NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Continuum MAGAZINE

Clean Energy Innovation at NREL

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Spring 2011 | Issue 1 Vol. 1

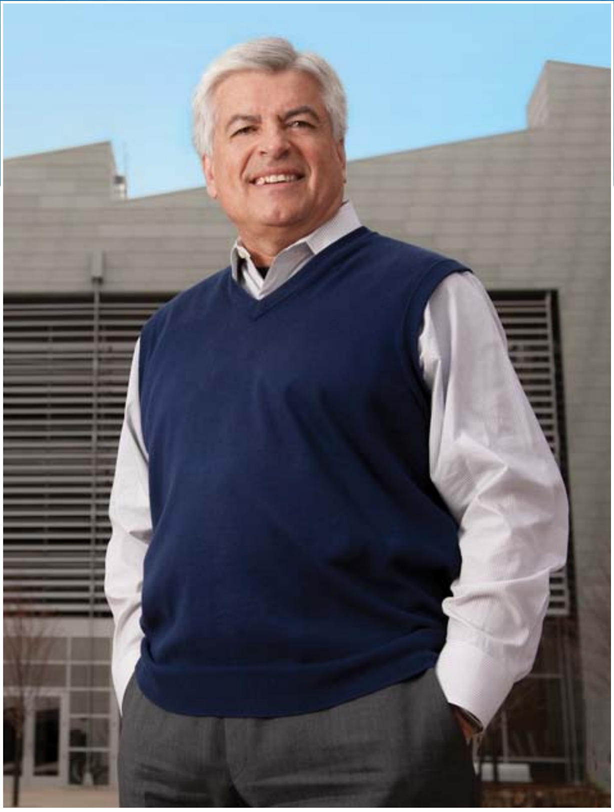
The Utility-Scale Future

New Facility to Transform
U.S. Energy Infrastructure

Wind Innovation Enables
Utility-Scale

Leading Solar Expertise –
A Launch Pad to the Future

Dan Says



A New Magazine for a New NREL Era

As NREL evolves in its mission to help lead the nation toward a clean energy future, efforts are evolving as well to communicate our successes along the way. What you're reading today is the inaugural edition of an exciting new webzine and magazine dedicated to stepping beyond the technical journals to reveal the laboratory's vital work in a real-world context for important stakeholders near and far. With each quarterly issue, Continuum will provide incisive insights into the latest and most impactful clean energy innovations, while spotlighting those talented researchers and unique facilities that make it all happen.

Over its 33-year history, NREL has been in on the ground floor of most all of the technologies employed by today's growing renewable energy industries. So it is especially gratifying that we now are working to ensure that those technologies can be deployed and utilized at the scale required to truly really make a difference for the nation. Read on and you'll learn how NREL's wind energy and solar energy research has helped those respective technologies achieve the utility-scale prominence they hold today.

And as these technologies become ever more mainstream, our laboratory is increasingly engaged in an essential next step: finding ways to maximize reliance on renewable resources like the sun and wind, while at the same time maintaining the fundamental reliability and cost-effectiveness of the present-day electricity grid. NREL's much-anticipated Energy Systems Integration Facility—with its own high-performance computing center—will offer first-ever, grid-scale modeling capabilities that will allow NREL and utility researchers to simulate the real-time ebb and flow between various electricity generation systems and the fluctuating demands of electricity consumers.

With this and future issues, I hope you find Continuum provides both a compelling and a useful look into NREL's ongoing contributions to our collective energy future.

Dr. Dan E. Arvizu
Director
National Renewable Energy Laboratory

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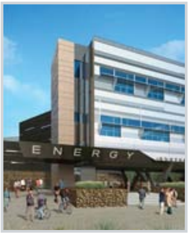


Articles

Energy Systems Integration Facility to Transform

U.S. Energy Infrastructure

Energy Systems Integration Facility (ESIF)

The nation's electricity infrastructure needs a 21st century overhaul. NREL's newest research facility will lead the way.

ESIF will house a variety of research that aims to overcome challenges related to interconnnection and integration of renewable energy onto the electric grid.

Everyone knows that Thomas Edison invented the light bulb. But not many know that one of his greatest inventions was not the invention itself, but the research laboratory from whence it came. Edison's original research and development laboratory in Menlo Park, N.J., was the first of its kind and revolutionized the process of technological research.

Later, the fusion of business and technology achieved at his West Orange, N.J., facility provided a model for modern corporate and governmental research, development, and testing laboratories. It was there that Edison tested the basis for making the generation and distribution of electricity commercially feasible.

Now, more than a century after the electric age began, our nation's electricity generation, transmission, and distribution infrastructure is poised for a 21st century hi-tech overhaul. Enabling the integration of renewable energy, more efficient utilization of existing production technology, advanced communications and controls, and information technology on our nation's aging grid require unique capabilities that are not found in today's energy infrastructure.

This presents a number of challenges that need to be overcome. To do so will require a dedicated facility that can carry out research, development, and megawatt-scale testing of critical transmission and distribution-level components of future electric supply and demand systems.

Enter the Energy Systems Integration Facility (ESIF).

Nearly four years in the making, the ESIF will enable complex multi-system research, development, validation and testing by fully integrating advanced simulation and data analysis. Complex system modeling and simulation with hardware validation at megawatt-scale powers is the unique feature of the ESIF, which is funded by the U.S. Department of Energy (DOE). This will provide laboratory assets required to transform the electricity system by collapsing the time from innovation to market and enabling deployment speeds and scales commensurate with national objectives.

Importantly, this partnering facility will provide industry partners the opportunity to work with DOE's National Renewable Energy Laboratory (NREL). They will also be able to insert their individual technologies into a controlled integrated energy system platform to test and optimize the technologies to reduce the risk of early market penetration.

"ESIF will do something different. It will fill research gaps and provide a national focal point for systems-integration R&D. ESIF will be one of a few facilities in the country capable of providing for the fully integrated field-testing of hardware and software technologies, enabling advanced visualization and simulation, establishing a virtual utility operations platform, and providing Smart Grid interoperability testing and validation," said Robert Shapard, chairman of GridWise Alliance.

With ESIF's **first-of-its-kind** features and capabilities, NREL will be able to fully assess systems as a whole—a system made up of many interacting and interdependent subsystems—and realize the performance and reliability impacts from generation, to transmission, to distribution, and the built environment.

Understanding the vision of the ESIF and recognizing this facility will provide innovative solutions, industry has shown a growing interest in being a part of the ESIF.

"No integrated system and component testing capability similar to the ESIF currently exists in the public- or private-sectors, substantiating a clear national need for the level of research and testing the ESIF can accommodate," said Dr. Dave Mooney, director of NREL's Electricity, Resources and Building Systems

Integration Center. "Participation from utilities, equipment manufacturers, renewable systems integrators, universities, and other national labs and related industries in fully utilizing ESIF's capabilities will dramatically accelerate the research required to transform the energy system to one that is cleaner, more secure, and more reliable."

Research Focus

With the collaboration of industry partners and NREL's more than 30 years of experience, the ESIF will house a variety of research that aims to overcome technical barriers to effectively and reliably operating energy systems with high levels of renewable energy. Integration research will include, but is not limited to:

- Building and facility systems,
- Community power generation and microgrids,
- Utility generation, and
- Grids that incorporate renewable energy (solar, wind, hydrogen, advanced vehicles), energy efficiency technologies, electricity system architectures, and grid interoperability.

