NREL
Transforming ENERGY

# ESIF 2021

## Associate Director's Letter

Energy is at a turning point: in one direction, a comprehensive leap toward clean and affordable energy, built on inclusivity and diverse collaboration; in the other, ongoing carbon dependence and hamstrung progress. It's increasingly clear that our future is with the first direction, and we are moving forward with confidence and expertise toward viable and technically sound alternatives that align with the U.S. Department of Energy (DOE) goals set by the Biden-Harris administration. The path ahead is achievable, but the exact steps will depend on the results of advanced research and development (R&D) to deliver secure, sustainable, and equitable energy transitions.

For nearly a decade, the Energy Systems Integration Facility (ESIF) has consistently been at the forefront of clean energy systems integration, finding the best options for energy transitions and demonstrating secure and resilient deployment. We've made significant progress to date—but now it's time to truly scale the achievements made by utilities, vendors, academia, and the other researchers who leverage this unique DOE user facility. With recent extensions to the ESIF's R&D capabilities, we can now look beyond—from neighborhoods and communities to the bulk grid and energy transmission, and to the integration of millions of new, larger, and more diverse hybrid devices.

Leveraging experience and assets from a rich history of past projects, the ESIF is now the tip of the spear for an expanded research capability, Advanced Research on Integrated Energy Systems (ARIES). The ARIES platforms performs research at a scale that reflects the real diversity and size of energy system transitions. With ARIES, we can perform electric grid experiments at ten times greater power than before and leverage an emulation environment to evaluate the cybersecurity of experimental systems comprising millions of devices. We can create hypothetical, realistic energy systems within the safety of the lab to de-risk bold, upcoming solutions and to carry new technologies safely and swiftly to real-world deployment.

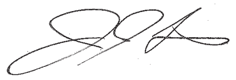
ARIES is taking off at a decisive time for the National Renewable Energy Laboratory's (NREL's) energy systems research: Communities and utilities across the United States are setting nearer-term targets to reduce their carbon footprints, spurred on by supportive government policies and a public that is pushing for more aggressive action. Perhaps a signal of the times, ARIES was visited this year by the U.S. president, secretary of energy, and many other state and local leaders. It seems a consensus is forming that the time for significant clean energy progress has arrived.

Entire cities, the U.S. government, and the world's largest energy companies are now turning directly to our laboratory for the technical knowledge and physical capabilities that can facilitate an energy transformation like none other in history. It is a heavy assignment, no doubt; especially at a time when so much else is in flux and at risk of cyber threats and natural disasters. But with the ARIES buildout, we are adapting and meeting the moment by growing our capabilities and refining our scientific scope.

Within ARIES, the ESIF maintains its original role of advancing research at the grid edge to better integrate energy technologies from electricity and thermal to water and hydrogen fuels. In the last year, researchers at the ESIF demonstrated the black-start capabilities of autonomous grid restoration using grid-forming inverters and completed a milestone 5,000 hours of performance testing on an electrolyzer stack.

We are also achieving extraordinarily detailed pictures of energy systems using high-performance computing. We've integrated a suite of amazing NREL software tools, including dGen™—which won a 2021 R&D 100 Award for the ability to forecast the adoption of distributed energy resources. When this analysis capability is used alongside our hardware and research assets, as it is now with the ARIES buildout, the ESIF achieves an impact in energy systems integration research that is available nowhere else. By putting exceptional capabilities in the hands of our outstanding researchers and partners, we are taking on the difficult questions that can unlock the next steps toward clean, equitable, and efficient energy everywhere.

Sincerely,



Juan Torres
Associate Laboratory Director for Energy Systems Integration at NREL

Martha Symko-Davies
Laboratory Program Manager for the Energy Systems Integration Facility at NREL

The ESIF 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 and is a designated DOE user facility.



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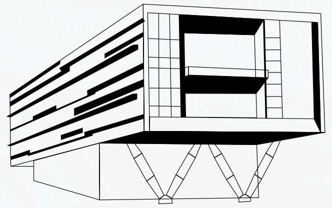
# STEPPING INTO THE FUTURE WITH ARIES

## ESIF KEY PERFORMANCE INDICATORS FOR FISCAL YEAR 2021

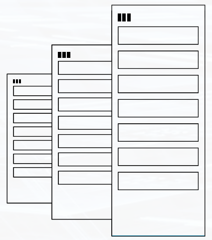
### ESIF LABORATORIES



174 Users

Utilization – 82%

### HPC DATA CENTER



535 Users

Availability – 95%

Utilization – 90%

The Energy Systems Integration Facility (ESIF) supports research conducted through the Advanced Research on Integrated Energy Systems (ARIES) platform. ARIES is the world's most advanced platform for clean power grid integration research, testing, and validation. It is a digital-physical ecosystem that extends beyond the National Renewable Energy Laboratory (NREL), connecting other national labs and research partners globally.

ARIES research addresses the fundamental integrated energy systems at-scale challenges of:

- Variability in the physical size of new energy technologies being added to the energy system
- Controlling large numbers (millions to tens of millions) of interconnected devices
- Integrating multiple diverse technologies that have not previously worked together.

In its first years of operation, ARIES:

- Performed a black start using 100% renewable resources after an unexpected outage
- Partnered with the U.S. Department of Defense to develop resilient and renewable microgrid systems
- Convened experts from several national labs for the Grid Modernization Laboratory Consortium (GMLC) FlexPower project, a fully operational, multimegawatt, hybrid power plant that will be capable of demonstrating all types of dispatchability, reliability, and resilience services.

**To learn more about these projects, and many more, visit the *ARIES Annual Report*.**

# INTEGRATION LABORATORIES: GRID MODERNIZATION

## RENEWABLE ENERGY-TO-GRID INTEGRATION

### Scalable Approach to Microgrid Integration Allows Self-Organizing Community Resilience

NREL is showing the way toward resilient and autonomous energy systems for communities with the project Reorg: Resilience and Stability Oriented Cellular Grid Formation and Optimization for Communities with Solar PVs and Mobile Energy Storages. With support from the U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE) Solar Energy Technologies Office (SETO), Reorg is aimed at designing and demonstrating artificial intelligence (AI)-based tools for adaptively resilient distribution networks.

The tools include a software suite for intelligent analysis and control, deployed across distributed energy resource (DER) aggregators and utility infrastructure, that allows microgrid cells to island or cluster with surrounding cells as needed to form self-reliant sections of the distribution grid. This approach leverages local distributed solar photovoltaics (PV), battery energy storage, and behind-the-meter DERs to power communities to provide dynamic stability and resilience. Reorg has immediate importance to many communities that are seeking power system resilience, among them a remote 5-MW community in Aspen, Colorado, with 760 residential and 379 commercial customers served by project partner Holy Cross Energy.

In the first year of work, Reorg began designing the underlying AI tools that coordinate resilience across two levels: one for higher-level clustering to coordinate and reorganize cellular grid formations and one for intercell control to optimize DERs for local resilience. The research team will first validate their method on hardware devices and an emulated power system within the ESIF and then demonstrate the technology on a real distribution system that often experiences natural hazards, such as wildfires and blizzards. Results from the demonstration will be circulated with help from partner National Rural Electric Cooperative Association (NRECA) to support remote and rural communities with reproducible tools for real-time resilience.

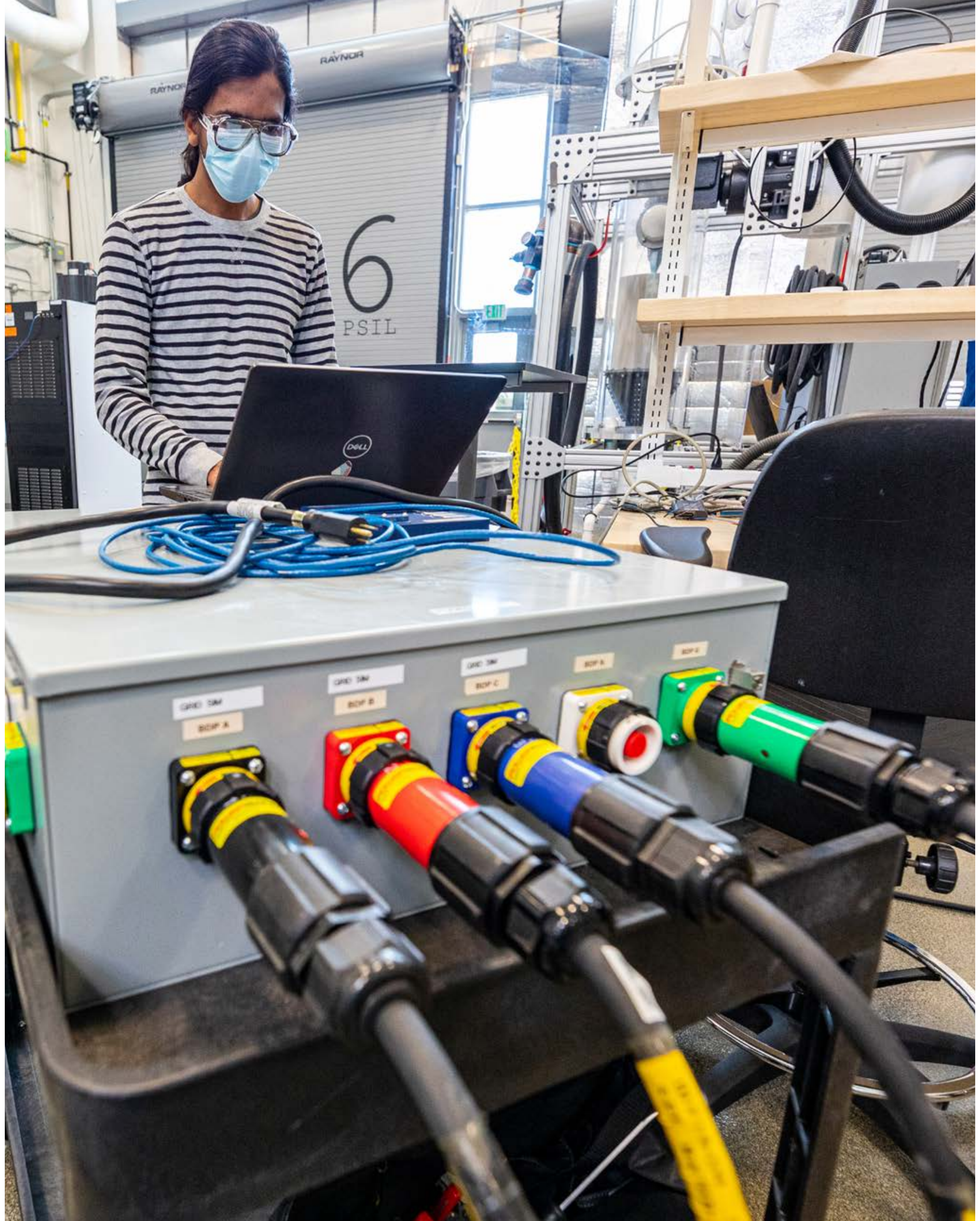
## HELICS Handles Hardware-Software Communications for Expanding NREL's Simulation Capabilities

The Hierarchical Engine for Large-Scale Infrastructure Co-Simulation (HELICS) continues to push the frontier of what is possible in simulating complex energy systems. HELICS is a mainstay in ESIF modeling and analysis as well as validation projects, connecting cyber and physical simulations across multiple domains and even other national laboratory capabilities. This allows NREL and partners to scale up and synchronize integrated simulations. HELICS emerged from a collaboration within DOE's GMLC.

In Fiscal Year 2021, HELICS was upgraded to Version 3.0, which included the buildout of a new Python interface as well as other key usability enhancements, such as improved support documentation to complement HELICS's accessible, open-source design. The upgraded buildout arrived alongside ARIES expansions, which has tied HELICS tighter into NREL's power systems simulation back end, helping to facilitate real-time synchronized software and hardware communications among NREL's growing energy device fleet and within its newly established virtual emulation environment.

HELICS has been central to several major projects—it was applied in multiple use cases of the Advanced Distribution Management System (ADMS) Test Bed for simulating custom distribution grid controls on replica systems for industry and utility partners, the Grid Optimization with Solar (GO-Solar) effort by SETO to demonstrate advanced situational awareness through AI-assisted grid measurements, and the NREL cyber range to connect virtual cybersecurity tools to real hardware simulations. In each case, HELICS has allowed researchers to simulate interactions for tens of thousands of simulated nodes and hundreds of hardware devices. Although developed for power-specific research, HELICS is functional for cosimulations in any industry, and it supports a growing and diverse user base.






## Utilidata and New York State Explore Volt-Volt Ampere Reactive Optimization with Cosimulations

The energy software company Utilidata is working with NREL to demonstrate the value of their novel volt-volt ampere reactive optimization (VVO) solution. The project was awarded by the New York Energy Research and Development Authority (NYSERDA) to demonstrate the value of advanced grid solutions integrating and leveraging solar smart inverter functionality to optimize grid performance. NREL established a cosimulation platform on HELICS that will use the Utilidata VVO strategy to integrate smart inverters, advanced metering infrastructure (AMI), and diverse distribution voltage control assets. The team has begun formulating power-hardware-in-the-loop testing in the ESIF, followed by a field test with a major utility in New York State, National Grid. The field test will provide National Grid with the results of VVO on their distribution feeders, demonstrating the value of enhanced control to deliver reliable, secure service.

## Improving Utility Operations with Advanced Data Collection, Grid Visibility

In a high impact collaboration, NREL deployed AMI for within the grid operations of partner San Diego Gas & Electric Company (SDG&E). AMI, an integrated system of smart meters, allows utilities to collect real-time, highly detailed energy use data at the individual customer level. With AMI, utilities can better monitor, operate, and control the grid based on real data models and improve situational awareness. NREL first developed and validated models of SDG&E's feeders to demonstrate use case scenarios on the ADMS Test Bed. The test bed setup allows the project team to try novel control approaches; in one example, NREL is demonstrating how SDG&E could use AMI data alone—without any information about feeder design—to control its distribution systems. SDG&E and NREL have recently analyzed the AMI data using NREL's high-performance computing (HPC) and 3D visualization capabilities, allowing SDG&E to identify modernization strategies that improve grid control and their customer service.

This project is supported in part by the DOE Office of Electricity.

## North American Renewable Integration Study Highlights Opportunities for a Continental, Low-Carbon Grid

In a significant achievement for electric grid modeling, NREL, DOE, and Natural Resources Canada released the results of the multiyear North American Renewable Integration Study (NARIS). This study provides insight to grid planners, utilities, industry, policymakers, and other stakeholders about the challenges and opportunities for continental system integration to support a low-carbon future electric grid.

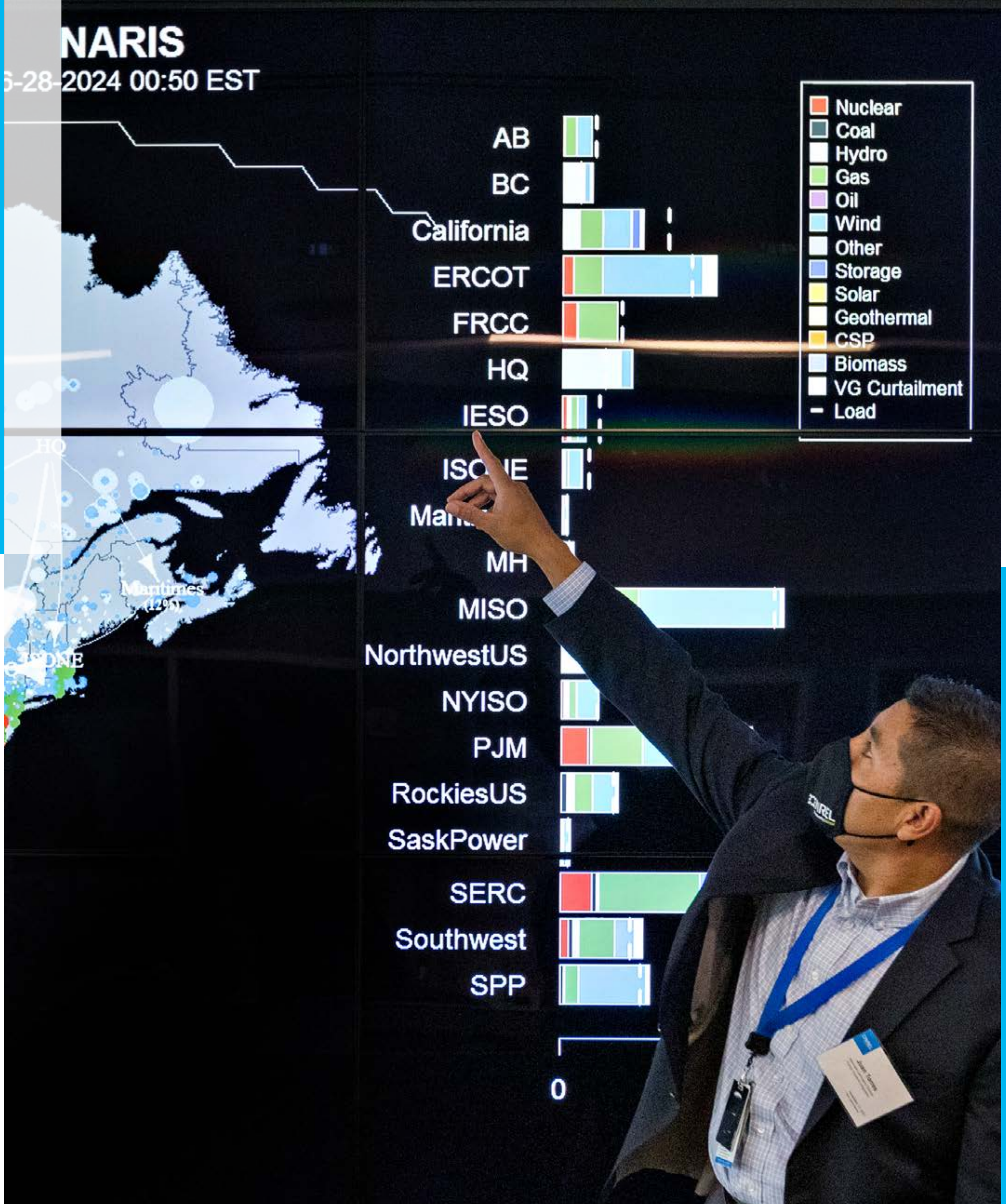
For this study, NREL developed and evaluated four scenarios using a variety of models—including NREL's Regional Energy Deployment System (ReEDS™), the R&D 100 Award-winning Distributed Generation Market Demand (dGen™) model, and the Probabilistic Resource Adequacy Suite (PRAS). Results show that a future low-carbon North American grid can be achieved through multiple pathways and that increasing electricity trade and expanding transmission between countries could have significant system benefits.

## GO-Solar: Enabling Visibility and Controllability for 100% Distributed Energy Resource Penetration

In partnership with Hawaiian Electric Company and the SETO program Enabling Extreme Real-Time Grid Integration of Solar Energy (ENERGISE), NREL has developed a method that enables utilities to monitor, estimate, and operate millions of PV arrays using minimal sensor data. For the project, named Grid Optimization with Solar (Go-Solar) researchers demonstrated two approaches for managing large-scale distributed PV systems. The first, predictive state estimation, is a learning algorithm that communicates with a small number of energy sensors to estimate and forecast the operation states of an entire system. The second, online multi-objective optimization, is a pair of algorithms that communicates with both PV systems and legacy systems to dispatch the devices at different timescales.

