WIND ENERGY FACILITIES

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

WIND ENERGY TECHNOLOGIES OFFICE

U.S. Department of Energy facilities span the United States and offer wind research capabilities to meet industry needs.

capabilities

- Advanced Manufacturing
- High-Performance Computing
- Resource Characterization
- Grid Integration
- Field Testing
- Drivetrain Testing
- Blade Testing

Pacific Northwest National Laboratory
Washington

- Coastal Wind Profiling Radars
- Grid Systems Engineering Building: Electricity Infrastructure Operations Center
- Lidar Buoy Loan Program

Lawrence Livermore National Laboratory
California

- High-Performance Computing Innovation Center
- Mobile Observational Instruments
- Site 300 Test Facility

Idaho National Laboratory
Idaho

- Critical Infrastructure Test Range
- Human System Simulation Laboratory
- Microgrid Test Bed
- Power and Energy Real-Time Digital Simulation
- Wireless Test Bed

Sandia National Laboratories
New Mexico

- Advanced Simulation and Computing
- Facility for Antenna and Radar Cross-Section Measurement
- Lightning Simulator
- Infrastructure Assurance and Non-Destructive Testing Facility
- Scaled Wind Farm Technology Facility
- Wake Imaging Measurement System

National Renewable Energy Laboratory
Colorado

- Composites Manufacturing Education and Technology Facility
- Controllable Grid Interface
- Dynamometers
- High-Performance Computing Center
- Field Research Validation Sites
- Structural Testing Laboratory

DEPARTMENT OF ENERGY WIND

FACILITIES

Argonne National Laboratory
Illinois

- Advanced Photon Source Technical Facility
- Atmospheric Radiation Measurement Southern Great Plains Site
- Leadership Computing Facility
- Tribology Laboratory
- Wind Resource Instrumentation

Oak Ridge National Laboratory
Tennessee

- Carbon Fiber Technology Facility
- Institute for Advanced Composites Manufacturing Innovation: Composite Materials and Process Technology Area
- Manufacturing Demonstration Facility

Massachusetts Clean Energy Center
Massachusetts

- Wind Technology Testing Center

Clemson University
South Carolina

- Duke Energy eGrid
- SCE&G Energy Innovation

ACCELERATING INDUSTRY ADVANCEMENTS

Testing facilities make it possible for wind technology companies and inventors to validate and commercialize their technologies. This guide represents the wind laboratory and testing facilities supported by the U.S. Department of Energy (DOE), which are available for industry use and that make it possible for industry players to increase reliability, improve efficiency, and reduce the cost of wind energy.

DOE wind energy testing facilities are geographically diverse and possess unique capabilities that allow the nation to usher in new and innovative generations of wind energy technology.

DOE laboratory and testing facilities span the United States and offer wind research capabilities to meet industry needs.