Labs and Equipment

To support these areas of research, the 185,000-sq. ft. ESIF will house approximately 200 scientists and engineers, more than 14 fully equipped laboratories, the Insight Visualization Center, High Bay Control Room, and several outdoor test beds.

Visualization Capabilities

Planned electricity systems visualization capabilities at the ESIF go beyond what would be found in a typical utility operations center. Fully integrated with hardware-in-the-loop at power capabilities, an experimental distribution bus, and a high-performance computing center, the ESIF visualization center will offer a view of complex systems operations internal to the laboratory, as well as the ability to visualize complex systems simulations and operations in a completely virtual environment. Additionally, the visualization center will offer a view of the impact of systems operating in the laboratory on a simulated system through the hardware- and systems-in-the-loop capability.

Hardware-in-the-Loop at Power

Hardware-in-the-loop simulation is not a new concept, but adding megawatt-scale power takes research to another dimension. Equipped with grid simulators, the ESIF's Smart Power Lab is the test lab for development of the power electronics components and circuits used in clean and sustainable energy integration.

"The ESIF will be the place to do hardware-in-the-loop testing with low to megawatt–scale power capability," said Dr. Bill Kramer, senior engineer at NREL, "bringing research to the forefront of today's technology. It will allow researchers and manufacturers to conduct integration tests at power and actual load levels in real-time simulation, and evaluate component and system performance before going to market." Dr. Kramer provides the ESIF design-build firm with mechanical and electrical lab planning guidance from both a functional and safety perspective.

Distribution Bus Network

The research electrical distribution bus is a specialized network capable of connecting multiple sources of energy, interconnecting laboratories, and experiments to test and simulate equipment. It is what connects power electronics, megawatt-scale grid simulators, electrical

"The ESIF will be the place to do hardware-in-the-loop testing with low to megawatt–scale power capability," said Dr. Bill Kramer, senior engineer at NREL.

ESIF Snapshot

- Cost : $135M
- Square feet: 185,000
- Occupants: 200
- Super computer: petascale
- State-of-the-art electric systems simulation and visualization in an HPC environment
- Component and systems testing and validation at MW-scale powers
- Integration of functioning systems with utility system simulations for real-time, real-power evaluation of high-penetration scenarios
- Construction complete: summer 2013

load banks, smart grid technology evaluation capabilities, and power electronic inverters and converters. Integrated throughout the ESIF, the distribution bus is tied into a SCADA (Supervisory Control and Data Acquisition) system that centrally collects, displays, and stores information from data collection points across all ESIF labs.

The distribution bus electrically connects experiments between labs and will enable the operation and performance characterization of integrated power systems and components using a variety of renewable energy and fossil fuel powered electric generators, coupled with appropriate loads, grid simulators, and storage systems.

High-Performance Computing Capability

In addition to the visualization capabilities of the Smart Power Lab, the ESIF will include a high-performance computing and data center that will expand NREL's capabilities in modeling and simulation of renewable energy technologies and their integration into the existing energy infrastructure. The HPC capability will allow large-scale simulation and modeling of fully integrated systems; molecular and nanoscale simulation that evade direct observation; and the integration of resource mapping and forecasting to perform simulated forecasts and risk analysis.

The petaflop-scale (one petaflop equals one quadrillion floating-point operations per second) high-performance computer will enable large-scale modeling and simulation of material properties, processes, and fully integrated systems that would be too expensive, too dangerous, or even impossible, to study by direct experimentation and help NREL researchers advance renewable energy and energy efficiency technologies. "Among other things, NREL will use high-speed computing as an analysis tool to view problems from different dimensions and points of view," said Dr. Kramer. "Sometimes turning a problem upside down and sideways provides a deeper level of understanding of the problem, leading to a faster solution."

The ESIF will achieve a minimum power usage effectiveness rating of 1.06 for the High Performance Computing Center, making the facility one of the most energy efficient in the world.

Sustainable NREL

Edison envisioned the ideal laboratory as a unique and cutting-edge assembly of equipment that would set an unprecedented standard of excellence. Add NREL's expertise—and you have the ESIF.

This showcase facility will not only meet the nation's crucial research objectives for integrating clean and sustainable energy technologies into the grid, but will be built in accordance with the U.S. Green Buildings Council's standards and is expected to achieve at minimum LEED (Leadership in Energy and Environmental Design) Gold Certification.

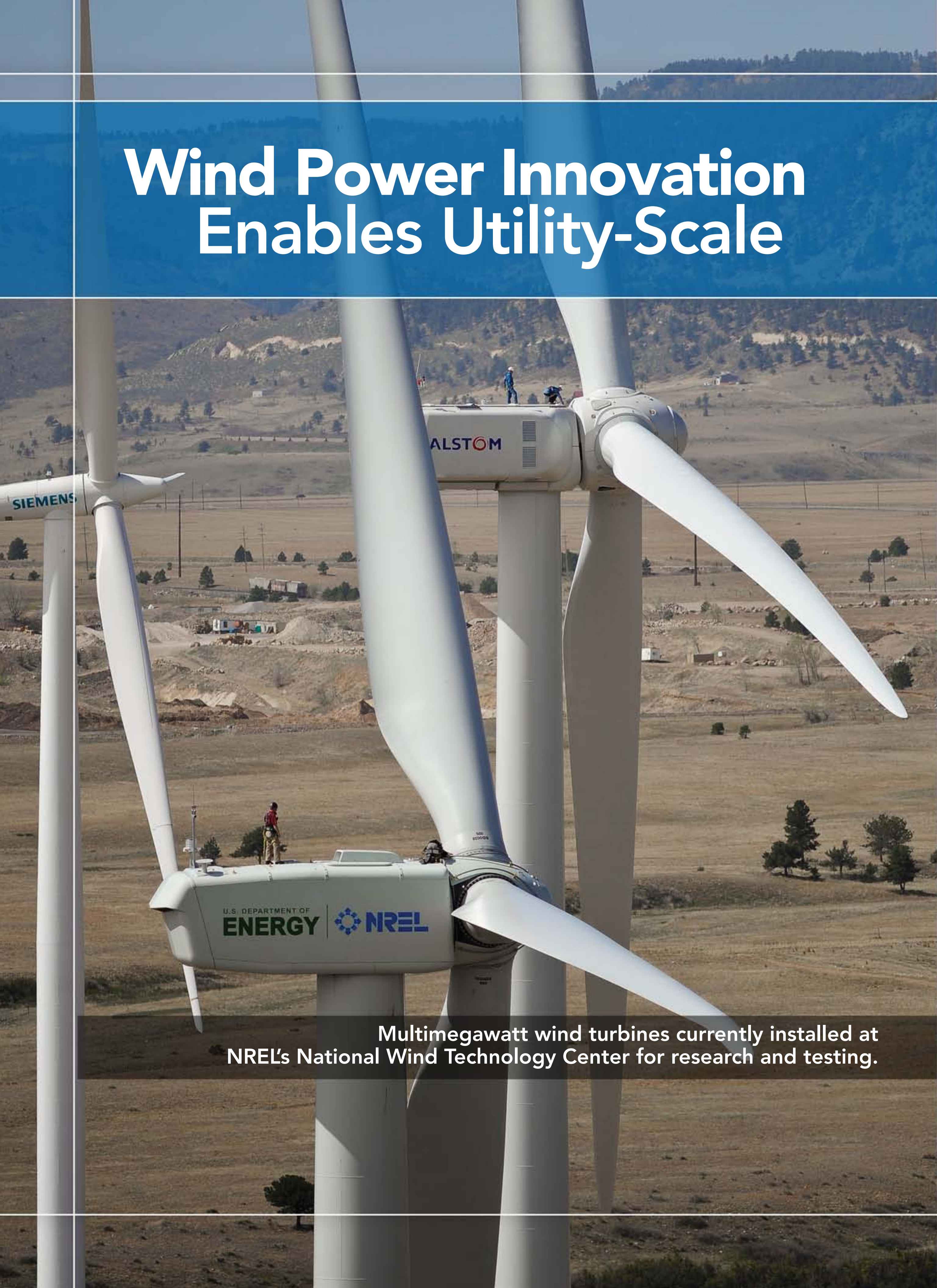
Following the lead of NREL's newest campus addition, the Research Support Facility, the ESIF will demonstrate NREL's commitment to a sustainable energy future with its energy-saving workplace environment. The ultra-efficient building design will include energy efficient features such as natural ventilation through operable windows, daylighting, open air cubicles, and radiant heating and cooling.

