



ARIES2022



Message From ARIES DOE Lead

“With an energy system that is undergoing dramatic transformations, ARIES is a flexible platform that provides the opportunity to develop and evaluate new technologies at a size and scale that matters. ARIES is critical for implementing some of our most important programs, including Clean Energy to Communities (C2C).”

Kevin Lynn, ARIES Lead and Director of Grid Modernization,
U.S. Department of Energy

See more about the recently launched C2C program on page 18.

ARIES supports the clean energy goals of the U.S. Department of Energy (DOE) to put the United States on a path to carbon-free electricity by 2035 and economy-wide, net-zero greenhouse gas emissions by 2050.



Message From External Advisory Board Member

“By 2050, Xcel Energy will provide 100% carbon-free electricity to our 3.7 million electric customers and achieve net-zero greenhouse gas emissions for our natural gas operations. We’ve also pledged to provide the infrastructure and energy to run all vehicles in our service area with carbon-free electricity or other clean energy.

To reach these goals, we need research partners specialized in integrating clean and advanced energy technologies into our electric grids. And we also need new research tools that can support development and demonstration at a real-world scale.

This is why Xcel Energy is so excited to partner with NREL and the Department of Energy in developing the Advanced Research on Integrated Energy Systems (ARIES) platform.

From preparing for the coming shift toward electrified mobility; to building in resilience and cybersecurity at every level of our operations; to identifying the best path to reach decarbonization goals, ARIES will help us to accelerate solutions for a clean energy future. We’re looking forward to what’s next.”

Alice K. Jackson, Senior Vice President, System Strategy and Chief Planning Officer
Xcel Energy



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IMPACT AT A GLANCE

Our Partners: Impact at a Glance

139 multidisciplinary research projects

\$40 million in FY 2022 funded research

12 DOE offices engaged

22 non-DOE partners. Key partners include government agencies and organizations at the federal, state, and local levels; utilities; industry and commercial organizations; and nonprofit and academic partners.

83% increase in non-DOE partnership funding since FY 2021

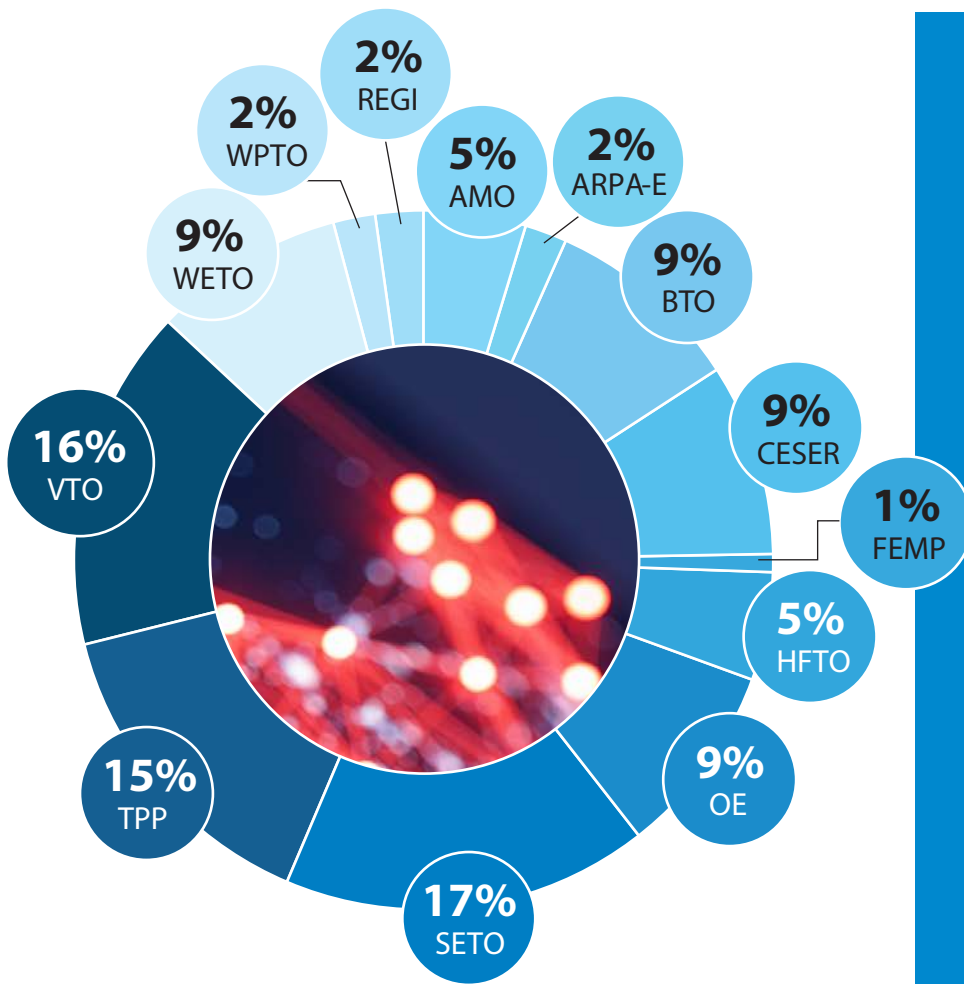
Learn more about the NREL facilities that make ARIES research possible:

Advanced Computing Annual Report

Energy Systems Integration Facility

Stewardship Summary
















Sponsors of ARIES Research Projects

- AMO** Advanced Manufacturing Office
- ARPA-E** Advanced Research Projects Agency-Energy
- BTO** Building Technologies Office
- CESER** Cybersecurity, Energy Security, and Emergency Response
- FEMP** Federal Energy Management Program
- HFTO** Hydrogen and Fuel Cell Technologies Office
- OE** Office of Electricity
- SETO** Solar Energy Technologies Office
- TPP** Technology Partnership Program
- VTO** Vehicle Technologies Office
- WETO** Wind Energy Technologies Office
- WPTO** Water Power Technologies Office
- REGI** Renewable Energy Grid Integration

ASSET TECHNOLOGY ICON LEGEND:

Look for these icons throughout the next section:

- | | |
|---|---|
|  Buildings |  Microgrid |
|  Cyber |  Power Electronics |
|  Grid |  Solar |
|  Hydro |  Storage |
|  Hydrogen |  Vehicles |
| |  Wind |



ARIES RESEARCH HIGHLIGHTS

NextGen Charging Profiles Help Minimize Grid Impacts, Cut Charging Costs

Sponsor: **VTO**



NREL is studying how environmental, grid, and vehicle conditions affect the performance of electric vehicles (EVs) and EV supply equipment. This research will minimize grid impacts and charging costs while providing new strategies for charging and energy storage integration. The evaluation data are allowing researchers to better emulate EV charging, which will lead to improvements for EVs, chargers, and charging control systems. The project results will help industry, partners, and stakeholders make critical grid-planning decisions.



U.S. Collaboration With India Uses ARIES to Redesign Power Distribution

Sponsors: DOE Office of Energy Efficiency and Renewable Energy (EERE), The Indian Ministry of Science and Technology, and Washington State University



ARIES is a key part of a joint U.S.-India project because it serves as a research platform for new designs of renewable power distribution systems. The project involves more than 30 research and industry organizations across India and the United States. The goal of the partnership is to make it easier for people in both countries and around the world to use renewable energy, storage, and smart grid technologies for remote and islanded communities. The NREL project team built a microgrid capability within ARIES to see how easy it would be for remote communities to use standardized and stable grid designs.