When properly tuned, these algorithms can provide results within 1% of the current system voltage using sensor data from only 30% of the system nodes. Utilities could use this method to monitor and control millions of DERs without building communications channels to connect to each.






## NREL Uses Advanced Simulation to Show Customer-Sited Energy Transactions Can Support Distribution Systems

With partners Exelon and the Energy Web Foundation, NREL researchers designed a unique simulation to evaluate the potential for customers to transact energy in a novel architecture of distributed markets using blockchain technology. This approach to distributed markets allows any customer and any device to participate in the energy market because it has pricing that accurately represents the asset's value to the grid. In practice, customer-sited transactions enable significantly increased DER hosting capacity without infrastructure upgrades. Using the HELICS simulation framework, NREL designed a cosimulated feeder in which interconnected DERs transact power with each other and the grid, demonstrating the benefits of customer-sited participation for distributed energy systems. NREL explored real-world implementation pathways and value propositions of DERs in distributed markets using the Energy Web Foundation's blockchain-based platform. The project will also allow Exelon to pilot and deploy distributed devices that are facilitated by peer-to-peer transactions, presenting a cost-effective solution that increases customer benefits and enhances grid sustainability and resilience.

## Advanced Distribution Management System Test Bed Continues to Address Modern Grid Operations

The ADMS Test Bed acts as distribution system in a box—a reconfigurable research environment capable of exploring future electric grid operations. In FY 2021, NREL completed multiple use cases on the ADMS Test Bed with wide participation from industry. In one use case with electric cooperative Central Georgia EMC, researchers have begun developing a model distribution system with high penetrations of renewables to understand how future systems can perform fault location, isolation, and service restoration. In another use case, researchers are demonstrating flexible controls for DER dispatch. With partners Xcel Energy and Schneider Electric, NREL evaluated the impact of ADMS network model quality on VVO and demonstrated increased energy savings with increased model quality and reduced voltage exceedances. Ongoing and upcoming ADMS Test Bed projects will be able to assess factors in grid reliability at an even larger scale, thanks to the ARIES buildout.

**Watch: "Enabling Realistic Communications Evaluations for ADMS, Insights and Opportunities" to learn about more ADMS Test Bed partnerships.**

# ENERGY STORAGE


## HYBRED Battery Stack Design Tool Gives Second Life to Batteries, Provides Commercial Solution for Industry Partner

Working with Centrica, NREL explored the untapped potential of operating and controlling different battery types together as a single coordinated system. As part of this work, NREL and Centrica have developed a design tool for hybrid battery energy storage systems. The aptly named HYBrid Robust Energy Storage Design (HYBRED) tool helps customers choose the best system at the right size, cost, and performance for their needs. An important aspect of this work is that it looked specifically at how to effectively incorporate end-of-use batteries, giving a second life to commercial batteries that come from electric vehicles (EVs), residential, or utility applications. HYBRED will now be integrated into a product by Centrica to target cost savings and reliability for its customers. For this project, NREL installed Centrica's grid-edge controller to study the design trade-offs of cost and performance for mixed-technology battery storage stacks and used the findings to generate improved algorithms for hybrid stack operation. The research team found that with the right design and controls, hybrid solutions that use second-life batteries could outperform other storage approaches, depending on application and technologies.

**Watch: "Centrica and NREL Pursue a Cost-Effective Hybrid Battery Storage System" to learn more about this partnership.**

# ENERGY SECURITY


## NREL-Eaton Project Advances Edge-Level Threat Detection for Operational Technology

In collaboration with Eaton Corporation, NREL continued work on the Advanced OT Edge-Level Data-Driven Threat Detection project. Awarded by the DOE Technology Commercialization Fund, this project aims to develop an operational technology (OT) intrusion detection system for cyber-physical security. The team integrated commercially available hardware and software products into NREL's cyber range at the ESIF. The cyber range is an advanced simulation environment that combines all requirements for achieving utility-scale system, network, and application security research.

Cyber solutions on the market today are predominantly designed to protect information technology networks, leaving a gap in solutions for critical OT cybersecurity. The NREL-Eaton team built a solution to improve intrusion detection in critical systems by distinguishing between cyberattacks and a physical malfunction, such as an electrical fault. Eaton's commercial hardware and software products were integrated into NREL's cyber range, then subjected to a cyberattack on a virtualized field device connected to a virtualized substation management platform. The team deployed the intrusion detection solution and evaluated the product's performance and value for end users. These evaluations led researchers to establish a classification of disruptive events and alarm verifications, allowing for the generation of intelligent alerts.

In the coming year, the team will continue refining the tool for eventual industry use and commercialization. The technology will provide nuanced insight into potential system anomalies for utilities, substation operators, and other organizations that rely on critical OT assets.

## Researchers Evaluate Hydropower Security with Cybersecurity Value-at-Risk Framework

With support from the DOE EERE Water Power Technologies Office and in collaboration with Argonne National Laboratory, NREL developed the Cybersecurity Value-at-Risk Framework (CVF). CVF is a tool for hydropower operators to perform custom cybersecurity assessments of their plants and understand how certain investments can improve overall resilience. The tool draws on NREL's previous work developing the Distributed Energy Resource Cybersecurity Framework (DER-CF). During the past year at the ESIF, the team identified factors that would influence the probability of a cyberattack, assigned values to control implementations for risk scoring, and developed attack patterns that are unique to hydropower.

**The cyber range is an advanced simulation environment that combines all requirements for achieving utility-scale system, network, and application security research.**

## Automated Threat Detection Offers Agile Solution for Firmware Vulnerabilities

Nearly all electronics depend on firmware to help them operate, including the millions of power-connected devices in our energy system. Any vulnerability in firmware can become a hidden door into the network for cyberattackers. A multi-laboratory DOE GMLC cybersecurity project called Firmware Command and Control uses analysis and machine learning to detect vulnerabilities and unexplained changes in firmware. At this stage in the project, analysis tool sets have been successfully tested on open-source firmware in previously unmonitored devices, and the team has secured two nondisclosure agreements from equipment vendors to analyze their proprietary firmware. Researchers are also building representations of malware in a common language so cyber threat information can be more easily shared, stored, and acted on. The final product from the project will be an agile embedded response capability that shares threats to upstream energy security operations.



## An Evaluation Platform Bed Simulates Cyber Threats for Smart Buildings

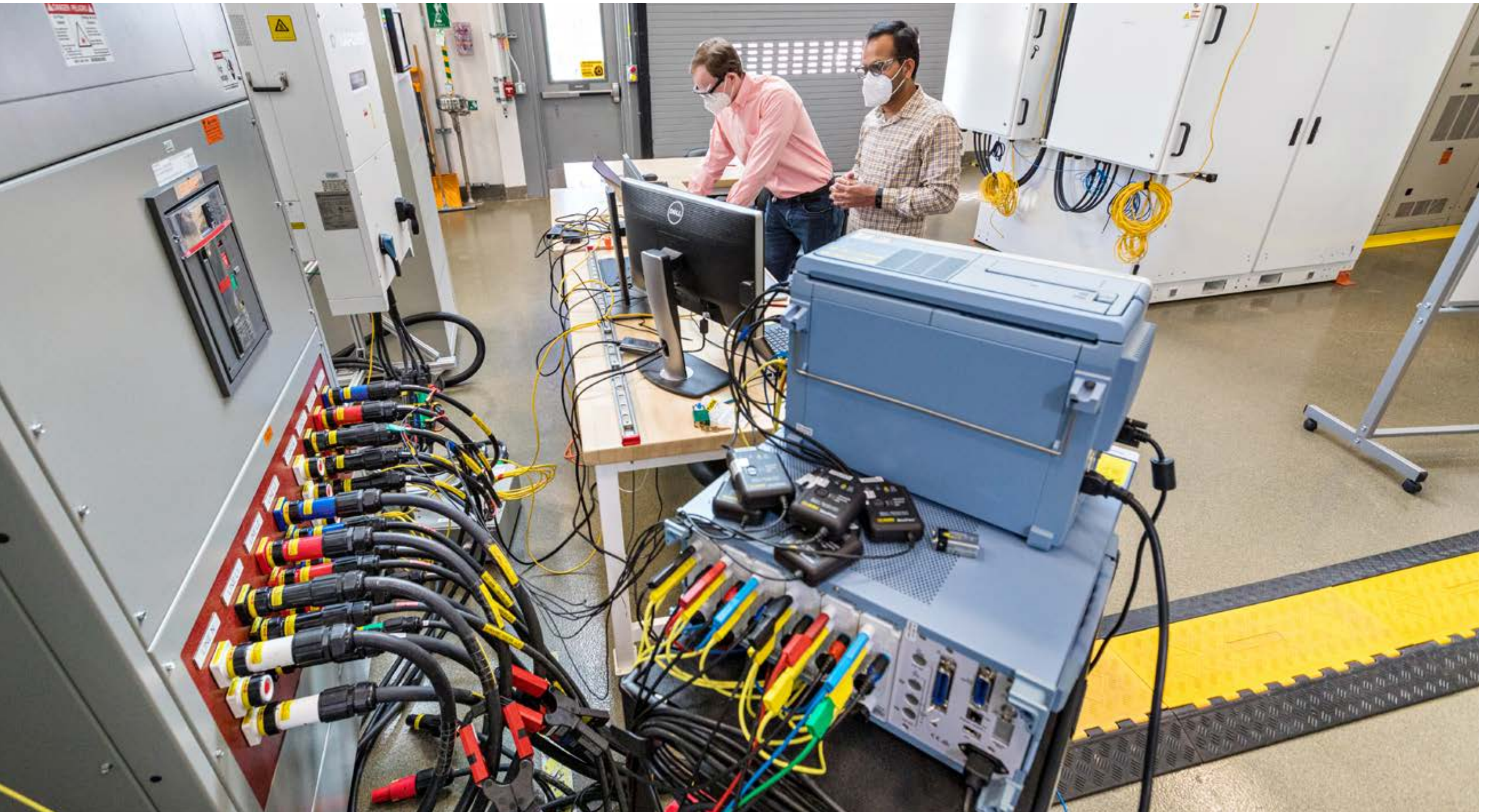
Smart buildings are generally not equipped to identify and assess faults from cyberattacks. To address this issue, NREL collaborated with multiple partners and the DOE EERE Building Technologies Office (BTO) to develop a test bed that can be used to evaluate more effective fault detection algorithms. The evaluation platform emulates an automation-enabled building with the components it would have in the real world, including virtual devices, and a central controller, known in the industry as a building automation system. The effort was supported by a larger project called Building Intelligence with Layered Defense Using Security-Constrained Optimization and Security Risk Detection (BUILD-SOS).

In the project's first year, the NREL team used the evaluation platform to demonstrate a rogue device attack on the virtual devices and communications system of a modeled building. In the second year of the project, a demonstration will be conducted on a real building on the campus of the University of Central Florida, with the University of Massachusetts Lowell generating the cyberattacks and Siemens providing the hardware for data collection. Eventually, the project team will run cosimulations to study more complex problems, for example, coordinated attacks on not only one but multiple commercial buildings on a feeder.

## Clean Energy Cybersecurity Accelerator

In October 2021, NREL and DOE announced the launch of the Clean Energy Cybersecurity Accelerator, a technology partnership of federal experts, industry partners in the energy sector, and innovators to accelerate the development of new cybersecurity solutions for the nation's evolving electric grid. The accelerator provides an environment where innovative cybersecurity technologies can be evaluated with realistic power, control, and network layers against threat scenarios without putting customers at risk. The accelerator is designed to identify the most urgent security gaps in the modern electric grid and to expedite disruptive solutions to market with private and public support.

# ENERGY RESILIENCE



## A Resilient Framework Sustains Power for Essential Services in a Catastrophe

NREL and the University of Minnesota are reformulating post-catastrophe responses for critical services with a project funded by the Advanced Research Projects Agency–Energy, named Rapidly Viable and Sustained Grid. When an outage occurs, critical facilities such as a hospital cannot afford to black out. Generators provide some relief, but severe storms can cause physical damage to the surrounding electric grid, leaving the facility in a precarious state of weak or intermittent backup power.

For this project, the team developed a framework that coordinates the resources needed for the rapid energization and enduring support of critical infrastructure. The intelligent framework allows these resources to form microgrids that can seamlessly connect to or disconnect from the larger grid. The research team will implement this solution at various scales: a solo building, a campus where multiple buildings provide power to a central core, a neighborhood with hundreds of residential buildings, and a neighborhood that is integrated into the restored grid. The framework employs a novel net load management scheme that extends the horizon of the backup generation, prioritizing renewable energy resources such as distributed PV and batteries while minimizing diesel fuel usage.

The project began work in 2019 with integrated hardware testing of a novel grid-forming inverter control. Increasingly larger power-hardware-in-the-loop experiments at the ESIF are being executed as the project nears conclusion. The final demonstration will include nine inverters and one diesel genset, with the total power exceeding 1 MW.

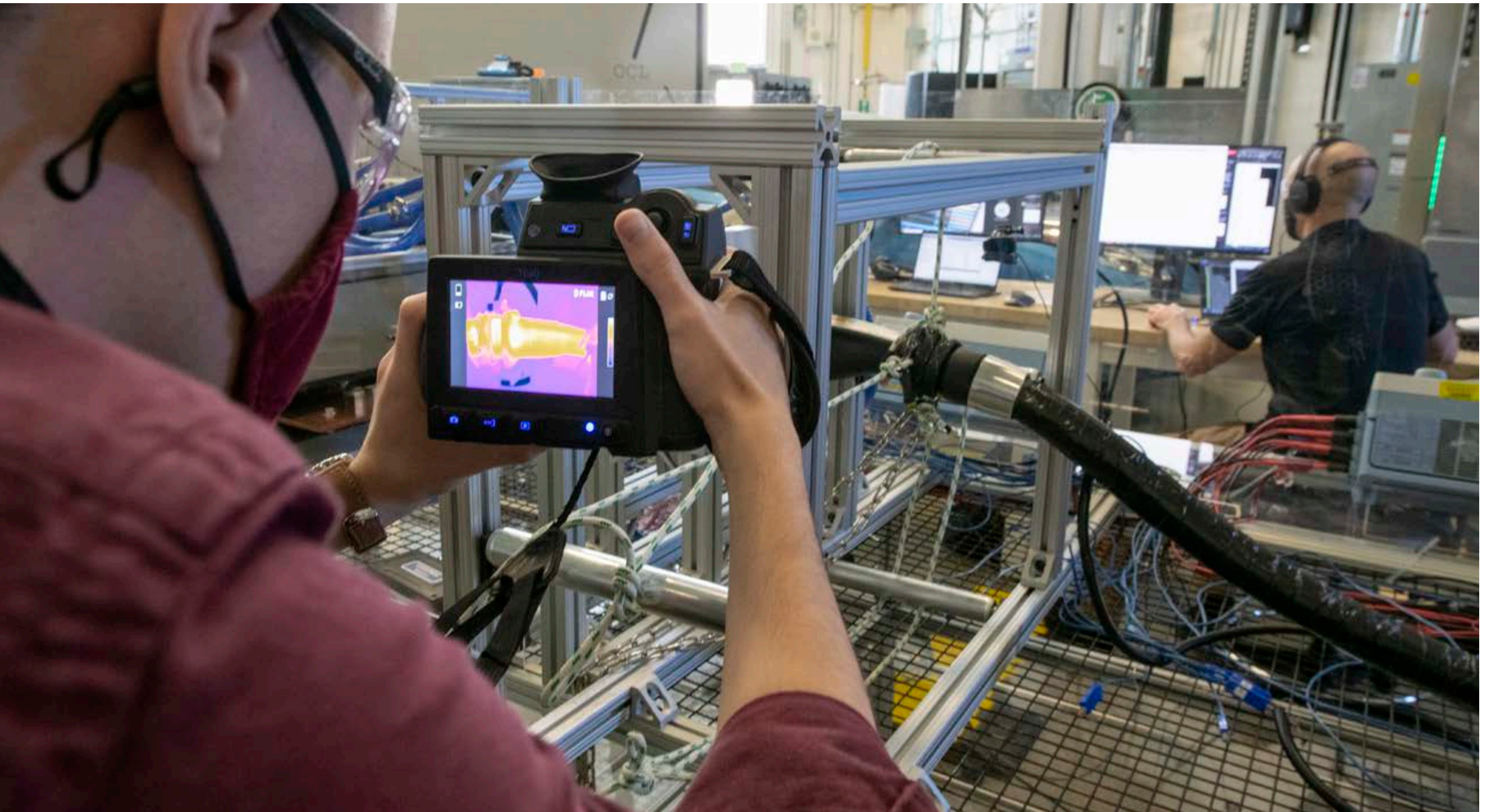
## Advancing Black-Start Capabilities with Renewables

NREL joined with industry partners Siemens, Holy Cross Energy, and the University of Columbia to explore bottom-up black-start capabilities using grid-forming inverters. In a SETO-funded project called Autonomous and Resilient Operation of Energy Systems with Renewables (AURORA), the research team is demonstrating autonomous grid restoration and dynamic reconfiguration using grid-forming inverters and controllable assets without communications and human intervention. This innovative approach could significantly reduce recovery time from natural disasters and cyberattacks for grids with high amounts of renewable and inverter-based resources.

## Forecasting Threats Helps Make the Right Adaptations

The North American Energy Resilience Model (NAERM) makes it possible to get ahead of emergencies, helping electricity, natural gas, and communications systems withstand and rapidly recover from disruptions. NREL supported the development of wildfire and earthquake simulations for the "what if" scenarios that show the grid's response to changing conditions. The team also generated transmission and distribution files for cosimulations that represent power loads shared by DERs. NREL's real time operations platform was installed on the Amazon Web Services cloud to allow users to simulate, visualize, and interact with realistic energy models. Thanks to cross-sector analysis from eight national laboratories, the engineering-class model moved into production in the summer of 2021.

# ADVANCED MOBILITY



## Industry Collaboration Supports New Vehicle Charging Standard

Leveraging the ESIF's Electric Vehicle Research Infrastructure (EVRI) evaluation platform and with funding from the DOE EERE Vehicle Technologies Office (VTO), researchers are collaborating with EV and charging equipment manufacturers and component suppliers on a new high-power charging standard. High-power charging infrastructure has a capacity up to 3.75 MW—seven times more than the current light-duty fast-charging technology, which peaks at 500 kW. Transferring this much energy during a short duration requires uniquely designed cabling, connectors, and charging inlets. Dubbed the Megawatt Charging System (MCS), the new standard will provide commercial fleets with a necessary layer of equipment certainty.

Following the first high-power EV charging connector evaluation in September 2020, NREL cohosted a second round of evaluations in July and August 2021 in collaboration with the Charging Interface Initiative. At this year's event, researchers conducted expanded studies to consider more real-world cases for safety and durability within the MCS standard. This evaluation series provided the opportunity for researchers and industry participants to discuss the technical merit of different equipment parameters pertaining to the MCS standard and come to consensus. Such evaluations help ensure that the new standard is interoperable, which is critical to ensuring broad, consistent access to charging stations, and it will allow EV manufacturers to have confidence in station compatibility as new models come to market.