Meeting the Challenge

Transforming the nation's energy infrastructure is a tall order and arguably the most significant challenge facing our country today. The breakthrough energy technologies and interconnection solutions that NREL and its industry partners will develop and test in this dedicated facility will be critical to transforming the nation's energy infrastructure at an unprecedented rate, bringing with it a secure and sustainable energy future to the United States.

Were Edison alive today and witness to the ESIF, he would probably marvel over the advanced technology and modernized design of one of his greatest inventions, and applaud NREL's efforts in advancing DOE's and our nation's energy goals.

Wind Power Innovation Enables Utility-Scale



Multimegawatt wind turbines currently installed at NREL's National Wind Technology Center for research and testing.

NREL scientists are confident that continued research will enable wind energy to make major contributions to meeting the nation's electrical demand.

In the 1930s, a farmer in South Dakota built a small wind turbine on his farm, generating enough electricity to power his radio. He never dreamed that it might be possible one day for his descendants to have multi-megawatt wind turbines on the farm towering several hundred feet above his barn and generating enough electricity to power thousands of homes.

In the '70s and '80s, with the advent of the first small wind farms in California, many members in the power industry thought wind power was an interesting concept. They never dreamed the technology would one day become the fasting growing electricity resource in the world.

When the scientists at the National Renewable Energy Laboratory (NREL) began conducting wind energy research in the late '80s and early '90s, they knew that innovation born from research could make a significant difference in the technology's advancement and industry growth.

For the next two decades, they worked diligently with industry partners developing and testing innovations that would lower the cost of wind energy and increase production and reliability. These innovations included more aerodynamic designs for airfoils, permanent-magnet direct-drive drivetrains, state-of-the-art control systems, and stronger lighter-weight materials and design codes.

Thanks to the efforts of NREL and its industry partners, today that farm in South Dakota is home to seven 1.5-megawatt (MW) turbines capable of powering about 2,600 homes. And by the end of 2010, U.S. wind energy capacity topped 40,000 MW (enough to power about 10 million homes), was cost-competitive in many areas, and was the fastest growing energy industry in the nation.

Although 40,000 MW sounds like a lot of electricity, it represents about 2% of our nation's electricity demand. But the researchers at NREL are confident that with continued research, wind energy can contribute much more.

Alstom 3-MW EcO 100 wind turbine at NREL. NREL will conduct certification testing on the Alstom's new 60-Hz model and validate the performance of its unique drivetrain concept.

State-of-the-Art Test Facilities

When NREL first started conducting wind energy research in the 1980s on a site just south of Boulder, Colo., its test facility consisted of a few small wind turbines and an office building. Most people driving by didn't even notice it was there. In 1994, NREL completed construction on a 2.5-MW dynamometer test facility and the U.S. Department of Energy (DOE) dedicated the site as a National Wind Technology Test Center (NWTC).

Since then, the facility has continued to grow and increase its research and development capabilities. In addition to the 2.5-MW dynamometer, the site now hosts three multi-megawatt test turbines that feed power into the electric grid. These generating giants make it easy to spot the site from more than 20 miles away. The NWTC is also home to two 600-kW advanced research turbines, numerous small wind energy test turbines, and a structural testing laboratory capable of testing wind turbine blades up to 50 meters in length.

Today, NREL's test facility is one of a select few in the United States accredited through the American Association of Laboratory Accreditation to perform the tests required by turbine certification agencies, financial institutions, and other organizations. Certification testing validates the performance of new wind turbine designs and paves the way for manufacturers to begin commercial production.

Utility-Scale Turbine Development

For more than two decades, NREL has worked with industry partners such as General Electric (GE) Wind Energy, Clipper Windpower, Siemens, and Vestas to improve the performance of utility-scale wind turbines. NREL's work with GE Wind and its predecessors contributed to the design and commercial production of GE's 1.5-MW commercial wind turbine now operating in wind farms worldwide.

In 2009, DOE purchased a GE 1.5-MW wind turbine and installed it at the NWTC for long-term research and testing. Data collected from this turbine will lead to increased reliability and performance of current and future wind turbines, helping achieve the aspiration of supplying 20% of the nation's electricity from wind energy by 2030. Planned areas of research include the turbine's aerodynamic design,

Research and testing on large turbines at NREL include a 1.5-MW GE turbine purchased by DOE (front), an Alstom 3-MW turbine (center), and a Siemens 2.3-MW turbine (background).

Alstom wind turbine dedication. NREL's Dana Christensen shakes hands with Alstom's Andy Geissbuehler.

the effects of turbulence on its structural loads and performance, and how the combination of these factors may affect wind plant performance.

A competitive solicitation issued by NREL resulted in the signing of a cooperative research and development agreement (CRADA) with Siemens to install and test a 2.3-MW utility-scale wind turbine at the NWTC in 2009. The Siemens' project is the largest government-industry research partnership for wind power generation ever undertaken in the United States. The purpose of the multi-year CRADA is to increase the performance and reliability of future wind turbine designs by studying the performance and aerodynamics of this new class of large, land-based machines. Areas of research include structural and performance testing; modal, acoustics, and power quality testing; aerodynamic testing; and turbine performance enhancements.

The Siemens' project is the largest government-industry research partnership for wind power generation ever undertaken in the United States.

NREL installed its third multi-megawatt wind turbine, an Alstom 3-MW ECO 100, at the NWTC in 2010. Under a Work for Others Agreement with Alstom, NREL is testing the company's new 60-Hz model to finalize the International Electrotechnical Commission requirements for type certification. The successful outcome of this test will enable Alstom to begin commercial production of the ECO 100 in the United States. Philippe Cochet, senior vice president of Alstom Power's Wind and Hydro business divisions, said, "NREL is a well-respected authority on technical issues related to wind energy and the renewable energy market in general. Having their input and validation will give our customers confidence that our equipment is fully suited to the particular characteristics of the U.S. wind energy market."

Increasing Gearbox Reliability

Gearbox reliability is an ongoing challenge for the wind energy industry. Gearbox failures require expensive and time-consuming replacement, significantly increasing the cost of wind plant operation while reducing power output and revenue. In an effort to increase gearbox reliability, NREL launched a Gearbox Reliability Collaborative (GRC) in 2007 that brought together the world's leading tubine manufacturers, consultants, and experts from more than 30 companies and organizations.

The goal of the GRC is to validate the typical design process—from the wind turbine system loads to bearing rating—through a comprehensive dynamometer and field-test program on extensively instrumented gearboxes. This design analysis will identify gaps in the design process to improve reliability of future designs and retrofit packages.