[Read more about this joint U.S-India project.](#)

ARIES Project Achieves a First-of-Its-Kind Milestone for Heavy-Duty Hydrogen Truck Refuel

Sponsor: HFTO



A collaboration led by DOE's Hydrogen and Fuel Cell Technologies Office (HFTO) reached a major milestone for hydrogen fueling: The team filled a hydrogen truck's fuel tank in under 10 minutes, which rivals conventional fuel times for diesel big rigs and is a 10-time improvement over current hydrogen fueling. NREL also worked with industry partners Air Liquide, Honda, Shell, and Toyota. This achievement will propel hydrogen forward by allowing industry to collaborate to develop fast-fueling protocols, safety codes, and hardware devices.

[Read more about this major hydrogen fueling milestone.](#)

Common Type of Wind Turbine Can Form the Grid—A Breakthrough for 100% Clean Energy

Sponsor: WETO



Type 3 wind turbines, one of the most used wind technologies, can now supply baseline power to the grid without requiring fossil-fueled or other resources to set grid stability. Demonstrations with GE using ARIES showed that the wind turbine can provide the sort of fundamental power necessary to anchor the grid around stable frequencies and voltages. This makes it possible for wind turbines alone to form a grid, such as when disconnected from the larger grid or in high-renewable energy systems. This also opens new value streams for wind energy participating in power systems.

[Read more about this breakthrough.](#)



ARIES Adds Hydrogen to Hybrid Power Plant to Study Flexible Generation

Sponsors: **DOE's Grid Modernization Laboratory Consortium (GMLC)** project funded in part by **WETO, HFTO, WPTO, OE**



Using ARIES, NREL and more than a dozen partners are exploring how renewable power plants can operate as a flexible energy source when paired with energy storage from hydrogen. The FlexPower project brings NREL together with other national laboratories (Idaho National Laboratory and Sandia National Laboratories) to develop a hybrid generation power plant enhanced with energy storage at NREL's Flatirons Campus. This electrons-to-molecules scheme is being evaluated in a Grid Modernization Initiative (GMI)-funded project that will reduce costs via standardization and through the possibility of scaling up electrolyzer integration. Such hybrid power plants will accelerate the adoption of variable renewable energy and hydrogen generation by proving new value streams for these resources.

[Read more about how the research will help smooth the transition to clean energy.](#)

Cyber Range Accelerates Tech to Market, Starting With Strong Authentication for Distributed Energy Resources

Sponsors: **CESER and EERE**



To understand and address security gaps in energy systems, DOE's Office of Energy Efficiency and Renewable Energy (EERE) and Office of Cybersecurity, Energy Security, and Emergency Response (CESER), sponsoring utilities Berkshire Hathaway Energy, Duke Energy, and Xcel Energy, and NREL launched the Clean Energy Cybersecurity Accelerator (CECA)—a technology accelerator program aimed at building cybersecurity into renewable energy technologies to stay ahead of evolving threats. The accelerator's first cohort, which includes Blue Ridge Networks, Sierra Nevada Corporation, and Xage Security, is validating its proposed solutions in the ARIES cyber range, which provides a safe emulated environment to evaluate cybersecurity innovations without putting customers or utility networks at risk.

[Read more about the first cohort members.](#)

Microgrid in Cordova, Alaska, Is Model for Resilient, Local Energy

Sponsors: **DOE's Grid Modernization Initiative (GMI)**, cost-shared by **City of Cordova, AK**



The city of Cordova, Alaska is enhancing the resilience of its microgrid with support from DOE's GMLC program, nine industry partners, and three other national laboratories (Idaho National Laboratory, Sandia National Laboratories, and Pacific Northwest National Laboratory). The resilience-enhancing technologies include new energy storage, new controls for its hydropower resources, and a fleet of meters, sensors, and advanced zonal controls using smart metering infrastructure to manage recovery, improve resilience, and support the city's fishing economy by serving seasonal and critical loads. Using ARIES, the city of Cordova validated its improved microgrid against plausible events, such as power loss from an earthquake or avalanche, allowing the local electric cooperative to observe and control the network with more precision. This is important for Cordova and indigenous communities throughout Alaska because microgrids are their last resort for energy, and controls make it easier to adapt during critical events.





