Computational Study." Presented at the American Chemical Society National Meeting and Exposition, Denver, Colorado, March 22–26, 2015.

Palmintier, B. 2014. "Energy Systems Integration: Connections for the Future." Presented at the IEEE Power and Energy Society Boston Technical Meeting, Waltham, Massachusetts, October 21, 2014.

Palmintier, B. 2015. "(Distribution) Modeling Research at NREL." Presented at the National Grid Workshop on Distributed Generation: Understanding the Current Challenges and Opportunities, Syracuse, New York, March 10, 2015.

Palmintier, B. 2015. "The Integrated Grid Modeling System (IGMS) for Combined Transmission and Distribution Simulation." Presented at the IEEE Power and Energy Society General Meeting, Denver, Colorado, July 29, 2015.

Park, J.-S., et al. 2015. "First-Principles Study of Low Σ Grain Boundaries in CdTe." Presented at the American Physical Society March Meeting, San Antonio, Texas, March 2–6, 2015.

Park, J.-S., et al. 2015. "Hybrid Functional Study of Stability and Electronic Structure of Cu2ZnSn(S,Se)4 Polytypes." Presented at the Chemical Society National Meeting and Exposition, Denver, Colorado, March 22–26, 2015.

Pesaran, A., G.H. Kim, and S. Santhanagopalan. 2015. "Coupled Mechanical-Electrochemical-Thermal Modeling For Accelerated Design of EV Batteries." Presented at the 28th Electric Vehicle Symposium, Kintex, Korea, May 3–6, 2015.

Qazi, N.A., H. Wang, M. Bolla, J.C.K. Tang, E.R. Hawkes, and R.W. Grout. 2015. "A Priori Study of the Stochastic Model for Discrete Phase Acceleration in a Temporally Evolving Planar Jet Using DNS." Presented at the Ninth International Symposium on Turbulent and Shear Flow Phenomena, Melbourne, Australia, June 30–July 3, 2015.

Qazi, N.A., H. Wang, M. Bolla, J.C.K. Tang, E.R. Hawkes, G. Yeoh, and R.W. Grout. 2015. "Direct Numerical Simulation of the Influence of Stokes Number on Velocity and Particle Concentration Distributions in Particle-Laden Round Jets." Presented at the 8th International Symposium on Turbulence Heat and Mass Transfer, Sarajevo, Bosnia and Herzegovina, September 15–18, 2015.

Sengupta, M., A. Habte, P. Gotseff, A. Lopez, A. Weekley, Y. Xie, C. Molling, and A. Heidinger. 2015. "The Next-Generation Satellite Product for NREL's National Solar Radiation Data Base (NSRDB)." Presented at the 3rd International Conference on Energy and Meteorology, Boulder, Colorado, June 22–26, 2015.

Sitaraman, H., M.A. Sprague, and J. Stickel. 2015. "Simulations of Coupled Reaction and CFD for Enzymatic Hydrolysis of Biomass." Presented at the Nek5000 User/Developer Meeting, Argonne National Laboratory, Lemont, Illinois, July 14–16, 2015.

Sheng, S. 2015. "Wind Turbine Condition Monitoring, Reliability Database, and O&M Research Update." Presented at the GRC Annual Meeting, Golden, Colorado, February 17–18, 2015. NREL/PR-5000-63868.

Wei, S.-H. 2015. "Diffusion of Interstitial Defects in Semiconductors: The Case in CdTe." Presented at the 42nd Conference on the Physics and Chemistry of Surfaces and Interfaces, Snowbird, Utah, January 18–22, 2015.

Wei, S.-H. 2015. "First-Principles Study and Design of Functional Materials for Energy Applications." Presented at the 9th International Conference on Computational Physics, Singapore, January 7–11, 2015.

Wei, S.-H. 2015. "First-Principles Study of Defect Control in Thin-Film Solar Cell Materials." Presented at the International Conference on Materials for Advanced Technologies, Singapore, June 28–July 3, 2015, and at the International Photonics and OptoElectronics Meetings, Wuhan, China, June 16–18, 2015.

Wei, S.-H. 2015. "First-Principles Study of Defects in Solar Cell Absorbers: The Case of CdTe." Presented at the Materials Research Society Spring Meeting, San Francisco, California, April 6–10, 2015.

Wei, S.-H., J. Ma, and J.-H. Yang. 2015. "Diffusion of Interstitial Defects in CdTe." Presented at the American Physical Society March Meeting, San Antonio, Texas, March 2–6, 2015.

Xie, Y., and M. Sengupta. 2015. "A Fast Radiative Transfer Model for Solar Resource Assessment and Forecasting." Presented at the 3rd International Conference on Energy and Meteorology, Boulder, Colorado, June 22–26, 2015.

Zhang, C., N. Waksmanski, V. Wheeler, E. Pan, and R. Larsen. 2015. "Effective Properties of Functionally Graded Material and Prediction of Elastic Properties of Photodegraded Polymeric Films." Presented at the ASCE Engineering Mechanics Institute Congress, Stanford, California, June 18, 2015. NREL/PR-2C00-64666.

Zhang, C., Santhanagopalan, S., A. Pesaran, E. Sahraei, and T. Wierzbicki. 2015. "Coupling of Mechanical Behavior of Lithium-Ion Cells to Electrochemical-Thermal Models for Battery Crush." Presented at the Advanced Automotive Battery Conference, Detroit, Michigan, June 15–19 2015.

Ziegler, J.L., S. Pannala, D.J. Robichaud, and M.R. Nimlos. 2015. "Reactor Simulations for Catalytic Upgrading of Pyrolysis Vapors." Presented at the American Chemical Society National Meeting and Exposition, Denver, Colorado, March 22–26, 2015.

Technical Reports

Mai, T., C. Barrows, A. Lopez, E. Hale, M. Dyson, and K. Eurek. 2015. Implications of Model Structure and Detail for Utility Planning: Scenario Case Studies using the Resource Planning Model. (Technical Report) NREL/TP-6A20-63972. Golden, CO: National Renewable Energy Laboratory.

O'Connell, N., E. Hale, I. Doebber, and J. Jorgenson. 2015. On the Inclusion of Energy-Shifting Demand Response in Production Cost Models: Methodology and a Case Study. (Technical Report) NREL/TP-6A20-64465. Golden, CO: National Renewable Energy Laboratory.

Sickinger, D., O. Van Geet, and C. Ravenscroft. 2014. *Energy Performance Testing of Asetek's RackCDU System at NREL's High Performance Computing Data Center.* (Technical Report) NREL/TP-2C00-62905. Golden, CO: National Renewable Energy Laboratory.

ESIF Secure Data Center Publications

Fact Sheet

"Fuel Cell Technology Status Analysis Project: Partnership Opportunities." NREL/FS-5400-62944.

Technical Reports

Kurtz, J., G. Saur, S. Sprik, and C. Ainscough. 2014. *Backup Power Cost of Ownership Analysis and Incumbent Technology Comparison*. (Technical Report) NREL/TP-5400-60732. Golden, CO: National Renewable Energy Laboratory.

Mai, T., C. Barrows, A. Lopez, E. Hale, M. Dyson, and K. Eurek. 2015. Implications of Model Structure and Detail for Utility Planning: Scenario Case Studies using the Resource Planning Model. (Technical Report) NREL/TP-6A20-63972. Golden, CO: National Renewable Energy Laboratory.

O'Connell, N., E. Hale, I. Doebber, and J. Jorgenson. 2015. On the Inclusion of Energy-Shifting Demand Response in Production Cost Models: Methodology and a Case Study. (Technical Report) NREL/TP-6A20-64465. Golden, CO: National Renewable Energy Laboratory.