## GEMINI-XFC Project Supports Integrated Electrified Mobility and Grid Operations

Increasing vehicle electrification will require the extensive use of extreme fast charging (XFC), especially for larger vehicles. Without the right design, control, and coordination, XFC could cause voltage spikes or otherwise disturb local power grids. In a collaboration between NREL and Lawrence Berkeley National Laboratory and funded by the VTO, the Grid-Enhanced, Mobility-Integrated Network Infrastructures for Extreme Fast Charging (GEMINI-XFC) project is designing and evaluating vehicle-to-grid control schemes to optimize EV integration at a regional scale.

Researchers recently coupled transportation and distribution system models to implement an optimal control scheme and infrastructure siting methodology for the greater San Francisco Bay Area, down to the resolution of individual parcels. This level of geographic fidelity allows researchers to understand where charging might be needed and what the corresponding impact on the distribution system might be. It ensures that future charging infrastructure is allocated in an efficient and effective manner for wide-scale adoption.

# GRID-INTERACTIVE BUILDINGS

## Intelligent Controls Show Lower-Cost Option to Achieving Grid-Interactive Buildings

NREL and partners have demonstrated AI controls for commercial building energy management. The AI algorithms allow buildings to self-optimize in cases where the grid requests power for demand response and when the building loses grid connection entirely.

The project is named Multi-Objective Deep Reinforcement Learning Control (MODRLC) and is part of the BTO Grid-Interactive Efficient Buildings initiative. MODRLC brings together NREL, the University of Colorado Boulder, and smart building startup QCoefficient. The team's goal is to create controls that avoid the cost of detailed engineering models by the instead learning optimal energy management. The advantages of this approach are that the method can be adapted and scaled to other buildings, unlike detailed models that must be customized for each building. The controls are a mix of AI reinforcement learning and traditional methods, resembling how adoption could realistically roll out in industry.

The researchers trained and ran their AI-integrated controls in a few representative scenarios. In one simulation, the building loses grid connection, and the algorithms must save energy while maintaining a degree of comfort and reliability. In another, the building is given 4 hours of notice that it will allocate power for grid services, a task that must also be balanced with user and building needs. The algorithms learned an optimal response to these sudden shifts in operation and showed that an AI-augmented approach is lower cost than standard model-based methods to energy management. The research team is now working to deploy the controls in a field test on a commercial building in New York City.


**AI controls learn optimal energy management for grid-interactive buildings, avoiding the cost of developing detailed models.**

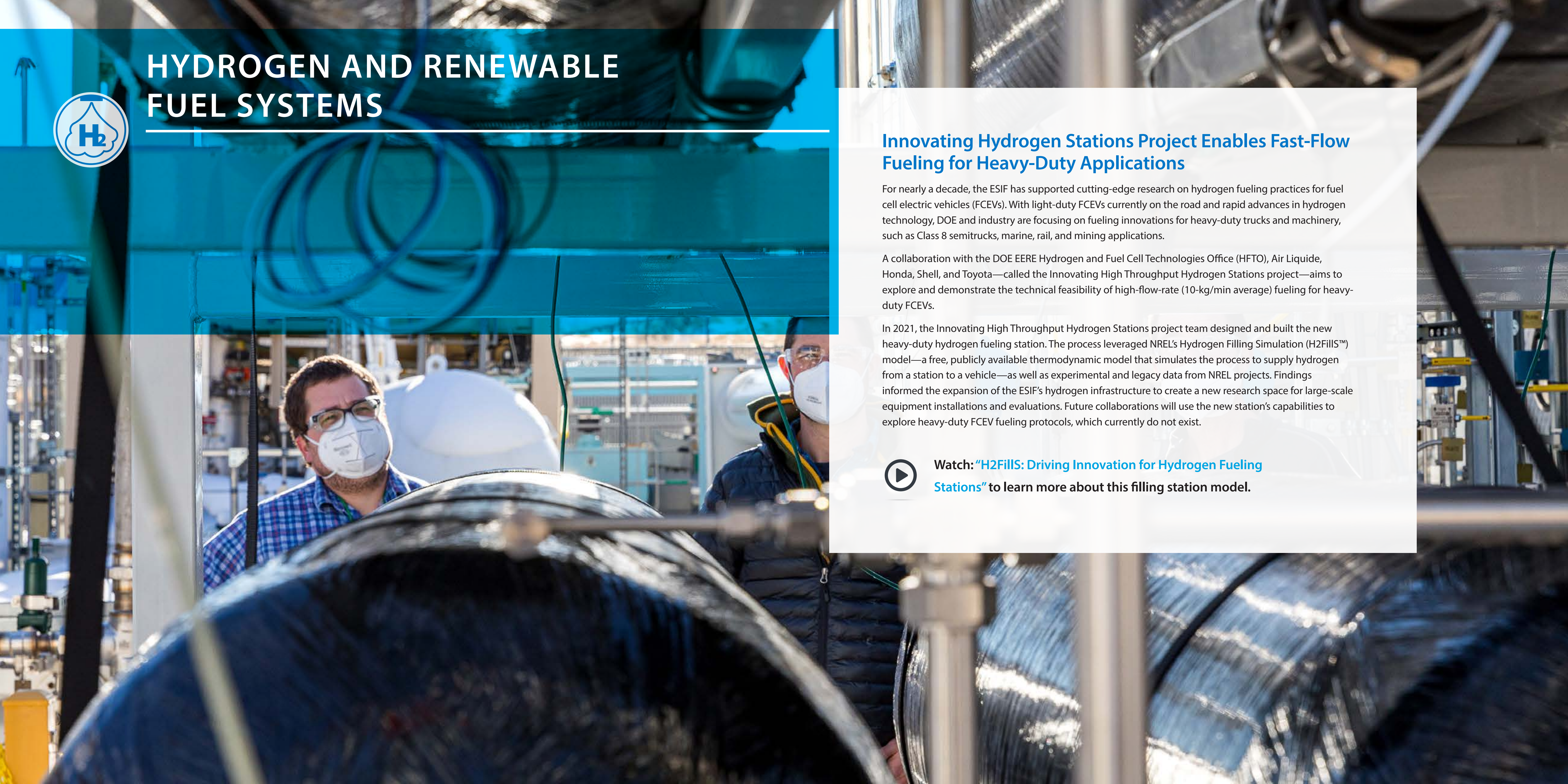
## New Energy-Efficient, Demand-Flexible Technologies Decarbonize Energy Consumption in Supermarkets

Supermarkets can be a significant player in demand flexibility by providing building-level optimization of power consumption. This opportunity is being studied in a BTO-supported 3-year cooperative research and development agreement between Emerson Electric and NREL that recently performed proof-of-concept experiments for flexible, advanced controls for supermarkets. The project team developed an advanced supermarket model to accurately capture power and energy consumption of commercial buildings with large refrigeration loads. They also built the first proof-of-concept control architecture using Emerson controllers and evaluated initial control algorithms. The team designed a permanent communications bridge between NREL and Emerson's Helix Innovation Center, in Dayton, Ohio, a cutting-edge innovation center focused on accelerating supermarket, residential, and other commercial building technologies.

## Measuring the Value of Resident Safety in Energy-Efficient Buildings in Extreme Weather

Extreme weather events and power outages have become more prevalent across climates and are compromising buildings not designed to withstand these conditions, such as freezing temperatures in Texas or heat waves in Oregon. Research teams at three national laboratories are working to quantify how energy-efficiency technologies and design measures impact building resilience in extreme weather conditions. With support from BTO, the teams at NREL, Lawrence Berkeley National Laboratory, and the Pacific Northwest National Laboratory investigated the energy resilience of several types of residential buildings, including single-family homes, multifamily buildings, and nursing homes.

In this project, named Valuation of Energy Efficiency for Energy Resilience Research, the research teams created a standardized methodology to quantify the net impact of different scenarios by compiling historic outage data to simulate the impacts of a variety of building design measures during power outages. This work helps to understand whether safe indoor conditions were achievable during extreme weather events with changes in energy-efficiency measures. NREL adapted the ResStock™ analysis tool to include building simulation modeling methodologies to support resilience valuation and to characterize hazard risks; simulations were run on NREL's HPC in the ESIF.



# HYDROGEN AND RENEWABLE FUEL SYSTEMS

## Innovating Hydrogen Stations Project Enables Fast-Flow Fueling for Heavy-Duty Applications

For nearly a decade, the ESIF has supported cutting-edge research on hydrogen fueling practices for fuel cell electric vehicles (FCEVs). With light-duty FCEVs currently on the road and rapid advances in hydrogen technology, DOE and industry are focusing on fueling innovations for heavy-duty trucks and machinery, such as Class 8 semitrucks, marine, rail, and mining applications.

A collaboration with the DOE EERE Hydrogen and Fuel Cell Technologies Office (HFTO), Air Liquide, Honda, Shell, and Toyota—called the Innovating High Throughput Hydrogen Stations project—aims to explore and demonstrate the technical feasibility of high-flow-rate (10-kg/min average) fueling for heavy-duty FCEVs.

In 2021, the Innovating High Throughput Hydrogen Stations project team designed and built the new heavy-duty hydrogen fueling station. The process leveraged NREL's Hydrogen Filling Simulation (H2FillS™) model—a free, publicly available thermodynamic model that simulates the process to supply hydrogen from a station to a vehicle—as well as experimental and legacy data from NREL projects. Findings informed the expansion of the ESIF's hydrogen infrastructure to create a new research space for large-scale equipment installations and evaluations. Future collaborations will use the new station's capabilities to explore heavy-duty FCEV fueling protocols, which currently do not exist.

**Watch: "H2FillS: Driving Innovation for Hydrogen Fueling Stations" to learn more about this filling station model.**

## MW+ Electrolyzer Capability Development and Validation with Nel Hydrogen

Hydrogen is a versatile energy carrier that can be used for vehicles, electrification, and energy storage. In June 2021, DOE launched its first Energy Earthshot—Hydrogen Shot—to reduce the cost of producing clean hydrogen by 80% to $1 per 1 kg in 1 decade ("1 1 1"). Water electrolyzer manufacturers, such as Nel Hydrogen US (formerly known as Proton Energy Systems), are developing megawatt-sized electrolysis systems to take advantage of economies of scale and reduce costs to less than $500/kW, and they are turning to NREL to help validate these systems using the electrolyzer stack evaluation platform at the ESIF.

Extending a 15-year relationship, NREL and Nel joined forces again to push hydrogen production technology to the next level and complete 5,000 hours of performance testing on Nel's next-generation proton exchange membrane (PEM) electrolyzer stack. In preparation, engineers and researchers at the ESIF increased the size of balance-of-plant components to reach the flow rates (e.g., water, hydrogen, heat) required by Nel's 750-kWe electrolyzer stack. Throughout the performance validation, NREL collected data on cell- and stack-level voltage and H2-in-O2 measurements, key metrics to help Nel gain insight into stack degradation and progress toward extending stack life.

The operational goal was achieved in the presence of a small group of supporters who gathered both in person and online to watch the timer reach 5,000 hours. Although these electrolyzer stacks are expected to reach a life at least 10 times longer, data collected during this beginning-of-life time is critical to achieving Nel's goals for efficiency, cost, and durability prior to commercial release.

## Researchers Validate Durability of High-Temperature Fuel Cell Membranes in Aviation Applications

NREL conducted several long-term experiments for the fuel cell startup company HyPoint to provide third-party validation of HyPoint's polybenzimidazole-based high-temperature PEM fuel cell stacks for aviation applications. Although NREL has years of research experience characterizing and validating low-temperature PEM materials, this project was the first to use the ESIF's capabilities to evaluate high-temperature PEM materials. NREL successfully performed several degradation tests, including a 1,350-hour (8-week) continuous load-cycling experiment at 180°C, to characterize the degradation effects of more than 5,000 takeoff and cruising cycles. Researchers also used electrochemical impedance spectroscopy to determine cell resistance and understand changes during prolonged operation. This work supports the potential advancement of fuel cells into sustainable aviation applications.

## Fuel Cell Stack Durability Testing for Heavy-Duty Applications

NREL is performing long-term durability testing on PEM fuel cell stacks for heavy-duty vehicle applications with industrial partner Cummins. The expected lifetime for a commercial long-haul truck is more than 1 million miles. To achieve this challenging target, the industry is working to develop efficient heavy-duty PEM fuel cell systems that have four to five times better durability than the current fuel cell systems used for passenger cars.

Using test conditions provided by Cummins, NREL researchers performed accelerated stress tests on full-size short stacks with a power output of approximately 5 kW. The tests induce high levels of acceleration in a short, focused time frame and simulate what might happen in a real stack exposed to specific operating conditions over a long period (years of operation). This work is essential for Cummins to understand fuel stack degradation processes in heavy-duty vehicle applications prior to entering the marketplace.

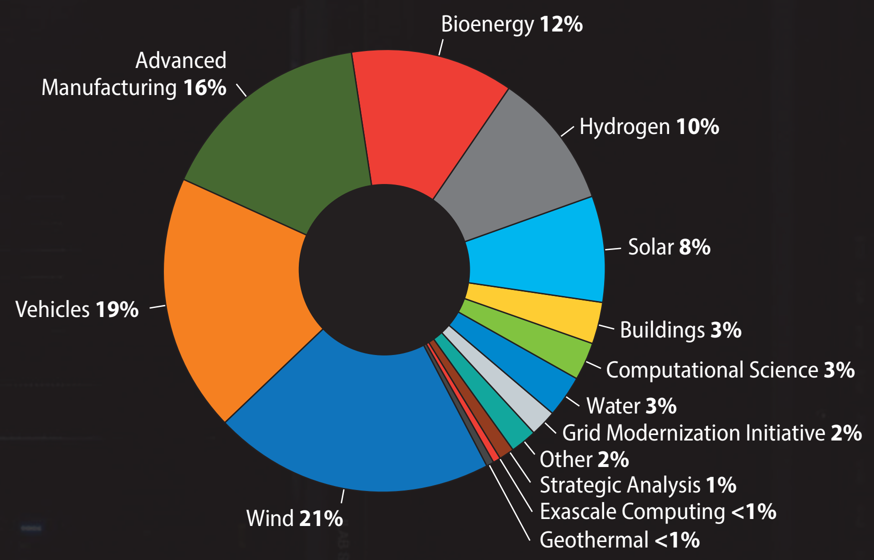
# HIGH-PERFORMANCE COMPUTING, DATA INTEGRATION, AND ANALYSIS

NREL's HPC Data Center houses supercomputing systems and visualization capabilities that can help solve today's toughest energy challenges.

NREL HPC researchers collaborate with scientists, engineers, industry partners, and EERE to develop cross-cutting capabilities that provide the critical foundation upon which rapid breakthrough science is made possible. Our advanced visualization technology supports knowledge discovery through dynamic interaction with data.

To learn more about these projects and many others, visit the *Advanced Computing Annual Report*.

| EERE Office | # of FY 2021 projects |
|---|---|
| Advanced Manufacturing Office | 22 |
| Bioenergy Technologies Office | 23 |
| Building Technologies Office | 20 |
| Computational Science/Industry/LDRD | 48 |
| Grid Modernization Initiative | 30 |
| Geothermal Technologies Office | 1 |
| Hydrogen and Fuel Cell Technologies Office | 19 |
| Solar Energy Technologies Office | 31 |
| Strategic Analysis | 22 |
| Vehicle Technologies Office | 41 |
| Wind Energy Technologies Office | 34 |
| Water Power Technologies Office | 11 |
| **Total** | **302** |




*Percentage of computing resources used across technology areas*

## NREL Shows Los Angeles Can Achieve Reliable, 100% Renewable Energy

NREL released the landmark Los Angeles 100% Renewable Energy Study (LA100), which explored how the second largest city in the nation could achieve a 100% clean energy future by 2045—or as soon as 2035. Funded by the Los Angeles Department of Water and Power, in partnership with the University of Southern California, Colorado State University, and Kearns & West, NREL performed a first-of-its-kind power systems analysis of the Los Angeles Department of Water and Power's existing generation, transmission, and distribution assets. NREL used the Eagle supercomputer to integrate dozens of modeling tools and methods to incorporate input data from multiple sources, run more than 100 million simulations, and provide detailed results—pushing existing tool sets to new levels of sophistication.

LA100 identified a methodology for multi-tool integration to better capture the complexity of the energy transition and related community impacts and demonstrated how a 100% renewable energy system can operate reliably. It also benefited from robust community participation and serves as an example for other cities and regions pursuing pathways to clean energy systems.

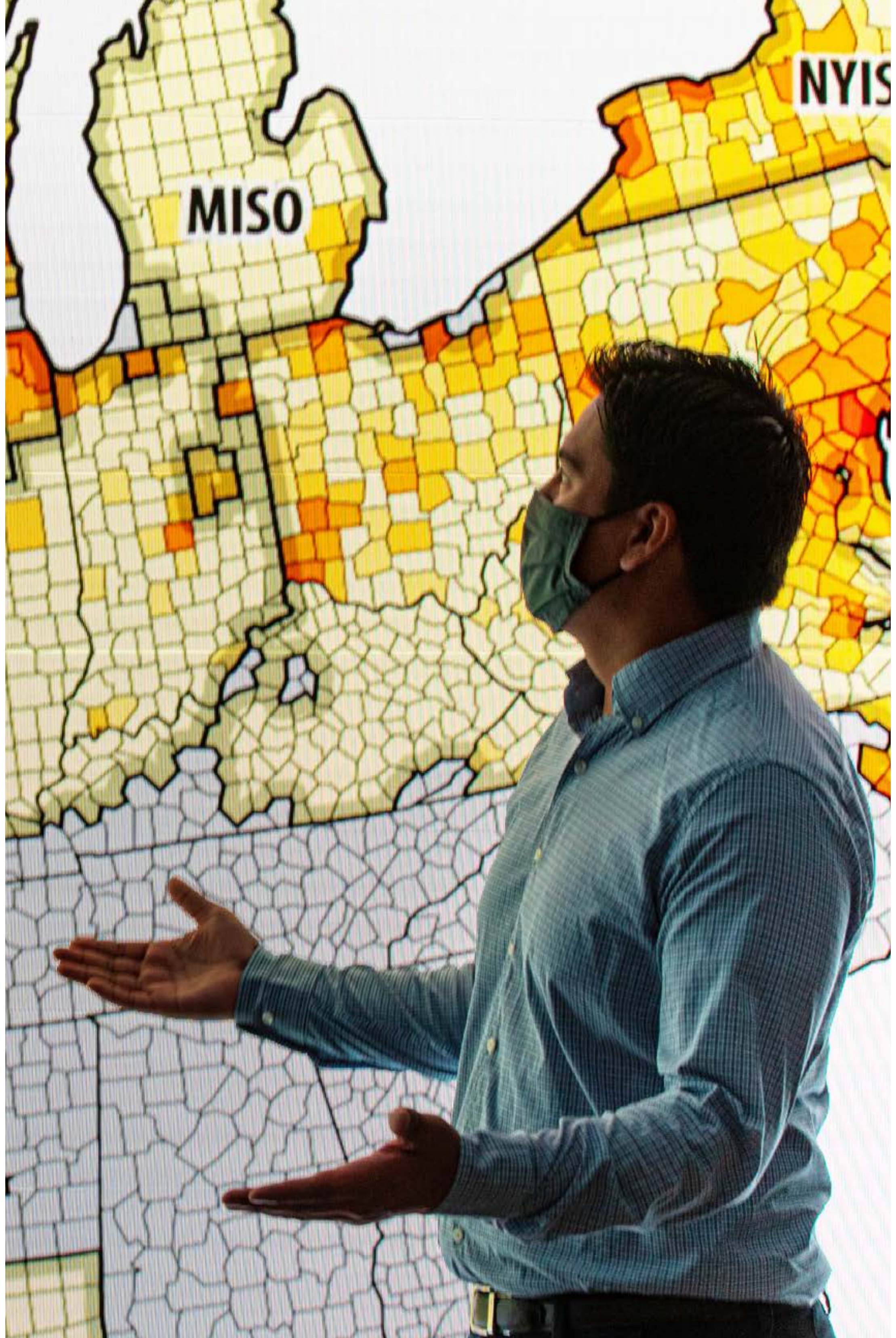
## NREL Improves State-of-the-Art Solar Forecasts and Reduces Uncertainty by Half

NREL and the National Center for Atmospheric Research recently developed the Weather Research and Forecasting-Solar (WRF-Solar) ensemble prediction system under funding from SETO. This is the first publicly available, probabilistic, numerical weather prediction model specifically designed to provide specialized data for solar power applications. Leveraging the Eagle supercomputer to process National Solar Radiation Database (NSRDB) data covering the years from 2016 through 2018, WRF-Solar simulated forecasts and applied ensemble calibration to improve solar irradiance forecasts. This high-quality, probabilistic forecasting capability, which is publicly available for use across the solar industry, provides a calibrated and unbiased system that significantly improves the current state of the art for solar forecasts and reduces uncertainty by 50% from current levels.