High-Power Charging Standard Will Extend Electrification Across Transportation Sector

Sponsor: **VTO**



Electric vehicle industry experts and scientists at NREL are working on a new high-power charging standard, MCS (Megawatt Charging Systems), that will push electrification beyond passenger cars. To ensure the new standard is compatible across charging station and truck manufacturers, DOE, the California Energy Commission (CEC), and the Charging Interface Initiative (CharIN) have hosted evaluations of high-power charging connectors at NREL. These evaluation events convene manufacturers in a neutral, collaborative environment to validate their designs, discuss their approaches, and reach consensus. This helps the electric vehicle industry to quickly and safely adopt new technologies.

Grid Restoration Is Possible With 100% Renewables, As Shown in Small-Scale NREL Demonstration

Sponsor: **SETO**



NREL engineers designed a research platform with 40 Siemens inverters to show how renewable energy devices can provide resilience by recovering electricity following an outage. The platform is a small version of a realistic system—solar, battery, and wind power all connected on a distribution network and part of a project named AURORA. This project, led by Siemens and with partners Columbia University and Holy Cross Energy, can de-risk new controls for integrating more renewable energy and providing resilience.

Digital Twin Will Demonstrate Resilient Microgrid Controls Before Deployment

Sponsor: **SETO**



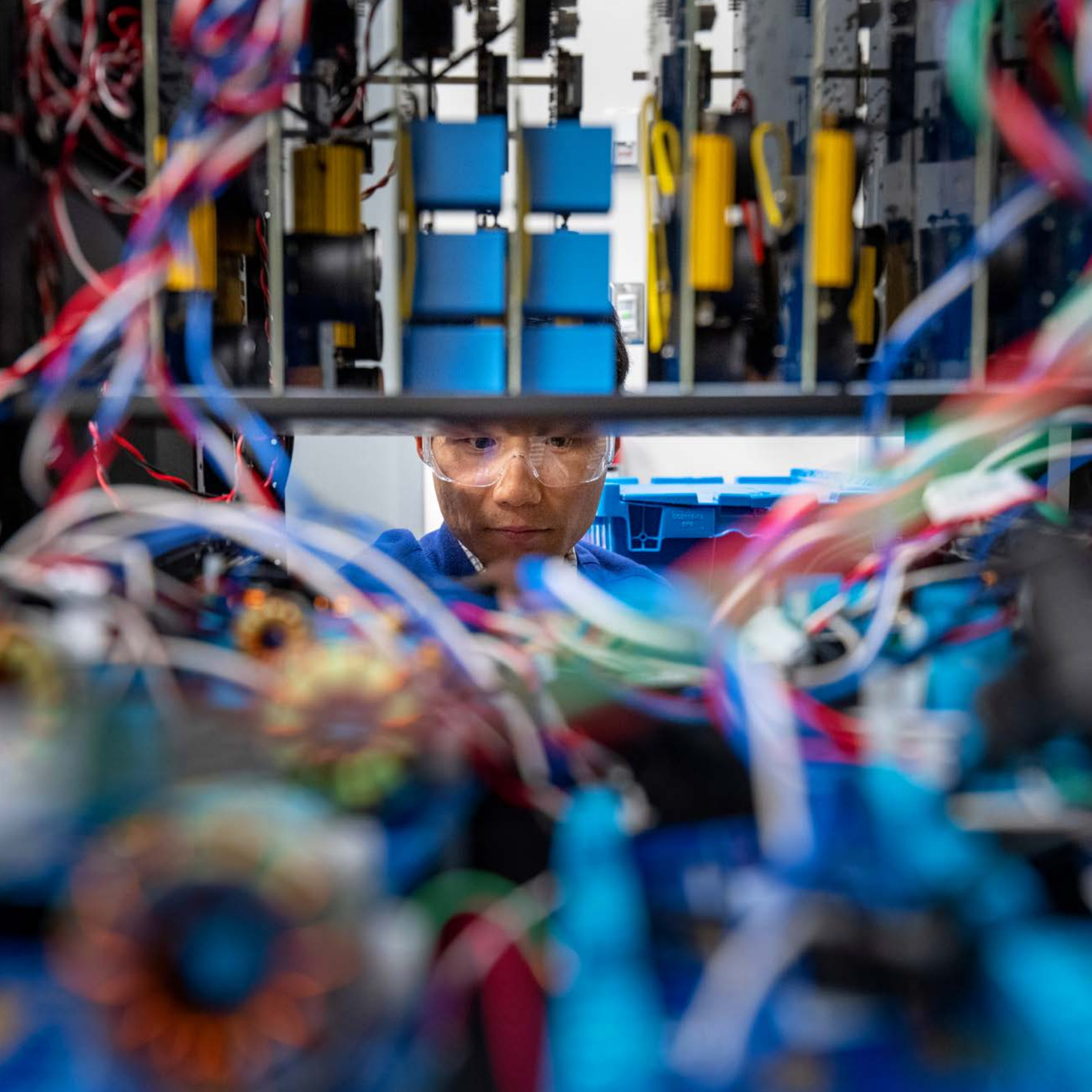
NREL and partners are developing an advanced control architecture to improve microgrid resilience and reduce downtime after disturbances. Microgrids are key factors in strengthening grid resilience because they can disconnect from the traditional grid to operate autonomously and function as a grid resource for faster system response and recovery. With ARIES assets, the team will evaluate a new control architecture by connecting a physical microgrid to power system simulations. This unique digital twin approach replicates challenges faced by utilities managing microgrids, helping them evaluate and improve their resilience strategies and deal with increasingly extreme events. Partners include utilities, industry, universities, and a state government, collaborating toward a workable architecture and example for community-scale microgrids.

