August 20, 2014 – Participants take a ride in a Mercedes-Benz B Class F- Cell car at a Ride and Drive Event held at the NREL. *(Photo by Dennis Schroeder/NREL)*

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

The world turns on energy; it powers everything from computers to rockets, and its availability, generation, and use have become international concerns. What are the environmental implications? What does a clean, sustainable energy future look like? As one of the U.S. Department of Energy's primary laboratory for renewable energy and energy efficiency research and development, the National Renewable Energy Laboratory (NREL) is tasked with offering solutions to the world's energy challenges.

NREL focuses on advancing breakthroughs in fundamental science, innovating new technologies, integrating energy systems, and advancing related engineering. The lab receives about $380 million a year in funding, yet contributes more than $870 million in economic impacts nationally according to a recent study conducted by the Business Research Division at the University of Colorado's Leeds School of Business.

NREL has a unique, world-class workforce. The staff at NREL is highly educated, with 31% holding doctorate degrees and another 32% with master's degrees. With NREL located in Golden, the majority (98%) live in Colorado's metropolitan Front Range counties. The staff includes citizens from 55 countries, with the majority (57%) contributing in core research and development. The NREL staff grew by 5.5% in 2013 and 6.6% in 2014.

NREL draws a host of visitors, primarily for business and science and technology related meetings. In 2014, NREL hosted more than 24,700 visitors. Visitor spending totaled over $1.2 million in 2014 alone. On top of NREL's economic contributions, the Education Center at NREL hosts youth programs, community programs, and other guests who are seeking to learn about the exciting ways that NREL is helping address world energy problems through scientific research.

One of the most recent contributions to this effort was via the 2013 launch of the Energy Systems Integration Facility (ESIF), which aids in the research of clean energy technology integration into existing energy infrastructure. This facility has already produced large successes, and is expected to continue to positively impact clean energy integration. In 2015, ESIF will examine a convergence of electric power and transportation with Toyota. ESIF was named Laboratory of the Year by *R&D Magazine* editors in 2014, an esteemed award for the most important technological innovations.

NREL frequently partners with other organizations in this way, and has nearly 300 partnership agreements with industry. Under these collaborative relationships, technology is often transferred for commercialization and use in the private sector. As of 2014, a total of 166 new technologies were transferred from NREL. In fact, NREL

has been awarded 40 technology transfer awards since 1997, aided 30 clean-energy startups, and issued over 440 U.S. patents. These collaborations and transfers enable hundreds of companies each year to develop clean energy technology, creating benefits beyond the lab itself.

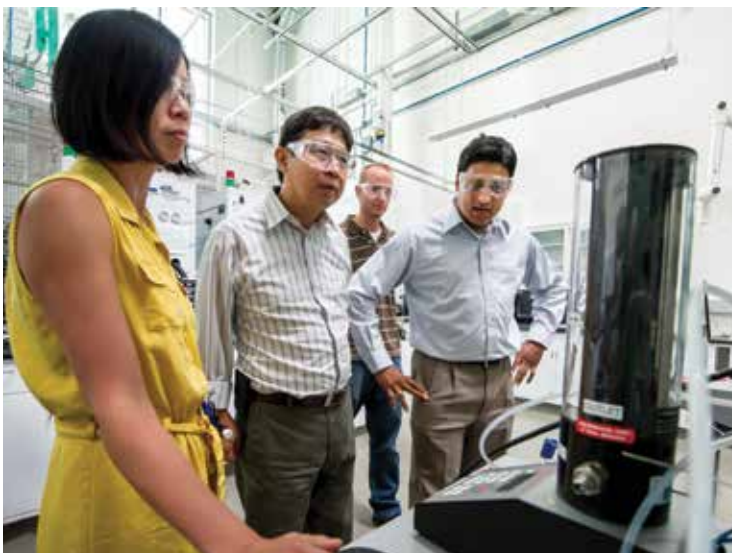
The Industry Growth Forum (IGF), hosted annually by NREL, is one of the longest-running events held in the clean technology sector. Presentations from 30 emerging clean energy companies are featured at the IGF each year, and are awarded commercialization services from NREL. The IGF provides these companies, as well as clean technology venture capitalists, investment bankers, and business development executives with the opportunity to collaborate on developing clean energy at companies around the world.

