

U.S. Department of Energy's Wind Energy Technologies Office—Lasting Impressions

State of the Industry: 1980–Today

Wind energy has the potential to provide a large portion of the nation's electricity. From the birth of the U.S. wind industry in 1980 to the 90 gigawatts (GW) of capacity installed today, wind power is expanding across the United States, with utility-scale turbines deployed in 41 states, distributed wind deployed in all 50 states, and the nation's first offshore wind farm deployed off the coast of Rhode Island in 2016. Texas alone has more installed wind power than all but five countries around the world.

Throughout the past decade, the U.S. wind industry has grown significantly and represents about 30% of newly installed generating capacity since 2009. Wind energy will continue to be a fundamental component of the next era of energy projects that connect to the electricity grid. Interest in wind power continues to grow as next-generation technologies continue to make wind an affordable clean energy solution.

The U.S. wind industry isn't just generating clean electricity for American homes, it also employs more than 100,000 professionals nationwide. These jobs include those at more than 500 manufacturing facilities across the United States, including dedicated wind facilities in every region that manufactures turbine components such as towers, blades, and assembled nacelles.

A Vision for the Future of U.S. Wind Power

The U.S. Department of Energy's (DOE) Wind Energy Technologies Office (WETO), in close cooperation with the wind industry, revisited the findings of the 2008 DOE *20% Wind Energy by 2030* report to develop the *Wind Vision Report*, a renewed vision for U.S. wind power research, development, and deployment through 2050. The *Wind Vision Report* quantifies a scenario where wind energy supplies 10% of the country's electricity in 2020, 20% in 2030, and 35% in 2050. Included in the *Wind Vision Report* are:

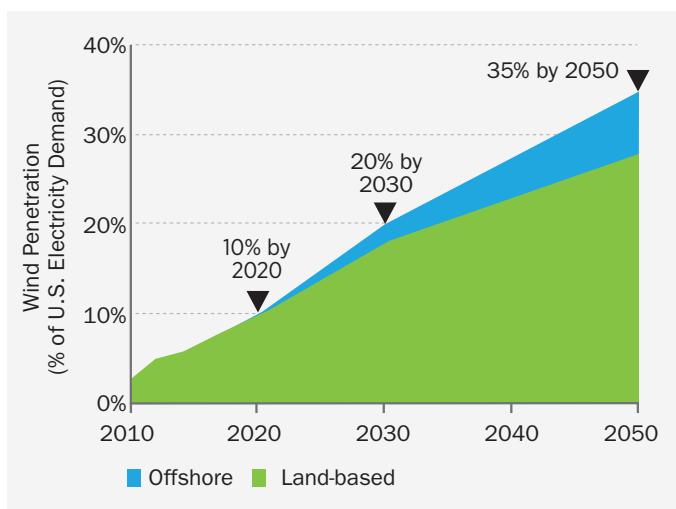
- A characterization of industry progress to date, and how recent developments and trends have impacted wind industry growth
- A quantification of the social, economic, and environmental benefits of a robust wind energy future
- A roadmap addressing the challenges to achieving high levels of wind as a part of the country's clean energy mix.



Photo from Siemens AG, NREL 19687

The Wind Energy Technologies Office's Role in Innovation—Moving the Nation's Power Dial

Plugging into the nation's abundant wind resources for electric power generation will stabilize energy costs, help secure energy independence, and improve our environment. DOE's WETO recognizes that wind is an affordable, domestic, renewable, and plentiful energy resource. For almost four decades, WETO has conducted energy science R&D aimed at improving performance, lowering costs, and accelerating deployment of wind technologies on land and offshore. The cost of energy from wind power, in areas with good wind resources, has decreased from more than \$0.55/kWh in 1980 (current dollars) to under \$0.03/kWh today in the interior region of the United States. WETO partners with national laboratories, industry, universities, and other federal agencies to conduct energy science research and development activities that enable industry to develop innovative technologies and increase wind energy deployment throughout the country.