ESIF Researcher Publications (Non-Lab)

Fact Sheet

"Making Fuel Cells Cleaner, Better, and Cheaper." NREL/FS-5900-63382.

Conference Papers (Published Proceedings)

Jin, X., J. Maguire, and D. Christensen. 2014. "Model Predictive Control of Heat Pump Water Heaters for Energy Efficiency." In *Next Generation: Reaching for High Energy Savings: Proceedings of the 2014 ACEEE Summer Study on Energy Efficiency in Buildings*: 133–145. Washington, DC: American Council for an Energy-Efficient Economy. NREL/CP-5500-61505.

Journal Articles

Long, H., and B.S. Pivovar. 2014. "Computational Modeling of Degradation of Substituted Benzyltrimethyl Ammonium." *ECS Transactions* 64(3): 1,211–1,219. NREL/JA-2C00-63926.

Sturgeon, M.R., C.S. Macomber, C. Engtrakul, and B.S. Pivovar. 2014. "Baseline BTMA Degradation as a Standard for Cationic Degradation in AEMFCs." NREL/JA-5900-62344. *ECS Transactions* 64(3): 1,201–1,209.

Wheeler, D., and M. Ulsh. 2014. "(Invited) Manufacturing Readiness and Cost Impacts for PEM Stack and Balance of Plant." *ECS Transactions* 64(3): 897–908. NREL/JA-5900-63957.

Presentations

Gevorgian, V. 2014. "NREL's Controllable Grid Interface for Testing Renewable Energy Technologies." Presented at the Second International Workshop on Grid Simulator Testing of Wind Turbine Drivetrains, North Charleston, South Carolina, September 17, 2014. NREL/PR-5D00-62998.

Technical Reports

Neubauer, J., and M. Simpson. 2015. *Deployment of Behind-The-Meter Energy Storage for Demand Charge Reduction*. (Technical Report) NREL/TP-5400-63162. Golden, CO: National Renewable Energy Laboratory.

Reda, I., M. Dooraghi, and A. Habte. 2014. *NREL Pyrheliometer Comparisons: September 22-26, 2014 (NPC-2014)*. (Technical Report) NREL/TP-3B10-63050. Golden, CO: National Renewable Energy Laboratory.

Rivkin, C., R. Burgess, and W. Buttner. (2015). *Hydrogen Technologies Safety Guide*. (Technical Report) NREL/TP-5400-60948. Golden, CO: National Renewable Energy Laboratory.

Other

U.S. Department of Energy Hydrogen and Fuel Cells Program 2014 Annual Merit Review and Peer Evaluation Report. DOE/GO-102014-4503. Golden, CO: National Renewable Energy Laboratory.

Power Systems Engineering Publications

Book Chapter

Ela, E., B. Kirby, I. Krad, and V. Gevorgian. 2015. "Section 5: Analysis of Steady-State Reliability and Detailed Costs Using the FESTIV Model." In *Modeling and Analysis of Value of Advanced Pumped Storage Hydropower in the United States*, 5.1–5.26. Oak Ridge, TN: Argonne National Laboratory. NREL/CH-5D00-60469.

Brochure

Dean, J., K. Anderson, R. Robichaud, M. Hillesheim, R. Hunsberger, and S. Booth. 2015. "Army Net Zero: Guide to Renewable Energy Conservation Investment Program (ECIP) Projects, June 2015." Golden, CO: National Renewable Energy Laboratory. NREL/BR-7A40-62947.

Fact Sheet

"Best Practices Handbook for the Collection and Use of Solar Resource Data for Solar Energy Applications." NREL/FS-5D00-63844.

Conference Papers (Preprints)

Aho, J., L.Y. Pao, P. Fleming, and E. Ela. 2015. "Controlling Wind Turbines for Secondary Frequency Regulation: An Analysis of AGC Capabilities Under New Performance Based Compensation Policy: Preprint." Paper presented at the 13th International Workshop on Large-Scale Integration of Wind Power Into Power Systems as Well as on Transmission Networks for Offshore Wind Power Plants, Berlin, Germany, November 11–13, 2014. NREL/CP-5D00-62815.

Cui, M., J. Zhang, A. Florita, B.-M. Hodge, D. Ke, and Y. Sun. 2015. "Optimized Swinging Door Algorithm for Wind Power Ramp Event Detection: Preprint." Presented at the IEEE Power and Energy Society General Meeting, Denver, Colorado, July 26–30, 2015. NREL/CP-5D00-63877.

Cui, M., J. Zhang, A. Florita, B.-M. Hodge, D. Ke, and Y. Sun. 2015. "Solar Power Ramp Events Detection Using an Optimized Swinging Door Algorithm: Preprint." Presented at the ASME International Design Engineering Technical Conferences & Computers and Information in Engineering Conference Boston, Massachusetts, August 2–5, 2015. NREL/CP-5D00-64093.

Habte, A., A. Andreas, L. Ottoson, C. Gueymard, G. Fedor, S. Fowler, J. Peterson, E. Naranen, T. Kobashi, A. Akiyama, and S. Takagi. 2014. "Spectroradiometer Intercomparison and Impact on Characterizing Photovoltaic Device Performance: Preprint." Paper presented at Solar 2014, San Francisco, California, July 6–10. NREL/CP-5D00-62215.

Habte, A., M. Sengupta, I. Reda, A. Andreas, and J. Konings. 2014. *"Calibration and Measurement Uncertainty Estimation of Radiometric Data: Preprint."* Paper presented at Solar 2014, San Francisco, California, July 6–10. NREL/CP-5D00-62214.

Hasan, I., T. Husain, M.W. Uddin, Y. Sozer, I. Husain, and E. Muljadi. 2015. "Analytical Modeling of a Novel Transverse Flux Machine for Direct Drive Wind Turbine Applications: Preprint." Paper presented at the IEEE Energy Conversion Congress and Exposition, Montreal, Canada, September 20–24, 2015. NREL/CP-5D00-64745.

Honrubia-Escribano, A., F. Jimenez-Buendia, A. Molina-Garcia, J.A. Fuentes-Moreno, E. Muljadi, and E. Gomez-Lazaro. 2015. "Analysis of Wind Turbine Simulation Models: Assessment of Simplified versus Complete Methodologies: Preprint." Paper presented at the ISEF 2015 – XVII International Symposium on Electromagnetic Fields in Mechatronics, Electrical and Electronic Engineers, Valencia, Spain, September 10–12, 2015. NREL/CP-5D00-64699.

Hsu, P., and E. Muljadi. 2015. "Permanent Magnet Synchronous Condenser for Wind Power Plant Grid Connection Support: Preprint." Paper presented at the IEEE 2015 9th International Conference on Power Electronics (ICPE 2015-ECCE Asia), Seoul, Korea, June 1–5. NREL/CP-5D00-63734.

Hsu, P., E. Muljadi, Z. Wu, and W. Gao. 2015. "Permanent Magnet Synchronous Condenser with Solid State Excitation: Preprint." To be presented at the 2015 IEEE Power and Energy Society General Meeting, Denver, Colorado, July 26–30. NREL/CP-5D00-63735.

Hsu, P., Z. Wu, E. Muljadi, and W. Gao. 2015. "Voltage Regulation Using a Permanent Magnet Synchronous Generator with a Series Compensator: Preprint." Paper presented at the IEEE Energy Conversion Congress and Exposition, Montreal, Canada, September 20–24, 2015. NREL/CP-5D00-64747.