- Advanced Manufacturing
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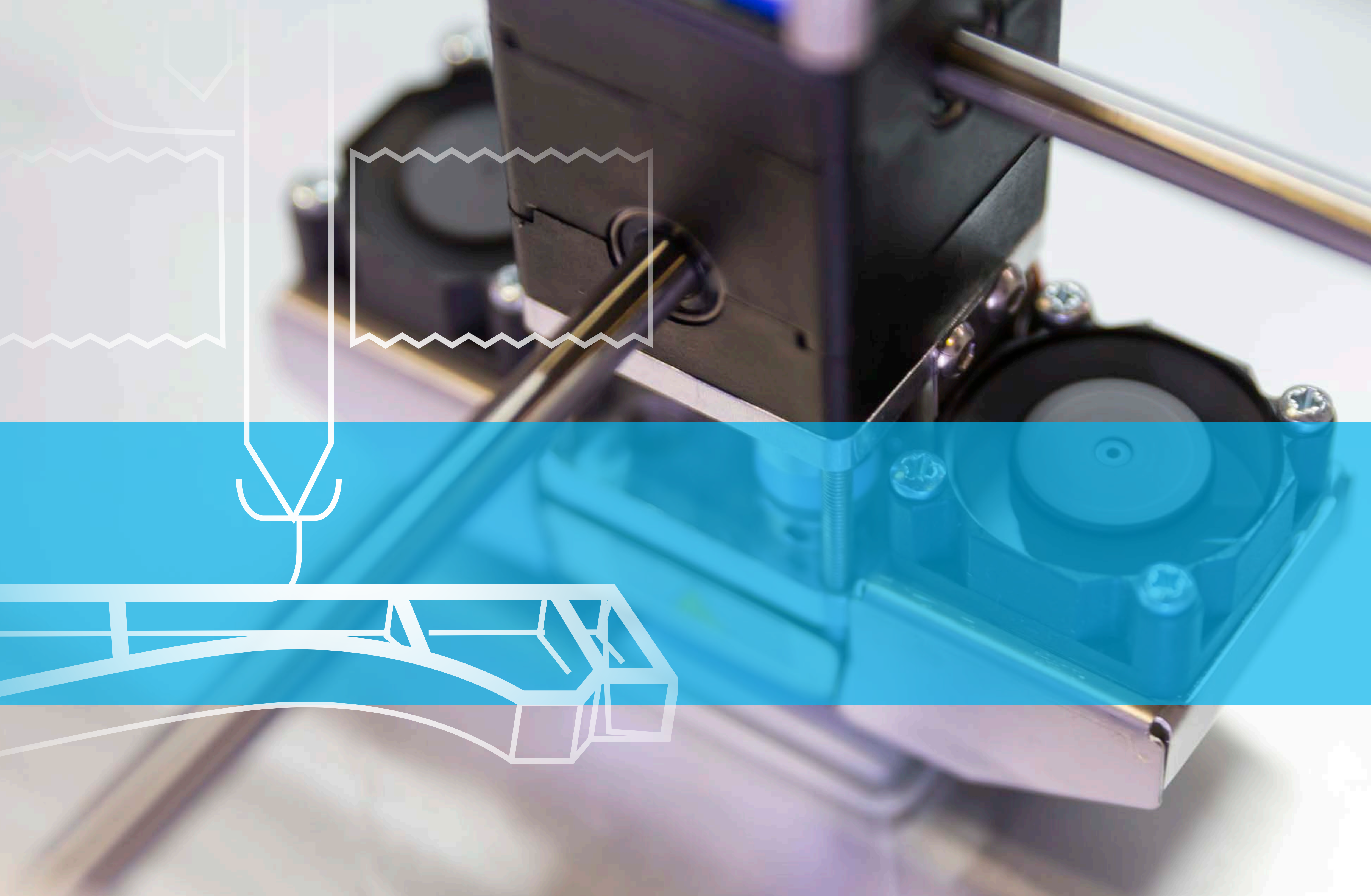
- High-Performance Computing
- Grid Integration
- Field Testing
- Drivetrain Testing
- Blade Testing



advanced manufacturing

INNOVATIVE CONSTRUCTION METHODS, COMBINED WITH WORKFORCE TRAINING, ENHANCE U.S. GLOBAL COMPETITIVENESS

Advanced manufacturing uses inventive construction techniques, such as additive manufacturing, or three-dimensional (3D) printing, to construct components more efficiently and enable rapid prototyping of unique designs. DOE-supported advanced manufacturing facilities enable industry, small businesses, universities, and others to develop new wind turbine components and tooling and provide education and workforce training to position the United States as a global leader in manufacturing.

SPECIALIZED CAPABILITIES IN WIND INDUSTRY COMPOSITE RESEARCH HELP EXPEDITE MANUFACTURING INNOVATION

***National Renewable Energy Laboratory's** Composites Manufacturing Education and Technology Facility*

The Composites Manufacturing Education and Technology (CoMET) facility, located at the National Wind Technology Center (NWTC) at the National Renewable Energy Laboratory (NREL), paves the way for innovative wind turbine components and accelerated manufacturing. The CoMET facility is critical to NREL's exploration of thermoplastic resins for wind turbine blades. Available for use by industry partners and university researchers, the 10,000-square-foot facility expedites manufacturing innovation by enabling researchers to design, prototype, test, and manufacture composite wind turbine blades and other components in one location. The CoMET facility provides:

- Full-scale blade component tooling and fixtures
- Rapid prototyping of novel blade materials and production methods
- Molding, assembly, bonding, and finishing
- Segmented 3D-printed blade tooling
- Composite material mixing and dispensing equipment.