Rapid and Robust Grid Recoveries Become Possible With Intelligent Algorithms

Sponsor: **ARPA-E**



An NREL-supported Advanced Research Projects Agency-Energy (ARPA-E) project could fundamentally change how large grid outages are managed by demonstrating recoveries for critical infrastructure. Using algorithms built by the University of Minnesota and NREL, this new method identifies resources that can rapidly energize and sustain the grid for long periods of time. The multiple partners on this project will soon validate their “rapidly viable grid” design on ARIES assets, showing that the method works in a replica grid environment, and preparing it for adoption where resilience is most needed on real energy systems.



LAB CAPABILITIES AND BUILDOUTS

ARIES Expands Its Hydrogen Capabilities With New 1.25-MW PEM Electrolysis System, 600-kg Ground Storage System, Hydrogen Compressor, Toyota 1-MW PEM Fuel Cell Generator, and 3.7-MW Integrated Cooling System

Collaborators: **HFTO, Toyota**

Partners and researchers can now create, store, and use hydrogen in a full grid environment. "Achieving carbon neutrality requires all of us to explore new applications of zero-emission technology, including how that technology will integrate with other systems, which the project with NREL will identify," said Christopher Yang, group vice president of Business Development, Fuel Cell Solutions, at Toyota.



Behind-the-Meter Storage at MW Scale Adds New Battery Emulator Capability

Collaborators: **VTO, BTO**

Behind-the-meter storage, electric vehicles, and building assets are having a greater impact on power distribution systems. ARIES can now emulate DC batteries and other storage systems as they appear on the grid.

Future Cyber Range Capabilities Will Expand Simulation Environment Research

Collaborators: **CESER and EERE**

With a connection to more than 20 MW of energy system hardware, the cyber range provides one of the most advanced simulation environments in the national laboratory system. The capability is being significantly expanded through fiscal years 2023 and 2024 to enhance the ease of use and autonomy for cybersecurity researchers to develop, deploy, and analyze complex cyber-physical environments.