NREL has earned hundreds of awards that recognize its contributions to furthering clean energy technology. This includes 57 prestigious R&D 100 awards from *R&D Magazine,* 95 scientific and technical society awards and honors, and 49 agency awards. NREL produces some of the most innovative and important clean energy research in the world. On top of its multimillion dollar annual economic impact, the lab will continue to produce monumental technology to improve our lives and advance our clean energy future.

NREL is operated for DOE by The Alliance for Sustainable Energy, LLC.

Above: September 4, 2014 - L-R, Daniel Rowe (CSIRO-Senior Research Scientist) and NREL engineers, Mariko Shirazi and Blake Lundstrom, work on SmartGrid testing at the Power Systems Integration Lab (PSIL) at the NREL Energy Systems Integration Facility (ESIF). *(Photo by Dennis Schroeder/NREL)*

Below: July 23, 2014 - L-R, NREL scientist Huyen Dinh, Paul Yu, Eric Bonn, and Balsu Lakshmanan, all from General Motors (GM) view the instruments in the Fuel Cell Development and Test Lab at the ESIF. GM and NREL are working together in a Cooperative Research and Development Agreement project.
(Photo by Dennis Schroeder/NREL)



September 6, 2011- NREL researcher Grant Balzer, a member of the OPX ARPA-E team, sub cultures strains of metabolically engineered bacteria for biodiesel production at NREL's bioscience research lab. *(Photo by Dennis Schroeder/NREL)*

BIOFUELS: PARTNERING TO GROW A BIOFUELS SUCCESS STORY

The Partners

OPXBIO, a Boulder, Colorado company aiming to create bio-based chemical products to replace petroleum-based ones, in 2010 partnered with the National Renewable Energy Laboratory (NREL). Its mission was to develop a bioprocess for the conversion of carbon dioxide and hydrogen gas feedstock to fatty acids and renewable fuels for a U.S. Department of Energy (DOE) Advanced Research Projects Agency-Energy (ARPA-E) project.

Johnson Matthey, a multinational specialty chemicals and clean technologies company headquartered in the United Kingdom, also participated in the project. ARPA-E provided $6 million in grants and OPXBIO added $2 million to the DOE-sponsored project that concluded in 2013.

Biodiesel Innovation

During the ARPA-E project, OPXBIO perfected its Efficiency Directed Genome Engineering (EDGE) technology. The EDGE technology was employed to develop microbes that can efficiently utilize hydrogen and carbon dioxide to produce a bio-based diesel fuel.

The processing developed by OPXBIO, NREL, and Johnson Matthey starts with hydrogen and carbon dioxide. The carbon dioxide supplies the carbon, which is the backbone of the fuel molecule, and the hydrogen supplies the energy. The gases are mixed in a large bioreactor with the microbe, and the microorganism takes up the gases and converts those directly to a diesel molecule. The diesel molecule can be used as biodiesel or upgraded with a catalyst to produce traditional diesel or jet fuel.

EDGE allows OPXBIO to bioengineer methods for redesigning genetic microbes at a rate 5,000 times faster than any conventional bioengineering method. It removes the need for random genetic changes and replaces it with the ability to purposefully program the desired genetic code in a microbe. EDGE allowed OPXBIO to develop the microbe to make BioAcrylic at commercially viable rates in two years, while conventional technologies would have taken about five years.

The ARPA-E program provided OPXBIO with funding and an opportunity to work with NREL's experts to develop and refine its technology. In 2010, OPXBIO presented at NREL's 23rd Industry Growth Forum where it won the Outstanding Venture Award.