The Wind Vision Report can be found at
<https://www.energy.gov/eere/wind/maps/wind-vision>

■ Simulation Codes and Design Tools

WETO developed turbine simulation codes to streamline design development and reduce costs of technology commercialization. These codes allow designers to build virtual models of blades and full systems to predict performance in different environments before prototypes are even constructed.

- Publicly available codes such as FAST and AeroDyn are now widely used by universities, government agencies, and industry. The NALU and SOWFA high-fidelity simulation codes use computational fluid dynamics techniques and run on DOE high-performance computing resources, enabling researchers to model the performance of entire wind farms and to study methods to optimize wind plant performance.
- In support of the Atmosphere to Electrons (A2e) initiative for wind plant optimization, DOE's National Renewable Energy Laboratory (NREL) has developed the WISDEM™ tool, which models all aspects of wind plants from components to operations in a comprehensive, system cost-of-energy analysis. Using WISDEM with the controls-based model FLORIS, NREL has simulated the potential of wind plant controls to steer wakes within a plant to reduce energy losses over the course of the year by 20%–30% and increase overall plant energy production by 5% or more.
- The Numerical Manufacturing and Design Tool (NuMaD) blade software tool significantly reduces development time compared to conventional tools; blade software tool significantly reduces development time compared to conventional tools; a blade model previously requiring 15 hours to complete can now be completed in less than an hour.

■ Next-Generation Component Design and Fabrication

WETO conducts research that facilitates the development of next-generation wind turbine components such as rotor blades, drivetrains, generators, power electronics, and towers. Research and development in this area include advanced design studies, design competitions, industry collaboratives, and materials characterization studies. Many of these innovations have been incorporated by industry into modern commercial wind turbines. More than 140 specific wind energy patents are tied to DOE-funded research; DOE ranks first in wind energy patents and citations linked to commercial wind companies.

- Advanced airfoils led to new turbine blade designs that produced 30% more energy than previous designs and are now the industry standard.



Photo by Warren Gretz, NREL 12420

- Researchers fabricated a 1.5-MW single-drive, permanent-magnet drivetrain that reduced the total cost of production by 12.8%. A planetary gearbox and a medium-speed (190 rpm), permanent-magnet generator reduced tower-head weight and total drivetrain costs.
- The Structural and Mechanical Adaptive Rotor Technology (SMART) project developed a wind turbine rotor with integrated trailing-edge flaps designed for the control of rotor aerodynamics. Blades outfitted with a trailing-edge flap, running along roughly 20% the blade's total length, exhibit fewer microstrains and stressors as the turbine operates.
- WETO partnered with DOE's Advanced Manufacturing Office (AMO), Oak Ridge National Laboratory, Sandia National Laboratories, and TPI Composites to apply additive manufacturing, commonly known as 3D printing, to the production of wind blade molds. This innovative process will demonstrate the utility of Big Area Additive Manufacturing as a platform for renewable energy systems, explore innovation that can lead to reduced costs in wind blade manufacturing, and assess the potential for increasing U.S. manufacturing competitiveness through innovative applications that advance clean energy technologies.

■ Turbines

Modern wind turbines are increasingly cost-effective and reliable, and have scaled up in size to multimegawatt power ratings. Since 1999, the average turbine generating capacity has increased by 180% to 2 MW for turbines installed in 2015. WETO research has helped facilitate this transition through the development of longer, lighter rotor blades, taller towers, more reliable drivetrains, and performance-optimizing control systems. Furthermore, improved turbine performance has led to a more robust domestic wind industry that saw wind turbine technology exports grow from \$16 million in 2007 to \$149 million in 2015.