Since the GRC was launched, it has tested two nonproprietary gearbox designs on NREL's 2.5-MW dynamometer test bed and in the field. Data collected from the nonproprietary gearbox testing will be made publicly available, which is an unprecedented resource for industry. Gearbox modelers will be able to use the data for analyses and complex model validations. The data will also be used to better define gearbox design processes and to validate predicted fatigue loading.

Gearbox modelers will be able to use the data for analyses and complex model validations.

The long-term research conducted on the Alstom turbine is aligned with the GRC objectives to increase gearbox reliability. During the first phase of the study, NREL will build its own model of the Alstom wind turbine using the lab's design code. NREL will then compare its model to Alstom's

Siemens utility-scale wind turbine at the National Wind Technology Center.

model and to field measurements to identify and understand any design code shortcomings. This will enable NREL to better predict wind turbine loads and advance its design and analysis tools, which are made available to the wind industry. By providing industry with state-of-the-art design codes, NREL is helping to develop advanced, more reliable wind turbine technology.

For NREL, the opportunity to study Alstom's new drivetrain configuration may lead to innovative approaches to mitigate loads that reduce gearbox reliability and will validate simulation models for improving future designs. For Alstom, the long-term research at the NWTC will provide the company with an opportunity to test the machine's durability under the extreme wind conditions often experienced at the site and the tests will validate its performance on the U.S. grid, ensuring its successful entry into the U.S. market.

Leading Solar Expertise –

A Launch Pad to the Future

The Amonix 7700 Solar Power Generator is an example of a concentrating PV system that is well-matched to utility-scale projects.

NREL is speeding solar devices from the lab to utility-scale operation.

Before a rocket blasts off into the atmosphere, the stratosphere, and eventually to orbit and payload stage, it must first be earthbound, supported within a strong framework, and perched on a rock-solid foundation. When it comes to solar research, the National Renewable Energy Laboratory's (NREL) trajectory has had the benefit of a solid foundation in fundamental science and has followed a successful "flight plan"—a well-tuned strategy. Consequently, the lab has entered its own "payload stage" in commercialization and deployment of solar technologies.

NREL's 30-year history and unique leadership make it especially suited to lead the effort in speeding solar devices from the lab to utility-scale operation.

Since its inception in 1977, NREL has focused on increasing solar efficiency, reducing the costs of producing those technologies, and helping to bring them to market. NREL's successes in the solar realm are impressive—from the dozens of times it has broken the record for solar efficiencies, to a host of patents and licenses on solar devices, to hundreds of U.S. companies that have collaborated with the lab and adopted the resulting technological breakthroughs.

Another stellar achievement is the number of R&D 100 Awards that the NREL solar research teams have garnered 21 since 1984 (see sidebar). The awards are given out by *R&D Magazine* and identify each technology as one of the top 100 technological innovations of the award year.

These accomplishments are the direct results of a strategy that NREL is using to bring about the vision of creating a national, sustainable energy system by 2050 that is carbon-neutral, highly efficient, affordable, reliable, and supports high-value domestic jobs. At the utility-scale level, the laboratory has made great progress in two solar technology areas: photovoltaics (PV) and concentrating solar power (CSP).

Before the turn of the century, NREL worked on some of the world's first solar power towers—Solar One and Solar Two.

Photovoltaics

The first viable PV cells were developed in 1954 by Bell Laboratories. In the 1970s the global oil crisis demonstrated the need for alternative energy. It was then that the Solar Energy Research Institute (which later became NREL) began managing many research subcontracts involving crystalline silicon materials. The contracts were for research and development (R&D) that successfully reduced the amount of silicon required in PV devices, and hence their cost. These activities played an instrumental role in helping the solar silicon industry evolve and led to NREL's leadership in solar cell research.

Since 1996, PV research has been performed at the National Center for Photovoltaics (NCPV), which is based at NREL and funded by the U.S. Department of Energy (DOE). The NCPV is charged with accelerating PV as a viable energy option in the United States. It focuses on innovations in PV technology that drive industry growth in U.S. PV manufacturing. DOE has directed the center to use the resources and capabilities of the national labs and universities to serve the U.S. PV industry. The NCPV enhances communication and catalyzes strategic partnerships between these entities and also

R&D 100 Awards for NREL Solar Program Technologies

1984 - CIS Solar Cell

1991 - Tandem Solar Cell

1991 - CdTe Solar Cell

1992 - Solar Detoxification of Contaminated Groundwater

1993 - Silicon Defect Mapping System

1994 - Transpired Solar Collector

1997 - PV Optics Software

1998 - Solar Roof Shingle

1999 - CIS Solar Module

2001 - Triple-Junction Solar Cell

2002 - PowerView™ Module Smart Glass

2003 - High-Rate Module Process

2004 - Flexible CIGS Module

2005 - Sinton Silicon Evaluation System

2007 - HEMM Concentrator Solar Cell

2008 - IMM Solar Cell
Hybrid CIGS

2009 - SkyTrough™ Parabolic Trough
Ultra-Accelerated Weathering System

2010 - Black Silicon Wet-Chemical Etch
Amonix 7700 Solar Power Generator

functions as a source for knowledge and research facilities within the DOE system.

Ryne Raffaelle has been director of the NCPV since 2009, a role that allows him to interact with solar energy leaders in the United States and around the world. "The NCPV is truly without peer when it comes to PV research and development and is currently the envy of the wider international PV community," he says. "We are most recognized for tremendous basic scientific discovery that is enabling technologies that make a real difference in the everyday lives of citizens of our nation, and around the world."

Within the PV research sphere, NREL has concentrated on two areas: thin-film and high-efficiency solar cells.

Thin-Film Solar Cells

Thin-film solar cells use less than 1% of the raw material of silicon wafer-based solar cells, leading to significant cost advantages. They can also be applied to flexible materials such as metal foil or even plastic film, expanding their use.

Thin-film research at NREL gained notice in 1980 by scientists worldwide when efficiencies passed 10%. NREL collaborated with Boeing in 1984 for the first solar cell to pass 10% efficiency, using films thinner than a human hair. The cell was made from copper indium diselenide (CIS). In the early 1990s, the group worked with Golden Photon to create the first large-area device made from cadmium telluride (CdTe).

NREL made rapid progress in 1994 by surpassing 15% efficiency and then reaching 17.7% in 1996 for copper indium gallium diselenide (CIGS). One of the more popular thin-film solar cells to be developed with NREL participation in the last 30 years is the Uni-Solar triple-junction amorphous-silicon solar module, which resembles a traditional roof shingle.

In 2003, NREL co-developed, with First Solar, a new method for producing CdTe modules. In 2004, NREL joined with Global Solar to develop a new lightweight, flexible, CIGS module. For 16 years, NREL held the world record for conversion efficiency. Today, CIGS cell efficiencies at NREL are at 20%.

High-Efficiency Solar Cells

In the late 1980s, NREL experimented with a new type of solar cell made by using multiple solar cell junctions of differing materials: gallium indium phosphide and gallium arsenide. The resulting "tandem" solar cell led to record efficiencies. The technology was licensed for space applications in the early 1990s to Spectrolab and EMCORE corporations and has since become the industry standard for powering Earth-orbiting satellites.

The technology came back to earth quickly, however, when NREL stimulated interest in high-efficiency solar cells. In 2002, the lab organized the first international conference on solar concentrators using high-efficiency solar cells. Solar concentrators use lenses or mirrors to concentrate the sun's energy several hundred times, increasing the electricity generated by super-efficient solar cells by the same factor.

