



# TRANSFORMING ENERGY THROUGH SCIENCE

The National Renewable Energy Laboratory (NREL) is the U.S. Department of Energy's (DOE's) primary national laboratory for renewable energy and energy efficiency research. From scientific discovery to accelerating market adoption, NREL deploys its deep technical expertise and unmatched breadth of capabilities to drive the transformation of our nation's energy resources and systems.

## At NREL, we never stop innovating.

Whether it is growing the scientific body of knowledge, developing analysis for policy and decision makers, engineering an integrated energy infrastructure, or establishing valuable partnerships to bring the next generation of technology to market, innovation is at the core of our work.

## NREL Impacts: From Concept to Market

NREL's commitment to scientific discovery propels researchers to fill the gaps in energy knowledge and disrupt current-generation technology. The laboratory responds to market challenges by identifying these knowledge gaps and providing market insight that informs the technology landscape. This market-facing approach positions NREL to have impact across a breadth of industry sectors while simultaneously growing the nation's body of energy research.

NREL's research achievements have:

- Helped launch several successful companies and have made solar photovoltaics one of the fastest-growing energy sectors in the United States

- Increased solar cell efficiency using perovskites by converting sunlight to electricity—from 3.8% to more than 20% in the past six years
- Contributed to dramatic reductions in the levelized cost of electricity (LCOE), now providing power at 4-7 cents per kilowatt hour (kWh)
- Led to greater understanding of photosynthetic systems of hydrogen, fuel, and chemical production, as well as genetic and pathway engineering of micro-organisms
- Demonstrated cellulosic ethanol cost parity with gasoline at a pilot scale
- Decreased the cost of converting biomass into cellulosic ethanol by 67%.

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“Continuous scientific innovation and development of disruptive technologies are essential if we are to successfully address the energy challenges facing our nation and the world. These are hallmarks of the research and development being done at NREL.”

—Martin Keller, Director,  
National Renewable Energy Laboratory

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## Recent Successes Boost Clean Energy Advancements

NREL's innovations span the spectrum of clean energy, renewable electricity, and energy efficiency. The laboratory is home to three national research centers—for solar, wind, and bioenergy—and several programs that advance cutting-edge research in areas such as strategic energy analysis and energy systems integration. The following summaries highlight recent successes in NREL's key research areas.

## FAST FACTS

NREL's staff of nearly **1,700 full- and part-time employees** and **700 visiting researchers, 80 post-doctoral students, 234 student interns**, and contractors collectively hail from more than **70 countries** and **hold more than 2,700 academic degrees**. Total NREL payroll in FY 2015 was more than **\$170 million**.

NREL and its employees have garnered many prestigious scientific and professional awards each year, including **58 R&D 100 awards**. NREL researchers publish **more than 1,000 scientific and technical materials** annually in such journals as *Science*, *Nature*, and the *Proceedings of the National Academy of Sciences*.

The most recent study of NREL's economic impact was completed in 2015; that impact totaled **\$872.3 million** nationwide for FY 2014.

NREL's main **327-acre campus** is in Golden, Colorado. The laboratory operates the National Wind Technology Center on **305 acres** 13 miles north of Golden.



## Informing Research with Strategic Energy Analysis

Groundbreaking analyses have helped redefine what's possible for renewable energy. NREL's core energy analysis, technology development, and deployment teams are aligned so that insights gained at all scales inform the next set of research questions. Lessons from market-driven projects define performance and cost goals



for early-stage research and development. Key analysis reports from NREL support decision makers across the country and around the world in their efforts to transform energy systems.

- Numerous NREL studies show that U.S. power systems can operate reliably and affordably with significantly higher levels of renewable energy. In the *Wind Vision Report*, NREL assessed the economic, environmental, and social benefits of future scenarios in which domestic wind power supplies 30% of U.S. electrical demand in 2050.



- In any NREL assessment on rooftop solar photovoltaic (PV) technical potential in the United States, researchers used detailed light detection and ranging (LiDAR) data for 128 cities nationwide and estimated a total of 1,118 gigawatts (GW) in capacity, equivalent to 39% of the nation's electricity sales.

## Integrating Energy Systems at all Scales

As the percentage of electricity generated from renewable energy sources increases on our nation's grid, it is critical to understand and model how to integrate all electricity sources and upgrade our aging infrastructure. At NREL, energy systems integration is a vital area of research that addresses the challenges of integrating clean energy sources into the national energy infrastructure, much of which is conducted at NREL's Energy Systems Integration Facility (ESIF).

- ESIF is the nation's premier facility for research, development, and demonstration of the components and strategies needed to optimize our entire energy system.
- The capabilities housed within ESIF enable complex system modeling, simulation, and hardware validation at the megawatt scale and includes more than 15 experimental laboratories, such as a 3-D visualization room for researchers to experience large-scale systems in a virtual environment.
- ESIF's peta-scale high-performance computing (HPC) and data management system provides a multitude of simulation capabilities, such as testing high-penetration scenarios on the grid from variable sources of renewable energy.