Research Collaboration

For NREL scientists, the chance to work with OPXBIO's microbe was an opportunity to grow research in a new direction. "This project will enable NREL to gain expertise on this unique microbe that can use hydrogen, carbon dioxide to create a new direct drop-in fuel, meanwhile OPXBIO can take advantage of NREL's in-house expertise in microbial hydrogen and carbon dioxide metabolism," NREL principal scientist Pin-Ching Maness said.

OPXBIO has national influence and grown to 65 employees with offices located in Boulder, Colorado. It ranked in the top 15 Hottest Companies in Biobased Chemicals according to Biofuels Digest for 2013–2014. OPXBIO has raised more than $50 million in equity investment and project funding since 2010. Additionally, the company has entered into joint development agreements with industry partners and has positioned itself for the commercial launch of its first bio-based chemical products in 2016.

In April 2015, Cargill, a global supplier of carbohydrates and other biotech offerings, acquired OPXBIO's fermentation-based processes and systems. As reported in Biofuels Digest, "This sale of OPXBIO's technology to Cargill demonstrates the great progress OPXBIO has made towards product commercialization," said Mike Rosenberg, CEO of OPXBIO. "Cargill has all the right capabilities and experience to deliver products produced from OPXBIO's technology to customers."

Above: September 6, 2011- NREL staff scientist Carrie Eckert, a member of the OPX ARPA-E team, measures hydrogen production of engineered microbe in a gas chromatograph at the NREL bioscience research lab. To the right is principal scientist Pin Ching Maness and scientist Jianping Yu. *(Photo by Dennis Schroeder/NREL)*

Below: September 6, 2011- NREL researcher Ryan Sullivan, a member of the OPX ARPA-E team, screens for improved enzymatic activity to improve biodiesel productivity at the NREL bioscience research lab. *(Photo by Dennis Schroeder/NREL)*

April 22, 2014 - The 4.7 MW of solar photovoltaic array provides power at Ft. Carson Army Base in Colorado Springs, Colorado. *(Photo by Dennis Schroeder)*

NREL'S PARTNERSHIPS WITH DOD SUPPORT NATIONAL ENERGY SECURITY AND TRANSFORM U.S. ENERGY ECONOMY

Energy Security, Environmental Stewardship

The National Renewable Energy Laboratory (NREL) and the U.S. Department of Defense (DOD) work together on energy efficiency, renewable energy, and energy systems integration projects that make significant strides toward achieving DOD's energy goals. These projects demonstrate technologies with potential for broad market adoption.