Photo by Dennis Schroeder, NREL

- Wind turbine initiatives, including WindPact and Low Wind Speed Turbine, supported innovative prototypes and early commercial growth of turbines that reach higher wind classes and capture much more energy.
- The Competitiveness Improvement Project (CIP) supports manufacturers of small and medium wind turbines to optimize their designs, develop advanced manufacturing processes, and perform turbine testing. CIP awardee Northern Power Systems of Vermont achieved a 15% energy production

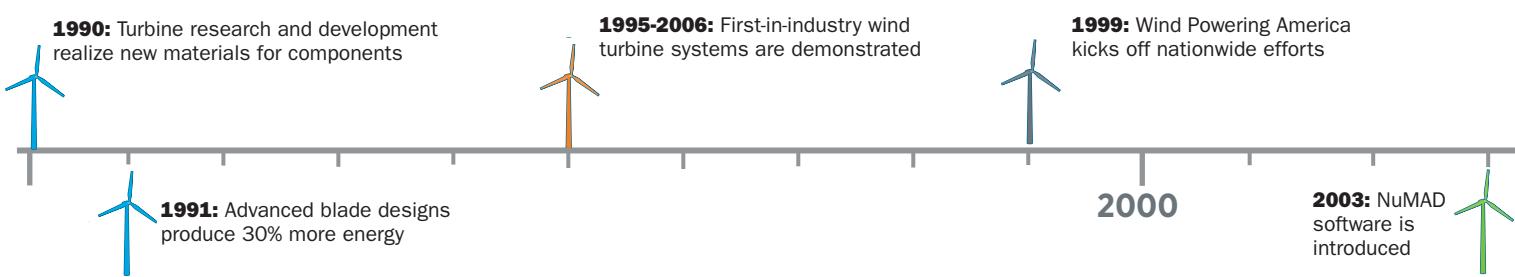
Wins in Wind: 1990–Today

■ Simulation Codes and Design Tools

■ Next-Generation Component Design and Fabrication

■ Turbines

■ Analysis



increase for the NPS-100 turbine by increasing blade length and improving blade aerodynamics; Pika Energy of Maine reduced blade costs by approximately 90% by developing an innovative tooling and cooling strategy to produce blades using injection-molded plastic; and Bergey Windpower of Oklahoma developed a new wind turbine model, the Excel 15, which is anticipated to produce 85% more energy than the previous model.

■ Testing and Demonstration

WETO has supported testing centers across the nation that enable researchers and industry partners to conduct a wide range of system, component, and field tests to identify and resolve technical design issues.

- The Utility-Industry Wind Turbine Verification Program tested and evaluated prototype utility-scale wind turbines prior to deployment. This program expanded the market for wind power by introducing the benefits of wind to several electric utilities that today are key wind players.
- DOE's National Wind Technology Center in Colorado employs field, drivetrain, and blade test facilities to test next-generation turbine designs and components.
- The Wind Technology Testing Center in Boston, Massachusetts, is the nation's first large wind blade test facility, with the capability to test blades up to 90 meters in length and suitable for wind turbines up to 15 MW, as anticipated for offshore installations.
- In 2013, America's largest and one of the world's most advanced drivetrain test facilities opened at Clemson University in Charleston, South Carolina. Funded in part by DOE, the Clemson facility can currently test drivetrains up to 7.5 MW and will also have a 15 MW test rig.
- In 2013, DOE commissioned the Scaled Wind Farm Technology (SWiFT) Facility in Texas. As the first public facility to use multiple turbines to measure performance in a wind plant environment, SWiFT aims to reduce turbine-to-turbine interactions, develop advanced rotors, and improve the validity of advanced simulation models.



Photo by Derek Berry, NREL

as Wind Powering America, were critical in enabling wind to break out of California and develop in markets across the country. In 2014, DOE announced WINDEXchange, a new hub for stakeholder engagement and outreach.

- WINDEXchange helps communities weigh the benefits and costs of wind energy, understand the deployment process, and make wind development decisions supported by the best available fact-based information. <https://energy.gov/eere/wind/windexchange>
- DOE's past initiative, Wind Powering America, was responsible for 15% of U.S. wind deployment under its tenure by supplying state and local policymakers with objective information and tools such as the Jobs and Economic Development Impact (JEDI) model to promote sound decision-making about wind energy policies and deployment in their jurisdictions.