The Amonix 7700 Solar Power Generator is an example of a concentrating PV system that is well-matched to utility-scale projects. Thirteen of these generators have been installed at the Solar Technology Acceleration Center in Aurora, Colo.

In May 2005, NREL announced that it had confirmed a new solar cell record efficiency of 37.9%. A month later, Spectrolab, Inc., the lab's industry research partner, announced an even higher record with a 39%-efficient cell.

NREL built on that success in a partnership with Amonix to develop the Amonix 7700 Solar Power Generator, which uses Fresnel lenses to focus the sun's rays onto ultrahigh-efficiency solar cells. This bulk power generator produces 40% more energy than conventional fixed PV panels and is well-matched to utility-scale solar energy projects, especially in dry, sunny climates. In 2010, NREL and Amonix received an R&D 100 Award for this technology.

According to the Solar Energy Industries Association, as of January 2011 a total of 2.1 GW of PV capacity was installed in the United States with more than 16 GW under construction or in the development stage.

The DOE Solar Program recently announced the SunShot Initiative (see sidebar), which is dedicated to expanding the market for solar technologies by helping solar energy reach cost parity with other baseload electricity generation sources across the United States.

Concentrating Solar Power

CSP systems produce electricity by using mirrors to concentrate the sun's energy to heat a working fluid to drive conventional turbines that convert heat to electricity. By using thermal storage, such as molten salt, or by supplementing the solar plant with natural gas, CSP systems can deliver electricity when utilities need it most, which is typically at times of high demand in late afternoon or early evening. This "dispatchability" adds significantly to the value of power delivered by utility-scale solar power plants.

NREL's roots in CSP go back to the 1970s with the development of the High-Flux Solar Furnace. Since the early 1990s, NREL has added many more CSP research capabilities, including laboratories dedicated to optical materials and thermal storage. These capabilities have allowed NREL to make solid gains in developing CSP technology for utility-scale use, including scientific advances in materials and processes used in parabolic trough systems and power towers.

Parabolic Trough Systems

A parabolic trough system consists of arrays of parabolic mirrors that collect heat from the sun and focus it on receiver tubes that contain a heat-transfer fluid. The hot fluid is sent through a series of heat exchangers, which release the heat to generate high pressure steam. That steam is then fed to steam turbines that generate electricity.

In the mid-1980s to early 1990s, nine commercial parabolic trough power plants were constructed at three locations in the Mojave Desert in California for a combined capacity of 354 MW—and they are still operating today. In an effort to make parabolic trough plants cost-effective in southwest markets and without incentives, NREL established the USA Trough Initiative, a partnership with U.S. industry. The effort helped expand U.S. industry involvement and competitiveness in worldwide trough development activities and helped advance U.S. knowledge of this technology.

Today, NREL uses state-of-the-art facilities to characterize collectors and receivers. The laboratory's work in this area falls primarily within the following: determining optical efficiency, measuring heat loss, developing and testing concentrators, and advancing optical characterization. NREL also enables the CSP industry by developing and testing advanced mirrors and receiver tube coatings.

One such effort involved collaboration with SkyFuel, Inc., a small company headquartered in Arvada, Colo., and earned an R&D 100 Award for the SkyTrough parabolic trough. The result of more than a dozen years of collaboration, SkyTrough is unique in that its mirrors are made of lightweight aluminum sheets covered with ReflecTech mirror film, the component that NREL helped develop. Lighter and less expensive to manufacture than glass mirrors, ReflecTech is also much easier to transport and install, and less prone to break.

These types of scientific advances at NREL have helped bring about reductions in operation, maintenance, and system costs, which in turn have led to a significant decrease in the cost of parabolic trough-generated electricity. The costs have fallen from more than $ 0.28 per kilowatt-hour (kWh) in the 1980s (in 2009 dollars) to costs approaching $0.18/kWh today, which is approaching current costs in intermediate load markets.

Power Towers

A power tower system uses a large field of flat, sun-tracking mirrors called heliostats to focus and concentrate sunlight onto a receiver on the top of a tower. The receiver contains heat-transfer fluid that becomes hot enough to convert water into steam, which is then used in a conventional turbine generator to produce electricity.

SkyFuel's Chief Technology Officer Randy Gee, left, and NREL Senior Scientist Gary Jorgensen led the team that developed a thin silver polymer film to substitute for bulkier glass mirrors on solar-collecting troughs.

In the 1980s and early 1990s, NREL worked with Sandia National Laboratories on some of the world's first solar power towers—Solar One and Solar Two. Solar One used water/steam as the heat-transfer fluid. The plant was later converted into Solar Two, which used molten nitrate salt because of its superior heat-transfer and energy-storage capabilities.

Today, NREL continues to improve power tower technology by supporting the U.S. industry with the development of advanced system performance models, conducting research on advanced thermal energy storage materials and design concepts, and investigating advanced high-temperature thermodynamic cycles.

NREL is also researching ways to improve the thermal characteristics of currently available storage materials and developing and characterizing advanced nanofluids and phase-change materials for future thermal storage applications.

A Proven, Working Technology

According to the Solar Energy Industries Association, as of February 2011, 508 MW of CSP utility-scale projects were operating in the United States, 399 MW were under construction, and 9,146 MW were under development, for a total of more than 10 GW.

Rock-Solid Launch Pad + Well-Aimed Flight Plan = Direct Hit

Using tools such as cooperative research and development agreements, licensing, and technology partnerships, NREL has helped stimulate the market for solar technologies and assisted the growth of solar start-ups, such as Abound Solar, Amonix, First Solar, Global Solar, and SkyFuel.

Companies such as these exist across the country and create jobs as they grow. The National Solar Jobs Census was compiled in August 2010 by The Solar Foundation (a nonprofit organization), Green LMI Consulting, Cornell University, and others. The census identified 93,502 solar workers in the United States, roughly double the number estimated for 2009. In addition, employers from all of the studied subsectors expected significant employment growth well into 2011.

A 30-year history of excellence in solar R&D and a well-honed strategy have combined to make NREL the pre-eminent laboratory to lead solar technologies to the utility-scale level. In this way, NREL is enabling solar energy to help protect the environment, achieve U.S. energy security, reduce petroleum dependence, create new jobs, and boost the nation's economy.

Shooting for the Sun

When Energy Secretary Steven Chu announced the SunShot Initiative on February 15, 2011, it harkened back to President Kennedy's famous "moon shot" speech delivered to Congress on May 25, 1961. The goals Kennedy outlined set the United States on a path to regain the lead in the space race and land an American safely on the moon by the end of that decade. Similarly, the goal of SunShot is to restore America's once-dominant position in the global market for solar photovoltaics (PV) and concentrating solar power (CSP).

Analysis from NREL indicates that at an installed cost for utility-scale solar electricity of roughly 6 cents per kWh without subsidies, solar energy would reach cost parity with other baseload electricity generation sources across the United States. At this level, rapid, large-scale adoption of solar electricity across the United States would be possible.

Dana Christensen, NREL's deputy director for science and technology, calls it a "Herculean challenge" to bring solar energy to the marketplace at grid parity, but one that would pay enormous dividends. "The organization, the country that makes it happen first is going to control the market. This is a big jobs opportunity. It's a technology opportunity that is truly leveraging what is really good about our country—and that's innovating things into the marketplace quickly," he said.