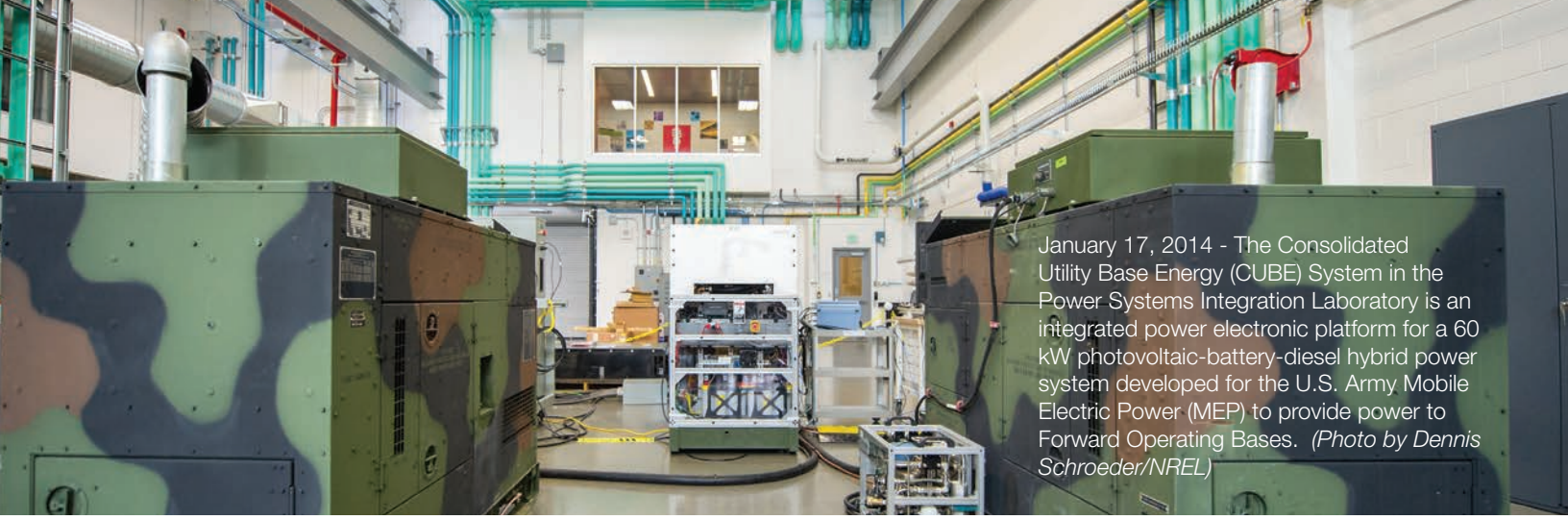
The DOD comprises all four branches of the armed services—Army, Navy, Air Force, and Marines—and is the single-largest consumer of energy in the world, spending nearly $19 billion annually. Its mission is to "provide the military forces needed to deter war and to protect the security of our country." This goal requires operational energy, facilities energy, and energy-related elements of mission assurance. Realizing the value of clean energy is found in cost effectiveness and the power to secure the nation, the DOD's energy policy focuses on reducing energy costs, decreasing reliance on foreign oil, ensuring energy security and resiliency, and achieving sustainability goals.

In alignment with NREL's mission to address the nation's energy and environmental goals, the lab transfers knowledge and creates partnerships for market relevant technologies. NREL's strategic partners are important as they often provide prototype manufacturing and pathways to energy markets for greater impact on the U.S. energy economy. The lab's capabilities in energy innovation support DOD branches in areas including strategic energy management, renewable energy generation, energy efficiency, microgrids, and energy storage.

Strategic Energy Management

NREL offers expertise in developing decision-support software tools complementing DOD's focus on strategic energy management. These tools enhance the department's energy management planning capability, providing an integral first step to measurement and centralized energy performance reporting.

A key tool supporting DOD's strategic energy management is NREL's Renewable Energy Optimization (REopt) tool. REopt is an energy planning platform offering concurrent, multiple technology integration and optimization capabilities to help clients meet their cost savings and energy performance goals. REopt is currently being used to perform analysis for the Marine Corps and the Army Energy Initiatives Task Force. The Navy also hired NREL to screen all of its sites for potential renewable energy project opportunities with the goal of half of sites reaching net zero by 2020. From that analysis, the Navy chose its top project prospects for further development.



January 17, 2014 - The Consolidated Utility Base Energy (CUBE) System in the Power Systems Integration Laboratory is an integrated power electronic platform for a 60 kW photovoltaic-battery-diesel hybrid power system developed for the U.S. Army Mobile Electric Power (MEP) to provide power to Forward Operating Bases. *(Photo by Dennis Schroeder/NREL)*

Renewable Energy Generation

The DOD's goal is to have 25% of the energy it uses come from renewables by 2025. To help the DOD reach this goal, the U.S. Department of Energy (DOE) and NREL are aiding in the establishment of "net zero energy installations," or NZEIs, which produce as much energy on-site as its buildings, facilities, and fleet vehicles consume on an annual basis. The U.S. Marine Corps Air Station (MCAS) Miramar in California is one example of a NZEI. The DOE and NREL performed an assessment at MCAS to evaluate the potential for achieving energy reduction goals. MCAS Miramar is now on track to achieve a 43% reduction in facility source Btu through base-initiated projects. NREL developed an additional plan that would allow the base to achieve a 90% reduction by 2017 if all recommendations are implemented.

