U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

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

State of the Industry: 1980–Today

Wind energy is an important part of the U.S. energy mix. From the birth of the U.S. wind industry in 1980 to the 110 gigawatts of capacity installed today, wind power continues to expand across the country. Utility-scale turbines are deployed in 41 states, turbines deployed in distributed applications provide on-site power or support local distribution networks across all 50 states, and the nation's first offshore wind projects have been deployed off the coasts of Rhode Island and Virginia.

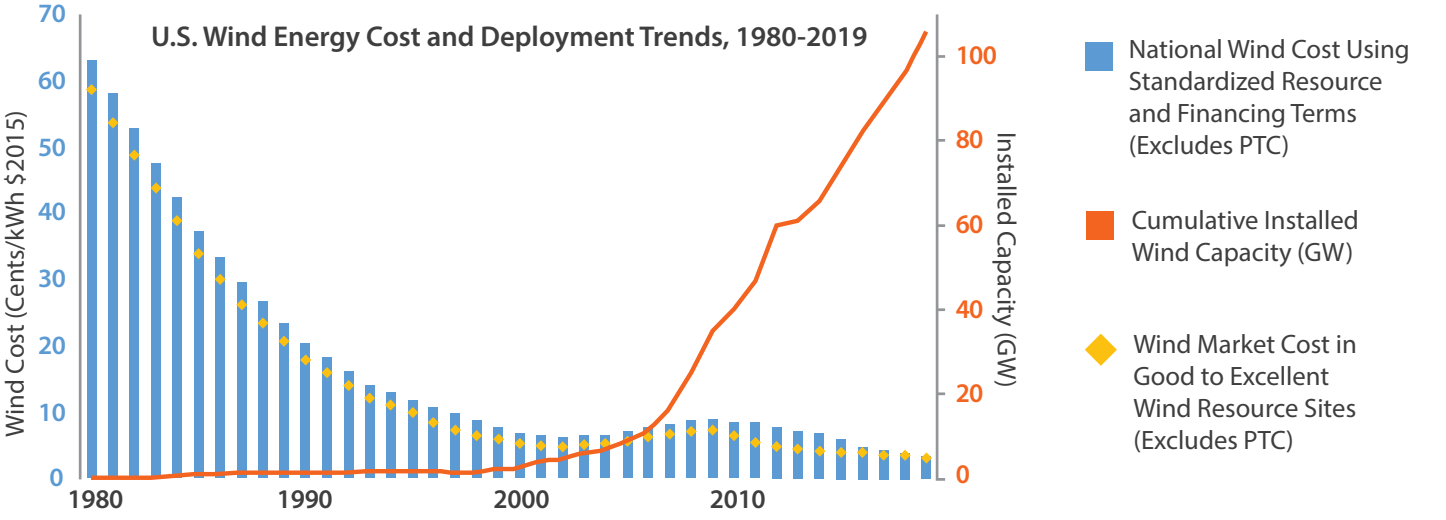
Throughout the past decade, the U.S. wind industry has grown significantly, representing between 20% and 40% of newly installed generating capacity in recent years and confirming that wind energy will continue to be a fundamental component of the next era of energy projects that connect to the electricity grid. The levelized cost of wind energy has decreased from more than 60 cents per kilowatt-hour in 1980 to 3.5 cents per kilowatt-hour today, and interest in wind power continues to grow as next-generation technologies make wind an affordable clean energy solution.

The U.S. wind industry does more than just generate 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. And the job opportunities continue after the turbines are installed; wind turbine technician is one of the fastest-growing jobs in the United States.

Photo from Siemens AG, NREL 19687

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

For the past four decades, the U.S. Department of Energy's (DOE's) Wind Energy Technologies Office (WETO) has supported a diversified research and development (R&D) portfolio to advance technologies that improve performance, reduce costs, and accelerate deployment of wind technologies on land and offshore. This work has driven down the cost of wind energy through competitively selected, cost-shared projects carried out in collaboration with industry, universities, research institutions, and other stakeholders. DOE ranks first in wind energy patents and citations linked to commercial wind companies, with more than 170 specific wind energy patents tied to DOE-funded research.



The early-stage, high-risk research and innovation supported by the Wind Energy Technologies Office (WETO) has been pivotal to the wind industry's success, contributing to innovations that have advanced the scale, efficiency, and competitiveness of wind energy.