Husain, T., Y. Sozer, I. Husain, and E. Muljadi. 2015. "Design of a Modular E-Core Flux Concentrating Axial Flux Machine: Preprint." Paper presented at the IEEE Energy Conversion Congress and Exposition, Montreal, Canada, September 20–24, 2015. NREL/CP-5D00-64748.

Jiang, H., Y.C. Zhang, J.J. Zhang, and E. Muljadi. 2015. "PMU-Aided Voltage Security Assessment for a Wind Power Plant: Preprint." To be presented at the 2015 IEEE Power and Energy Society General Meeting, Denver, Colorado, July 26–30. NREL/CP-5D00-63846.

Krad, I., E. Ibanez, and E. Ela. 2015. "Quantifying the Potential Impacts of Flexibility Reserve on Power System Operations: Preprint." Paper presented at the IEEE 2015 Annual Green Technology Conference, New Orleans, Louisiana, April 15–17. NREL/CP-5D00-63402.

Lundstrom, B., P. Gotseff, J. Giraldez, and M. Coddington. 2015. "High-Speed, Real-Time Visualization and State Estimation Platform for Monitoring and Control of Electric Distribution Systems: Implementation and Field Results: Preprint." Paper presented at the 2015 IEEE Power and Energy Society General Meeting, Denver, Colorado. NREL/CP-5D00-63260.

Milligan, M., H. Holttinen, J. Kiviluoma, A. Orths, M. Lynch, and L. Soder, 2014. "Market Designs for High Levels of Variable Generation: Preprint." Paper presented at the IEEE Power and Energy Society General Meeting, National Harbor, Maryland, July 27–31, 2014. NREL/CP-5D00-62280.

Mittal, S., M. Ruth, A. Pratt, M. Lunacek, D. Krishnamurthy, and W. Jones. 2015. "System-of-Systems Approach for Integrated Energy Systems Modeling and Simulation: Preprint." Paper presented at the Society for Modeling & Simulation International Summer Simulation Multi-Conference, Chicago, Illinois, July 26–29, 2015. NREL/CP-2C00-64045.

Muljadi, E., M. Singh, V. Gevorgian, M. Mohanpurkar, R. Havsapian, and V. Koritarov. 2015. "Dynamic Modeling of Adjustable-Speed Pumped Storage Hydropower Plant: Preprint." Paper presented at the 2015 IEEE Power and Energy Society General Meeting, Denver, Colorado, July 26–30. NREL/CP-5D00-63587.

Preciado, V., M. Madrigal, E. Muljadi, and V. Gevorgian. 2015. "Harmonics in a Wind Power Plant: Preprint." Paper presented at the 2015 IEEE Power and Energy Society General Meeting, Denver, Colorado, July 26–30. NREL/CP-5D00-63588.

Ruth, M., A. Pratt, M. Lunacek, S. Mittal, H. Wu, and W. Jones. 2015. "Effects of Home Energy Management Systems on Distribution Utilities and Feeders Under Various Market Structures: Preprint." Paper presented at the 23rd International Conference on Electricity Distribution, Lyon, France, June 15–18, 2015. NREL/CP-6A20-63500.

Sang, Y., H.B. Karayaka, Y. Yan, J.Z. Zhang, E. Muljadi, Y.-H. Yu. 2015. "Energy Extraction from a Slider-Crank Wave Energy under Irregular Wave Conditions: Preprint." Presented at OCEANS, Washington, D.C., October 19–22, 2015. NREL/CP-5D00-64875.

Sengupta, M., A. Weekley, A. Habte, A. Lopez, and C. Molling. 2015. "Validation of the National Solar Radiation Database (NSRDB) (2005-2012): Preprint." Paper presented at the European PV Solar Energy Conference and Exhibition, Hamburg, Germany, September 14–18, 2015. NREL/CP-5D00-64981.

Stark, G.B. 2015. "A Systematic Approach to Better Understanding Integration Costs: Preprint." Paper presented at the Energy Policy Research Conference, Denver, Colorado, September 10–11, 2015. NREL/CP-5D00-64930.

Wan, Z., A. Ahmed, I. Husain, and E. Muljadi. 2015. "Novel Transverse Flux Machine for Vehicle Traction Applications: Preprint." Paper presented at the 2015 IEEE Power and Energy Society General Meeting, Denver, Colorado July 26–30. NREL/CP-5D00-63661.

Wu, H., E. Ela, I. Krad, A. Florita, J. Zhang, B.M. Hodge, E. Ibanez, and W. Gao, W. 2015. "An Assessment of the Impact of Stochastic Day-Ahead SCUC on Economic and Reliability Metrics at Multiple Timescales: Preprint." Paper presented at the 2015 IEEE Power and Energy Society General Meeting, Denver, Colorado, July 26–30. NREL/CP-5D00-63714.

Wu, Z., P. Hsu, E. Muljadi, and W. Gao. 2015. "A Serially-Connected Compensator for Eliminating the Unbalanced Three-Phase Voltage Impact on Wind Turbine Generators: Preprint." Paper presented at the 2015 IEEE Power and Energy Society General Meeting, Denver, Colorado, July 26–30. NREL/CP-5D00-63875.

Zhang, J., B.-M. Hodge, S. Lu, H. Hamann, B. Lehman, J. Simmons, E. Campos, and V. Banunarayanan. 2015. "Baseline and Target Values for PV Forecasts: Toward Improved Solar Power Forecasting: Preprint." Presented at the IEEE Power and Energy Society General Meeting Denver, Colorado, July 26–30, 2015. NREL/CP-5D00-63876.

Conference Papers (Published Proceedings)

Baggu, M., R. Ayyanar, and D. Narang. 2015. "Feeder Model Validation and Simulation for High-Penetration Photovoltaic Deployment in the Arizona Public Service System." In *Proceedings of the 2014 IEEE 40th Photovoltaic Specialist Conference (PVSC)*: 2,088–2,093. NREL/CP-5D00-61129.

Cale, J., B. Palmintier, D. Narang, and K. Carroll. 2015. "Clustering Distribution Feeders in the Arizona Public Service Territory." In *Proceedings of the 2014 IEEE 40th Photovoltaic Specialist Conference (PVSC)*: 2,076–2,081. NREL/CP-5D00-63534.

Clark, K., N.W. Miller, M. Shao, S. Pajic, and R. D'Aquila. 2015. "Transient Stability and Frequency Response of the U.S. Western Interconnection under conditions of High Wind and Solar Generation." In *Proceedings of the 2015 Seventh Annual IEEE Green Technologies Conference (GreenTech)*: 13–20. NREL/CP-5D00-63421.

Dall'Anese, E., S.V. Dhople, and G.B. Giannakis. 2015. "Regulation of Dynamical Systems to Optimal Solutions of Semidefinite Programs: Algorithms and Applications to AC Optimal Power Flow." In *Proceedings of the 2015 American Control Conference (ACC)*: 2,087–2,092. NREL/CP-5D00-65134.

Dooraghi, M., A. Habte, I. Reda, M. Sengupta, P. Gotseff, and A. Andreas. 2014. "Quantifying the Impact of Incidence-Angle Dependence on Solar Radiometric Calibration." In *Proceedings of the 2014 IEEE 40th Photovoltaic Specialist Conference (PVSC)*: 2,662–2,667. Piscataway, NJ: Institute of Electrical and Electronics Engineers. NREL/CP-5D00-62116.