The Army partnered with NREL to optimize renewable energy strategies at nine installations in its portfolio. Results indicated that if all nine of the Army NZEI pilot sites achieve net zero energy, they would replace approximately 8% of the Army's current total installation energy use with renewable energy. In fact, if all Army installations worldwide were to achieve a 25% reduction in energy consumption, as the NZEI pilot sites can, the Army would save approximately 20 trillion Btu and up to $300 million in annual energy costs. The findings from NREL's collaboration with the Army are detailed in the report, *Army Net Zero Energy Roadmap and Program Summary.*

The NZEIs studied by NREL resulted in the production of a comprehensive report, *Net Zero Energy Military Installations: A Guide to Assessment and Planning,* which suggests employed technologies have potential for replication across the entirety of the DOD and other federal agencies. This report sets the stage for broad market adoption of such technologies.

Operational Energy

Nearly 75% of energy use across the DOD is derived from operations that include energy required for training, moving, and sustaining military forces and weapons platforms for military operations. In its focus on providing solutions that ensure access to reliable supplies of energy for operational needs while minimizing fuel delivery risks in the field, NREL, under a research agreement with Wyle Labs, is working with the Army to develop the Consolidated Utility Base Energy (CUBE) System—a solar, battery, and generator hybrid power system. The CUBE is intended to provide electricity to forward operating bases.

Army's Mobile Electric Power and Rapid Equipping Force funded a prototype CUBE system to validate its performance, reliability, and projected fuel savings through a fully integrated test at the DOE's Energy Systems Integration Facility (ESIF) on the NREL campus. The project aims to create a more resilient and reliable microgrid designed to protect against extended power outages caused by natural disasters, accidents, or attacks—and, ultimately, to enhance electric power security for the nation. Testing is performed in the ESIF's Power Systems Integration Laboratory, which contains an environmental chamber that provides expanded testing capabilities.