## NREL Modeling Could Reduce Wind Power Plant Energy Losses and Costs

Through the High-Fidelity Modeling project—funded by the DOE EERE Wind Energy Technologies Office (WETO) as part of the DOE Atmosphere to Electrons initiative—NREL is creating, verifying, and validating high-performance simulation tools for wind power plants. The goal of this work is to better understand wake formation and propagation and to help reduce wind power plant energy losses and costs. High-Fidelity Modeling complements DOE's Office of Science ExaWind exascale computing project: In anticipation of future exascale computing platforms, NREL created a graphics processing unit-capable computational fluid dynamics solver for wind energy applications to model ocean waves, bodies immersed in water, and the atmospheric boundary layer. NREL also recently performed a simulation of a 2-MW turbine that included high-fidelity simulations of offshore atmospheric boundary layer simulations over waves.






## Modeling Future Solar-Plus-Storage Adoption

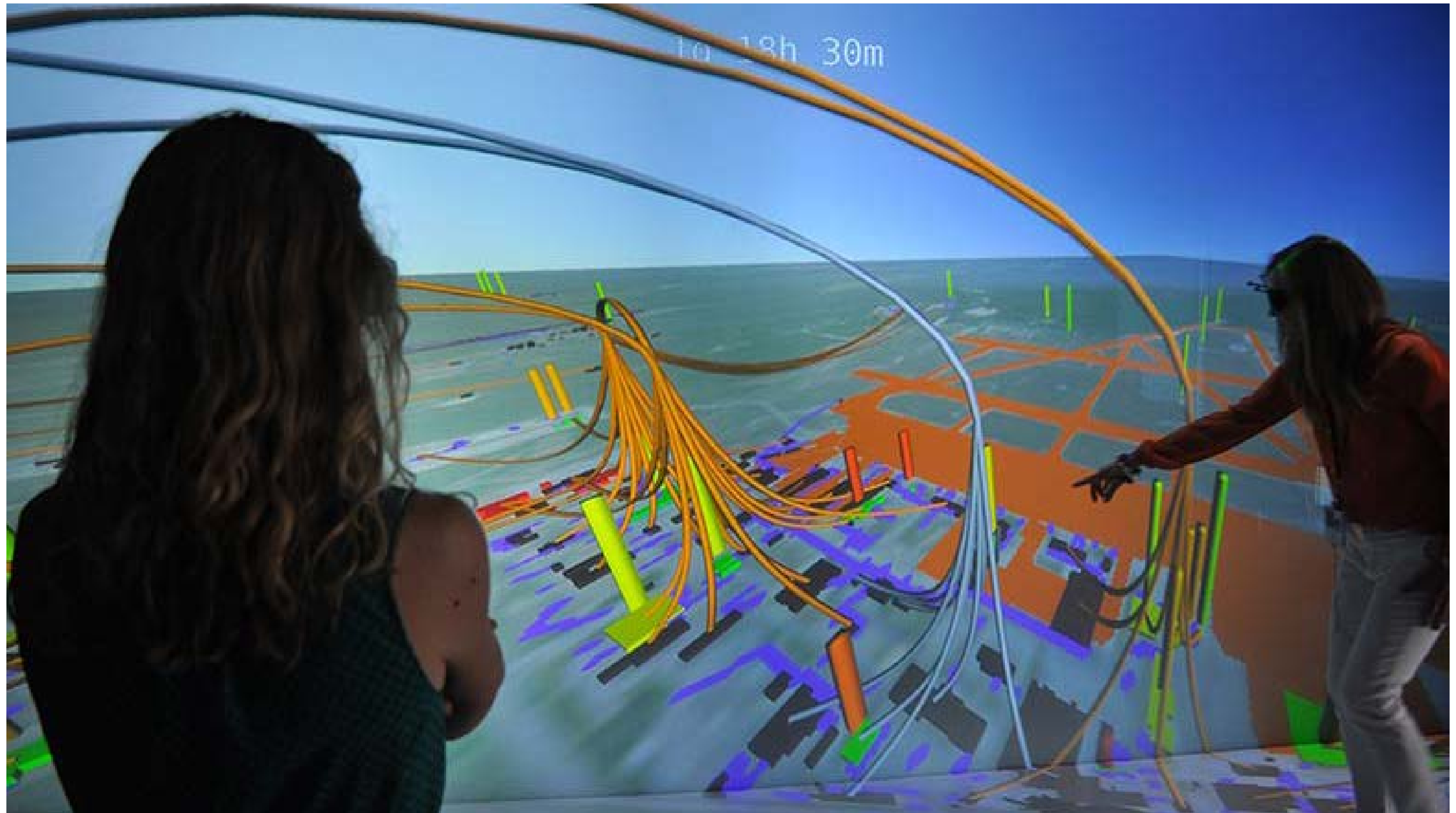
Energy storage is poised to become a significant part of the U.S. power system, but to measure the evolving value of storage is an inherently complex modeling challenge. NREL has been leading the Storage Futures Study, a multiyear research project that explores the potential role and impact of energy storage on the future grid. This work is part of DOE's Energy Storage Grand Challenge, a program to accelerate the development, commercialization, and utilization of next-generation energy storage technologies.

In one of several Storage Futures Study reports released in the past year, NREL examined the potential for distributed solar-plus-storage growth and identified key drivers of adoption. To do this, NREL integrated multiple technical and economic modeling tools on the Eagle supercomputer, including the R&D 100 Award-winning dGen model, which was augmented with new capabilities for the study. For all modeled scenarios, NREL found significant economic potential for behind-the-meter battery storage.

## Simulations Target Efficiency and Costs of Producing Metal Powder for Additive Manufacturing

Additive manufacturing, also known as 3D printing, enables the creation of lighter, stronger parts and systems and is revolutionizing the metals manufacturing industry; however, the industry currently lacks capabilities to tune the metal atomization to exact sizes, leading to excessive cost and material use. With support from the DOE Advanced Manufacturing Office, NREL and Ames Laboratory leveraged NREL's HPC to create 3D numerical and computational fluid dynamics simulations of new geometries for atomization trials that would enhance flow efficiency, increase the rate of metal powder production, and improve gas utilization. The study found that a smoother atomization gas flow pathway leads to less energy loss and improved flow efficiency. Recommended designs from the study are expected to have better performance, including reduction of atomization gas flow energy losses and part fouling, along with better melt spray formation. The recommendations are now being tested to determine the improvements in production rates and yields, which will inform the energy savings and cost reductions possible with the new technology options.

# HPC CAPABILITIES AND FACILITIES INVESTMENT



## Expanding HPC Capacity with Kestrel Procurement

NREL has selected its third-generation HPC system, called Kestrel. With approximately 44 petaflops of computing power, Kestrel will rapidly advance DOE's energy research at a pace and scale more than five times greater than Eagle. As the dedicated HPC system for EERE, Kestrel will play a critical role in computing across the portfolio, advancing research in computational materials, continuum mechanics, and large-scale simulation and planning for future energy systems. Kestrel's heterogeneous architecture is designed to enable emerging workflows that fuse simulations with new sensor data sources and AI, providing EERE and industry partners with the ability to tackle the challenges of moving to a renewable and sustainable energy future.

## Data Center Power and Cooling Upgrade

To prepare for the ESIF's new supercomputer to arrive, the HPC Operations team has partnered with the ESIF Operations and NREL Site Operations teams at NREL to initiate a 4-MW data center power and cooling upgrade, with planned completion in FY 2023.

## Vehicles Technologies Office Invests in Swift

The VTO has procured a new HPC resource, called Swift, to provide additional computing capability to complement Eagle and to support unprecedented computing demand across the VTO portfolio. The Swift cluster became operational in FY 2021 as a 440-node cluster with 28,160 compute cores and 2 PB of storage.

## Advancements in Scientific Visualization

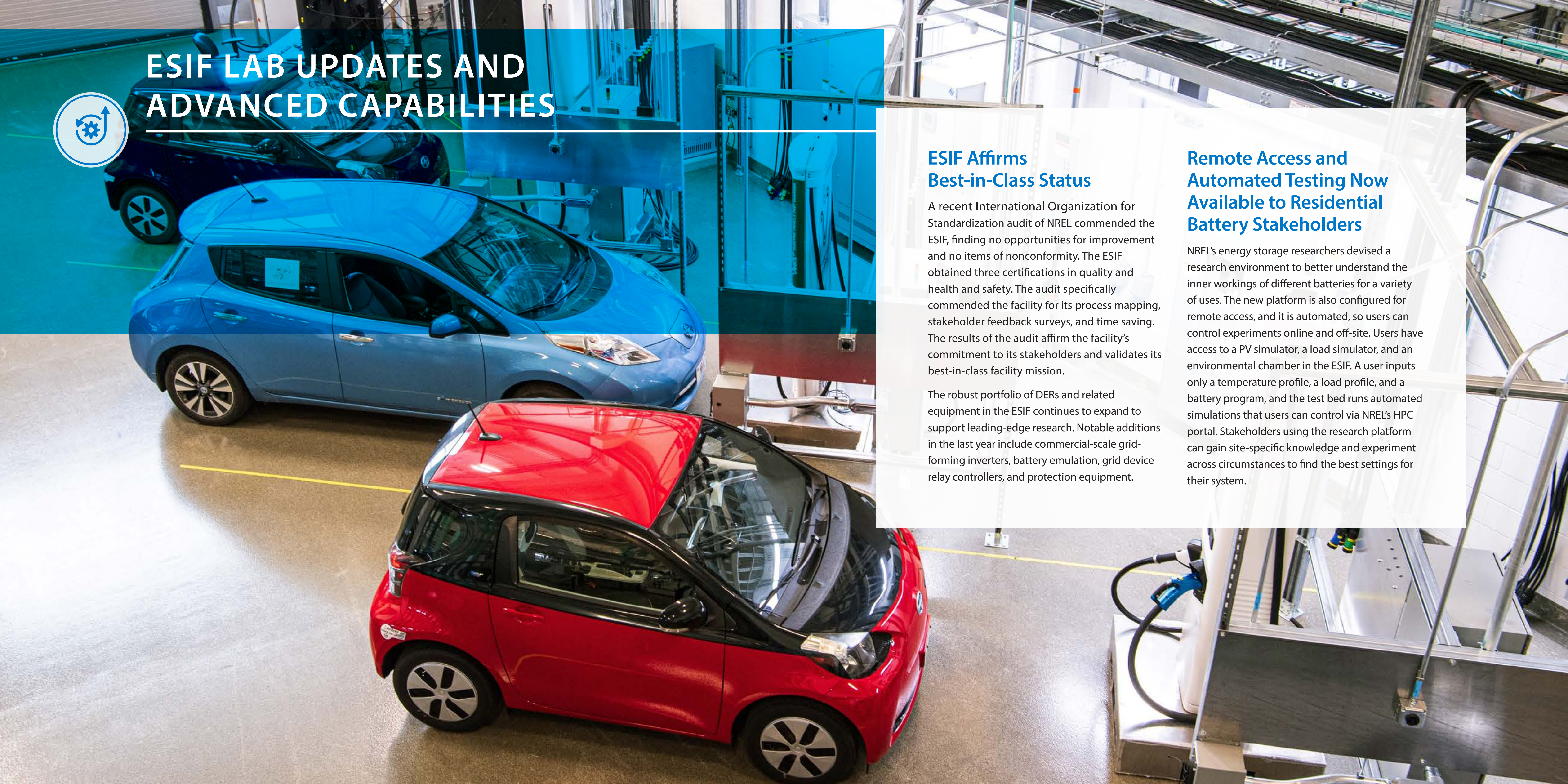
Imagine the potential for new discoveries if scientific data were brought to life and were physically immersive. During FY 2021, NREL implemented major upgrades to the Insight Center—EERE's state-of-the-art scientific visualization facility within the ESIF—bringing new technologies and interactive visuals to bear on the energy research landscape. These upgrades included the successful completion of 2D visualization capabilities in the Insight Center, with a 10-times update in the high-resolution display wall and new interconnected tactile displays.

## Artificial Intelligence for Data Center Operations

A key partnership with Hewlett Packard Enterprise adds AI to NREL's ESIF HPC Data Center. This upgrade brings together NREL's real-time data collection/aggregation/streaming system and Hewlett Packard's data monitoring/management system. Continuing into its third and final year, the Artificial Intelligence for Data Center Operations project has developed new power usage effectiveness and cooling ramp prediction models in addition to deploying a real-time anomaly detection module for the HPC and data systems. AI and machine learning advances are critical to HPC data centers, which increasingly need to rely on automation to keep pace with exascale growth and optimize the data center resources.

**With approximately 44 petaflops of computing power, Kestrel will rapidly advance DOE's energy research at a pace and scale more than five times greater than Eagle.**

# ESIF LAB UPDATES AND ADVANCED CAPABILITIES



## ESIF Affirms Best-in-Class Status

A recent International Organization for Standardization audit of NREL commended the ESIF, finding no opportunities for improvement and no items of nonconformity. The ESIF obtained three certifications in quality and health and safety. The audit specifically commended the facility for its process mapping, stakeholder feedback surveys, and time saving. The results of the audit affirm the facility's commitment to its stakeholders and validates its best-in-class facility mission.

The robust portfolio of DERs and related equipment in the ESIF continues to expand to support leading-edge research. Notable additions in the last year include commercial-scale grid-forming inverters, battery emulation, grid device relay controllers, and protection equipment.

## Remote Access and Automated Testing Now Available to Residential Battery Stakeholders

NREL's energy storage researchers devised a research environment to better understand the inner workings of different batteries for a variety of uses. The new platform is also configured for remote access, and it is automated, so users can control experiments online and off-site. Users have access to a PV simulator, a load simulator, and an environmental chamber in the ESIF. A user inputs only a temperature profile, a load profile, and a battery program, and the test bed runs automated simulations that users can control via NREL's HPC portal. Stakeholders using the research platform can gain site-specific knowledge and experiment across circumstances to find the best settings for their system.

## ESIF DC Power Upgrades Support Increased Battery, Vehicle, Photovoltaics, and Hydrogen Emulation

The ESIF completed several key upgrades to the DC power infrastructure. Upgrades included the addition of a bidirectional DC power station to bring the DC power capacity to 1.3 MW, new protection infrastructure using DC circuit breakers, and additional DC power distribution to key areas of the facility: the hydrogen integration lab and the Medium-Voltage Outdoor Test Area. The DC upgrades unlock emulation at power for vehicle charging and discharging, battery simulation, and load or source emulation for electrolysis and fuel cells. The new infrastructure lays the foundation for future DC microgrid capability development.

## One-Megawatt REDB Expansion Will Serve EV and Hydrogen Research

Sustained investments in the Research Electrical Distribution Bus (REDB) help integrate and amplify research activities across ESIF labs. A distribution enhancement of 1 MW, 1,000 V DC now connects the REDB to both outdoor areas and to the hydrogen electrolysis lab. These DC expansions represent modern DC protection technology, at power, paving the way for DC microgrids, DC coupling of energy storage, and EV or PV applications. It integrates hydrogen electrolysis and fuel cells at the ESIF, a key focus area for capability expansion.

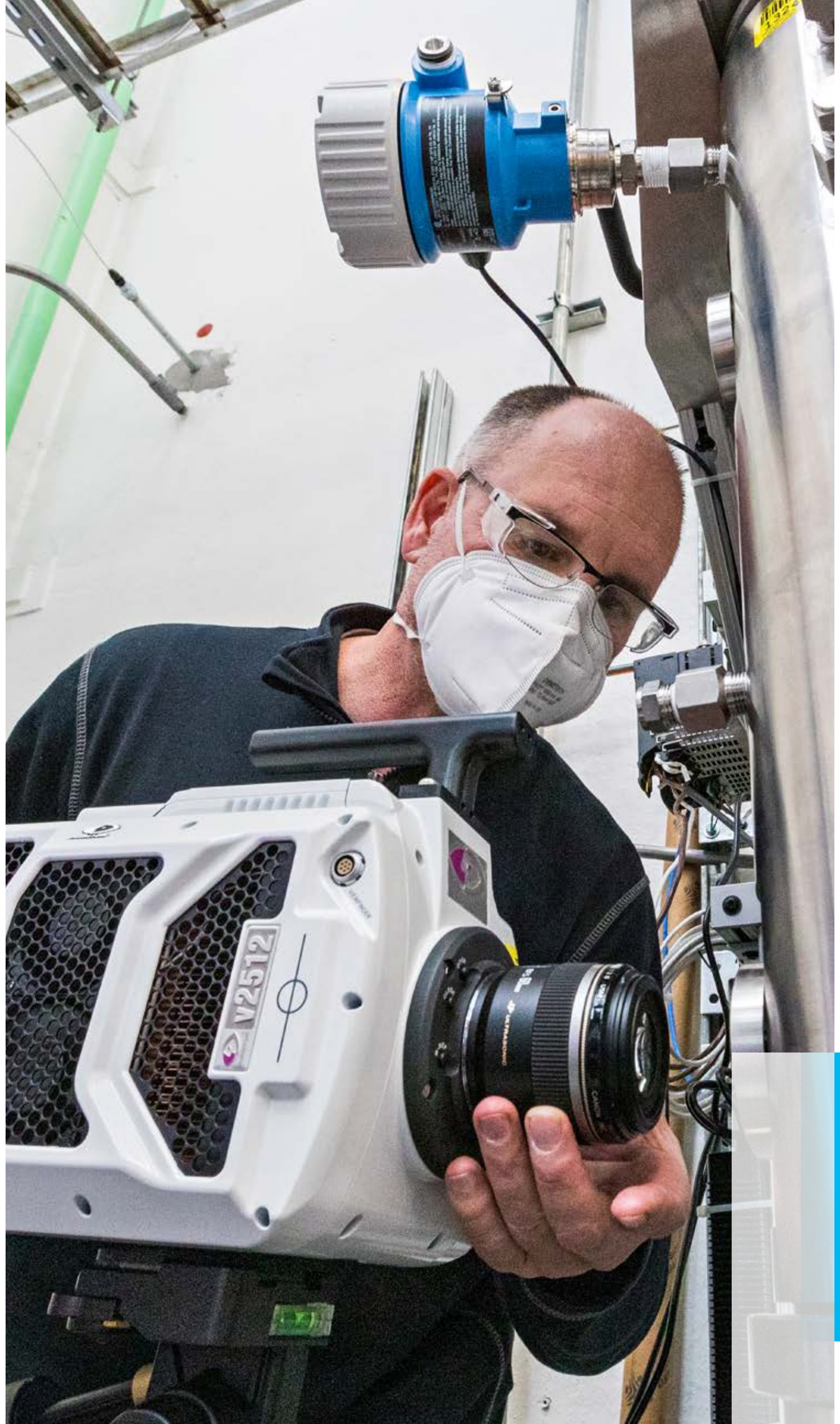
## Evaluation Platform Explores Grid Impacts of Electric Vehicle Charging Systems

NREL's EVRI expanded high-power charging capabilities for the notoriously difficult-to-electrify medium- and heavy-duty fleet. The installation of a third XFC coupled with emulation and simulation equipment enables flexible, faster, and repeatable XFC experiments. EVRI has been a key consideration in the buildout of ARIES, which will transform research into the grid impacts of site-integrated EV charging.