Genc, S., and M. Baggu. 2014. "Look Ahead Volt/VAR Control: A Comparison of Integrated and Coordinated Methods." In *Proceedings of the 2014 IEEE PES T&D Conference and Exposition*: 1–5. Piscataway, NJ: Institute of Electrical and Electronics Engineers. NREL/CP-5D00-63307.

Girsang, I.P., I. Dhupia, M. Singh, V. Gevorgian, E. Muljadi, and J. Jonkman. 2014. "Impacts of Providing Inertial Response on Dynamic Loads of Wind Turbine Drivetrain." In *2014 IEEE Energy Conversion Congress and Exposition (ECCE)*: 1,507–1,514. NREL/CP-5D00-63405.

Gotseff, P., J. Cale, M. Baggu, D. Narang, and K. Carroll. 2015. "Accurate Power Prediction of Spatially Distributed PV Systems using Localized Irradiance Measurements." In *Proceedings of the 2014 IEEE PES General Meeting*: 1–5. NREL/CP-5D00-60929.

Gu, Y., H. Jiang, Y.C. Zhang, and D.W. Gao. 2015. 2015. "Statistical Scheduling of Economic Dispatch and Energy Reserves of Hybrid Power Systems with High Renewable Energy Penetration." In *Proceedings of the 2014 48th Asilomar Conference on Signals, Systems and Computers*: NREL/CP-5D00-65139.

Hirsch, A., M. Deru, R. Langner, G. Stark, I. Doebber, J. Scheib, M. Sheppy, E. Bonnema, S. Pless, B. Livingood, and P. Torcellini. 2015. "Results and Lessons Learned From the DOE Commercial Building Partnerships." In *Next Generation: Reaching for High Energy Savings: Proceedings of the 2014 ACEEE Summer Study on Energy Efficiency in Buildings*. NREL/CP-5D00-63121.

Hoke, A., S. Chakraborty, and T. Basso. 2015. "Power Hardware-in-the-Loop Framework for Advanced Grid-Interactive Inverter Testing." *Proceedings of the 2015 IEEE Power & Energy Society Innovative Smart Grid Technologies Conference (ISGT)*: 1–5. NREL/CP-5D00-63265.

Hoke, A., S. Chakraborty, and T. Basso. 2015. "Testing Advanced Photovoltaic Inverters Conforming to IEEE Standard 1547 – Amendment 1." In *Proceedings of the 2014 IEEE 40th Photovoltaic Specialist Conference (PVSC)*: 1,014–1,021. NREL/CP-5D00-61205.

Holttinen, H., M. O'Malley, M. Milligan, and J.C. Smith. 2015. "Recommended Practices for Wind Integration Studies." In *Proceedings of the 2014 IEEE PES General Meeting*: 1–5. NREL/CP-5D00-64909.

Hsu, P., and E. Muljadi. 2015. "Damping Control for Permanent Magnet Synchronous Generators and Its Application in a Multi-turbine System." In *Proceedings of the 2014 Australasian Universities Power Engineering Conference (AUPEC)*. NREL/CP-5D00-62797.

Ibanez, E., and M. Milligan. 2015. "Comparing Resource Adequacy Metrics and Their Influence on Capacity Value." In *Proceedings of the 2014 International Conference on Probabilistic Methods Applied to Power Systems (PMAPS)*: 1–6. NREL/CP-5D00-63647.

Ibanez, E., I. Krad, and E. Erik. 2015. "Systematic Comparison of Operating Reserve Methodologies." In *Proceedings of the 2014 IEEE PES General Meeting*: 1–5. NREL/CP-5D00-64669.

Kim, J., G. Park, Y.C. Kiang, B. Lee, and E. Muljadi. 2015. "Voltage Control of a Wind Power Plant using the Adaptive Q-V Characteristic of DFIGs." In *Proceedings of the 2014 IEEE Symposium on Power Electronics and Machines for Wind and Water Applications (PEMWA)*: 1–5 NREL/CP-5D00-64466.

Krad, I., E. Ela, and V. Koritarov. 2015. "Quantifying the Operational Benefits of Conventional and Advanced Pumped Storage Hydro on Reliability and Efficiency." In *Proceedings of the 2014 IEEE PES General Meeting*: 1–5. NREL/CP-5D00-64672.

Krad, I., E. Ibanez, and E. Ela. 2015. "Quantifying the Potential Impacts of Flexibility Reserve on Power System Operations." In *Proceedings of the 2015 Seventh Annual IEEE Green Technologies Conference (GreenTech)*: 66–73. NREL/CP-5D00-65114.

Kumar, N., S. Venkataraman, D. Lew, G. Brinkman, D. Palchak, and J. Cochran. 2015. "Retrofitting Fossil Power Plants for Increased Flexibility." In *Proceedings of the ASME 2014 Power Conference*: 1–9. NREL/CP-6A20-61964.

Lee, J., Y.C. Kang,E. Muljadi, and P. Sorensen. 2015. "Droop Assignment Algorithm for the Inertial Control of a DFIG-Based Wind Power Plant for Supporting the Grid Frequency." In *2014 IEEE Symposium Power Electronics and Machines for Wind and Water Applications (PEMWA)*: 1–5. NREL/CP-5D00-64527.

Miller, N.W., M. Shao, R. D'Aquila, S. Pajic, and K. Clark. 2015. "Frequency Response of the US Eastern Interconnection Under Conditions of High Wind and Solar Generation." In *2015 Seventh Annual IEEE Green Technologies Conference (GreenTech)*: 21–28. NREL/CP-5D00-64947.

Milligan, M., H. Holttinen, J. Kiviluoma, A. Orths, M. Lynch, and L. Soder. 2015. "Market Designs for High Levels of Variable Generation." In *Proceedings of the 2014 IEEE PES General Meeting*: 1–5. NREL/CP-5D00-64913.

Palmintier, B. 2015. "Flexibility in Generation Planning: Identifying Key Operating Constraints." In *Proceedings of the 2014 Power Systems Computation Conference (PSCC)*. NREL/CP-5D00-62131.

Salapaka, S., B. Johnson, B. Lundstrom, S. Kim, S. Collyer, and M. Salapaka. 2015. "Viability and Analysis of Implementing Only Voltage-Power Droop for Parallel Inverter Systems." In *2014 IEEE 53rd Annual Conference on Decision and Control (CDC)*: 3,246–3,251. NREL/CP-5D00-61612.

Santoso, S., J. Ramos, and E. Muljadi. 2015. "Laboratory Experiences at the University of Texas." In *Proceedings of the 2014 IEEE PES General Meeting*: 1–21.

Sigrin, B., P. Sullivan, E. Ibanez, and R. Margolis. 2015. "Representation of the Solar Capacity Value in the ReEDS Capacity Expansion Model." In *Proceedings of the 2014 IEEE 40th Photovoltaic Specialist Conference (PVSC)*: 1,480–1,485 NREL/CP-6A20-63738.

Singh, M., A. Allen, E. Muljadi, and V. Gevorgian. 2015. "Oscillation Damping: A Comparison of Wind and Photovoltaic Power Plant Capabilities." In *2014 IEEE Symposium Power Electronics and Machines for Wind and Water Applications (PEMWA)*: 1–7. NREL/CP-5D00-64531.

Sinha, M., F. Dorfler, B.B. Johnson, and S.V. Dhople. 2015. "Virtual Oscillator Control Subsumes Droop Control." In *Proceedings of the 2015 American Control Conference (ACC)*: NREL/CP-5D00-62933.

Thomas, J.J., and S. Grijalva. 2014. "Increasing Transmission Capacity Utilization using Power Flow Routers." In *Proceedings of the 2014 IEEE PES T&D Conference and Exposition*: 1–5. Piscataway, NJ: Institute of Electrical and Electronics Engineers. NREL/CP-5D00-63326.