Technology Demonstration and Commercial Market Viability

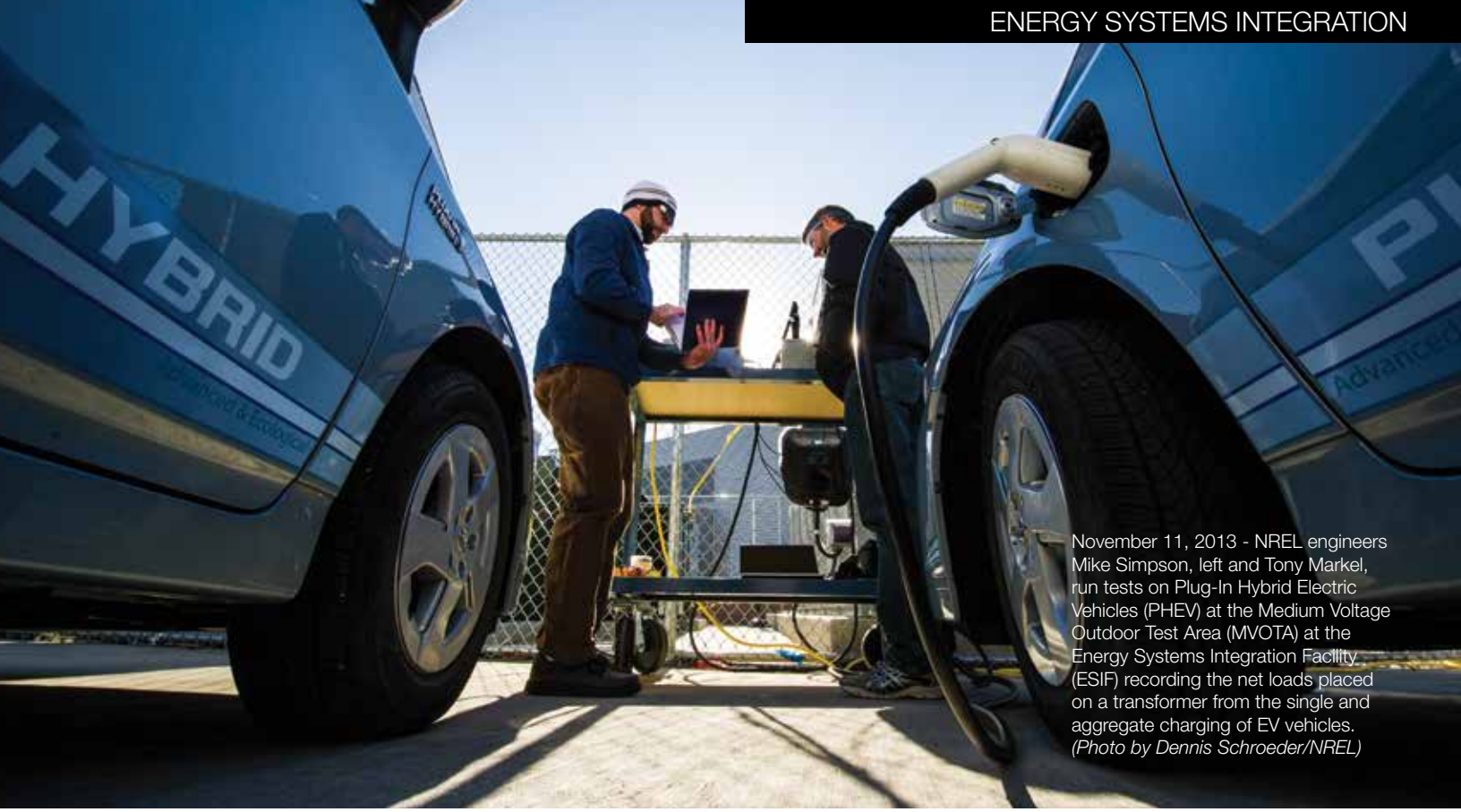
In 2011, NREL partnered with the Navy as part of a project focused on improving energy security. The investment was targeted at near-commercial technologies that would prove cost-efficient for the Navy. The scope of the project was to demonstrate technologies to reduce Navy energy use at installations in Hawaii and Guam. NREL worked with Navy to demonstrate eight technologies renewable energy generation, efficiency, and integration.

As part of this technology transition, NREL is working with key stakeholders to support industry commercialization of the cost saving technologies. This effort has the potential to create a diverse market of suppliers, increase U.S. jobs, and ultimately help to transform the U.S. energy economy.

Support National Energy Security and Transform U.S. Energy Economy

The missions of NREL and the DOD complement one another: "The military's mission is operational excellence, and the cost of energy has been a huge variable that they can't predict," said NREL's DOD Energy Program Director Steve Gorin. "In the case of NREL, our mission is to innovate and to work with others to get technologies out there and transform the energy economy. Put the two together, and you have an early adopter with a huge market working alongside an energy innovator."

Leeds School of Business
UNIVERSITY OF COLORADO BOULDER
BUSINESS RESEARCH DIVISION



November 11, 2013 - NREL engineers Mike Simpson, left and Tony Markel, run tests on Plug-In Hybrid Electric Vehicles (PHEV) at the Medium Voltage Outdoor Test Area (MVOTA) at the Energy Systems Integration Facility (ESIF) recording the net loads placed on a transformer from the single and aggregate charging of EV vehicles. *(Photo by Dennis Schroeder/NREL)*

NREL'S ENERGY INTEGRATION PARTNERS HELP TO ADVANCE CLEAN ENERGY DEPLOYMENT

Exploring Energy Systems Integration

The National Renewable Energy Laboratory (NREL) is primarily known for its research in renewable energy and energy-saving technologies—solar and wind power, biofuels, and efficient buildings and vehicles. In addition, since 2013 the laboratory has focused on integrating clean energy technologies and energy infrastructure. To support this important research the Energy Systems Integration Facility (ESIF) was brought on line. During ESIF's first year of operation, research collaborations have already made an important impact on clean energy deployment.