Photo by Shawn Smallwood, NREL 17329

■ Resource Characterization and Grid Integration

WETO efforts in resource characterization have given energy planners an understanding of the wind's resource potential and have allowed manufacturers to design more cost-effective and reliable turbines, helping grid operators integrate electricity from the nation's wind resources.

- The TurbSim code provides designers with realistic wind inflow for turbine simulation models, yielding higher confidence in the performance and reliability of new turbine systems.
- Utility power system simulations using high-resolution synthesized wind data have become the world standard for conducting renewable energy integration studies.
- The WindSENSE project increases awareness of wind conditions and energy forecasts so grid operators can make informed scheduling decisions, especially during extreme events such as wind ramps.
- By working closely with Western utilities and system operators, WindSENSE improves integration of wind generation into the grid while maintaining grid reliability.

■ Market Acceleration and Barrier Reduction Activities

In the 1990s, wind development had largely occurred at a few sites in California and had not established a foothold elsewhere in the country. DOE-funded market acceleration and environmental initiatives, such

■ Testing & Demonstration

■ Resource Characterization & Integration

■ Market Acceleration & Barrier Reduction Activities



2004: 1.5-MW permanent magnet drivetrain reduces cost of production 12.8%

2008: 20% Wind Energy by 2030 report is released



2010

2011: Nation's first large-blade test facility opens



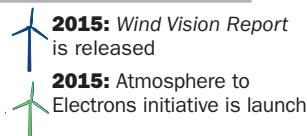
2011: A National Offshore Wind Strategy: Creating the U.S. Market is released

2013: Clemson drivetrain test facility opens



2014: WINDEXchange is launched

2015: Wind Vision Report is released
2015: Atmosphere to Electrons initiative is launched
2016: National Offshore Wind Strategy: Facilitating Development of the U.S. Offshore Wind Industry is released



Leading U.S. Wind Energy Innovation

DOE's Wind Energy Technologies Office (WETO) invests in energy science research and development activities and technology solutions that enable industry innovation, while continually addressing market and deployment barriers, including siting and environmental impacts. WETO is dedicated to driving down the cost of wind energy with more efficient, more reliable, and more predictable wind energy systems. Most of the Office's work falls under three topics: the Atmosphere to Electrons initiative, which analyzes the complex physics of wind farms; cutting-edge research on next-generation wind technologies; and market acceleration and deployment activities.

- **WETO's Atmosphere to Electrons Initiative is optimizing wind plant systems** that produce more power, leading to the wind plant of the future—a collection of intelligent and innovative machines operating in a highly coordinated way. DOE is partnering with government, academia, and industry to improve the reliability of next-generation wind turbines and wind plant systems that address the complex dynamics of winds created by turbulent weather, variable terrain, and wakes. For example, supercomputers at DOE's national laboratories can model the complexity of wind plant flow physics and enable industry to take the next steps in developing both evolutionary and transformational innovation technologies.

- **WETO enables industry growth and U.S. competitiveness** through research and development activities that lower the cost of electricity from wind. These include new drivetrain configurations that weigh less than current designs and are installed on taller towers that can access the stronger wind resources at greater heights above the ground. In addition to developing cost-effective technologies that can be used both on land and offshore, DOE supports the emerging U.S. offshore wind industry by characterizing offshore wind resources, conducting research needed to address U.S.-specific challenges such as deep water and hurricanes, and supporting innovative demonstration projects that are among the first of their kind making their way through permitting, approval, and grid interconnection processes in the United States.

- **WETO's market acceleration efforts leverage intergovernmental partnerships** to reduce market barriers for wind project development, including issues related to transmission access and grid integration and siting concerns such as radar and wildlife. WETO funds earlystage R&D activities that reduce siting constraints to wind energy, including research to avoid, minimize, and mitigate environmental impacts and competing human uses in a cost-effective manner.

With continued science-driven research, U.S. wind technologies can provide global leadership in the next generation of wind technology innovations, driving economic benefits for U.S. manufacturers, businesses, and consumers.



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