Simulation Codes and Design Tools

Turbine simulation codes funded by WETO streamline design development and reduce costs of technology commercialization. These codes, which allow designers to build virtual models of blades and full systems to predict performance in different environments before prototypes are even constructed, include the following:

- Publicly available codes such as OpenFAST and AeroDyn are now widely used by universities, government agencies, and industry. The Software fOr Wind Farm Applications (SOWFA) high-fidelity simulation code uses computational fluid dynamics techniques and runs on DOE high-performance computing resources, enabling researchers to model the performance of entire wind farms and study methods to optimize wind plant performance. ExaWind combines three open-source codes: Nalu-Wind, AMR-Wind, and OpenFAST, enabling the highest-fidelity wind plant simulations to run on next-generation exascale-class supercomputers.
- To support wind plant optimization, DOE's National Renewable Energy Laboratory (NREL) developed the Wind-Plant Integrated System Design and Engineering Model (WISDEM®), a systems engineering software tool that models all aspects of wind plants from components to operations in a comprehensive cost-of-energy analysis. Using WISDEM with the controls-based model FLOw Redirection and Induction in Steady State (FLORIS), NREL has simulated wake steering within a wind 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 simplifies the process of creating three-dimensional wind turbine blade models and 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-funded research facilitates the development of next-generation wind turbine components such as rotor blades, drivetrains, generators, power electronics, and towers. R&D in this area includes 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 and include the following:

- Between 2011 and 2016, DOE funded the design, fabrication, and testing of a 1.5-megawatt (MW) single-drive, permanent-magnet drivetrain that reduced the total cost of energy by 12.8%. A planetary gearbox and a medium-speed (190 revolutions per minute), permanent-magnet generator reduced tower-head weight and total drivetrain costs.
- Innovations supported by DOE and now used in most commercial wind turbines allowed for significantly longer blades and thus more energy captured by each turbine without compromising reliability. The bend-twist innovation developed under the Sweep-Twist Adaptive Rotor (STAR) program represented an inherent structural design that allowed for twisting to reduce stress on blades in high winds. The flat-back design flattened the trailing edge of the blade for strength, and the airfoil-shaped outer portion increased wind capture.

Photo from ONYXInSight

- Manufacturing and Additive Design of Electrical Machines Enabled by 3D Printing (MADE3D) is a new approach to designing and fabricating electric machines. The topology-optimization software helps reduce weight and improves torque densities using high-performance, low-cost materials and multimaterial printing technologies.
- WETO partnered with DOE's Advanced Manufacturing Office, Oak Ridge National Laboratory, Sandia National Laboratories, and TPI Composites to apply additive manufacturing, commonly known as 3D printing, to the production of wind turbine blade molds—demonstrating how 3D printing can reduce manufacturing costs and increase U.S. manufacturing competitiveness.

Wind Turbines

Modern wind turbines are increasingly cost-effective and reliable, and utility-scale turbines have scaled up in size to multimegawatt power ratings. Since 1999, the average wind turbine generating capacity has more than tripled, to 2.55 MW for turbines installed in 2019. WETO research has helped facilitate this transition by developing longer, lighter rotor blades, taller towers, more reliable drivetrains, and performance-optimizing control systems, including:

Photo by Dennis Schroeder, NREL 20375

- Wind turbine initiatives, such as WindPact and Low Wind Speed Turbine, support innovative prototypes and early commercial growth of turbines that reach higher wind classes and capture much more energy.
- The Competitiveness Improvement Project (CIP) helps manufacturers of small- and medium-sized wind turbines advance wind energy as a low-cost distributed generation technology by helping them

Wins in Wind: 1990–Today

Simulation Codes and Design Tools | Next-Generation Component Design and Fabrication | Turbines | Analysis

1990: Turbine research and development realize new materials for components

1995-2006: First-in-industry wind turbine systems are demonstrated

1999: Wind Powering America kicks off nationwide efforts

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

1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006

Mid-1990s to late 2000s: Advancements in blade design increase energy capture

2003: NuMAD software is introduced

reduce technology costs, optimize their designs, develop advanced manufacturing processes, and perform certification testing. CIP awardee Bergey Windpower of Oklahoma developed a new wind turbine model, the Excel 15, which is anticipated to cut costs by 50% compared to 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. These facilities provide platforms for industry to access world-class research capabilities that are essential for the advancement of the technology, but are too costly for most companies to support individually, and include the following:

- 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 at NREL's Flatirons Campus in Colorado employs utility-scale research turbines, dynamometers, a controllable grid interface, energy storage, and high-performance computing facilities to develop and evaluate new technologies at a scale that replicates the real world.
- The Wind Technology Testing Center in Massachusetts tests blades up to 107 meters in length—suitable for wind turbines up to 15 MW.
- Clemson University's Energy Innovation Center in South Carolina can test wind turbine drivetrains up to 15 MW and also features a controllable grid interface.

Photo by Derek Berry, NREL 20067

- DOE's Scaled Wind Farm Technology (SWiFT) facility in Texas is 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.

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 as Wind Powering America, were critical in enabling wind to break out of California and develop in markets across the country. These activities included:

- In 2014, DOE announced WINDExchange, a new hub for stakeholder engagement and outreach that 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. windexchange.energy.gov
- 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) models to promote sound decision-making about wind energy policies and deployment in their jurisdictions.