Wang, X., M. Yue, and E. Muljadi. 2015. "PV Generation Enhancement with a Virtual Inertia Emulator to Provide Inertial Response to the Grid." In *Proceedings of the 2014 IEEE Energy Conversion Congress and Exposition (ECCE)*: 17–23. NREL/CP-5D00-62311.

Weissbach, R., W.L. Wang, B.M. Hodge, M.H. Tang, and J. Sonnenmeier. 2015. "Generation of Simulated Wind Data using an Intelligent Algorithm." In *Proceedings of the 2014 North American Power Symposium (NAPS)*: NREL/CP-5D00-60981.

Williams, T., J. Fuller, K. Schneider, B. Palmintier, B. Lundstrom, and S. Chakraborty. 2014. "Examining System-Wide Impacts of Solar PV Control Systems with a Power Hardware-in-the-Loop Platform." In *Proceedings of the 2014 IEEE 40th Photovoltaic Specialist Conference (PVSC)*: 8–13. Piscataway, NJ: Institute of Electrical and Electronics Engineers. NREL/CP-5D00-61287.

Zhang, J., A. Florita, B.M. Hodge, and J. Freedman. 2015. "Ramp Forecasting Performance from Improved Short-Term Wind Power Forecasting." In *Proceedings of the ASME 2014 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference (IDETC/CIE 2014)*. NREL/CP-5D00-64249.

Zheng, Y.C., A. Allen, and B.-M. Hodge. 2015. "Impact of Distribution-Connected Large-Scale Wind Turbines on Transmission System Stability during Large Disturbances." In *Proceedings of the 2014 IEEE PES General Meeting*: 1–5. NREL/CP-5D00-63676.

Journal Articles

Blanc, P., B. Espinar, N. Geuder, C. Gueymard, R. Meyer, R. Pitz-Paal, B. Reinhardt, D. Renne, M. Sengupta, L. Wald, and S. Wilbert, S. 2015. "Direct Normal Irradiance Related Definitions and Applications: The Circumsolar Issue." *Solar Energy* 110: 561–577. NREL/JA-5D00-63177.

Bracale, A., J. Barros, A.S. Cacciapuoti, G. Chang, and E. Dall'Anese. 2015. "Guest Editorial Introduction to the Special Issue on 'Advanced Signal Processing Techniques and Telecommunications Network Infrastructures for Smart Grid Analysis, Monitoring, and Management.'" *EURASIP Journal on Advances in Signal* Processing. NREL/JA-5D00-64945.

Bruendlinger, R., T. Strasser, G. Lauss, A. Hoke, S. Chakraborty, G. Martin, B. Kroposki, J. Johnson, and E. de Jong. 2015. "Lab Tests: Verifying that Smart Grid Power Converters are Truly Smart." *IEEE Power and Energy Magazine* 13(2): 30–42. NREL/JA-5D00-63146.

Cui, M., D. Ke, D., Y. Sun, D. Gan, J. Zhang, and B.M. Hodge. 2015. "Wind Power Ramp Event Forecasting Using a Stochastic Scenario Generation Method." *IEEE Transactions on Sustainable Energy* 6(2): 422–433. NREL/JA-5D00-63441.

Dall'Anese, E., S.V. Dhople, B.B. Johnson, and G.B. Giannakis. 2015. "Decentralized Optimal Dispatch of Photovoltaic Inverters in Residential Distribution Systems." *IEEE Transactions on Energy Conversion* 29(4): 957–967. NREL/JA-5D00-61503.

Dall'Anese, E., S.V. Dhople, B.B. Johnson, and G.B. Giannakis. 2015. "Optimal Dispatch of Residential Photovoltaic Inverters Under Forecasting Uncertainties." *IEEE Journal of Photovoltaics* 5(1): 350–359. NREL/JA-5D00-62347.

Davoudi, A., J.M. Guerrero, F. Lewis, R. Balog, B. Johnson, W. Weaver, L. Wang, C. Edrington, R. Blasco-Gimenez, A. Dominguez-Garcia, and M.Y. Chow. 2015. "Guest Editorial: Advanced Distributed Control of Energy Conversion Devices and Systems." *IEEE Transactions on Energy Conversion* 29(4): 819–822. NREL/JA-5D00-63404.

Draxl, C., A. Clifton, B.-M. Hodge, and J. McCaa. 2015. "Wind Integration National Dataset (WIND) Toolkit." *Applied Energy* 151: 355–366. NREL/JA-5000-63400.

Fahimi, B., O. Mohammed, H. Toliyat, J. Kirtley, S. Pekarek, L. Parsa, K. Hameyer, A. Sarikhani, E. Muljadi, and J. Hendershot. 2015. "Guest Editorial: Optimal Design of Electric Machines." *IEEE Transactions on Energy Conversion* 30(3). NREL/JA-5D00-65096.

Gevorgian, V., Y.C. Zhang, and E. Ela. 2015. "Investigating the Impacts of Wind Generation Participation in Interconnection Frequency Response." IEEE Transactions on Sustainable Energy 6(3): 1,004–1,012. NREL/JA-5D00-62014.

Girsang, I.P., J.S. Dhupia, E. Muljadi, M. Singh, and L.Y. Pao. 2015. "Gearbox and Drivetrain Models to Study Dynamic Effects of Modern Wind Turbines." *IEEE Transactions on Industry Applications* 50(6): 377–386. NREL/JA-5D00-61856.

Henze, G.P., G.S. Pavlak, A.R. Florita, R.H. Dodier, and A.I. Hirsch. 2015. "An energy Signal Tool for Decision Support in Building Energy Systems." *Applied Energy* 138: 51–70. NREL/JA-5500-63340.

Honrubia-Escribano, A., T. Garcia-Sanchez, E. Gomez-Lazaro, E. Muljadi, and A. Molina-Garcia. 2015. "Power Quality Surveys of Photovoltaic Power Plants: Characterisation and Analysis of Grid-Code Requirements." *IET Renewable Power Generation* 9(5): 466–473. NREL/JA-5D00-63672.

Jiang, H. Y.C. Zhang, J.J. Zhang, G.W. Gao, and E. Muljadi. 2015. "Synchrophasor-Based Auxiliary Controller to Enhance the Voltage Stability of a Distribution System With High Renewable Energy Penetration." *IEEE Transactions on Smart Grid* 6(4): 2,107–2,115. NREL/JA-5D00-63371.

Khodayar, M., and H. Wu. 2015. "Demand Forecasting in the Smart Grid Paradigm: Features and Challenges." *Electricity Journal* 28(6): 51–62. NREL/JA-5D00-64946.

Kroposki, B. 2015. "Energy Storage in the Future Grid." *IEEE Electrification Magazine* 3(3): 62–64. NREL/JA-5D00-64520.

Ma, J., and S.H. Wei. 2015. "Origin of the Structural Diversity of M2O3 (M=Al, Ga, In)." *Computational Materials Science* 104: 35–39. NREL/JA-5D00-57495.

Ma, Z., A. Pesaran, V. Gevorgian, D. Gwinner, and W. Kramer. 2015. "Energy Storage, Renewable Power Generation, and the Grid: NREL Capabilities Help to Develop and Test Energy-Storage Technologies." *IEEE Electrification Magazine* 3(3): 30–40. NREL/JA-5500-64373.