Additional Digital Real-Time Simulators Expand Future Energy System Research*

“The digital real-time simulator allows us to replicate a real-world environment control setup and investigate how thousands or millions of grid devices will interact when they are combined on a large scale. This is an ideal way for researchers and industry partners to study future energy systems and accelerate new technology adoption,” said Rob Hovsapien, ARIES research lead in hybrid energy systems.

*Internal NREL capital investment

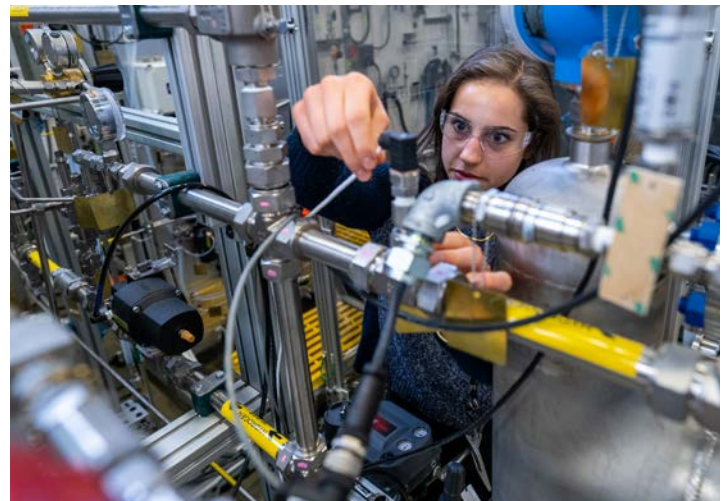
The Controllable Grid Interface 2 Team Breaks Ground, Installs All Main Components

Collaborators: **WETO, WPTO, SETO**

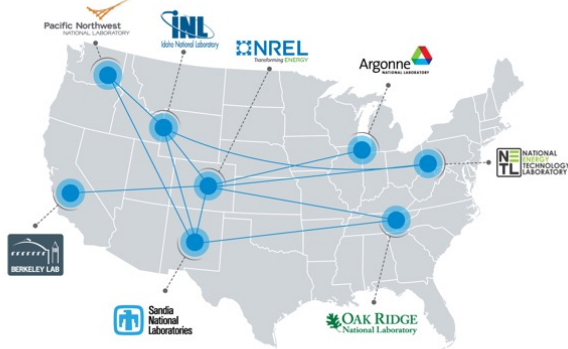
NREL’s Controllable Grid Interface (CGI) 2 will expand ARIES grid recovery and restoration research capabilities to a 20-MW capacity from the current CGI 7-MW capability. “When both CGIs are online, it will allow for new customizable research configurations as the second CGI has additional power outputs (including 5 kV DC), and you can combine the two CGIs (7 MW and 20 MW) in one experiment,” says NREL researcher Jeroen van Dam.

Electrolyzer Stack Evaluation Platform Increases Electrolysis Capabilities*

Upgrades to the electrolyzer stack evaluation platform allow researchers at NREL’s Energy Systems Integration Facility (ESIF) to collaborate with industry to evaluate integrated electrolysis systems up to 1-MW scale. Additions in the past year make hydrogen production from electrolysis more efficient and affordable.







Demonstration With Pacific Northwest National Laboratory Brings Us One Step Closer to SuperLab Vision

Collaborators: **DOE Office of Science, Pacific Northwest National Laboratory**

“ARIES and ESnet-OSCARS SuperLab enables a collaborative environment between national laboratories to accelerate the research of future energy systems,” said Rob Hovsopian, ARIES research lead in hybrid energy systems. In early FY 2022, a demonstration showed that advanced control systems in a simulated Cordova, Alaska, microgrid could enable it to maintain power to critical resources, such as the hospital, during an extreme weather event.

Read more about this multi-laboratory demonstration.