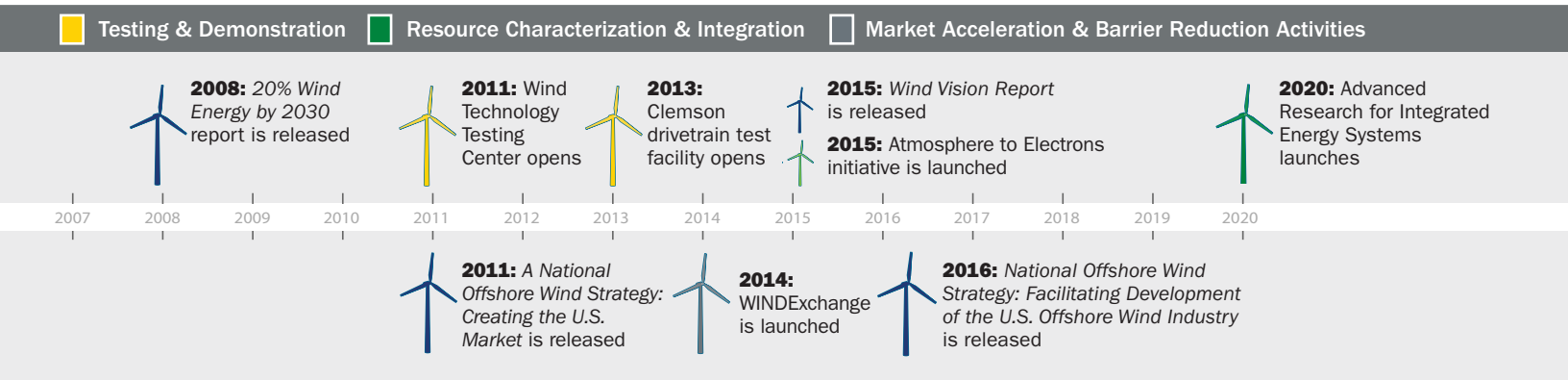
Photo by Shawn Smallwood, NREL 17329

- Workforce development and education activities like the DOE Collegiate Wind Competition help ensure that qualified workers and skilled scientists and engineers will support continued industry growth.
- WETO programs work to reduce wind energy environmental impacts and help protect wildlife. An ultrasonic bat deterrent system, developed with DOE funding and commercialized by NRG Systems, is now widely deployed at wind farms in the United States and abroad.

Resource Characterization and Grid Integration

WETO's wind energy resource characterization R&D gives energy planners an understanding of wind's resource potential, allows manufacturers to design more cost-effective and reliable turbines, and helps grid operators integrate electricity from the nation's wind resources. Progress in this area includes the following:

- The TurbSim code provides designers with realistic wind inflow for turbine simulation models, yielding higher confidence in the performance and reliability of new wind 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.
- High-fidelity wind data collected by WETO-funded projects have resulted in improved wind forecasts, which the National Oceanic and Atmospheric Administration has incorporated into widely used operational weather forecast models.
- To support resource characterization for offshore wind energy, DOE owns and makes available to industry two lidar buoys that collect comprehensive meteorological and oceanographic data while moored at sea.
- In 2020, NREL launched the Advanced Research for Integrated Energy Systems (ARIES) platform at its Flatirons Campus. ARIES allows full experimentation of integrated energy systems and enables DOE and industry to mitigate the technical, operational, and financial risks of large-scale energy integration.



Leading U.S. Wind Energy Innovation

WETO invests in energy science R&D activities to advance technologies for offshore, land-based, and distributed wind energy. These activities enable technology and operational solutions and spur innovation, while also addressing market and deployment barriers such as siting and environmental impacts and systems integration. Most of WETO's work falls under three topics: wind energy cost reduction, siting and environmental solutions, and integration of wind energy into the energy system of the future. Specifically:

- **WETO enables industry growth and U.S. competitiveness** through R&D 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 siting concerns such as radar and wildlife. WETO funds early-stage R&D activities that reduce siting constraints to wind energy, such as research to avoid, minimize, and mitigate environmental impacts and competing human uses in a cost-effective manner.
- **WETO's efforts enable the integration of substantial amounts of wind energy** into the dynamic and rapidly evolving energy system of the future. WETO supports R&D to understand the transmission needs for wind integration, enable wind to provide a wide range of reliability and resiliency services, identify storage and other technologies that complement wind generation, and design wind-specific cybersecurity methodologies to make wind systems resilient to potential cyberattacks.

With continued science-driven research, WETO-funded activities can enable research and industry partners to provide global leadership in the next generation of wind technology innovations, driving economic benefits for U.S. taxpayers, businesses, and consumers.

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For more information, visit: energy.gov/eere/wind

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