For more information:
https://www.nrel.gov/wind/iacmi.html

A HUB FOR PUBLIC-PRIVATE PARTNERSHIPS THAT DEMONSTRATES ADVANCED TECHNOLOGY SCALABILITY

***Oak Ridge National Laboratory's** Carbon Fiber Technology Facility*

Oak Ridge National Laboratory's (ORNL's) Carbon Fiber Technology Facility located in Oak Ridge, Tennessee, provides the wind energy industry with a flexible, highly instrumented carbon fiber line that can be used to demonstrate advanced technology scalability.

The facility serves as a national test bed for government and commercial partners to produce market-development volumes of prototypical carbon fibers before commercial production scale. Capabilities include:

- A 390-foot-long processing line
- Customizable unit operation configuration
- A thermal (conventional) conversion line
- A melt-spun precursor fiber production line
- An advanced technology conversion line.

For more information:
https://www.ornl.gov/content/carbon-fiber-technology-facility

DEVELOPMENT AND CHARACTERIZATION OF MANUFACTURING PROCESSES

Oak Ridge National Laboratory's *Institute for Advanced Composites Manufacturing Innovation: Composite Materials and Process Technology Area*

Led by ORNL, the Institute for Advanced Composites Manufacturing Innovation's (IACMI's) Composite Materials and Process Technology Area accelerates wind energy industrialization by supporting the advancement of new manufacturing concepts. With the capacity to produce full-scale demonstration components, the IACMI facility focuses on the development and characterization of energy-efficient, high-rate, and low-variability composites. Capabilities include:

- Composites production with an emphasis on the use of low-cost carbon fibers
- Production of fiber types and composite architectures
- Equipment and testing that can cover prototyping and/or scaling technologies
- Nondestructive evaluation of composites, 3D printing, and composites recycling.

For more information:
http://bit.ly/ORNLIACMI

AN UNMATCHED ENVIRONMENT FOR BREAKTHROUGHS IN ADDITIVE MANUFACTURING

Oak Ridge National Laboratory's *Manufacturing Demonstration Facility*

ORNL's Manufacturing Demonstration Facility (MDF) offers a national resource for industry to advance state-of-the-art technologies and revolutionize the way products are designed and built. Drawing on its close ties with industry and world-leading capabilities in materials development, characterization, and processing, ORNL has created an unparalleled environment for breakthroughs in additive manufacturing, or 3D printing.

The MDF provides world-leading tools and expertise that enable industry users to produce innovative wind turbine components and tooling, reduce prototyping and production times, and increase product reliability, all the while focusing on decreasing the cost of wind technologies. MDF capabilities include:

- Two large-scale Big Area Additive Manufacturing composite printers
- Additive manufacturing of materials from metals to composites
- Lightweight metals processing
- Magnetic field processing
- Roll-to-roll processing
- Low-temperature materials synthesis.

For more information:
http://web.ornl.gov/sci/manufacturing/mdf/


elif _operation == "MIRROR_Z":
mirror_mod.use_x = False
mirror_mod.use_y = False
mirror_mod.use_z = True
#selection at the end -add back the
mirror_ob.select= 1
modifier_ob.select=1
bpy.context.scene.objects.active =
print("Selected" + str(modifier_ob)) #
70

high-performance computing

SYSTEMS THAT SIMULATE COMPLEX PHENOMENA TO ADVANCE UNDERSTANDING OF WIND ENERGY AND TECHNOLOGIES

Supercomputers, or massively parallel high-performance computers (HPCs), employ large numbers of parallel processors to address scientific and engineering challenges. By carrying out trillions of calculations each second, these HPCs can simulate some of the most complex physical, biological, and chemical phenomena and help scientists understand these processes at unprecedented levels—from seeing individual atoms used in nanoscale engineering to visualizing the entire planet for global studies of earth systems. HPC systems are also being used to model the complex 3D wind flow through a wind farm. These supercomputers advance the fundamental understanding of whole wind plants' flow physics, aiding plant-level innovations and further reducing the cost of electricity from wind.