ARIES Visualization Capabilities Expand With Addition of 2D Platform

Collaborator: **EERE**

“The 2D visualization platform allows us to see the context and details of large-scale grid models of a community at the same time, as shown in this image of San Francisco. The new capabilities allow us to ask bigger questions at scale, such as, ‘What happens to the grid if 50% of houses in the San Francisco metropolitan area put solar on their rooftops?’” said Kenny Gruchalla, a senior researcher in NREL’s Computational Science Center.

Power Electronic Grid Interface Increases Evaluation Capabilities With New Built Out 2.5-MVA Synchronous Machine

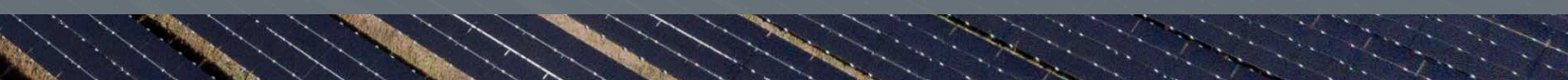
Collaborators: **SETO, WETO**

“There are so many types of grid controls for inverters. We need to know which controls are best in what situations. With the Power Electronic Grid Interface within ARIES, we have an ideal place to evaluate controls, such as upcoming grid-forming methods, alongside other resources and controls,” said Barry Mather, group manager of Integrated Devices and Systems at NREL and ARIES research lead for Power Electronics.

High-Flow-Rate Heavy-Duty Hydrogen Filling Station Instrumental in Achieving Milestone

Collaborators: **HFTO, Air Liquide, Honda, Shell, and Toyota**

NREL and industry collaborators are designing high-throughput hydrogen stations to fill heavy-duty vehicles. This year the team hit a milestone: 5 minutes and 43 seconds to refill a semitruck-sized tank—a rate 10 times faster than current fuel cell vehicle filling.



ENGAGEMENT AND OUTREACH

ARIES is engaging with communities, industry leaders, and academic partners to ensure its research and capabilities meet real-world needs. FY 2022 engagement and outreach activities included:

- Hosting and introducing ARIES capabilities to U.S. government leaders and dignitaries from around the world
- Meeting and consulting with the External Advisory Board, made up of 14 members with utility, industry, academic, and governmental perspectives
- Presenting ARIES capabilities at various energy conferences and regional/community events
- Soliciting an ARIES Advanced Distribution Management System (ADMS) Test Bed user call that brought in 4 new partners for 2 projects to evaluate leading-edge management solutions for the electric grid
- Connecting research capabilities and assets with other national laboratories
- Engaging communities to support their energy transition strategies.





Most Downloaded ARIES Publications

1. *Electrification of Aircraft: Challenges, Barriers, and Potential Impacts*
2. *Photovoltaic Plant and Battery Energy Storage System Integration at NREL's Flatirons Campus*
3. *A Roadmap Toward Sustainable Aviation Ecosystem*



LOOKING AHEAD

“How will our energy system change?” This question resounds for systems large and small, simple and complex. It’s new terrain for everyone, but many companies, communities, and energy leaders are now finding their footing with ARIES. The research capabilities here can prepare us for power systems of the future by emulating the world outside, and upcoming partnerships will show what is really possible with ARIES.

National

ARIES will be the proving ground for concepts that can transform community energy systems. On January 18, 2023, Secretary Granholm launched DOE’s [C2C program](#) at the Conference of Mayors. C2C will provide up to \$50 million in funding to help local governments, utilities, and community-based organizations achieve their clean energy goals. Participants in C2C will use ARIES to leap from idea to implementation in their respective energy transitions.

International

The country of Lithuania is transitioning to 100% renewable energy, and to achieve this extraordinary goal, the government will use ARIES—the only platform able to integrate and validate all of its options for clean, safe, and equitable energy.

Similarly, utilities are relying on ARIES to deploy upcoming technologies—first on a risk-free replica grid with ARIES and then live. The Israel Electric Corp. is one example. The utility is collaborating with NREL to improve its power restoration and fault identification approach.