New Research Capability

The ESIF provides NREL's partners with tools necessary to evaluate the performance of new equipment under real-world conditions via grid simulation. This is accomplished by looping buses carrying high-voltage alternating-current (AC) and direct-current (DC) power throughout the building and monitoring them in a utility-style control room, complete with a supervisory control and data acquisition system— the same type of control system used by utilities and grid operators. A power-hardware-in-the-loop (PHIL) capability allows the hardware to be connected to a software simulation. The ESIF includes a thermal distribution bus, integrated fuel distribution buses, and specialized laboratories.

Modernizing the Grid

This kind of utility-scale electrical research facility is ideal for testing advanced inverters that convert the DC power of solar panels, fuel cells, and batteries into the AC power used by the grid. Moreover, advanced inverters include special features for grid support, such as the ability to stay connected to the grid when the grid voltage momentarily sags. Both Advanced Energy and Solectria tested advanced inverters with capacities as great as 1 megawatt (MW) at the ESIF, and Advanced Energy used the ESIF's PHIL capability.

NREL used the testing to develop preliminary test procedures for advanced inverters, which provided valuable guidance to various national standards-development efforts aimed at easing the integration of high penetrations of distributed resources. Additionally, NREL is collaborating with Alstom Grid to implement a comprehensive modeling, analysis, visualization, and hardware study of smart inverters using a representation of a Duke Energy feeder line. In 2015, NREL will evaluate inverters submitted to Google's Little Box Challenge, which aims to inspire the creation of smaller, more efficient, and less costly inverters, potentially spurring more solar power installations.

In addition to testing inverters, NREL is also helping to put them to good use. Research with SolarCity—the nation's largest solar power provider—and the Hawaiian Electric Companies (HECO) is examining how advanced inverters can provide grid support that would ease

Left: January 23, 2014 - Employees work in the control room at the ESIF.

Below: August 19, 2014 - Partners, American Vanadium, tour their cell cube flow battery in an NREL lab at the Energy Systems Integration Facility (ESIF). *(Photos by Dennis Schroeder/NREL)*

concerns about the impacts of high penetrations of photovoltaic (PV) power on reliability. Based on preliminary results from this testing, HECO is now accepting new applications for home PV systems in areas with high penetrations of PV power. This will allow at least 2,500 additional customers to connect their solar power systems to the grid by April 2015.

Ametek, the leading supplier of grid simulators for photovoltaic inverter testing, supplied 12 of its grid simulators to the ESIF to create a 1-MW grid simulator. When the simulators suffered some reliability issues, NREL worked with Ametek to identify the root cause of the failures and resolve the issues. The system improvements that Ametek made were carried forward into its product line to ensure a much more reliable system going forward.

Both minigrids and microgrids are seeing increased utility interest because of their ability to either connect to a larger grid or operate independently. Control systems for these new grid solutions, however, are still in their infancy. To advance this technology, NREL partnered with Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) to develop a solar microgrid controller that will recognize when new solar power is introduced to the grid. This plug-and-play technology will allow newly connected solar generation to be automatically "discovered" and configured by the main generation control system. NREL created an interconnected microgrid system at the ESIF to test the hardware's ability to manage the output power of a diesel generator in the presence of a load bank and solar simulator.

Utility Simulations

In 2015, NREL will work with San Diego Gas & Electric to examine the potential to form islanded microgrids—small portions of the grid that can operate independently of it—by adding energy storage and a control system to areas with high penetrations of PV power. This approach improves reliability by keeping the microgrids operating during a grid outage. The study will examine control systems and optimal energy storage and placement.

NREL has also worked with Wyle Labs and the U.S. Army to develop a mobile minigrid for the Army's forward operating bases. Called the Consolidated Utility Base Energy System, it combines solar panels and diesel generators with battery storage to deliver a 31% savings on diesel fuel, a significant benefit when fuel is transported through potentially hostile territory.