## Data Systems Serve Commercial Buildings Research

The commercial buildings research team expanded their computing power with upgraded data management and integrated data acquisition and made upgrades to key applications, such as thermal handling and refrigeration.






## At-Scale Integrated Hydrogen System Expands Research Capabilities

The research hydrogen system at the ESIF integrates hydrogen production, compression, storage, and dispensing into a unified system. Upgrades in FY 2021 incorporated heavy-duty, fast-fueling capabilities to improve and validate vehicle fueling performance. Every improvement advances the goal of deploying hydrogen FCEVs that are clean, efficient, refuel quickly, and provide a long driving range.

## A Performance Milestone for the Hydrogen Stack Test Bed

The Hydrogen Stack Test Bed reached a performance milestone of 5,000 hours of operation on an electrolyzer stack. This effort was made possible through upgrades to the power and gas handling to accommodate testing a device with up to 1-MW electrolysis.

## Emulations Help Mitigate the Impact of Cyber Threats to Distributed Energy Systems

NREL continues to integrate the cyber range with other capabilities. This year, researchers leveraged the cyber range to connect an EV fast charger in the laboratory to an emulated distributed energy system and safely simulate high-consequence cyberattack scenarios. NREL also completed an initial configuration for incorporating ADMS into this cybersecurity research environment.

NREL has a long history of studying communications and control systems to address the inherent cybersecurity risks of increased interconnections among new devices and the electric grid. The research center recently established a new architecture for Grid Research End-to-End Network for Communications (GREEN-C). The facility-wide research communications infrastructure will connect the cyber range to hardware and devices throughout the lab, including connectivity to NREL's Flatirons Campus. The control interface for GREEN-C and the nexus for virtual connection with the cyber range will be located in the much-anticipated Energy Security and Resilience Visualization Laboratory. Construction will begin in FY 2022.

## Facility Upgrades Enable Hydrogen Research and Safety

The ESIF's energy science laboratories offer users a modern wet chemistry space to evaluate new fuel cell and electrolyzer materials and manufacturing technologies. The hydrogen testing capabilities were boosted by the installation of seven new electrolysis test stations. In addition, the ESIF has been equipped to field-test novel hydrogen leak sensors, a safety measure prototyped in-house by NREL's own hydrogen wide-area monitoring system project.

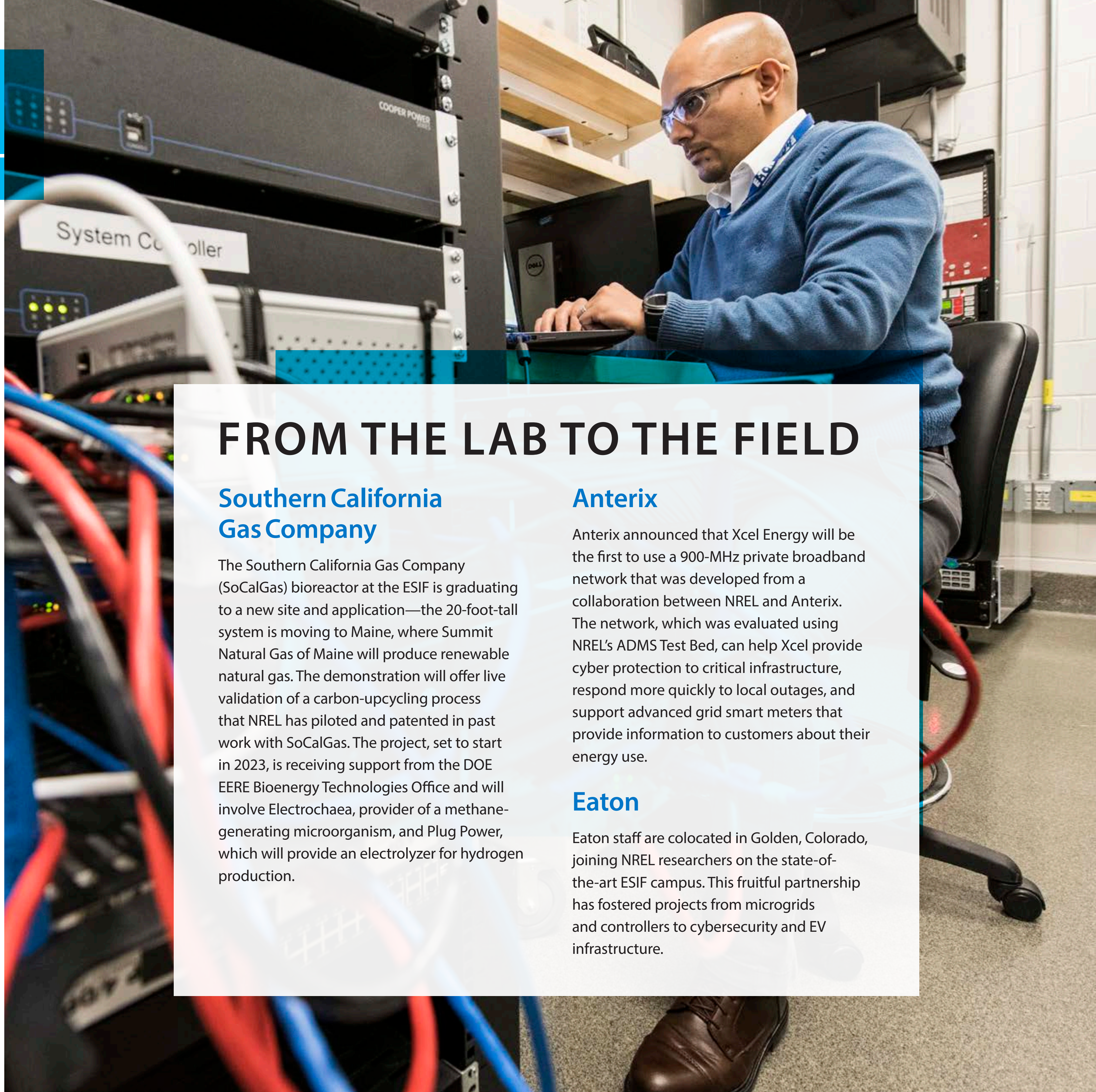
The ESIF laboratories were fully operational throughout FY 2021 despite the challenges presented by the COVID-19 pandemic. Laboratory capacities were established in accordance with the DOE COVID-19 Safety Plan and adjusted periodically, following guidance from health officials. Scheduling tools helped ensure that capacity limitations were met, when applicable, and facilitated laboratory closures for cleaning as well as contract tracing.

These measures proved effective. The ESIF maintained a laboratory productivity rate greater than 90% for the year, with no instances of transmission of COVID-19 among laboratory workers.

# PARTNERS

3M
Air Liquide
ALD Nanosolutions
Amphenol Thermometrics
Amplitude Systèmes
Analog Devices
Anterix
Blue Frontier
California Air Resources Board GO-Biz
Centrica
Chemours
Clarios Advanced Solutions, LLC
Colorado State University
ComEd
Cornell University
Cummins
Dioxide
Eaton Corporation
Ecolectro
EIC Laboratories
Electric Hydrogen
Electric Power Research Institute
Electricore, Inc.
ElectroCat Consortium
Element One
Emerson
Enertronics, Inc.
EOn-Sun
Eonti, Inc.
Eskom
Exelon Corporation
ExxonMobil
Feasible
Fiat Chrysler Automobiles
Ford Motor Company
Frontier Energy
General Electric
General Motors Company
Giner ELX
Hawaiian Electric Company
Holy Cross Energy
Honda Motor Company
Hygge
Hyperlight Energy
HyPoint
Hyundai Motor Company
Ivys
Lubrizol
Mainstream Engineering
Massachusetts Institute of Technology
Mastercard
Membrion
NanoSpray
National Rural Electric Cooperative Association
Nel Hydrogen
New York State Energy Research and Development Authority
Nikola Motor Company
Oceanit Labs
Overdrive
Pennsylvania State University
pH Matter
Plug Power
Proton OnSite
Public Service Company of New Mexico
Resilient Power Systems
San Diego Gas & Electric Company
Shell
Shifted Energy
Shine JuiceBox 3.0
Siemens Corporation
Southern California Gas Company
Solar Dynamics
Span.io
STRATIS IoT
Survalent
Switched Source, LLC
T4D Lab
TCPoly
Tetramer Technologies, LLC
Titan Advanced Energy Solutions
Toyota Motor Corporation
Treadstone
Triton Systems
U.S. Department of Defense
University of Colorado Boulder
University of Columbia
University of Delaware
University of Tennessee Space Institute
XMarkLabs, LLC
Yaskawa Solectria Solar





# FROM THE LAB TO THE FIELD

## Southern California Gas Company

The Southern California Gas Company (SoCalGas) bioreactor at the ESIF is graduating to a new site and application—the 20-foot-tall system is moving to Maine, where Summit Natural Gas of Maine will produce renewable natural gas. The demonstration will offer live validation of a carbon-upcycling process that NREL has piloted and patented in past work with SoCalGas. The project, set to start in 2023, is receiving support from the DOE EERE Bioenergy Technologies Office and will involve Electrochaea, provider of a methane-generating microorganism, and Plug Power, which will provide an electrolyzer for hydrogen production.

## Anterix

Anterix announced that Xcel Energy will be the first to use a 900-MHz private broadband network that was developed from a collaboration between NREL and Anterix. The network, which was evaluated using NREL's ADMS Test Bed, can help Xcel provide cyber protection to critical infrastructure, respond more quickly to local outages, and support advanced grid smart meters that provide information to customers about their energy use.

## Eaton

Eaton staff are colocated in Golden, Colorado, joining NREL researchers on the state-of-the-art ESIF campus. This fruitful partnership has fostered projects from microgrids and controllers to cybersecurity and EV infrastructure.

# DOE PROGRAM RESEARCH

## Advanced Research Projects Agency-Energy

Algorithms (GRID DATA)

- SMART-DS: Synthetic Models for Advanced & Realistic Testing of Distribution systems and Scenarios

Creating Innovative and Reliable Circuits Using Inventive Topologies and Semiconductors (CIRCUITS)

- A High-voltage, High-reliability Scalable Architecture for Electric Vehicle Power Electronics

Prime PERFORM SDS

Rapidly Viable and Sustained Grid

## Advanced Manufacturing Office

Grid Application Development, Testbed, and Analysis for MV SiC (GADTAMS)

## Building Technologies Office

3.2.6.80 NREL- Multiobjective Deep Reinforcement Learning for Grid-interactive Energy-Efficient Buildings

3.4.6.53 NREL - Machine-Learning-Driven and Site-Specific Weather Inference for Building Energy Forecasting

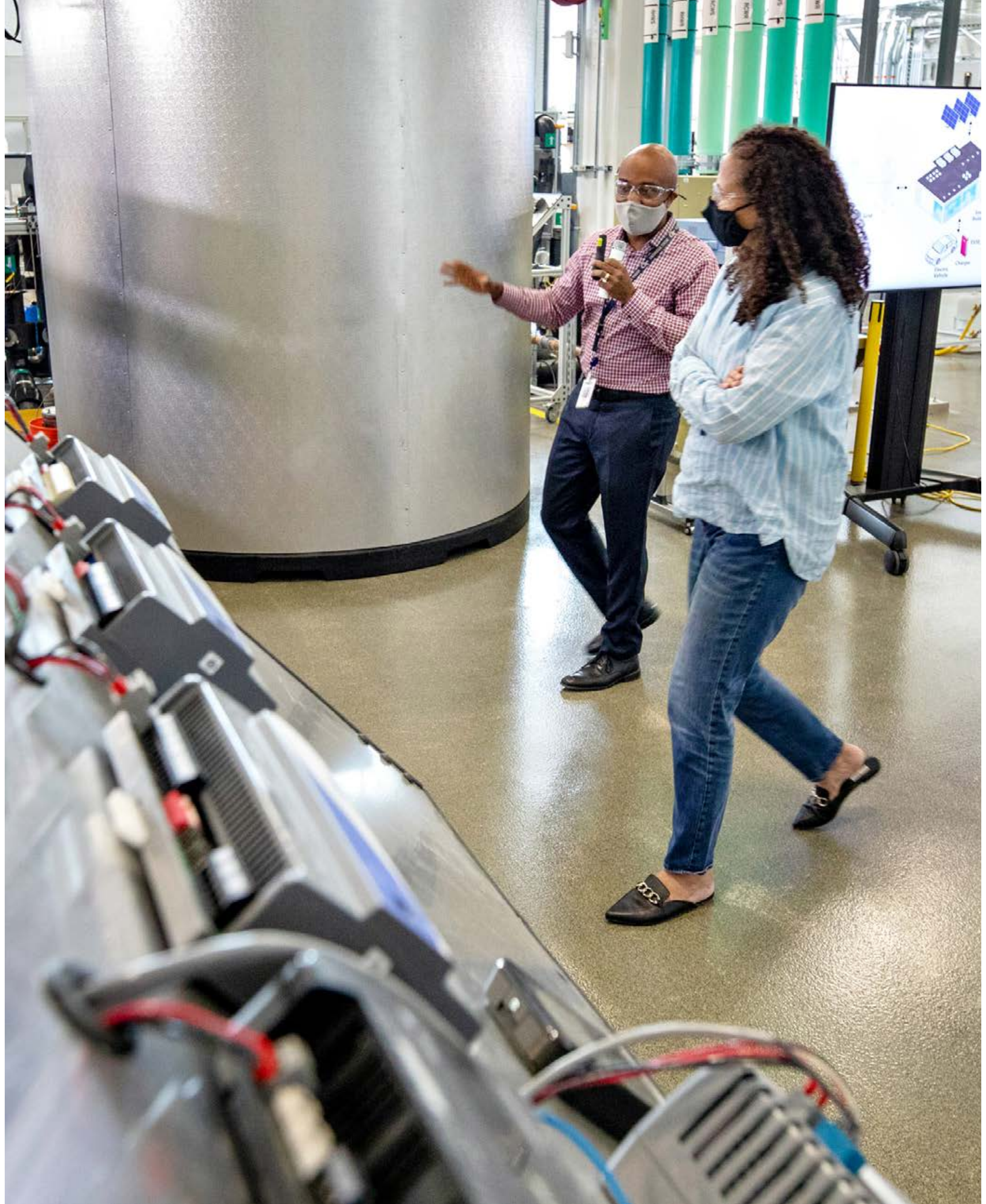
Weather Inference

Uniform Method Project

Building Intelligence with Layered Defense Using Security-Constrained Optimization and Security Risk Detection (BUILD-SOS)

Valuation of Energy Efficiency for Energy Resilience Research





**GMLC Category 1 Projects:**

1.4.04 Advanced Sensor Development

1.5.03 Increasing Distribution System Resiliency using Flexible DER and Microgrid Assets Enabled by OpenFMB

2.1.1 Federated Architecture for Secure and Transactive Distributed Energy Resource Management Solutions (FAST-DERMS)

2.4.2 Multi-Port Modular Medium-Voltage Transactive Power Electronics Energy Hub (M3PE-HUB)

2.5.2 Grid Services, Energy Services Interfaces & Grid Connected Devices

4.2.5 Technical Assistance: Grid-interactive Efficient Buildings

4.2.4 Integrated Distribution System Planning Training

## Cybersecurity, Energy Security, and Emergency Response

Wind Cybersecurity Consortium

Securing Energy Infrastructure Executive Task Force (SEI)

GridEx Planning

Advanced OT Threat Detection

CyberFire Support

Cyber Testing for Resilient Industrial Control Systems (CyTRICS)

Cybersecurity R&D Coordination

## Grid Modernization

### GMLC Category 1 Projects:

1.3.2 HELICS+

1.3.3 Near-term Resilience and Reliability

1.4.18 Computational Science for Grid Management

2.1.1 Federated Architecture for Secure and Transactive Distributed Energy Resource Management Solutions (FAST-DERMS)

2.5.2 Grid Services, Energy Services Interfaces & Grid Connected Devices

4.2.1 Foundational Assistance to ISO/RTOs under Electricity Market Transformation

4.2.2 Technical Assistance to State Public Utility Commissions

4.2.3 Future Electric Utility Regulation

4.2.4 IntelIntegrated Distribution System Planning: Education, Training and Assistance

4.2.5 Technical Assistance: Grid-interactive Efficient Buildings

5.2.3 Blockchain for Optimized Security and Energy Management (BLOSEM)

6.1.1 Clusters of Flexible PV-Wind-Storage Hybrid Generation (FlexPower)

6.1.2 Design and Optimization Infrastructure for Tightly Coupled Hybrid Systems (DISPATCHES)

### GMLC Category 2 Projects:

GM0237 Advanced Distribution Management System Testbed Development

WGRID-38 North American Renewable Integration Study (NARIS)

### GMLC Resilient Distribution Systems Projects:

1.5.03 Increasing Distribution Resiliency using Flexible DER and Microgrid Assets Enabled by OpenFMB

1.5.7 Laboratory Valuation Analysis Team

## Hydrogen and Fuel Cell Technologies Office

EHIL Grid Val

### GMLC Category 1 Projects:

6.1.2 Design and Optimization Infrastructure for Tightly Coupled Hybrid Systems (DISPATCHES)

## Office of Electricity Delivery and Energy Reliability

SuperFACTS; Federated Sensor Network to Identify Dynamic Interactions Among Critical Infrastructure and Inverter Based Energy Resources

Distribution Transformation Tool (DiTTo)

Power Distribution Sensing and Communications (TCF-20-20213)