ADVANCED COMPUTING TECHNOLOGIES HELP ACCELERATE WIND ENERGY UNDERSTANDING AND INNOVATION

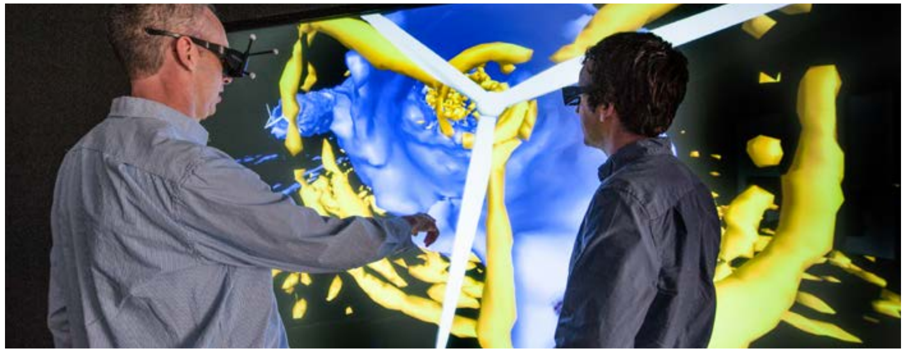
Lawrence Livermore National Laboratory's *High-Performance Computing Innovation Center*

Lawrence Livermore National Laboratory's (LLNL's) High-Performance Computing Innovation Center in Livermore, California, provides companies with access to LLNL's supercomputers, software, and domain expertise, as well as practiced guidance on the application of advanced computing technologies.

Through enabling collaborative agreements, LLNL's High-Performance Computing Innovation Center can help companies increase their understanding of complex technologies and systems, accelerate their innovation processes, and expand the value they derive from computing. From design simulations to analysis, LLNL's High-Performance Computing Innovation Center can help the wind energy industry in a variety of ways including:

- Forecasting
- Computational modeling
- Software improvement
- Data analytics
- Engineering design.

For more information:
http://hpcinnovationcenter.llnl.gov



PETAFLOP SUPERCOMPUTER HELPS COMPANIES EXPLORE WIND ENERGY EFFECTS AND PROMOTES ENERGY SYSTEMS INTEGRATION DISCOVERY

National Renewable Energy Laboratory's *High-Performance Computing Center*

NREL has the largest HPC system in the world dedicated to advancing renewable energy and energy efficiency technologies. The system features a 2.24-petaflop supercomputer called Peregrine, which helps researchers investigate wind turbine wakes using computational fluid dynamics and software developed by NREL (such as the Simulator for Wind Farm Applications).

NREL's HPC system also enables exploration of the impacts of high penetrations of renewable energy on the future power grid. NREL's HPC capabilities include:

- High-fidelity modeling and simulation software tools
- A Linux cluster that uses a fast InfiniBand network to connect nodes and has 2.25 petabytes of disk space
- A Gyrfalcon Mass Storage System
- A large Oracle StorageTek robotic tape library
- A set of high-performance T10000C tape drives.

For more information:
https://hpc.nrel.gov/

HIGH-PERFORMANCE COMPUTING HELPS PREDICT AND IMPROVE WIND TECHNOLOGY PERFORMANCE

Sandia National Laboratories' *Advanced Simulation and Computing*

Sandia National Laboratories' Advanced Simulation and Computing program offers computing capabilities that help the wind industry achieve overall wind energy cost reductions and increased turbine performance. Recent wind research at the facility has supported advancement in designing more effective wind turbine blades by predicting their performance and behaviors before they are built, developing wind turbine blade noise prediction methods, and improving the ability to predict power-generation impacts from wakes and the motion of air within an array of wind turbines.