## Advancing NREL's Roots in Solar Photovoltaics

PV technologies have been a foundational research area for NREL from its inception. The National Center for Photovoltaics (NCPV) embraces this focus, and PV research at NREL continues to advance innovation.

- NREL established a new efficiency record in 2014 of 46% for a III-V multijunction concentrator PV cell.



- NREL researchers developed a new ultrafast spectroscopic probe to design sunlight-to-fuel photoelectrodes that are more efficient. The probe is sensitive to charge-carrier dynamics at important semiconductor interfaces, and NREL has been using the probe to explore the beneficial role of multi-junction cells.

## Optimizing Wind Energy Technologies

For nearly 30 years, NREL has helped the wind energy industry with their design and research innovations. The comprehensive capabilities of the National Wind Technology Center (NWTC)—ranging from expert staff and industry-leading research facilities and equipment to specialized computer simulation tools—have been used to design, develop, and deploy several generations of advanced wind energy technology.

- Established by researchers at NREL, The Gearbox Reliability Collaborative (GRC) is a joint venture among manufacturers, owners, operators, researchers, and consultants to decrease the occurrence of gearbox failures through the industry.
- The next great research challenge is to better understand the environmental factors impacting individual wind turbines and optimize entire wind plant performance.
- NREL researchers developed the Simulator for Wind Farm Applications (SOWFA), a software framework that predicts the effects of a full range of atmospheric conditions and terrain on turbine blade structures, gearboxes, and drivetrains. New wind farm control ideas tested in SOWFA show impressive results, with potential annual

energy capture increases up to 5%, which could translate into millions of dollars of revenue annually for a commercial wind farm.

### Manufacturing beyond Biofuels

NREL is also home to the National Bioenergy Center (NBC), established in October 2000 to support the science and technology goals of DOE's Bioenergy Technologies Office. NREL's research in bioenergy optimizes processes to convert renewable biomass feedstocks into transportation fuels, chemicals, and products.

- Computational and molecular modeling capabilities are leading to more rational design of enzymes for bio-synthesized products, using experimental and theoretical tools to engineer enhanced cellulose enzymes.
- Scientists with NREL's photobiology group developed a process to genetically engineer a type of cyanobacterium into ethylene—a chemical used in the manufacture of plastics and polyester, and the largest emitter of carbon dioxide (CO<sub>2</sub>) in the chemical industry. NREL's process is one of the first demonstrations that cyanobacterial engineering can be a viable approach to generating everyday materials, while avoiding up to 1 billion tons of carbon emissions a year.



### Revolutionizing Vehicles with Hydrogen

Research in hydrogen fuel cells has the potential to revolutionize the way we power vehicles, offering cleaner, more-efficient alternatives to the combustion of gasoline and other fossil fuels. Additionally, fuel cells are scalable for a variety of other applications such as stationary power and portable devices. NREL's research aims to produce hydrogen economically from sustainable resources and to develop cost-effective, high-performance fuel cell technologies.

- NREL's new hydrogen fueling station is part of NREL's Hydrogen Infrastructure Testing and Research Facility (HITRF), where scientists are able to produce renewable hydrogen through electrolysis, test fuel cell vehicle and infrastructure components, and improve hydrogen fueling methods.



### Fueling Mobility through Sustainable Transportation

Transportation accounts for 71% of U.S. petroleum use and 33% of the nation's carbon emissions. NREL accelerates widespread adoption of high-performance, low-emission, energy-efficient passenger and freight vehicles, as well as alternative fuels and related infrastructure. The laboratory's researchers also explore ways to fast-track progress toward energy savings and greenhouse gas reduction goals by integrating advancements in electric-drive, fuel cell, and biofuel vehicle technologies with renewable energy generation, charging and fueling systems, power grids and building systems, urban planning and policy, and fleet operations.

### Harnessing Untapped Wave and Tidal Resources

NREL's water power efforts focus on the research and development of emerging marine and hydrokinetic technologies that harness energy from untapped wave, tidal, and other water-current resources. Laboratory researchers also study impoundment-based hydropower technologies to improve their efficiency, flexibility, and environmental compatibility to improve the cost effectiveness of these well-established electric-generating technologies.

- NREL teamed with Sandia National Laboratories to win the 2015 Hydrodynamic Modeling Competition using the modeling software they created: the Wave Energy Converter Simulator, or WEC-Sim. The collaborators applied open-source tools that were jointly developed for the water-power industry as a way to help unlock the potential terawatts of power available in U.S. wave resources.

### Powering Buildings with Efficient Design

NREL building energy research is focused on both reducing building energy use and controlling building electricity demand to accommodate more renewable electricity. NREL has been a leader in the contracting and design aspects of zero-energy buildings. Our Research Support Facility is the world's largest zero-energy office building, and its principles have been applied to more than 50 new buildings across the United States.