Mancilla-David, F., J.L. Dominguez-Garcia, M. De Prada, O. Gomis-Bellmunt, M. Singh, and E. Muljadi. 2015. "Modeling and Control of Type-2 Wind Turbines for Sub-Synchronous Resonance Damping." *Energy Conversion and Management* 97: 315–322. NREL/JA-5D00-64157.

Mather, B., and S. Shah. 2015. "In Divergence There is Strength: Measuring and Mitigating Solar PV Impacts in Southern California Using Power Factors Other than One." *IEEE Power and Energy Magazine* 13(2): 62–70. NREL/JA-5D00-63101.

Muljadi, E., and Y.H. Yu. 2015. "Review of Marine Hydrokinetic Power Generation and Power Plant." *Electric Power Components and Systems* 43(12): 1,422–1,433. NREL/JA-5D00-63412.

Orwig, K.D., M.L. Ahlstrom, V. Banunarayanan, J. Sharp, J.M. Wilczak, J. Freedman, S.E. Haupt, J. Cline, O. Bartholomy, H.F. Obadiah, B.-M. Hodge, C. Finley, D. Nakafuji, J.L. Peterson, D. Maggio, and M. Marquis. 2015. "Recent Trends in Variable Generation Forecasting and Its Value to the Power System." *IEEE Transactions on Sustainable Energy* 6(3): 924–933. NREL/JA-5D00-63007.

Palmintier, B., B. Lundstrom, S. Chakraborty, T. Williams, K. Schneider, and D. Chassin. 2015. "Power Hardware-in-the-Loop Platform With Remote Distribution Circuit Cosimulation." *IEEE Transactions on Industrial Electronics* 62(4): 2,236–2,245. NREL/JA-5D00-61697.

Reda, I., J. Konings, and Y. Xie. 2015. "Method to Measure the Broadband Longwave Irradiance in the Terrestrial Direct Solar Beam." *Journal of Atmospheric and Solar-Terrestrial Physics* 129: 23–29. NREL/JA-3B10-63293.

Riesz, J., and M. Milligan. 2015. "Designing Electricity Markets for a High Penetration of Variable Renewables." *Wiley Interdisciplinary Reviews: Energy and Environment* 4(3): 279–289. NREL/JA-5D00-64441.

Singh, M., A. Allen, E. Muljadi, V. Gevorgian, Y.C. Zhang, and S. Santoso. 2015. "Interarea Oscillation Damping Controls for Wind Power Plants." *IEEE Transactions on Sustainable Energy* 6(3): 967–975. NREL/JA-5D00-61145.

Tong, W., S. Chowdhury, A. Mehmani, A. Messac, and J. Zhang. 2015. "Sensitivity of Wind Farm Output to Wind Conditions, Land Configuration, and Installed Capacity, Under Different Wake Models." Journal of Mechanical Design 137(6). NREL/JA-5D00-62243.

Wu, H., M. Shahidehpour, A. Alabdulwahab, and A. Abusorrah. 2015. "Demand Response Exchange in the Stochastic Day-Ahead Scheduling With Variable Renewable Generation." *IEEE Transactions on Sustainable Energy* 6(2): 516–525. NREL/JA-5D00-64246.

Wu, H., M. Shahidehpour, A. Alabdulwahab, and A. Abusorrah. 2015. "Thermal Generation Flexibility With Ramping Costs and Hourly Demand Response in Stochastic Security-Constrained Scheduling of Variable Energy Sources." *IEEE Transactions on Power Systems* 30(6): 2955–2964. NREL/JA-5D00-65128.

Wu, J., A. Botterud, A. Mills, X. Zhou, B.-M. Hodge, and M. Heaney. 2015. "Integrating Solar PV (Photovoltaics) in Utility System Operations: Analytical Framework and Arizona Case Study." *Energy* 85: 1–9. NREL/JA-5D00-63937.

Zhang, J., A. Florita, B.-M. Hodge, S. Lu, H.F. Hamann, V. Banunarayanan, and A.M. Brockway. 2015. "Suite of Metrics for Assessing the Performance of Solar Power Forecasting." *Solar Energy* 111: 157–175. NREL/JA-5D00-63024.

Zhang, J., B.-M. Hodge, and A. Florita. 2015. "Joint Probability Distribution and Correlation Analysis of Wind and Solar Power Forecast Errors in the Western Interconnection." *Journal of Energy Engineering* 141(1). NREL/JA-5D00-58507.

Zhang, J., C. Draxl, T. Hopson, L.D. Monache, E. Vanvyve, and B.-M. Hodge. 2015. "Comparison of Numerical Weather Prediction Based Deterministic and Probabilistic Wind Resource Assessment Methods." *Applied Energy* 156: 528–541. NREL/JA-5D00-64750.

Zhang, Y.C., E. Muljadi, D. Kosterev, and M. Singh. 2015. "Wind Power Plant Model Validation Using Synchrophasor Measurements at the Point of Interconnection." *IEEE Transactions on Sustainable Energy* 6(3): 984–992. NREL/JA-5D00-58643.

Posters

Habte, A., M. Sengupta, and I. Reda. 2015. "A Method to Estimate Uncertainty in Radiometric Measurement Using the Guide to the Expression of Uncertainty in Measurement (GUM) Method." NREL/PO-5D00-63900.

Hodge, B. 2015. "Value of Improved Wind Power Forecasting in the Western Interconnection." NREL/PO-5D00-60980.

Reda, I., J. Konings, Y. Xie, M. Dooraghi, and M. Sengupta. 2015. "Measuring Broadband IR Irradiance in the Direct Solar Beam." NREL/PO-3B10-63754.

Ruth, M., A. Pratt, M. Lunacek, S. Mittal, H. Wu, and W. Jones. 2015. "Effects of Home Energy Management Systems on Distribution Utilities and Feeders Under Various Market Structures." NREL/PO-6A20-64413.

Presentations

Ainsworth, N. 2015. "U.S. Army SOCOM Grand Challenge #3: TALOS Technical Roadmap: Near, Medium, Long Term." NREL/PR-5D00-64386.

Brancucci Martinez-Anido, C., A. Florita, and B.-M. Hodge. 2014. "The impact of Improved Solar Forecasts on Bulk Power System Operations in ISO-NE." Presented at 4th Solar Integration Workshop, Berlin, Germany, November 10, 2014. NREL/PR-5D00-63082.

Brancucci Martinez-Anido, C., B.-M. Hodge, D. Palchak, and J. Miettinen. 201. "The impact of Distributed Wind on Bulk Power System Operations in ISO-NE." Presented at the 13th Wind Integration Workshop, Berlin, Germany, November 11, 2014. NREL/PR-5D00-63083.

Draxl, C., and B.-M. Hodge. 2015. "Wind Integration National Dataset (WIND) Toolkit." Presented via webinar, July 14, 2015. NREL/PR-5000-64961.

Habte, A. 2015. "Uncertainty Estimation of Radiometric Data using a Guide to the Expression of Uncertainty in Measurement (GUM) Method." Presented at the ICEM Conference, Boulder, CO, June 25, 2015. NREL/PR-5D00-64984.

Habte, A., M. Sengupta, and A. Lopez. 2015. "Developing the Next Generation of Gridded TMYs." Presented at ASHRAE 2015 Annual Conference, June28, 2015. NREL/PR-5D00-64464.

Milligan, M. 2015. "Missing Money—Will the Current Electricity Market Structure Support High (-50%) Wind/Solar?" Presented at the AWEA Wind Power Conference, Orlando, Florida, May 18, 2015. NREL/PR-5D00-64324.