In addition to a computer facility and operational support, the Advanced Simulation and Computing program offers industry users:

- Multiphysics simulation codes that incorporate physics and engineering models
- Physics and engineering models that represent a large variety of physical and engineering phenomena
- Methods, metrics, and standards to assess code and model credibility and to quantify confidence in calculation results
- Integrated, high-performance computational systems.

For more information:
http://www.sandia.gov/asc/

ADDITIONAL FACILITIES WITH HIGH-PERFORMANCE COMPUTING CAPABILITIES INCLUDE:

- Argonne National Laboratory's Leadership Computing Facility (see Resource Characterization, p. 10)
- Idaho National Laboratory's Power and Energy Real-Time Digital Simulation (see Grid Integration, p. 17)


Anguilla
St. Kitts & Nevis
Saint Thomas

resource characterization

WIND RESOURCE DATA COLLECTION TO HELP OPTIMIZE WIND ENERGY PERFORMANCE

Developing, siting, and operating a wind farm require accurate assessments of available wind resources, which allow wind farms to supply clean, renewable power to businesses and homeowners at lower costs by ensuring that wind turbines operate closer to maximum capacity. Further improvement in this area relies upon consistent wind resource data collection that will help optimize the performance of wind turbines moving forward. To design and deploy the most efficient systems, U.S. developers require facilities and equipment that collect, organize, and make accessible large amounts of wind resource data.

WORLD-CLASS COMPUTING FACILITIES THAT SUPPORT ACCURATE WIND FORECASTING AND PREDICTION

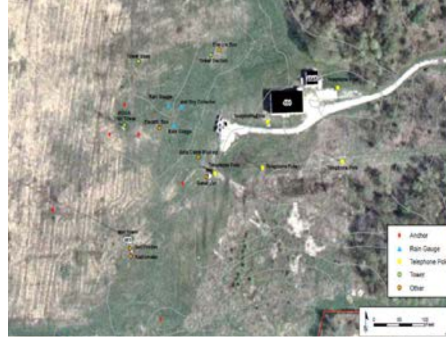
Argonne National Laboratory's *Leadership Computing Facility*

Argonne National Laboratory's Leadership Computing Facility in Argonne, Illinois, accelerates major scientific discoveries and engineering breakthroughs in partnership with the computational science community. Available to any researcher in the world with a large-scale computing problem, the Argonne Leadership Computing Facility deploys two diverse high-performance computer architectures that are 10 to 100 times more powerful than typical research computing systems.

To better simulate wind features in national forecast models, Argonne National Laboratory's Leadership Computing Facility has supported the advancement of wind predictions by:

- Increasing model resolution
- Improving physical representations from complex terrains.

For more information:
https://www.alcf.anl.gov



PROFILER, SODAR SYSTEMS, AND METEOROLOGICAL TOWER RECORD WINDS FROM 50 METERS TO MORE THAN 300 METERS ABOVE GROUND

Argonne National Laboratory's *Wind Resource Instrumentation*

The wind resource instrumentation housed at Argonne National Laboratory's atmospheric observatory includes a meteorological tower, multiple custom sodar systems, and the Radar Wind Profiler.

Currently deployed in Washington State for the second Wind Forecasting Improvement Project, the Radar Wind Profiler records winds from 300 meters (m) above the ground level and higher using the raw Doppler spectrum at a 30-second temporal and 50-m range resolution. As winds below 300 m are critical for optimal operations of wind turbines, Argonne custom built three sodar systems that report winds from 50 m to 300 m above the ground level with a time resolution of less than a minute. Meteorological tower capabilities include the following measurements:

- Temperature
- Dew point temperature
- Pressure
- Wind speed
- Wind direction at 10- and 60-m heights.

For more information:
http://www.evs.anl.gov/research-areas/climate-science/index.cfm

ADVANCED WIND RESOURCE ASSESSMENT TECHNOLOGY GOES WHERE THE NEED IS

Lawrence Livermore National Laboratory's *Mobile Observational Instruments*

From development to testing, accurate assessment tools are essential to characterizing a location's wind resource. In an effort to ensure that interested parties have the latest wind resource assessment technology, LLNL provides access to a variety of mobile observational instruments including:

- Lidars (wind profile measurements from 10 to 300 m)
- Infrared gas sensors for carbon dioxide and water vapor
- Sonic anemometry for the 3D wind vector and turbulence measurements
- Solar radiation
- Near-surface air temperature, humidity, and pressure.