- NREL's zero-energy building expertise extends to zero-energy urban districts via design assistance and the development of a computer design model for city planners.
- NREL's user-friendly design tools such as OpenStudio and Energy Design Assistance Program Tracker (EDAPT) are being used by an increasing number of utilities to provide accurate building modeling and support to the \$8 billion/year utility incentive industry aimed at encouraging high-efficiency buildings.

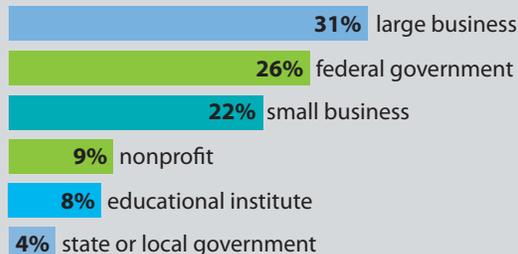
## TECHNOLOGY PARTNERSHIPS (FY 2015)

231 new partnership agreements

\$33 million in new partnership agreements value

684 active partnership agreements

Including NREL's 231 new agreements in FY 2014, the laboratory maintained a total of 684 active partnerships.



## PATENTS (FY 2015)

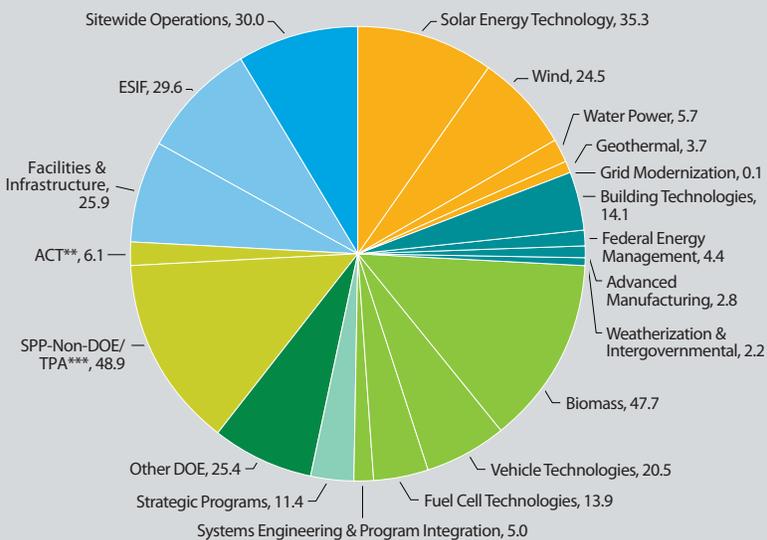
221 issued U.S. patents      137 pending U.S. applications

55 issued foreign patents      142 pending foreign applications

## NREL FUNDING

More than 80% of NREL's funding is through DOE's Office of Energy Efficiency and Renewable Energy.

### FY 2015 FUNDS BY NREL PROGRAM \$357M



\*Strategic Partnership Projects

\*\*Agreements for Commercializing Technology

\*\*\*Technology Partnership Agreements

## Partners and Collaboration

Alongside NREL's commitment to innovation, partnerships are at the core of the laboratory's strategy. NREL collaborates with hundreds of partners across 46 states and 30 countries to commercialize renewable energy and energy efficiency technologies from industry, academia, nonprofit organizations, federal agencies, and international institutions; as well as state, local, and tribal governments. These collaborations allow NREL to tap the expertise of all clean energy-related sectors across the country while working with the Department of Energy to support its mission. With our partners, the laboratory can help advance America's security and prosperity by addressing today's energy and environmental challenges through transformative science and technology solutions.

NREL has 696 active partnerships and established 236 new partnership agreements in Fiscal Year 2015. By engaging with the private sector through a variety of research contracting mechanisms, as well as through licensing new technologies, federal investment in these partnerships has leveraged private funds by a factor of five. Every \$1 invested by DOE has attracted \$5 in private investment—continually creating new companies and new jobs.

## Achieving a Clean Energy Vision

Our ability to solve today's energy challenges will significantly affect the future of our nation's security, economy, and environment. Improving energy efficiency, developing domestic clean-energy sources, and modernizing our nation's energy infrastructure enhances our security by boosting domestic production and ensuring that our electrical, thermal, and transportation systems are resilient and reliable. It also strengthens our economy by creating thousands of manufacturing and service jobs, lowering price volatility, and making energy more affordable.

Finally, clean energy improves our environment and future climate conditions by reducing carbon in the atmosphere and decreasing global dependence on fossil fuels. We focus on creative answers to today's challenges at NREL—from breakthroughs in fundamental science to new clean technologies to integrated energy systems that power our lives each and every day.

## History

NREL started as the Solar Energy Research Institute (SERI) in 1977, spurred by national concern during the 1973 oil embargo. President Jimmy Carter visited SERI in 1978, and in 1979 said, famously: "No one can ever embargo the sun or interrupt its delivery to us." Thirteen years later, President George H.W. Bush elevated SERI to a national laboratory and changed its name to the National Renewable Energy Laboratory.

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