The goals of the initiative underscore solar energy's benefits to the United States and will have multiple benefits for the country: reaching cost parity with baseload energy rates, increasing solar PV market share, boosting domestic solar manufacturing, and reducing greenhouse gas emissions.

The United States is the world's largest consumer of electricity and, at the same time, has the largest solar resource of any industrialized country. Our country is also home to NREL's National Center for Photovoltaics, the world's leading solar energy research facility. This positions us to achieve and realize significant benefits from the wide-scale use of solar energy.

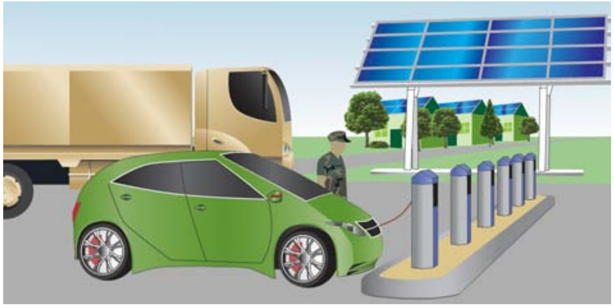
One parallel between SunShot and the moon shot is clear: securing a plentiful supply of clean, domestically produced energy has emerged as the imperative of our time, just as winning the space race was 50 years ago.

Renewable Energy on the Front Lines

This military-grade electric vehicle can travel more than 100 miles on single charge and can haul more than eight tons of cargo.

Army Model Integrates Vehicles, Renewables, & Microgrid

On the front lines of national security, the Department of Defense (DOD) recognizes that the adoption of renewable energy is vital to reducing dependence on foreign oil, addressing greenhouse gas emissions, and maximizing resources. the National Renewable Energy Laboratory (NREL) is working with the DOD and the U.S. Department of Energy (DOE) to integrate solar photovoltaics (PV), plug-in electric vehicles, and microgrid controls at Colorado's Fort Carson Army post. Through the coordination of generators and loads, the Fort Carson microgrid will help ensure uninterrupted electrical delivery to mission-critical facilities.



The NREL model integrates a solar photovoltaic canopy, plug-in electric vehicles and a renewable energy management unit.

NREL's role is part of the multi-year, multi-agency Smart Power Infrastructure Demonstration for Energy Reliability and Security (SPIDERS) project, which focuses on improving energy surety for military installations. Funded by the DOE Office of Electricity Delivery and Energy Reliability and the Federal Energy Management Program, the NREL project includes:

- Development of vehicle-to-grid communications methods
- Electric vehicle infrastructure planning
- Vehicle-to-grid usage scenario development.

Through the coordination of generators and loads, the Fort Carson microgrid will help ensure uninterrupted electrical delivery to mission-critical facilities.

"The ability to integrate electric vehicle charging with renewables supports several Army energy security challenges for the future," explains Vince Guthrie, utility programs manager, Fort Carson Directorate of Public Works. "Fort Carson is excited to have NREL developing the tools and systems needed to create value, both in the normal and microgrid operation of electric vehicles."

Designed for Defense Facilities and Civilian Locations

Generating renewable energy onsite using PV arrays and wind turbines is a high priority for DOD facilities. A microgrid that integrates renewable generation and electric vehicle energy storage offers improved energy security, cost savings, and reliability. Proximity of automobiles to infrastructure often makes parking facilities ideal locations for systems connecting electric vehicles, solar energy sources, and microgrids.

Future integrated systems may include a PV canopy to shade vehicles while providing energy for the microgrid and charging stations. The charging stations could act as energy management portals, feeding power to and from the grid.

"The ability to integrate electric vehicle charging with renewables supports several Army energy security challenges for the future," explains Vince Guthrie, utility programs manager, Fort Carson Directorate of Public Works.

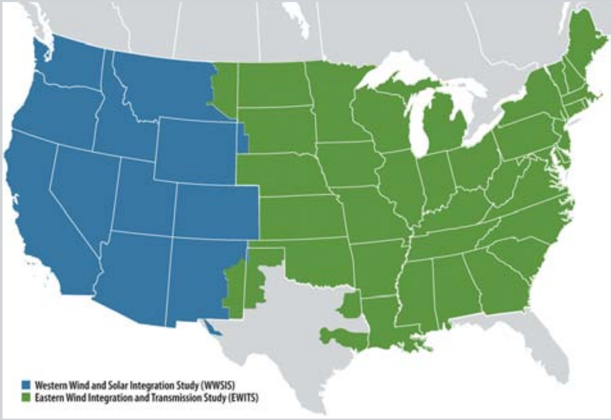
The project's ultimate goals are to minimize fuel consumption, energy cost, and emissions, while maximizing operational duration by integrating renewables, vehicles, the microgrid, and intelligent controls. Functional models of this system could be used to establish similar systems at other DOD installations. This military pilot demonstration, when proven viable, could help the DOE's Office of Electricity Delivery and Energy Reliability and the Office of Energy Efficiency and Renewable Energy create models for civilian applications.

About NREL's Electric Vehicle Grid Integration Effort

NREL's Electric Vehicle Grid Integration team works with automobile manufacturers, developers, and utilities to accelerate the development of transportation electrification and expand renewable energy generation.

Charging stations will feed power to and from the grid.

Integrating Wind and Solar on the Grid – NREL Analysis Leads the Way



To fully harvest the nation's bountiful wind and solar resources, it is critical to know how much electrical power from these renewable resources can be integrated reliably into the grid. To better inform the debate about the potential of such resources, the National Renewable Energy Laboratoty (NREL) has released four regional grid integration studies.

Taken together, these studies represent a major step forward in understanding the integration of large amounts of wind and solar resources into our electrical grid.

NREL is a leading expert in grid integration analysis of renewables, and collaborates closely with the power industry to share such transformative information. NREL has helped educate the power industry about the viability of significant penetration of renewable energy on the grid, while helping overcome and better understand operational, reliability, and economic concerns.

Eastern Wind Integration and Transmission

The Eastern Wind Integration and Transmission Study is one of the largest regional wind integration studies to date. Initiated in 2008, the study examines the operational impact of a significant energy penetration of wind on the power system in the Eastern Interconnection of the United States. The **Eastern Interconnection** is one of the two major alternating current (AC) power grids in North America. The other major interconnection is the Western Interconnection.

According to the study, 20-30% wind power is technically achievable, although transmission infrastructure upgrades and investment are necessary. In addition, drawing wind energy from a larger geographic area makes it both a less expensive and more reliable energy source, and wind power displaces substantial amounts of fossil fuels, resulting in emissions reductions. The study also pointed to the need for additional analysis to further examine the issues, including reliability impact.

Western Wind and Solar Integration Study

The Western Wind and Solar Integration Study examines the benefits and challenges of integrating up to 35% wind and solar energy penetration into the grid by 2017. The study finds that these targets are technically feasible and do not necessitate extensive additional infrastructure, but do require key changes to current operational practice.

Though wind and solar output vary over time and cannot be perfectly forecast, the technical analysis performed in this study shows that it is operationally possible to accommodate 30% wind and 5% solar energy penetration. The study also finds that a 27% wind and solar energy penetration across the Western Interconnection decreases fuel and emissions costs by 40% and carbon emissions by 25-45%, depending on the future price of natural gas.