For more information:
https://www-gs.llnl.gov/about/energy-security/windpower

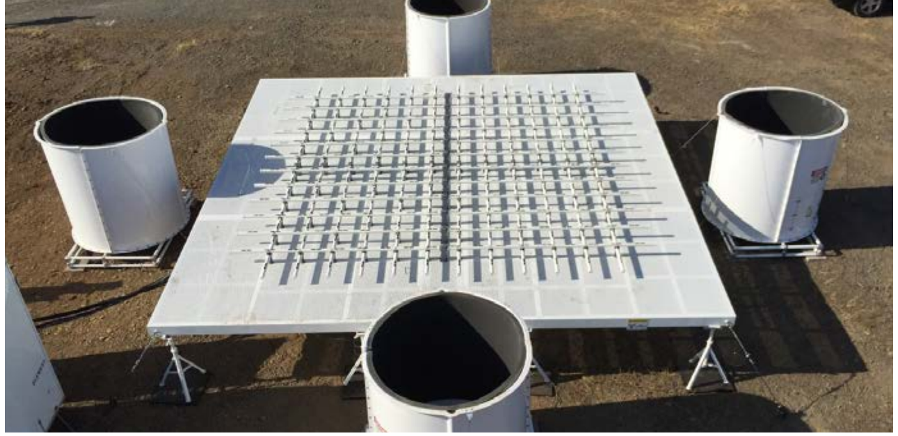
COMPLEX-TERRAIN EXPERIMENTAL TEST SITE IS IDEAL FOR WIND RESOURCE STUDIES

Lawrence Livermore National Laboratory's *Site 300 Testing Facility*

Improved characterization of the interactions between atmospheric inflow and turbines over various kinds of terrain can enable scientists and engineers to better model and design turbines and wind farms for optimal performance. LLNL's Site 300 is a 7,000-acre experimental test site located in the complex terrain of California's Altamont Pass wind resource area. The site's geographic location makes it ideal for wind resource studies. Features of the site include:

- Secure perimeter, roads, and an electrical distribution network
- Existing lines to a nearby power substation
- Well-characterized environmental assessments.

For more information:
https://wci.llnl.gov/facilities/site-300/about-site-300



PROFILING WIND RADARS IMPROVE U.S. WIND ENERGY FORECASTS

Pacific Northwest National Laboratory's *Coastal Wind Profiling Radars*

Pacific Northwest National Laboratory (PNNL) operates three wind profiling radars along the Washington and Oregon coasts that are equipped with radio acoustic sounding systems to provide temperature profile measurements in support of DOE studies to improve wind energy forecasts. In addition, the data are being fed to the National Oceanic and Atmospheric Administration's National Weather Service forecast models.

These profilers are complemented by four identical profilers installed by the National Oceanic and Atmospheric Administration along the California coast for the California Department of Water Resources. Spaced approximately 250 km apart, the profilers together provide a "picket fence" of wind profiles that are expected to significantly improve wind forecasts as far east as the central United States.

Each radar wind profiler location features:

- A 449-megahertz radar wind profiler
- A 10-m surface meteorological station equipped with a propeller-and-vane anemometer and radiometer
- Temperature, relative humidity, and barometric pressure sensors
- A rain gauge and global positioning system receiver to measure precipitation and integrated atmospheric water vapor, respectively.