Technology Agnostic Loss and Life Informed Dispatch of battEry Assets (TALLIDEA)



Maximizing Sensor Measurement Data through Adaptive Real Time Control

Office of Electricity Microgrids Resilient Operation of Networked Microgrids (RONM)

Cyber-Physical Dynamic System (CPDS) Modeling for Frequency Regulation and AGC Services of Distributed Energy Storage Resources

GridAPPS-D for ADMS Test Bed

Virtual Operator Assistant (VOA) – Powering the Next-generation Control Room by Artificial Intelligence and Digital Twins Technology

Autonomous Energy Grids: A new paradigm to enhance resiliency, security and reliability

Improving Distribution System Resiliency via Deep Reinforcement Learning (DRL4)

Cyber-Physical Dynamic System (CPDS) Modeling for Frequency Regulation and AGC Services of Distributed Energy Storage Resources

### GMLC Category 1 Projects:

1.4.18 Computational Science for Grid Management

2.1.1 Federated Architecture for Secure and Transactive Distributed Energy Resource Management Solutions (FAST-DERMS)

5.2.3 Blockchain for Optimized Security and Energy Management (BLOSEM)

6.1.2 Design and Optimization Infrastructure for Tightly Coupled Hybrid Systems (DISPATCHES)

### GMLC Category 2 Projects:

GM0237 Advanced Distribution Management System Testbed Development

### GMLC Resilient Distribution Systems Projects:

1.5.03 Increasing Distribution Resiliency using Flexible DER and Microgrid Assets Enabled by OpenFMB

1.5.7 Laboratory Valuation Analysis Team

## Nuclear Energy

### GMLC Category 1 Projects:

4.2.1 Foundational Assistance to ISO/RTOs under Electricity Market Transformation

6.1.1 Clusters of Flexible PV-Wind-Storage Hybrid Generation (FlexPower)

## Solar Energy Technologies Office

### GMLC Category 1 Projects:

North American Energy Resiliency Model (NAERM)

4.2.2 Technical Assistance to State Public Utility Commissions

4.2.3 Future Electric Utility Regulation

### GMLC Resilient Distribution Systems Projects:

1.5.03 Increasing Distribution Resiliency using Flexible DER and Microgrid Assets Enabled by OpenFMB

1.5.7 Laboratory Valuation Analysis Team

### Other Direct Projects:

32402 North American Renewable Integration Study (NARIS)

32887 PV Plant and Battery Energy Storage Integration

Systems Integration Testbed / Power Electric Grid Interface

2064 Adaptive Protections

2064 Risk Informed




2064 Advanced GFM

2064 Multi Level Cyber

2064 Improving Solar

2064 Grid Resiliency

TCF: Interface for PV

Borrego Springs

2243 REORG

2243 SAPPHIRE

2243 Deep Learning

2243 Sub to Electric Power Research Institute

2243 Sub to Brigham Young University

2243 Sub to Florida State University

2243 Sub to University of North Carolina

### FY 2019 SETO Lab Call Projects:

3.4.0.70 Solar Radiation Research Laboratory (SRRL)

3.3.0.5 The National Solar Radiation Database (NSRDB)

3.3.0.6 Interconnection & Interoperability Standards Accelerating Systems Integration Standards (ACCEL II)

3.4.0.86 Multi-Timescale Integrated Dynamic and Scheduling for Solar (MIDAS-Solar)

3.4.0.87 Artificial-Intelligence-Driven Smart Community Control for Accelerating PV Adoption and Enhancing Grid Resilience

3.4.0.80 Innovative Protection Systems for High-Pen PV Grids

### INTEGRATE Projects (Collaborative)

Southern California Gas Company

### ENERGISE Projects

#### NREL Primes:

Grid Optimization with Solar (GO-Solar)

Enhanced Control, Optimization, and Integration of Distributed Energy Applications (Eco-Idea)

#### NREL Subs:

Scalable/Secure Cooperative Algorithms and Framework for Extremely-high Penetration Solar Integration (SolarExPert)

Electric Access System Enhancement (EASE)

### Solar Forecasting II Projects

#### NREL Primes:

Solar Uncertainty Management and Mitigation for Exceptional Reliability in Grid Operations (SUMMER-GO)

### Advanced Systems Integration for Solar Technologies (ASSIST)

#### NREL Subs:

Enhancing Grid Reliability and Resilience through Novel Distributed Energy Resource Control, Total Situational Awareness, and Integrated Distribution-Transmission Representation (Lead: Arizona State University)

Enabling Cybersecurity, Situational Awareness and Resilience in Distribution Grids with High Penetration of Photovoltaics (Lead: Kansas State University)

Modeling and Control of Solar Photovoltaics for Large Grid Disturbances and Weak Grids (Lead: University of South Florida)

Protection and Restoration Solutions to Reliable and Resilient Integration of Grid-Connected Photovoltaic Installations and Distributed Energy Resources: Design, Testbed, Proof of Work, and Impact Studies (Lead: University of Oklahoma)

Solar Critical Infrastructure Energization System (Lead: Electric Power Research Institute)

Autonomous and Resilient Operation of Energy Systems with Renewables (Lead: Siemens Corp.)

## Water Power Technologies Office

Integrated Hydropower

Predictive Microgrid

Hydropower Cyber

Controller HIL Eval

### GMLC Category 1 Projects:

1.3.3 Near-term Resilience and Reliability

4.2.1 Foundational Assistance to ISO/RTOs under Electricity Market Transformation

6.1.1 Clusters of Flexible PV-Wind-Storage Hybrid Generation (FlexPower)

## Wind Energy Technologies Office

### GMLC Category 1 Projects:

4.2.1 Foundational Assistance to ISO/RTOs under Electricity Market Transformation

6.1.1 Clusters of Flexible PV-Wind-Storage Hybrid Generation (FlexPower)

### Wind Grid Projects—FY 2019 Start:

Atmosphere to Electrons to Grid (A2e2g)

Wind Grid Integration Stakeholder Engagement

Wind Power as Virtual Synchronous Generation (WindVSG)

Advanced Modeling, Dynamic Stability Analysis, and Mitigation of Control Interactions in Wind Power Plants

# KNOWLEDGE SHARING

## LEADERSHIP AND COLLABORATION

- Almost 20 years have passed since NREL staff led the inaugural effort behind the development of the **Institute of Electrical and Electronics Engineers Standard 1547**, and the laboratory continues to contribute invaluable technical guidance on safe and consistent interconnection for DERs. NREL researchers have released or drafted standards work on cybersecurity, microgrids, hybrid power plants, and blockchain-based energy markets. The expertise has followed from breakthrough research in the laboratory, where both large-scale collaborations and pioneering R&D are pointing to new technical requirements for emerging trends.
- NREL will co-lead the **Universal Interoperability for Grid-Forming Inverters Consortium**, also called UNIFI, streamlining renewable integration at all scales. SETO and WETO are cofunding the consortium, which will synergize research activities across more than 40 industry, university, and utility partners, setting new guidance for secure and reliable inverter operations.
- NREL currently hosts the secretariat duties for the **Global Power System Transformation (G-PST) Consortium**. The G-PST Consortium brings together key actors from around the world to foment a rapid clean energy transition by providing coordinated and holistic support and knowledge infusion to power system operators across five pillars of focus: system operator research, system operator technical support, workforce development, technology adoption, and open-source data and tools.
- With the **Wind Cybersecurity Consortium**, NREL has initiated a private-public partnership dedicated to improving the cybersecurity of the U.S. wind fleet through collaborative analysis, development, and information sharing. Work will be funded by the DOE Office of Cybersecurity, Energy Security, and Emergency Response and WETO.
- The HFTO is using the H2@Scale initiative to advance affordable hydrogen production, transportation, storage, and distribution on multiple fronts. NREL will co-lead the **Hydrogen from Next-generation Electroylzers of Water (H2NEW) consortium**, which conducts R&D to enable large-scale manufacturing of affordable electrolyzers that use electricity to split water into hydrogen and oxygen. The laboratory is also participating in the Million-Mile Fuel Cell Truck consortium, which aims to accelerate the development of fuel cells for heavy-duty vehicle applications, including long-haul trucks.
- NREL collaborated with the **Graduate Education Minority (GEM) Fellowship** organization to welcome 24 talented GEM students for a summer internship in 2021. Six of the fellows are in the first class of a dual mentorship initiative with BTO—the largest group of BTO fellows in the national laboratory system.



## WORKSHOPS, CONFERENCES, AND EVENTS

| Title | Date |
|---|---|
| Power Electronic Grid Interface Platform Workshop | October 2020 |
| ADMS Test Bed and Architectures for Grid-Edge Management Workshop | November 2020 |
| CyberForce Competition | November 2020 |
| ARIES Energy Storage Virtual Workshop | February 2021 |
| Cross-Laminated Timber Research Opportunities Workshop | April 2021 |
| Priorities and Pathways to Widespread Deployment of Thermal Energy Storage in Buildings | May 2021 |
| Testing for EVCharging Standard with the Charging Interface Initiative | July and August 2021 |

# INNOVATIONS

## SOFTWARE RECORDS AND RECORDS OF INVENTION

| Title | Primary NREL Center | NREL Number |
|---|---|---|
| resQ (An Intelligent Resilience Quantification Method for Improved Grid Planning and Operations) | 5D00 - Power Systems Engineering | SWR-20-108 |
| Athena - Shuttle Bus Optimization and Event Driven Simulator | 2C00 - Computational Sciences | SWR-20-105 |
| Athena - Digital Twin for Airport Terminal Traffic | 2C00 - Computational Sciences | SWR-20-106 |
| Ripple-Type Control for Resilient Networked Physical Systems | 5D00 - Power Systems Engineering | ROI-20-144 |
| Autonomous Blackstart Using Inverter-Based Resources | 5D00 - Power Systems Engineering | ROI-20-152 |
| DERComm (DER Communication Library for Control of Distributed Energy Resources) | 2C00 - Computational Sciences | SWR-20-110 |
| RTOPF-VPP (Real-Time Feedback-Based Optimization of Distributed Energy Resources for Virtual Power Plant Control Providing Grid Ancillary Services) | 2C00 - Computational Sciences | SWR-20-111 |
| Cyber Energy Emulation Platform, Infrastructure Baseline and Platform Deployment | 5R00 - Energy Security and Resilience | SWR-20-112 |
| EFFORT (EFFectiveness Of Rate sTructure for enabling demand response) FKA: DR-TOUT (Demand Response Time-Of-Use Tool) | 5D00 - Power Systems Engineering | SWR-20-114 |
| GET-Solar (Generation forecasting and parameter Estimation Tool for Solar) | 5D00 - Power Systems Engineering | SWR-20-115 |
| TEMPEST (Thermo-Electric Model for Powering Energy Storage Technologies) | 5D00 - Power Systems Engineering | SWR-20-116 |
| IEC61850-DNP3 (IEC61850 to DNP3 converter) | 2C00 - Computational Sciences | SWR-21-03 |
| Utility Planning Network Model Anomaly Detection | 5D00 - Power Systems Engineering | SWR-21-07 |
| cymepy cymepy | 5D00 - Power Systems Engineering | SWR-21-20 |



| Title | Primary NREL Center | NREL Number |
|---|---|---|
| pyDTS (Python Interface for Dispatcher Training Simulator) | 5D00 - Power Systems Engineering | SWR-21-22 |
| EMS2PC (Automating EMS to Planning Case Conversion) | 5D00 - Power Systems Engineering | SWR-21-23 |
| Battery-Free RFID Sensor Network System with Data Fusion for Human Presence Sensing | 5D00 - Power Systems Engineering | ROI-21-28 |
| SpIN (Sparse Invertible Networks) | 2C00 - Computational Sciences | SWR-21-28 |
| Sparse Invertible Neural Networks for Airfoil Design | 2C00 - Computational Sciences | ROI-21-29 |
| command_line_tools | 2C00 - Computational Sciences | SWR-21-29 |
| Characterization of Electric Power Distribution System Aggregate Flexibility | 5D00 - Power Systems Engineering | ROI-21-30 |
| Advanced Grid Support Functions (AGSF) | 5D00 - Power Systems Engineering | SWR-21-33 |
| MIDAS-DC-AC Tool: Fully Automating the Acquisition of AC Power Flow Solution MIDAS-DC2AC Tool | 5D00 - Power Systems Engineering | SWR-21-39 |
| RAVIS (Resource Forecast and Ramp Visualization for Situational Awareness) | 5D00 - Power Systems Engineering | SWR-21-44 |
| Distributed Energy Resources Risk Manager DER-RM | 5R00 - Energy Security and Resilience | SWR-21-45 |
| Hierarchical Control Framework for Management of Solar Power Plants | 5D00 - Power Systems Engineering | ROI-21-61 |
| 3D Campus Power Flow Visualization Intelligent Campus (STM) | 2C00 - Computational Sciences | SWR-21-51 |
| PsseReducer (PSSE Network Reduction) | 5D00 - Power Systems Engineering | SWR-21-55 |
| BTM-PV-Estimation (Behind-the-Meter Solar Generation Estimation) | 5D00 - Power Systems Engineering | SWR-21-56 |
| RegGIS (Regression Analysis of GIS data for Conductors) | 5D00 - Power Systems Engineering | SWR-21-58 |
| reV (The Renewable Energy Potential Model) Dashboard | 2C00 - Computational Sciences | SWR-21-59 |
| diverse_SR (Diverse Super-Resolution) | 2C00 - Computational Sciences | SWR-21-60 |
| OP HIL (Optimal Power Hardware-in-the-Loop Interfacing) | 5D00 - Power Systems Engineering | SWR-21-63 |
| ReV Supply Curve Viewer | 2C00 - Computational Sciences | SWR-21-66 |
| EconDispDash (Multi-Fidelity Economic Dispatch Dashboard) | 2C00 - Computational Sciences | SWR-21-70 |
| Development of Hierarchical Distributed Control for Distributed Energy Resource Management Using HELICS | 5D00 - Power Systems Engineering | SWR-21-76 |
| RLMoD (A Reinforcement Learning-Ready Mobility On Demand Simulator) | 2C00 - Computational Sciences | SWR-21-77 |
| Stochastic Soaring Raptor Simulator SSRS | 2C00 - Computational Sciences | SWR-21-78 |

# PATENT FILINGS

| Title | Primary NREL Center | NREL Number |
|---|---|---|
| System State Estimation with Asynchronous Measurements | 5D00 - Power Systems Engineering | 20-13 |
| Distribution System Flexibility Characterization | 5D00 - Power Systems Engineering | PROV/21-30 |
| Multi-Area Model-Free State Estimation | 5D00 - Power Systems Engineering | PROV/20-70A |
| Network-Cognizant Voltage Droop Control | 5D00 - Power Systems Engineering | 17-28 |
| Modular Scalable Power Conversion | 5D00 - Power Systems Engineering | 17-74 |
| Real Time Feedback-Based Optimization of Distributed Energy Resources | 5D00 - Power Systems Engineering | 16-124B |
| Heterogenous Network Topology Management and Control | 5D00 - Power Systems Engineering | 17-95 |
| Network Visualization, Intrusion Detection, and Network Healing | 5R00 - Energy Security and Resilience | 19-128 |
| Curtailment Control with Statistically Optimized Topology for Utility Scale Variable Generation | 5D00 - Power Systems Engineering | PROV/21-61 |
| Wireless Home Identification and Sensing Platform for Energy Reduction | 5D00 - Power Systems Engineering | PROV/21-28 |



# PUBLICATIONS

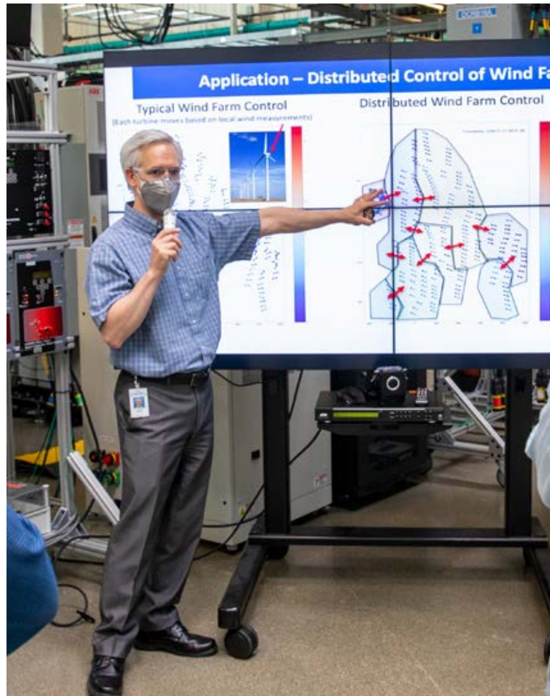
## 10 Most Downloaded Publications

1. *U.S. Solar Photovoltaic System and Energy Storage Cost Benchmark: Q1 2020*
2. *The Los Angeles 100% Renewable Energy Study (LA100)*
3. *Research Roadmap on Grid-Forming Inverters*
4. *The Technical and Economic Potential of the H2@Scale Hydrogen Concept within the United States*
5. *Cost Projections for Utility-Scale Battery Storage: 2021 Update*
6. "Q2/Q3 2020 Solar Industry Update"
7. *Storage Futures Study: The Four Phases of Storage Deployment: A Framework for the Expanding Role of Storage in the U.S. Power System*
8. *Electrification Futures Study: Scenarios of Power System Evolution and Infrastructure Development for the United States*
9. *Hybrid Energy Systems: Opportunities for Coordinated Research*
10. *The North American Renewable Integration Study (NARIS): A U.S. Perspective*

## PUBLICATION SPOTLIGHT:

### What We Know—and Do Not Know—About Achieving a National-Scale 100% Renewable Electric Grid

An article published in *Joule* by NREL researchers, "The Challenges of Achieving a 100% Renewable Electricity System in the United States," offered important insights into the technical and economic challenges that would need to be overcome to achieve 100% renewable electric power across all timescales. The paper organizes these challenges into two categories: (1) economically maintaining a balance of supply and demand and (2) designing technically reliable and stable electric grids using largely inverter-based resources. The authors highlighted a need to continuously reexamine the most effective pathway toward national emissions reduction and decarbonization goals—whether through 100% renewable electricity or another combination of low-carbon technologies.



## Conference Papers

Allen, A., G. Henze, K. Baker, G. Pavlak, and M. Murphy. 2021. "Evaluation of Topology Optimization to Achieve Energy Savings at the Urban District Level: Preprint" (NREL/CP-5500-77625). Presented at ASHRAE Virtual Winter Conference, February 9–11, 2021.

Bastos, A. F., S. Santoso, V. Krishnan, and Y. C. Zhang. 2020. "Machine Learning-Based Prediction of Distribution Network Voltage and Sensor Allocation" (NREL/CP-5D00-79002). Presented at the 2020 IEEE Power & Energy Society General Meeting (PESGM), August 2–6, 2020.

Beckers, K. F., D. Duplyakin, M. M. Martin, H. E. Johnston, and D. L. Siler. 2021. "Subsurface Characterization and Machine Learning Predictions at Brady Hot Springs: Preprint" (NREL/CP-5700-78975). Presented at the 46th Workshop on Geothermal Reservoir Engineering, February 16–18, 2021.