Nebraska Statewide Wind Integration Study

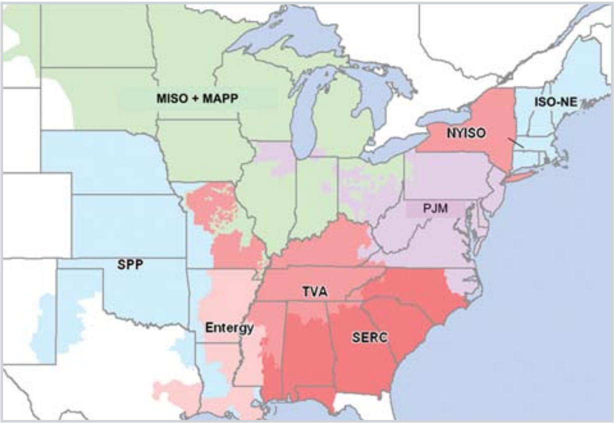
NREL worked with the Nebraska Power Association to conduct a state-wide wind integration study. The study looked at what it would cost to integrate wind-powered resources into the state's existing generation mix at much higher levels than exists today. The specific levels evaluated included new wind-powered generation, as a percent of total Nebraska electricity needs, at 10%, 20%, and 40% levels for the base year 2018.

Major carbon emission reductions were found in all scenarios, with CO_2 emissions dropping by more than 25 million tons per year in moving from the 10% wind scenario to the 40% wind scenario. The study also found that the cost of operating the power system differently to accommodate wind energy was modest, although exact integration costs varied depending on the methodology used to account for the costs.

Oahu Wind Integration and Transmission Study

NREL led in the Oahu Wind Integration and Transmission Study (OWITS) to examine grid and transmission integration of renewables as part of the Hawaii Clean Energy Initiative's Energy Agreement. The Hawaii Clean Energy Initiative includes an aggressive mandate for the State of Hawaii to generate 40% of its energy from renewable resources by 2030. The Energy Agreement includes a commitment to integrate up to 400 megawatts (MW) of wind energy from Molokai or Lanai and transmit it to Oahu via undersea cable systems (the "Big Wind" projects).

The Oahu study is an important application of integrating wind power onto a smaller electrical grid system than other grid integration studies have typically encountered. In addition, the undersea cable is state-of-the-art technology and really pushes the envelope of an undersea island-grid interconnection. Such technology and attaining a better understanding of its capabilities should prove quite helpful for domestic offshore wind development.



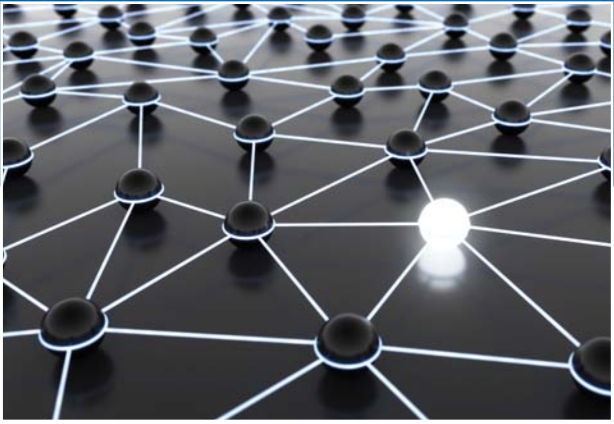
NREL has released four regional grid integration studies.

Findings Support Utility Scale

These four geographically and operationally diverse studies uncovered a handful of common, general findings:

- About 20-30% wind and solar energy penetration can be managed, but the role of wind forecasting is important to meet this objective, and additional work is needed to study the reliability impacts.
- Larger balancing areas (i.e., the designated authority responsible for system balancing of loads and generation) provide greater flexibility and easier accommodation of variable renewable energy sources such as wind and solar.
- Additional transmission will be needed to deliver wind power to market, and storage appears to be unnecessary to achieve this penetration.
- Results for the 30% case appear to be more challenging, and as the studies move forward, we anticipate more analysis will be done to achieve a better understanding of the operational challenges and potential solutions.
- High penetrations of wind reduce spot energy prices and production costs.
- Carbon emissions are reduced, but the level of reduction is a function of the displaced generation. The higher wind penetration cases tend to offset more coal than the lower penetration rates, consistent with an economically rational dispatch process.

Interoperability is Key to Smart Grid Success



The Smart Grid ensures the two-way flow of electricity and information between power plants and consumers.

Ever wonder what makes it possible to withdraw money securely from another bank's ATM, or call a friend with a different cell phone provider? The answer is "interoperability" and it refers to the capability of two or more networks, systems, devices, applications, or components to externally exchange and readily use information—securely and effectively. It's what enables communication between banks to allow consumers to withdraw cash at any ATM worldwide and communications between telephone networks to allow consumers to make cell phone calls to anyone on any network.

And just as this two-way communication allows access to money and phone calls nationwide, the Smart Grid—an automated electric power system that monitors and controls grid activities—ensures the two-way flow of electricity and information between power plants and consumers.

Smart Grid Interoperability

Interoperability is one of the greatest challenges facing the Smart Grid as a multitude of technologies, systems, and devices need to securely and effectively talk to each other.

"The very nature of adding information and communications technology to the electric power system (grid) and seamlessly linking legacy and next-generation systems and applications, making everything work together intelligently and securely," said Dick DeBlasio, chief engineer for renewable electricity and end use systems with NREL, "is a daunting task, yet critical to the success of the Smart Grid."

NREL Plugs In Smart Grid Standards

Early to recognize the need for Smart Grid interoperability, engineers at the National Renewable Energy Laboratory (NREL) were the first to lead the way in developing Smart Grid interoperability standards. In May 2009, the Institute of Electrical and Electronics Engineers (IEEE) announced an NREL-supported Smart Grid standards development initiative for bringing the power engineering, communications, information technology, and related industries together through the *IEEE P2030 Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System (EPS) and End-Use Applications and Loads*.

Through decades of support from the U.S. Department of Energy (DOE), NREL has provided leadership and support for research, testing, and standards development for distributed renewable electric technologies and the electric power systems as far back as 1980, and DeBlasio, from the start, has directed the research and coordination of the DOE/NREL support for IEEE standards development.

"In many ways, early efforts at NREL were the genesis of interoperability and interconnection of distributed renewable technologies with the electric power system and the start of modernizing the electric grid utilizing distributed resources with the publication of the *IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems* in 2003," said DeBlasio. "This is what we are now calling the Smart Grid. NREL was, and continues to be, in the forefront of Smart Grid R&D."

"Early efforts at NREL were the genesis of interoperability and interconnection of distributed renewable technologies with the electric power system and the start of modernizing the electric grid," said Dick DeBlasio, NREL chief engineer.

The IEEE P2030 guide—published in draft form in March 2011 for commenting, voting, and possible ratification as a standard by IEEE members—provides a knowledge base for understanding and defining Smart Grid interoperability of the electric power system with end-use applications and loads. IEEE P2030 provides a reference model and methodology to use to present interoperable design and implementation alternatives for systems that facilitate data exchange between Smart Grid elements, loads, and end-use applications.

Richard DeBlasio

DeBlasio was recently honored with the 2010 IEEE Charles Proteus Steinmetz Award for exceptional contributions to the development and/or advancement of standards in electrical and electronics engineering. An IEEE Life Senior Member, DeBlasio has been a member of the IEEE Standards Board since 1998.

IEEE 1547 has matured into a series of published standards and evolving projects that remain in the forefront and are applicable to existing and ongoing Smart Grid initiatives. Similarly, P2030 is growing into a series of standards that share the common goal of Smart Grid interoperability supported by interrelated and complementary technologies.