This is where energy alternatives come to life. The bold strategies being pursued by partners are within reach because of ARIES, where experiments are unconstrained by limits on power or computation and can push as far ahead as technology permits. With so many options to transform energy around the world, we look forward to what’s ahead with ARIES.



ADVISORY COMMITTEES

ARIES Steering Committee

The ARIES Steering Committee comprises the DOE Office of Energy Efficiency and Renewable Energy and NREL executive leadership. This committee meets quarterly and has oversight of and responsibility for ARIES research and development management, research impact, and financial and business practices.

ARIES External Advisory Board

The ARIES External Advisory Board provides an external perspective from industry, academia, and other government agencies/programs to NREL, DOE, and EERE on the research direction, on the RD&D gaps that ARIES should address, and on the development and deployment of the ARIES research platform.

External Advisory Board Members

Chair: Gary Smyth

Executive Director, Global R&D Laboratories
General Motors (retired)

Jeffrey Baumgartner

Vice President, Security and Resilience
Berkshire Hathaway Energy

Colton Ching

Senior Vice President, Planning & Technology
Hawaiian Electric Company

Lauren Faber O'Connor

Chief Sustainability Officer
Office of Los Angeles Mayor

Paula R. Glover

President
Alliance to Save Energy

Christopher Herbst

Vice President, Strategic Partnerships
and Innovation
Eaton

Robert Horton

Vice President, Environmental
Affairs and Sustainability
DFW Airport

Alice K. Jackson

Senior Vice President, System Strategy
and Chief Planning Officer
Xcel

Danielle W. Merfeld

Vice President and Chief Technology Officer
GE Renewable Energy

Teresa R. Pohlman

Director, Sustainability and Environmental
Programs
U.S. Department of Homeland Security

Ronald M. Segal

Chief Technology Officer
U.S. Army Futures Command

Emma Stewart

Chief Scientist
National Rural Electric Cooperative
Association

Timothy D. Unruh

Executive Director
National Association of Energy
Service Companies

Evan Wolff

Partner
Crowell and Moring LLP

Steering Committee Members

U.S. Department of Energy

- **Alejandro Moreno**, Acting Principal Deputy Assistant Secretary for the Office of Energy Efficiency and Renewable Energy
- **Michael Berube**, Deputy Assistant Secretary for Sustainable Transportation
- **Kevin Lynn**, ARIES Lead and Director of Grid Modernization
- **Derek Passarelli**, Golden Field Office Director
- **Carolyn Snyder**, Deputy Assistant Secretary for Energy Efficiency

NREL ARIES Team

- **Peter Green**, Deputy Laboratory Director-Science and Technology
 - **Johney Green**, Associate Laboratory Director
 - **Juan Torres**, Associate Laboratory Director
 - **Jennifer Kurtz**, ARIES Research Director and Center Director
 - **Jerry Davis**, ESIF and ARIES Laboratory Program Manager
 - **Jennifer Palmer**, ARIES Research Advisor and Technical Coordinator
- Rob Hovsopian, Matt Thornton, Ben Kroposki, Keith Wipke, Daniel Laird, Jennifer King, Steve Hammond, Murali Baggu, Vahan Gevorgian, Robb Wallen, Emanuel Mendiola, Przemyslaw Koralewicz, John Farrell, Andrew Meintz, Barry Mather, Jon White, Chad Blake, Panos Datkos, Greg Martin, Steve Nixon, Bridget Ford, Kim Van Becelaere, Mackenzie Reed, Jill Coughlin, and Anna Garcia.



NREL works with organizations—large and small—to expand the clean energy economy. You can partner with ARIES to accelerate renewable energy and energy-efficient solutions into practical applications. Watch for opportunities to work with us on the [ARIES webpage](#) or email us at ARIES@nrel.gov to discuss your project.



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