Bennett, D., A. Hasandka, M. D. Touhiduzzaman, and E. Vaughan. 2021. "Service-Based, Segmented, 5G Network-Based Architecture for Securing Distributed Energy Resources: Preprint" (NREL/CP-5R00-78055). Presented at the 2021 IEEE Power & Energy Society General Meeting, July 25–29, 2021.

Blonsky, M., P. Munankarmi, and S. Balamurugan. 2021. "Incorporating Residential Smart Electric Vehicle Charging in Home Energy Management Systems" (NREL/CP-5D00-80858). Presented at the 2021 IEEE Green Technologies Conference, April 7–9, 2021.

Brunhart-Lupo, N., S. Yellapantula, K. Gruchalla, and R. W. Grout. 2021. "Visualization of Jet Impingement and Ignition in a Piston-Cylinder Chamber" (NREL/CP-2C00-79848). Presented at the Twelfth ACM International Conference on Future Energy Systems, June 28–July 2, 2021.

Buster, G., M. Bannister, A. Habte, D. Hettinger, G. Maclaurin, M. Rossol, M. Sengupta, and Y. Xie. 2021. "Physics-Guided Machine Learning for Prediction of Cloud Properties in Satellite-Derived Solar Data" (NREL/CP-6A20-81255). Presented at the 48th IEEE Photovoltaic Specialists Conference (PVSC 48), June 20–25, 2020.

Cheung, L. C., S. Ananthan, M. J. Brazell, G. Vijayakumar, N. B. deVelder, and A. S. Hsieh. 2021. "Computation and Comparison of the Stable Northeastern US Marine Boundary Layer" (NREL/CP-50000-8566). Presented at the AIAA SciTech 2021 Forum, January 11–15 and 19–21, 2021.

Davenport, P., Z. Ma, W. Nation, J. Schirck, A. Morris, and M. Lambert. 2020. "Thermal Stability of Silica for Application in Thermal Energy Storage: Preprint" (NREL/CP-5700-77426). Presented at the 26th SolarPACES Conference 2020, September 28–October 2, 2020.

Diaz, Paul; Potter, Kristi; Johnson, Graham; Lopez, Anthony. 2021. "Uncertainty Visualization for Renewable Energy Potential" (NREL/CP-2C00-79743). Presented at the Twelfth ACM International Conference on Future Energy Systems, June 28–July 2, 2021.

Dutta, S., B. Majmunovic, S. Mukherjee, R. Mallik, G.-S. Seo, D. Maksimovic, and B. Johnson. 2021. "A Novel Decentralized PWM Interleaving Technique for Ripple Minimization in Series-Stacked DC-DC Converters" (NREL/CP-5D00-81216). Presented at the 2021 IEEE Applied Power Electronics Conference (APEC), June 9–12, 2021.

Dutta, S., M. Lu, R. Mallik, B. Majmunovic, S. Mukherjee, G.-S. Seo, D. Maksimovic, and B. Johnson. 2020. "Decentralized Control of Cascaded H-Bridge Inverters for Medium-Voltage Grid Integration" (NREL/CP-5D00-78885). Presented at the 21st IEEE Workshop on Control and Modeling for Power Electronics (IEEE COMPEL 2020), November 9–12, 2020.

Eseye, A. T., B. Knueven, X. Zhang, M. Reynolds, and W. Jones. 2021. "Resilient Operation of Power Distribution Systems Using MPC-Based Critical Service Restoration" (NREL/CP-2C00-80859). Presented at the 2021 IEEE Green Technologies Conference, April 7–9, 2021.

Eseye, A. T., X. Zhang, B. Knueven, and W. Jones. 2021. "Enhancing Distribution Grid Resilience Through Model Predictive Controller Enabled Prioritized Load Restoration Strategy" (NREL/CP-2C00-80934). Presented at the 52nd North American Power Symposium, April 11–14, 2021.

Fang, X., J. Tan, H. Yuan, S. Yin, and J. Wang. 2021. "Providing Ancillary Services with Photovoltaic Generation in Multi-Timescale Grid Operation: Preprint." Presented at the 2020 IEEE Power and Energy Society General Meeting (IEEE PES GM), August 3–6, 2020.

Gajanur, N., M. Greidanus, G.-S. Seo, S. Mazumder, and M. Abbaszada. 2021. "Impact of Blockchain Delay on Grid-Tied Solar Inverter Performance" (NREL/CP-5D00-80832). Presented at the IEEE 12th International Symposium on Power Electronics for Distributed Generation Systems (PEDG 2021), June 28–July 1, 2021.

Ghosh, S., R. Jain, S. Veda, and D. Terlip. 2021. "Improving Distribution System Operations Using Fleet Control of Electrolyzers" (NREL/CP-5D00-74600). Presented at the 2020 IEEE/PES Transmission and Distribution Conference and Exposition (T&D), October 12–15, 2020.

Gomes, G., J. Ugirumurera, and X. S. Li. 2020. "Distributed Macroscopic Traffic Simulation with Open Traffic Models" (NREL/CP-2C00-79173). Presented at the 23rd IEEE International Conference on Intelligent Transportation Systems (IEEE ITSC), September 20–23, 2020.



Goodrick, K. J., G.-S. Seo, S. Mukherjee, J. Roy, R. Mallik, B. Majmunovic, S. Dutta, D. Maksimovic, and B. Johnson. 2020. "LCOE Design Optimization Using Genetic Algorithm with Improved Component Models for Medium-Voltage Transformerless PV Inverters" (NREL/CP-5D00-78696). Presented at the 2020 IEEE Energy Conversion Congress and Exposition (ECCE), October 11–15, 2020.

Gostein, M., S. A. Pelaez, C. Deline, A. Habte, C. W. Hansen, B. Marion, J. Newmiller, M. Sengupta, J. S. Stein, and I. Suez. 2021. "Measuring Irradiance for Bifacial PV Systems" (NREL/CP-5K00-81131). Presented at the 48th IEEE Photovoltaic Specialists Conference (PVSC 48), June 20–25, 2021.

Guha, B., R. Jain, and S. Veda. 2021. "Bulk Grid Frequency Support Using Electrolyzers" (NREL/CP-5D00-75368). Presented at the 2020 IEEE Industry Applications Society Annual Meeting, October 10–16, 2020.

Habte, A., M. Sengupta, H. Yuan, G. Buster, and J. Tan. 2021. "Simulation of PV Variability as a Function of PV Generation and Plant Size" (NREL/CP-5D00-81332). Presented at the 48th IEEE Photovoltaic Specialists Conference (PVSC 48), June 20–25, 2021.

Habte, A., M. Sengupta, P. Gotseff, and C. A. Gueymard. 2021. "Annual Solar Irradiance Anomaly Features Over the USA During 1998-2017 Using NSRDB V3" (NREL/CP-5D00-79301). Presented at the 2020 47th IEEE Photovoltaic Specialists Conference (PVSC), June 15–August 21, 2020.

Jain, H., G.-S. Seo, E. Lockhart, V. Gevorgian, and B. Kroposki. 2020. "Blackstart of Power Grids with Inverter-Based Resources" (NREL/CP-5D00-79025). Presented at the 2020 IEEE Power & Energy Society General Meeting (PESGM), August 2–6, 2020.

Jain, R., K. Nagasawa, and S. Veda. 2021. "Power-to-Gas Systems for Active Load Management at EV Charging Sites with High DER Penetration" (NREL/CP-5D00-78836). Presented at the 2021 IEEE Transportation Electrification Conference & Expo (ITEC), June 20 – 25, 2021.

Jain, R., S. Veda, W. Becker, S. Ketring, and D. Ganger. 2021. "Application of Site Controllers for Electrification of Commercial Fleet Vehicles" (NREL/CP-5D00-74612). Presented at the 2020 IEEE/PES Transmission and Distribution Conference and Exposition (T&D), October 12–15, 2020.

Kim, J.-H., P. A. Jimenez, M. Sengupta, J. Yang, J. Dudhia, S. Alessandrini, and Y. Xie. 2021. "The WRF-Solar Ensemble Prediction System to Provide Solar Irradiance Probabilistic Forecasts" (NREL/CP-5D00-80399). Presented at the 2021 IEEE 48th Photovoltaic Specialists Conference (PVSC), June 20–25, 2021.

Lany, S., and A. Sharan. 2021. "First Principles Predictions of SnO2/CdTe and SnO2/CdCl2/CdTe Interface Structures" (NREL/CP-5K00-78986). Presented at the 2021 IEEE 48th Photovoltaic Specialists Conference (PVSC), June 20–25, 2021.

Liu, W., F. Ding, U. Kumar, and S. Paul. 2020. "Post-Disturbance Dynamic Distribution System Restoration with DGs and Mobile Resources" (NREL/CP-5D00-79031). Presented at the 2020 IEEE Power & Energy Society General Meeting (PESGM), August 2–6, 2020.

Liu, Y., A. Sagan, A. Bernstein, R. Yang, X. Zhou, and Y.C. Zhang. 2020. "Matrix Completion Using Alternating Minimization for Distribution System State Estimation" (NREL/CP-5D00-79140). Presented at the 2020 IEEE International Conference on Communications, Control, and Computing Technologies for Smart Grids (SmartGridComm), November 11–13, 2020.

Mahmud, R., A. Hoke, and D. Narang. 2020. "Fault Response of Distributed Energy Resources Considering the Requirements of IEEE 1547-2018" (NREL/CP-5D00-79032). Presented at the 2020 IEEE Power & Energy Society General Meeting (PESGM), August 2–6, 2020.

Meyers, T., and B. Mather. 2021. "Empirical Evaluation of GPS Clock Accuracy for Isochronous Droop-Based Inverters: Preprint" (NREL/CP-5D00-77573). Presented at the IEEE Energy Conversion Congress and Exposition (ECCE 2021), October 10–14, 2021.

Meyers, T., and B. Mather. 2021. "Time-Disciplined Non-PLL Active Synchronization for Grid-Forming Inverters" (NREL/CP-5D00-79941). Presented at the 2021 IEEE Texas Power and Energy Conference (TPEC), February 2–5, 2021.

Mirletz, B. T., and D. L. Guittet. 2021. "Heuristic Dispatch Based on Price Signals for Behind-the-Meter PV-Battery Systems in the System Advisor Model" (NREL/CP-7A40-81133). Presented at the 48th IEEE Photovoltaic Specialists Conference (PVSC 48), June 20–25, 2020.

Monzón, L., W. Johns, S. Iyengar, M. Reynolds, J. Maack, and K. Prabakar. 2020. "A Multi-Function AAA Algorithm Applied to Frequency Dependent Line Modeling" (NREL/CP-5D00-79033). Presented at the 2020 IEEE Power & Energy Society General Meeting (PESGM), August 2–6, 2020.

Mukherjee, S., B. Majmunovic, G.-S. Seo, S. Dutta, R. Mallik, B. Johnson, and D. Maksimovic. 2021. "A High-Frequency Planar Transformer with Medium-Voltage Isolation: Preprint" (NREL/CP-5D00-81219). Presented at the 2021 IEEE Applied Power Electronics Conference (APEC), June 9–12, 2021.

Mullowney, P., R. Li, S. Thomas, S. Ananthan, A. Sharma, J. S. Rood, A. B. Williams, and M. A. Sprague. 2021. "Preparing an Incompressible-Flow Fluid Dynamics Code for Exascale-Class Wind Energy Simulations: Preprint" (NREL/CP-2C00-79645). Presented at the International Conference for High Performance Computing, Networking, Storage, and Analysis (SC21), November 14–19, 2021.

Padullaparti, H., A. Pratt, I. Mendoza, S. Tiwari, M. Baggu, C. Bilby, and Y. Ngo. 2021. "Peak Load Management in Distribution Systems Using Legacy Utility Equipment and Distributed Energy Resources" (NREL/CP-5D00-80860). Presented at the 2021 IEEE Green Technologies Conference, April 7–9, 2021.

Panda, K., R. King, J. Maack, I. Satkauskas, and K. Potter. 2021. "Visualization of Multi-Fidelity Approximations of Stochastic Economic Dispatch" (NREL/CP-2C00-79785). Presented at the Twelfth ACM International Conference on Future Energy Systems, June 28–July 2, 2021.

Pandey, S., S. Srivastava, G. Kandaperumal, A. K. Srivastava, M. U. Mohanpurkar, and R. Hovsapian. 2020. "Optimal Operation for Resilient and Economic Modes in an Islanded Alaskan Grid" (NREL/CP-5C00-79034). Presented at the 2020 IEEE Power & Energy Society General Meeting (PESGM), August 2–6, 2020.

Panossian, N., T. Elgindy, B. Palmintier, and D. Wallison. 2021. "Synthetic, Realistic Transmission and Distribution Co-Simulation for Voltage Control Benchmarking" (NREL/CP-5D00-79943). Presented at the 2021 IEEE Texas Power and Energy Conference (TPEC), February 2–5, 2021.

Paret, P., J. E. Cousineau, S. Narumanchi, G.-Q. Lu, and K. Ngo. 2021. "Thermal and Mechanical Design of a High-Voltage Power Electronics Package" (NREL/CP-5400-81120). Presented at the 2021 IEEE Applied Power Electronics Conference (APEC), June 9–12, 2021.

Pelaez, S. A., C. Deline, B. Marion, B. Sekulic, J. Parker, B. McDanold, and J. S. Stein. 2020. "Field-Array Benchmark of Commercial Bifacial PV Technologies with Publicly Available Data" (NREL/CP-5K00-75963). Presented at the 2020 47th IEEE Photovoltaic Specialists Conference (PVSC), June 15–August 21, 2020.

Pratt, A., H. Padullaparti, I. Mendoza, M. Baggu, Y. Ngo, and H. Arant. 2021. "Defining a Use Case for the ADMS Test Bed: Fault Location, Isolation, and Service Restoration with Distributed Energy Resources" (NREL/CP-5D00-79798). Presented at the 2021 IEEE Innovative Smart Grid Technologies, North America (ISGT NA), February 15–18, 2021.

Pratt, A., I. Mendoza, M. U. Usman, S. Tiwari, H. Padullaparti, M. Baggu, and E. Lightner. 2020. "Using an Advanced Distribution Management System Test Bed to Evaluate the Impact of Model Quality on Volt/VAR Optimization: Preprint" (NREL/CP-5D00-74723). Presented at the 2020 IEEE Power and Energy Society Transmission and Distribution Conference and Exposition (IEEE PES T&D), October 12–15, 2021.

Raszmann, E., K. Prabakar, B. Mather, and J. Li. 2020. "Experimental Test Bed to Enable Realistic Evaluations for Direct Transfer Trip Relaying via Private Wireless LTE Communications" (NREL/CP-5D00-78714). Presented at the 2020 IEEE International Smart Cities Conference (ISC2), September 28–October 1, 2020.

Reynolds, M., I. Satkauskas, J. Maack, D. Sigler, and W. Jones. 2020. "Scenario Creation and Power-Conditioning Strategies for Operating Power Grids with Two-Stage Stochastic Economic Dispatch: Preprint." (NREL/CP-2C00-75363). Presented at the 2020 IEEE Power and Energy Society General Meeting (IEEE PES GM), August 3–6, 2020.

Sanghvi, A., and T. Markel. 2021. "Cybersecurity for Electric Vehicle Fast-Charging Infrastructure" (NREL/CP-5R00-81075). Presented at the IEEE Transportation Electrification Conference and Expo (ITEC), June 21–25, 2021.

Singh, A., X. Zhu, Xiangqi, B. Mather, and F. Gurara. 2020. "Grid Application and Controls Development for Medium-Voltage SiC-Based Grid Interconnects (NREL/CP-5D00-78721)." Presented at the IEEE Energy Conversion Congress & Exposition (ECCE), October 11–15, 2020.

Spyrou, E., V. Krishnan, O. Xu, and B. F. Hobbs. 2020. "What Is the Value of Alternative Methods for Estimating Ramping Needs?" (NREL/CP-5D00-79158). Presented at the 2020 IEEE Green Technologies Conference (GreenTech), April 1–3, 2020.

Velaga, Y. N., K. Prabakar, A. Singh, and P. K. Sen. 2021. "Traveling Wave Relays for Distribution Feeder Protection with High Penetrations of Distributed Energy Resources" (NREL/CP-5D00-81107). Presented at the 2021 IEEE Rural Electric Power Conference (IEEE REPC), April 26–30, 2021.

Velaga, Y. N., K. Prabakar, M. Baggu, and K. P. Schneider. 2021. "Evaluation of Centralized Model-Based FLISR in a Lab Setup" (NREL/CP-5D00-81006). Presented at the 2021 IEEE Rural Electric Power Conference (IEEE REPC), April 27–29 2020.

Vignola, F., J. Peterson, R. Kessler, A. Habte, P. Gotseff, M. Sengupta, and F. Mavromatakis. 2021. "Using Spectral Measurements to Characterize Solar Reference Cells on a Two-Axis Tracker" (NREL/CP-5D00-79316). Presented at the 2020 47th IEEE Photovoltaic Specialists Conference (PVSC), June 15–August 21, 2020.

Wang, B., A. Hoke, and J. Tan. 2021. "Power System Network Reduction for Power Hardware-in-the-Loop Simulation" (NREL/CP-5D00-81265). Presented at the 2021 IEEE Kansas Power and Energy Conference (KPEC), April 19–20, 2021.

Wang, J., B. Lundstrom, and A. Bernstein. 2020. "Design of a Non-PLL Grid-Forming Inverter for Smooth Microgrid Transition Operation" (NREL/CP-5D00-79037). Presented at the 2020 IEEE Power & Energy Society General Meeting (PESGM), August 2–6, 2020.

Wang, J., H. Padullaparti, S. Veda, I. Mendoza, S. Tiwari, and M. Baggu. 2020. "Performance Evaluation of Data-Enhanced Hierarchical Control for Grid Operations" (NREL/CP-5D00-79038). Presented at the 2020 IEEE Power & Energy Society General Meeting (PESGM), August 2–6, 2020.

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## Posters

Allen, J. M., P. J. Weddle, A. Verma, A. Mallarapu, F. Usseglio-Viretta, D. P. Finegan, A. M. Colclasure, W. Mai, V. Schmidt, O. Furat, D. Diercks, T. Tanim, K. Smith. 2021. "Modeling Lithium Diffusion in Battery Cathodes Considering Chemo-Mechanically Induced Damage" (NREL/PO-2C00-80050). Presented at the InterPore 2021 Online Conference, May 31–June 4, 2021.

Davenpot, P., Z. Ma, W. Nation, J. Schirck, A. Morris, M. Lambert. 2020. "Thermal Stability of Silica for Application in Thermal Energy Storage" (NREL/PO-5500-77830). Presented at the 26th International SolarPACES Conference, Albuquerque, New Mexico, September 28–October 2, 2020.

Draxl, C., M. Lawson, C. Farmer, T. Katzner, E. Quon, R. Sandhu, R. Thedin, C. Tripp. 2020. "Mesoscale Modeling to Characterize Eagle Soaring Habitat" (NREL/PO-5000-78207). Presented at the 13th Wind Wildlife Research Meeting, December 1–4, 2020.

Duplyakin, D., D. L. Siler, H. Johnston, K. Beckers, M. Martin. 2020. "Using Machine Learning to Predict Future Temperature Outputs in Geothermal Systems" (NREL/PO-2C00-76856). Presented at the GRC 2020 Annual Meeting & Expo, October 18–23, 2020.