Milligan, M., and E. Ibanez. 2015. "Capacity Value: Evaluation of WECC Rule of Thumb." Presented at the Western Electricity Coordinating Council Webinar, June 9, 2015. NREL/PR-5D00-64879.

Muljadi, E. 2015. "Wind Turbine Generator for Distributed Wind Systems." NREL/PR-5D00-64159.

O'Neill, B. 2015. "Energy Imbalance Market Panel." NREL/PR-5D00-64318.

Shirazi, M., and B. Lundstrom. 2014. "The Energy Systems Integration Facility - Electrical Testing Capabilities and Research Activities." NREL/PR-5B00-62968.

Stark, G.B. 2015. "A Systematic Approach to Better Understanding Integration Costs." Presented at Energy Policy Research Conference, Denver, Colorado, September 10, 2015. NREL/PR-5D00-64973.

Subcontract Reports

Brooks, W. 2015. *Field Guide for Testing Existing Photovoltaic Systems for Ground Faults and Installing Equipment to Mitigate Fire Hazards: November 2012–October 2013*. (Subcontract Report) NREL/SR-5D00-61018. Golden, Colorado: National Renewable Energy Laboratory.

Miller, N.W., M. Shao, S. Pajic, and R. D'Aquila. 2015. *Western Wind and Solar Integration Study Phase 3—Frequency Response and Transient Stability (Report and Executive Summary)*. (Subcontract Report) NREL/SR-5D00-62906. Golden, Colorado: National Renewable Energy Laboratory.

Papalexopoulos, A., C. Hansen, D. Perrino, and R. Frowd. 2015. *Modeling and Analysis of Wholesale Electricity Market Design: Understanding the Missing Money Problem; December 2013–January 2015*. (Subcontract Report) NREL/SR-5D00-64255. Golden, Colorado: National Renewable Energy Laboratory.

Technical Reports

Ahlstrom, M., C. Smith, D. Piwko, D. Lew, A. Bloom, T. Mai, K. Clark, and M. Milligan. 2015. *Relevant Studies for NERC's Analysis of EPA's Clean Power Plan 111(d) Compliance*. (Technical Report) NREL/TP-5D00-63979. Golden, Colorado: National Renewable Energy Laboratory.

Allen, A., M. Singh, E. Muljadi, and S. Santoso. 2015. *PMU Data Event Detection: A User Guide for Power Engineers*. (Technical Report) NREL/TP-5D00-61664. Golden, Colorado: National Renewable Energy Laboratory.

Anderberg, M., and M. Sengupta. 2014. *Comparison of Data Quality of NOAA's ISIS and SURFRAD Networks to NREL's SRRL-BMS*. (Technical Report) NREL/TP-5D00-62526. Golden, Colorado: National Renewable Energy Laboratory.

Andreas, A.M. 2015. *Improved Rotating Shadowband Radiometer Measurement Performance: Cooperative Research and Development Final Report, CRADA Number CRD-08-294*. (Technical Report) NREL/TP-5D00-63769. Golden, Colorado: National Renewable Energy Laboratory.

Basso, T. 2014. *IEEE 1547 and 2030 Standards for Distributed Energy Resources Interconnection and Interoperability with the Electricity Grid*. (Technical Report) NREL/TP-5D00-63157. Golden, Colorado: National Renewable Energy Laboratory.

DiOrio, N., A. Dobos, S. Janzou, A. Nelson, and B. Lundstrom. 2015. *Technoeconomic Modeling of Battery Energy Storage in SAM*. (Technical Report) NREL/TP-6A20-64641. Golden, Colorado: National Renewable Energy Laboratory.

Dooraghi, M. 2015. *Broadband Outdoor Radiometer Callibration Process for the Atmospheric Radiation Measurement Program*. (Technical Report) NREL/TP-5D00-65035. Golden, Colorado: National Renewable Energy Laboratory.

Dooraghi, M. 2015. *Solar Resource Measurements at FPL Energy—Equipment Only: Cooperative Research and Development Final Report, CRADA Number CRD-08-283*. (Technical Report) NREL/TP-5D00-64170. Golden, Colorado: National Renewable Energy Laboratory.

Draxl, C., B.-M. Hodge, A. Clifton, and J. McCaa. *Overview and Meteorological Validation of the Wind Integration National Dataset Toolkit*. (Technical Report) NREL/TP-5000-61740. Golden, Colorado: National Renewable Energy Laboratory.

Henze, G.P., G.S. Pavlak, A.R. Florita, R.H. Dodier, and A.I. Hirsch. 2014. *Energy Signal Tool for Decision Support in Building Energy Systems*. (Technical Report) NREL/TP-5500-63130. Golden, Colorado: National Renewable Energy Laboratory.

Hodge, B. M., A. Florita, J. Sharp, M. Margulis, and D. Mcreavy. 2015. *Value of Improved Short-Term Wind Power Forecasting*. (Technical Report) NREL/TP-5D00-63175. Golden, Colorado: National Renewable Energy Laboratory.

Hoke, A., A. Nelson, S. Chakraborty, J. Chebahtah, T. Wang, M. McCarty. 2015. *Inverter Ground Fault Overvoltage Testing*. (Technical Report) NREL/TP-5D00-64173. Golden, Colorado: National Renewable Energy Laboratory.

Hunsberger, R., and G. Mosey. 2015. *EPA RE-Powering America's Lands: Kansas City Municipal Farm Site—Biomass Power Analysis*. (Technical Report) NREL/TP-5D00-62097. Golden, Colorado: National Renewable Energy Laboratory.

Kiatreungwattana, K., O. Van Geet, and R. Hunsberger. *Energy Efficiency, Water Efficiency, and Renewable Energy Site Assessment: Northern Great Lakes Visitor Center, Ashland Wisconsin and Toumey Nursery, Watersmeet, Michigan*. (Technical Report) NREL/TP-7A40-63822. Golden, Colorado: National Renewable Energy Laboratory.

Kurnik, C., R.S. Butt, I. Metzger, O. Lavrova, S. Patibandla, V. Wagner, M. Frankosky, and G. Wiegand. 2015. *Design, Operation, and Controlled-Island Operation of the U.S. Department of Energy Solar Decathlon 2013 Microgrid*. (Technical Report) NREL/TP-7A40-62997. Golden, Colorado: National Renewable Energy Laboratory.

Mather, B. 2015. *Southern California Edison Grid Integration Evaluation: Cooperative Research and Development Final Report, CRADA Number CRD-10-376*. (Technical Report) NREL/TP-5D00-64556. Golden, Colorado: National Renewable Energy Laboratory.

Milligan, M., B. Kirby, T. Acker, M. Ahlstrom, B. Frew, M. Goggin, W. Lasher, M. Marquis, and D. Osborn. 2015. *Review and Status of Wind Integration and Transmission in the United States: Key Issues and Lessons Learned*. (Technical Report) NREL/TP-5D00-61911. Golden, Colorado: National Renewable Energy Laboratory.

Muljadi, E., M. Singh, and V. Gevorgian. 2014. *User Guide for PV Dynamic Model Simulation Written on PSCAD Platform*. (Technical Report) NREL/TP-5D00-62053. Golden, Colorado: National Renewable Energy Laboratory.

Nelson, A., A. Hoke, S. Chakraborty, J. Chebahtah, T. Wang, and B. Zimmerly. 2015. *Inverter Load Rejection Over-Voltage Testing: SolarCity CRADA Task 1a Final Report*. (Technical Report) NREL/TP-5D00-63510. Golden, Colorado: National Renewable Energy Laboratory.