Research Collaborations

Along with advanced inverters and minigrids, energy storage, battery storage in particular, is of growing interest to the utility industry, especially in regions with high penetrations of renewable energy. To help advance energy storage technologies, NREL is working with American Vanadium to test and develop its CellCube flow battery, which employs vanadium in redox reactions. Flow batteries have the advantage of capacity that is determined by the size of the tanks that hold the electrolyte, so they can be scaled up to a large size relatively cheaply.

The ESIF is also examining an important convergence of two energy domains that, until recently, were entirely separate: electric power and transportation. In collaboration with Toyota Motor Engineering & Manufacturing North America, the ESIF is testing the impact of a high-penetration deployment of plug-in hybrid electric vehicles on the power grid. The testing has confirmed the levels at which vehicle loads begin to affect power quality on the distribution grid.

NREL and General Motors (GM) are partnering on a multiyear, multimillion-dollar joint R&D effort to lower the cost of automotive fuel cell stacks. Several fuel cell test stands from GM have been installed in the ESIF and will be used by both NREL and GM researchers for fuel cell development efforts.

NREL INDUSTRY GROWTH FORUM LEADS CLEAN ENERGY PROGRESS

Leading the Cleantech Dialog

For 20 years, NREL's annual Industry Growth Forum (IGF) has attracted entrepreneurs and leaders in cleantech investment and industry, all seeking strategic investments and partnering opportunities.

The IGF has emerged as one of the nation's premier clean energy investment events. Each year it features presentations from 30 emerging clean energy companies, provocative panels led by thought leaders, and networking opportunities for attendees.

"The IGF has a proven track record of success for both our entrepreneurial and investor communities," said NREL Project Manager Kate Cheesbrough. "We have one of the longest running events in the cleantech sector and have built a solid reputation for putting together a very high quality roster of startup companies, which makes it an event not to be missed by top investors."

NREL Commercialization Partnerships

As part of NREL's Innovation and Entrepreneurial Center, IGF contributes to the mission of advancing renewable energy and energy efficiency technologies through support of the entrepreneurial community. In this spirit, the best IGF presenters are awarded commercialization services through NREL's Commercialization Assistance Program (NCAP).

Recent winners include:

- **HiQ Solar, Inc.** (Santa Clara, California) received the top prize, the Best Venture award, for developing a new generation photovoltaic string inverter, which promises to reduce the cost of commercial solar installations.
- **ClearCove Systems** (Rochester, New York) earned an Outstanding Venture award for its efforts in renewable energy resource recovery in wastewater treatment processes.
- **Wetzel Blade** (Pflugerville, Texas) took home an Outstanding Venture award for creating in innovative, field-assembled, component-based wind turbine blade.

The IGF has a significant economic impact, attracting starts, participants, and investors from all over the world. Our process is a proven success—the presenting cleantech companies have collectively raised more than $5 billion in growth financing since 2003.

IGF Continues to Support Emerging Technologies

The next IGF will feature presentations from 30 emerging clean energy companies, provocative panels led by thought leaders, one-on-one meetings, and organized networking opportunities. It will follow a tradition that recently included representatives from companies that convert biomass into biomethane for conversion to renewable electricity, improved photovoltaic cells, and created high-capacity cathodes for lithium ion batteries.

"The union of research and development successes with a receptive investment community will accelerate renewable energy and energy efficiency technology innovations into the marketplace," said Bill Farris, NREL associate laboratory director.

NREL continues to grow the legacy of the IGF and build industry partnerships that reach the marketplace, solve energy problems, and improve lives.

Above: Lutz Henckels, HIQ Solar, Inc. gives his company presentation to a panel of industry experts and investors at the 27th Industry Growth Forum in Denver, Colo. HIQ Solar, Inc. received the Best Venture award. *(Photo by Dennis Schroeder/NREL)*

Leeds School of Business
UNIVERSITY OF COLORADO BOULDER
BUSINESS RESEARCH DIVISION