Gotseff, P. 2020. "Toward Using PV Reference Cells for Solar Resource (i.e., PV Resource)" (NREL/PO-5D00-77626). Presented at Solar Power International 2020, September 14–October 27, 2020.

Mirletz, B. T., D. L. Guittet. 2021. "Heuristic Dispatch Based on Price Signals for Behind-the-Meter PV-Battery Systems in the System Advisor Model" (NREL/PO-7A40-80258). Presented at the IEEE Photovoltaic Specialists Conference 48, Miami-Fort Lauderdale, Florida, June 20–25, 2021.

Park, J., J. Pfeilsticker, K. Tjiptowidjojo, P. R. Schunk, S. A. Mauger, M. Ulsh. 2020. "An Experimental Investigation of Multilayer Flow in a Slide Die Coating Process" (NREL/PO-5900-77528). Presented at the 20th International Coating Science and Technology Symposium, September 20–23, 2020.

Rippy, K., L. Timmerman, Y. Zhao, J. Vidal. 2020. "Analysis in the Impurity MgOHCl in Molten Chloride Salts Toward Its Electrochemical Removal from CSP Plants During Operation" (NREL/PO-5500-77875). Presented at the 26th International SolarPACES Conference, Albuquerque, New Mexico, September 28–October 2, 2020.

Sprague, M. A., S. Ananthan, R. Binyahib, M. Brazell, M. Henry de Frahan, R. King, P. Mullowney, J. Rood, A. Sharma, S. Thomas, G. Vijayakumar, P. Crozier, L. Berger-Vergiat, L. Cheung, D. Dement, N. de Velder, D. Glaze, J. Hu, R. Knaus, D. H. Lee, N. Matula, T. Okusanya, J. Overfelt, S. Rajamanickam, P. Sakievich, T. Smith, J. Vo, A. Williams, I. Yamazaki, J. Turner, A. Prokopenko, R. Wilson, R. Moser, J. Melvin, J. Sitaraman. 2021. "ExaWind: Exascale Predictive Wind Plant Flow Physics Modeling" (NREL/PO-5000-80015). Presented at the Exascale Computing Project Annual Meeting, April 12-16, 2021.

Wang, J., A. Pratt, M. Baggu. 2019. "Integrated Synchronization Control of Grid-Forming Inverters for Smooth Microgrid Transition" (NREL/PO-5D00-74472). Presented at the 2019 IEEE Power and Energy Society General Meeting, Atlanta, Georgia, August 4-8, 2019.

Wang, J., M. Blonsky, F. Ding, S. Drew, M. Baggu, C. Bilby, B. Hannegan. 2020. "Performance Evaluation of Distributed Energy Resource Management via Advanced Hardware-in-the-Loop Simulation" (NREL/PO-5D00-76084). Presented at the IEEE Innovative Smart Grid Technology Conference, Washington, D.C., February 17–20, 2020.

Xie, Y., M. Sengupta. 2018. "A Fast All-sky Radiation Model for Solar Applications with Narrowband Irradiances on Tilted Surfaces (FARMS-NIT)" (NREL/PO-5D00-71722). Presented at the World Conference on Photovoltaic Energy Conversion (WCPEC-7), Waikoloa, Hawaii, June 10–15, 2018.

## Presentations

Allen, J., E. Young, J. Jasa, P. Bortolotti, R. King, G. Barter. 2021. "Progress on Optimizing Wind Farms and Rotor Designs Using Adjoints" (NREL/PR-2C00-80929).

Bernstein, A., B. Lundstrom, V. Salehi, J. Elizondo, C. Bilby. 2020. "Real-Time Optimization and Control of Next-Generation Distribution Infrastructure" (NREL/PR-5D00-78742). Presented at the Network Optimized Distribution Energy Systems (NODES) Workshop and Demonstration, January 16, 2020.

Boren, B. 2021. "Prototype and Codesign of Nascent Flexible Wave Energy Converter Concepts" (NREL/PR-5700-80625). Presented at the Seedling Showcase, August 11, 2021.

Brinkman, G., J. Novacheck, A. Bloom, J. McCalley. 2020. "Interconnections Seam Study" (NREL/PR-6A20-78161). Presented in October 2020.

Brunhart-Lupo, N., B. Bush, K. Gruchalla, K. Potter, S. Smith. 2021. "Collaborative Exploration of Scientific Datasets Using Immersive and Statistical Visualization" (NREL/PR-2C00-79574). Presented at SEA ISS 2021, March 22–26, 2021.

Brunhart-Lupo, N., S. Yellpantula, K. Gruchalla, R. Grout. 2021. "Visualization of Jet Impingement and Ignition in a Piston-Cylinder Chamber" (NREL/PR-2C00-80390). Presented at ACM e-Energy 2021, Tornio, Italy, June 28–July 2, 2021.

Bush, B., D. Inman. 2021. "Visual HPC Workflows for the Analysis of System Dynamics Models" (NREL/PR-6A20-80539). Presented at the 2021 International System Dynamics Conference, July 27, 2021.

CaraDonna, C., K. Tranbath. 2021. "ComStock™/COVID-19: U.S. Commercial Building Stock Analysis of COVID-19 Mitigation Strategies" (NREL/PR-5500-79335). Presented on February 22, 2021.

Cutler, D., S. Balamurugan, M. Blonsky, T. Elgindy, S. Ghosh, T. Kwasnik, J. Maguire, P. Munankarmi, D. Christensen, S. Hartnett, T. Christian. 2021. "Zero-Export Feeder Through Transactive Markets" (NREL/PR-7A40-80140). Presented at the HELICS User and Developer Meeting 2021, May 11, 2021.

Ding, F. 2021. "Grid-Edge Energy Resources to Shape Resilient Community Microgrids" (NREL/PR-5D00-79778). Presented on April 7, 2021.

Eseye, A. T., X. Zhang, B. Knueven, W. Jones. 2021. "Enhancing Distribution Grid Resilience Through Model Predictive Controller Enabled Prioritized Load Restoration Strategy" (NREL/PR-2C00-79535). Presented at the 52nd North American Power Symposium, April 11–14, 2021.

Eseye, A. T., B. Knueven, X. Zhang, M. Reynolds, W. Jones. 2021. "Resilient Operation of Power Distribution Systems Using MPC-Based Critical Service Restoration" (NREL/PR-2C00-79530). Presented at the 2021 IEEE Green Technologies Conference (GreenTech), April 7–9, 2021.

Frew, B. 2020. "Impacts of Renewable and Storage Technologies on Resource Adequacy" (NREL/PR-6A20-76094). Presented at the Austin Electricity Conference, March 5, 2020.

Frew, B. 2021. "The Solar Curtailment Paradox" (NREL/PR-5C00-80259). NREL Webinar, June 24, 2021.

Frick, N. M., A. Fontanini, E. Wilson, A. Parker. 2020. "End-Use Load Profiles for the U.S. Building Stock: Technical Advisory Group Meeting #7" (NREL/PR-5500-79104). Presented on May 26, 2020.

Frick, N. M., E. Wilson, A. Fontanini, E. Present. 2019. "End-Use Load Profiles for the U.S. Building Stock: Technical Advisory Group Meeting #4" (NREL/PR-5500-79099). Presented on September 20, 2019.

Frick, N. M., E. Wilson, A. Fontanini, E. Present. 2020. "End-Use Load Profiles for the U.S. Building Stock: Technical Advisory Group Meeting #6" (NREL/PR-5500-79103). Presented on March 5, 2020.

Frick, N.M., E. Wilson, A. Parker, A. D. Fontanini, M. Dahlhausen. 2021. "End-Use Load Profiles for the U.S. Building Stock: Technical Advisory Group Meeting #10" (NREL/PR-5500-79108). Presented on April 21, 2021.

Frick, N.M., E. Wilson, A. Parker, E. Present, A. Fontanini, J. Reyna. 2019. "End-Use Load Profiles for the U.S. Building Stock: Technical Advisory Group Meeting #5" (NREL/PR-5500-79102). Presented on December 17, 2019.

Gage, Samuel. 2020. "Technical Performance of Refractory Liners for Molten Chloride Salt Thermal Energy Storage Systems" (NREL/PR-5700-77846). Presented at SolarPACES 2020, September 28–October 2, 2020.

Griffin, M., B. Pecha, B. Adkins. 2021. "Advancing Catalytic Fast Pyrolysis Through Integrated Experimentation and Multi-Scale Computational Modeling" (NREL/PR-5100-78854). Presented on January 13, 2021.

Goyal, A., A. Zakutayev, V. Stavanovic, S. Lany. 2021. "Computational Fermi Level Engineering and Doping-Type Conversion of $Ga_2O_3$ Via Three-Step Processing"(NREL/PR-5K00-81059). Presented at the 2021 aterials Research Society Spring Meeting & Exhibit, April 17–23, 2021.

Goyal, A., S. Lany. 2021. "Ab Initio Study of Atomic and Electronic Structure of Promising $Ba_4XMn_3O_{12}$ (X=Nb, Ce, PR) Oxides for Solar Thermochemical Hydrogen Production" (NREL/PR-5K00-81060). Presented at the 2021 Materials Research Society Spring Meeting & Exhibit, April 17–23, 2021.

Guerra, O., J. Eichman. 2020. "The Role of Hydrogen in Future Energy Systems–Seasonal Energy Storage" (NREL/PR-5D00-78296). Presented at the RMEL On Demand Webinar, November 2, 2020.

Habte, A., M. Sengupta, H. Yuan, G. Buster, J. Tan. 2021. "Simulation of PV Variability as a Function of PV Generation and Plant Size" (NREL/PR-5D00-80237). Presented at the 2021 48th IEEE Photovoltaic Specialists Conference (PVSC), June 20–25, 2021.

Hobbs, B. F., V. Krishnan, P. Edwards, H. Sky, I. Krad, C. Siebenschuh, H. Hamann, R. Zhang, J. Zhang, B. Li, Y. Wang, S. Zhang. 2021. "Pro2R: Procurement of Ramping Product and Regulation in CAISO Using Probabilistic Solar Power Forecasts" (NREL/PR-5D00-80108). Presented at the SETO Workshop on Solar Forecasting, May 5–6, 2021.

Johns, W., L. Mozon, S. Iyengar, M. Reynolds, J. Maack, K. Prabakar. 2020. "A MIMO AAA Algorithm for Frequency Dependent Line Modeling" (NRL/PR-2C00-77213). Presented at the 2020 IEEE Power and Energy Society General Meeting, August 3–6, 2020.

Knueven, B., D. Mildebrath, C. Muir, J. Siirola, D. Woodruff, J-P. Watson. 2020. "mpi-sppy: Optimization Under Uncertainty for Pyomo" (NREL/PR-2C00-78043). Presented at the INFORMS Annual Meeting 2020, November 13, 2020.

Knueven, B., J-P. Watson, J. Ostrowski, D. L. Woodruff. 2021. "State-of-the-Art Techniques for Large-Scale Stochastic Unit Commitment" (NREL/PR-2C00-80357). Presented at the FERC Software Conference, June 23, 2021.

Koebrich, S., B. Sigrin, R. Spencer, P. Schwabe, S. Haase, S. Choi, J. Kramer. 2-21. "Distributed Solar Adoption in Orlando: A Household-Level Model for Distribution Resource Planning" (NREL/PR-6A20-77308). January 2021.

Kumler, A., J. K. Lundquist, J. King. 2021. "Probabilistic Day-Ahead Forecasting Using an Analog Ensemble Approach for Wind Farm Grid Services" (NREL/PR-5D00-80142). Presented at the Wind Energy Science Conference, Hannover, Germany, May 25–28, 2021.

Lundstrom, B., P. Koralewicz, B. Miller, J. Fossum, S. Truitt, J. Wang. 2020. "Considerations for Microgrid Co-Design: Performance Verification Approach, Metrics, and Interoperability" (NREL/PR-5D00-78143). Presented at the ARPA-E EMC2 Workshop, October 9, 2020.



Mauger, S., M. Wang, K.C. Neyerlin, T. van Cleve, M. Ulsh, M. Dzara, S. Pylypenko, F. Cetinbas, J. Park, R. Ahluwahlia, D. Meyers, L. Hu, S. Lister. 2020. "Influence of Ink Formulation and Drying Conditions on Ionomer Distribution in High-Performance Roll-to-Roll Coated Gas-Diffusion Electrodes" (NREL/PR-5900-76952). Presented at the PRiME/236th ECS Meeting, October 6, 2020.

McMillan, C., C. Schoeneberger, P. Kurup, J. Zhang. 2021. "Opportunities for Solar Industrial Process Heat in the United States" (NREL/PR-6A20-79083). Presented on February 3, 2021.

Muratori, M., P. Jadun, B. Bush, C. Hoehne, A. Yip, C. Ledna, L. Vimmerstedt. 2021. "The Transportation Energy and Mobility Pathway Options (TEMPO) Model" (NREL/PR-5400-80819). Presented in August 2021.

Newkirk, J. M., I. Nayshevsky, A. Sinha, A. Law, Q. Xu, B. To, P. F. Ndione, L. T. Schelhas, J. M. Walls, A. M. Lyons, D. C. Miller. 2019. "Artificial Liner Brush Abrasion of Coatings for Photovoltaic Module First Surfaces" (NREL/PR-5K00-75028). Presented at the International PV Soiling Workshop, October 30, 2019.

Padullaparti, H., A. Pratt, I. Mendoza, S. Tiwari, M. Baggu, C. Bilby, Y. Ngo. 2021. "Peak Load Management in Distribution Systems Using Legacy Utility Equipment and Distributed Energy Resources" (NREL/PR-5D00-79611). Presented at IEEE GreenTech 2021, April 9, 2021.

Panossian, N., T. Elgindy, B. Palmintier, D. Wallison. 2021. "Synthetic, Realistic Transmission and Distribution Co-Simulation for Voltage Control Benchmarking" (NREL/PR-5D00-78996). Presented at the Texas Power and Energy Conference, February 4, 2021.

Park, J. 2020. "Roll-to-Roll Direct Coating of Catalyst Inks on Membrane Films: Progress and Challenges" (NREL/PR-5900-77527). Presented at the 20th International Coating Science and Technology Symposium, September 21, 2020.

Parker, A., M. Dahlhausen, A. D. Fontanini, E. Wilson. 2020. "End-Use Load Profiles for the U.S. Building Stock: Technical Advisory Group Meeting #8" (NREL/PR-5500-79105). Presented on May 22, 2020.

Prabakar, K. 2021. "Enabling Interoperability on PV Inverters Using IEC 61850" (NREL/PR-5D00-78827). Presented on January 26, 2021.

Prabakar, K. 2021. "Evaluation of AC Microgrid Controllers" (NREL/PR-5D00-78911). Presented at the Watts on the Moon Webinar, January 21, 2021.

Prabakar, K., N. Brunhart-Lupo, N. Wunder, M. Lunacek, K. Potter, C. Pailing, K. Munch, A. Pratt. 2020. "Data Storage and Visualization Solutions for Real Time Simulations and Experiments" (NREL/PR-2C00-73884). Presented at the RTDS North American User's Group Meeting, May 13–16, 2020.

Prabakar, K., Y. N . Velaga, A. Singh, M. Reynolds, P. Sen, L. Monzon. 2020. "EMT Models to Evaluate Traveling Wave-Based Protection in Distribution System" (NREL/PR-5D00-77754). Presented at the 2020 EMTP User Conference, September 21–October 2, 2020.

Prasanna, A., K. McCabe, B. Sigrin, N. Blair. 2021. "Storage Futures Study–Distributed Solar and Storage Outlook: Methodology and Scenarios" (NREL/PR-7A40-80692). Presented on August 10, 2021.

Pratt, A. 2021. "Addressing Challenges for Single Microgrids and Networked Microgrids at Large Scales" (NREL/PR-5D00-79638). Presented at IEEE GreenTech, April 7–9, 2021.

Pratt, A. 2021. "Peak Load Management in Distribution Systems Using ADMS and DERMS" (NREL/PR-5D00-80151). Presented on June 9, 2021.

Pratt, A. 2021. "Advanced Distribution Management System (ADMS) Test Bed" (NREL/PR-5D00-80244). Presented on July 28, 2021.

Pratt, A. 2020. "Using an Advanced Distribution Management System Test Bed to Evaluate the Impact of Model Quality on Volt/VAR Optimization" (NREL/PR-5D00-77900). October 12–15, 2020.

Pratt, A., H. Padullaparti, I. Mendoza. 2021. "Defining a Use Case for the ADMS Test Bed: Fault Location, Isolation, and Service Restoration with Distributed Energy Resources" (NREL/PR-5D00-78838). Presented on February 16–18, 2021.

Quan, E., M. Lawson, C. Tripp, C. Draxl, R. Sandhu, R. Thedin. 2020. "Atmospheric Modeling to Enable Prediction of Golden Eagle Interactions with Wind Power Plants" (NREL/PR-5000-78464). Presented at the 13th Wind Wildlife Research Meeting, December 4, 2020.

Rahimi, M., H. Sitaraman, J. Lischeske, D. Sievers, J. Stickel. 2019. "Computational Fluid Dynamics Simulation of Compressible Non-Newtonian Biomass in a Compression-Screw Feeder" (NREL/PR-2C00-75580). Presented at the 2019 AIChE Annual Meeting, Orlando, FL, November 10, 2019.

Raszmann, E., K. Prabakar, B. Mather, J. Li. 2020. "Experimental Test Bed to Enable Realistic Evaluations for Direct Transfer Trip Relaying Via Private Wireless LTE Communications" (NREL/PR-5D00-77958). Presented at the IEEE International Smart Cities Conference, September 28–October 1, 2020.

Reynolds, T. 2021. "Cybersecurity Assessment Tools for Distributed Energy Resources" (NREL/PR-5R00-80524). Presented at Energy Exchange 2021, August 2–6, 2021.

Sandhu, R. C. Tripp, M. Lawson, E. Quon, R. Thedin, C. Draxl, C. Farmer, T. Katzner, B. Straw. 2020. "Quantifying Turbine-Level Risk to Golden Eagles Using a High-Fidelity Updraft Model and a Stochastic Behavioral Model" (NREL/PR-5000-78233). Presented at the 13th Wind Wildlife Research Meeting, December 2020.

Sethuraman, L., G. Vijayakumar, S. Ananthan, P. Paranthaman, J. Keller, R. King. 2021. "MADE3D: Enabling the Next-Generation High-Torque- Density Wind Generators by Additive Design and 3D Printing" (NREL/PR-5000-79384). Presented at the 5th Conference for Wind Power Drives (CWD) 2021, March 11, 2021.

Sitaraman, H., R. Grout. 2018. "An Orthological Recursive Bisection (ORB) Based Time Advancement Algorithm for CFD-DEM Solvers" (NREL/PR-2C00-72822). Presented at the 2018 AIChE Annual Meeting, Pittsburgh, Pennsylvania, October 29, 2018.

Sparn, B. 2021. "ENERGY STAR Residential Water Heater Specification and Test Method for Connected Residential Water Heaters" (NREL/PR-5500-79531). Presented at the 2021 Hot Water Forum, March 17, 2021.

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