Big Turbines Require Infrastructure Upgrades

Understanding the system requirements and technical issues associated with operating utility-scale turbines is critical to the National Renewable Energy Laboratory's (NREL) interactions with the power industry as renewable wind power source applications grow rapidly. To that end, NREL has been completing electrical infrastructure upgrades to accommodate utility-scale wind turbines at the National Wind Technology Center (NWTC).

> *Now the NWTC's electrical infrastructure can handle 10 MW, and three multi-megawatt turbines have been installed.*

At one time, the NWTC was able to handle up to 7 MW of wind power, but the installation of NREL's first megawatt-scale turbine in the fall of 2009 necessitated infrastructure upgrades. Now the NWTC's electrical infrastructure can handle 10 MW, and three multi-megawatt turbines have been installed: the U.S. Department of Energy's (DOE)/ General Electric's 1.5-MW turbine, Siemens 2.3-MW turbine, and Alstom 3-MW turbine.

NWTC Row 4 Infrastructure Upgrade Project

The megawatt-scale turbines reside in Row 4 at the NWTC, the eastern-most row on site. Interconnecting these large turbines required major electrical infrastructure upgrades, including road upgrades, installation of medium-voltage power for turbines, low-voltage power for data sheds, two new meteorology tower operations, telecommunication fiber optic cables, interconnection with grounding transformers and grounding reactors, and upgrades to utility interconnection switchgear. The last stage was interconnecting the Alstom 3-MW turbine to the main line along Row 4. Xcel installed a new circuit recloser—a self-contained device that automatically closes a breaker after it has been opened due to an electrical fault—on the distribution line serving the

The NREL model integrates a photovoltaic canopy, plug-in electric vehicles, and a renewable energy management unit.

NWTC, providing improved circuit protection. This upgrade was needed to accommodate the addition of the new 3-MW Alstom wind turbine. Once the Alstom turbine is online, the aggregate generation capacity of the NWTC will be an impressive 9.2 MW (including 1 MW of photovoltaics). The project upgrades went so well, they won a Gold Hard Hat Award for Outstanding Industrial Project in October 2010 from McGraw-Hill Construction.

Interconnection and Power Purchase Agreement

DOE's Golden Field Office has an Interconnection Agreement for the NWTC with the local utility, Xcel Energy. This agreement, signed on December 20, 2010, is the culmination of nearly three years of negotiations with Xcel as well as an American Recovery and Reinvestment Act-funded design and construction project at the NWTC. December 20, 2010, also became the NWTC's "Initial Energy Delivery Date," the date DOE was eligible to receive credit for energy exported under a Power Purchase Agreement (PPA). The DOE wind energy "generating facility" currently has a capacity of

2.9 MW; the energy credit is $44.96/MWh. The Siemens 2.3-MW and Alstom 3-MW wind turbines are owned by these cooperative research and development agreement partners and are covered by other PPAs between those partners and Xcel.

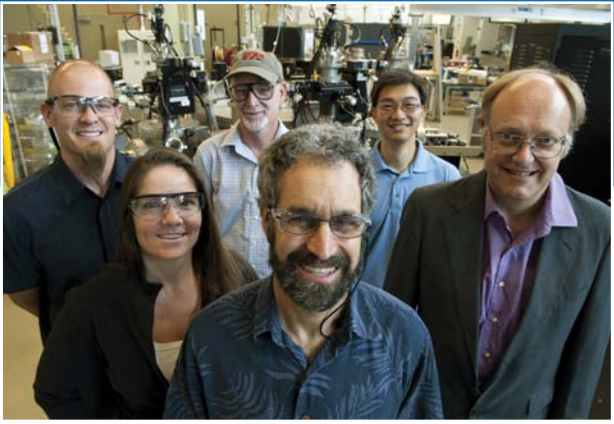
This agreement, signed on December 20, 2010, is the culmination of nearly three years of negotiations with Xcel as well as an American Recovery and Reinvestment Act-funded design and construction project at the NWTC.

The Alstom turbine is one of three multi-megawatt turbines installed at the NWTC.

The Bottom Line

The NWTC is home to the largest dedicated research and development fleet of utility-scale wind turbines being used for technical and operational analyses, enabling NREL to operate a realistic environment for research and analysis of renewable energy grid integration.

Paint It Black: One-Step Etch Cuts Solar Cell Costs



The scientists responsible for developing NREL's game-changing black silicon. In the front row, left to right, are Anna Duda, Howard Branz, and Vern Yost. In the back row, left to right, are Matt Page, Scott Ward, and Hao-Chih Yuan.

Cost is a major obstacle for the photovoltaic (PV) industry on its path to utility-scale deployment because generally, when it comes to solar cells, higher efficiencies mean higher price tags. But a team of scientists at the National Renewable Energy Laboratory (NREL) has defied this expectation with their "black silicon" nanocatalytic wet-chemical etch. Its name may be a mouthful, but this one-step process creates high-efficiency solar cells based on an innovative antireflection approach that promises to significantly reduce manufacturing costs, thereby helping propel PV toward cost-competitiveness.

> *This one-step process creates high-efficiency solar cells based on an innovative antireflection approach.*

A New Approach to Antireflection

Any light reflected from a solar cell surface is wasted, so PV manufacturers constantly seek ways to increase the amount of light absorbed by their solar cells. But standard antireflection methods, including antireflective coatings and etching large pyramids into the cell surface, add considerable cost to a solar cell—and they succeed only to a point: cells using both techniques still absorb only between 93% and 97% of the sunlight they receive.

> *At a cost of just a few cents per watt, the one-step technique has produced a black silicon cell with a validated 16.8% conversion efficiency.*

NREL has long been a leader in PV research and development, and led by Principal Scientist Howard Branz of NREL's Silicon Materials and Devices group, a team from the National Center for Photovoltaics had an idea. Using an untried antireflection principle, the team invented a simple process that submerges silicon wafers (the most common solar cell material) in a chemical bath. There, catalytic reactions rapidly etch millions of tiny holes in the silicon. This turns the wafers black, allowing them to absorb more than 98% of the sunlight they receive. At a cost of just a few cents per watt, the one-step technique has produced a black silicon cell with a validated 16.8% conversion efficiency.

A Cheaper Method, A Better Material

As a replacement for conventional antireflection methods, NREL's black silicon etch could reduce the cost of energy delivered over the life of a silicon PV array by 2% or 3%—significant progress toward the nation's solar energy goals. Plus, the NREL method actually simplifies solar cell processing, speeds throughput, uses less costly machinery, and produces fewer harmful byproducts than conventional antireflection techniques, making NREL's technology particularly appealing to PV manufacturers.

NREL won an R&D 100 Award in 2010 for the cutting-edge process, but in the lab's spirit of innovation, Branz's team hasn't stopped there. In fact, a new refinement has already yielded a black silicon cell with a validated efficiency of 18.2% this year. That's an efficiency gain of 1.4% over the existing process—meaning NREL's groundbreaking work with black silicon has only just begun.

About

Continuum Magazine is NREL's quarterly publication that showcases the laboratory's latest and most impactful clean energy innovations and the researchers and unique facilities that make it all happen.

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Contributing Authors

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Editorial Board

Heidi Blakley, Mary Anne Dunlap, Michelle Kubik, Heather Lammers, Susan Moon, Lauren Moughon

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National Renewable Energy Laboratory
1617 Cole Boulevard, Golden, Colorado 80401
303-275-3000 • www.nrel.gov

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