Palminier, B., and A. Pratt. 2015. *Evaluation of the Netherlands' International Test Facility for Smart Grids*. (Technical Report) NREL/TP-5D00-63638. Golden, Colorado: National Renewable Energy Laboratory.

Sengupta, M., A. Habte, S. Kurtz, A. Dobos, S. Wilbert, E. Lorenz, T. Stoffel, D. Renne, C. Gueymard, D. Myers, S. Wilcox, P. Blanc, and R. Perez. *Best Practices Handbook for the Collection and Use of Solar Resource Data for Solar Energy Applications. (Technical Report) NREL/TP-5D00-63112. Golden, Colorado: National Renewable Energy Laboratory.*

Silverman, T.J., P. McNutt, and J. Wohlgemuth. 2015. *Photovoltaic Array Field Characterization Report: University of Toledo R1 Arrays*. (Technical Report) NREL/TP-5J00-64998. Golden, Colorado: National Renewable Energy Laboratory.

Stark, G.B. 2015. *Systematic Approach to Better Understanding Integration Costs*. (Technical Report) NREL/TP-5D00-64502. Golden, Colorado: National Renewable Energy Laboratory.

Miscellaneous

Brochure

"ESIF User Guide." NREL/BR-5B00-64285.

Conference Papers (Published Proceedings)

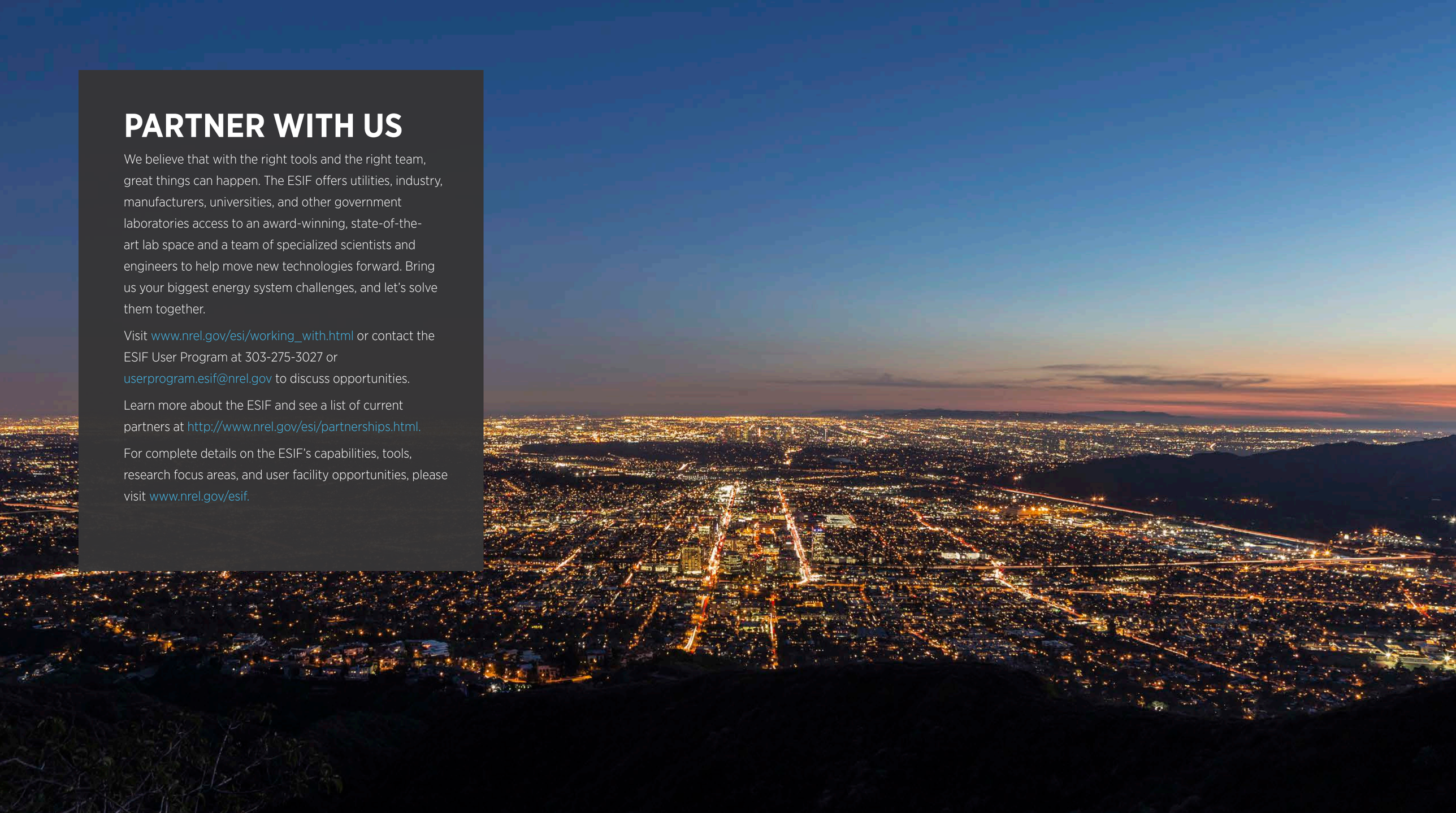
Scheib, J., S. Pless, and P. Torcellini. 2014. "Energy-Performance-Based Design-Build Process: Strategies for Procuring High-Performance Buildings on Typical Construction Budgets." In *Next Generation: Reaching for High Energy Savings: Proceedings of the 2014 ACEEE Summer Study on Energy Efficiency in Buildings:* 306–321. Washington, DC: American Council for an Energy-Efficient Economy. NREL/CP-5500-63122.

Sheppy, M., P. Torcellini, and L. Gentile-Polese. 2014. "An Analysis of Plug Load Capacities and Power Requirements in Commercial Buildings." *Next Generation: Reaching for High Energy Savings: Proceedings of the 2014 ACEEE Summer Study on Energy Efficiency in Buildings*. Washington, DC: American Council for an Energy-Efficient Economy. NREL/CP-5500-61528.

Torcellini, P., M. Sheppy, M. Deru, and M. Milan. 2014. "Attacking Plug Loads: A Campaign to Deploy Automated Plug Strip Controllers." In *Next Generation: Reaching for High Energy Savings: Proceedings of the 2014 ACEEE Summer Study on Energy Efficiency in Buildings*: 380–391. Washington, DC: American Council for an Energy-Efficient Economy. NREL/CP-5500-61676.

Management Report

Terry, S. 2015. *Laboratory Directed Research and Development (LDRD) Program: FY14 Annual Report*. (Management Report) NREL/MP-6A31-64003. Golden, CO: National Renewable Energy Laboratory.



PARTNER WITH US

We believe that with the right tools and the right team, great things can happen. The ESIF offers utilities, industry, manufacturers, universities, and other government laboratories access to an award-winning, state-of-the-art lab space and a team of specialized scientists and engineers to help move new technologies forward. Bring us your biggest energy system challenges, and let's solve them together.

Visit www.nrel.gov/esi/working_with.html or contact the ESIF User Program at 303-275-3027 or userprogram.esif@nrel.gov to discuss opportunities.

Learn more about the ESIF and see a list of current partners at http://www.nrel.gov/esi/partnerships.html.

For complete details on the ESIF's capabilities, tools, research focus areas, and user facility opportunities, please visit www.nrel.gov/esif.

National Renewable Energy Laboratory
15013 Denver West Parkway, Golden, CO 80401
303-275-3000 • www.nrel.gov

Printed on paper that contains recycled content.

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.

NREL/BK-5C00-65685 • April 2016