For more information:
http://wind.pnnl.gov/coastalwind.asp

BUOYS COLLECT METEOROLOGICAL AND OCEANOGRAPHIC DATA TO SUPPORT OFFSHORE WIND

Pacific Northwest National Laboratory's *Lidar Buoy Loan Program*

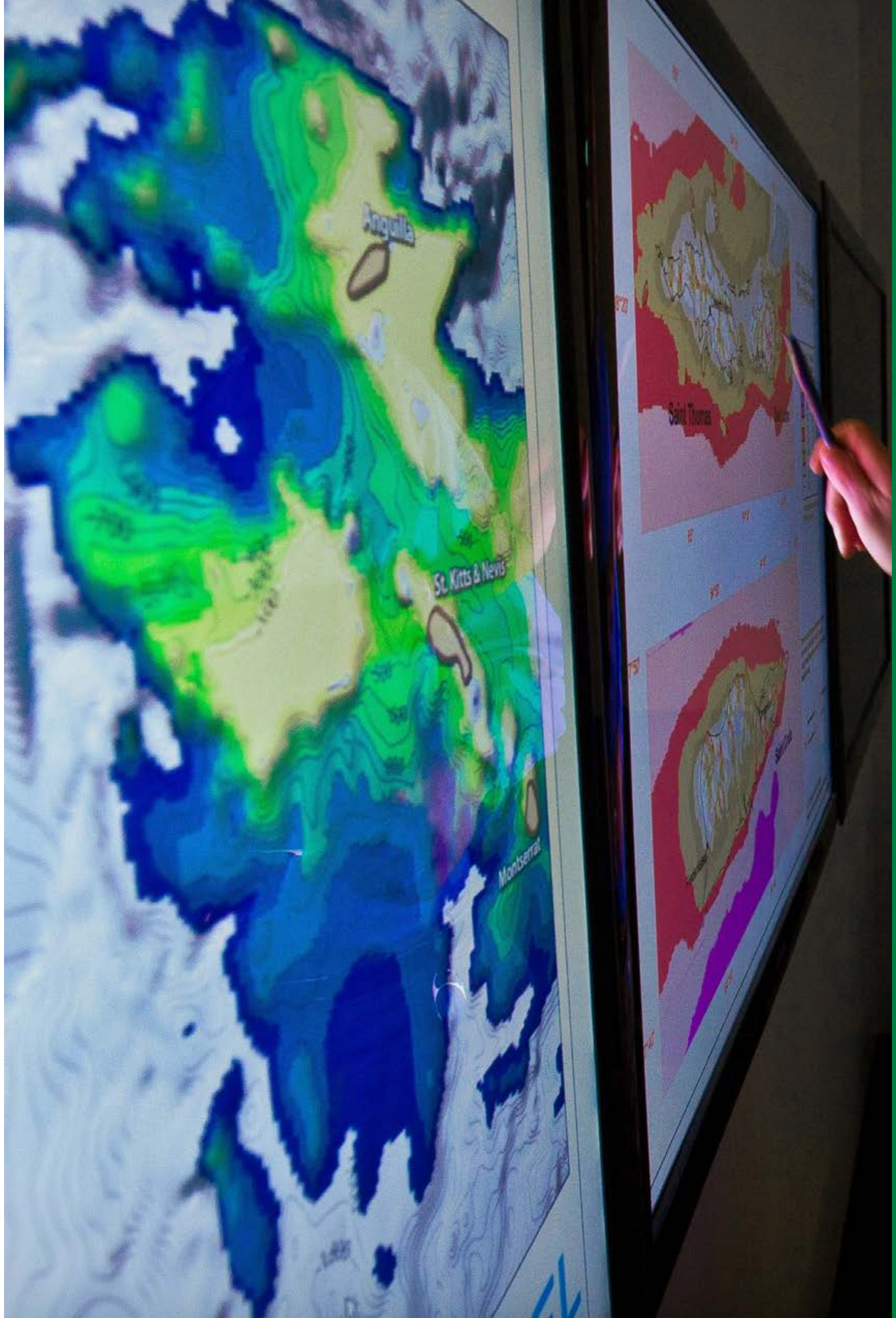
To support development of the country's offshore wind energy industry, PNNL manages the deployment of two DOE-owned lidar buoys that are available for loan to industry. The lidar buoy loan program equips qualified parties with the technology necessary to collect a comprehensive set of meteorological and oceanographic data that will help characterize offshore wind energy resources. The AXYS WindSentinel buoys are equipped with the following sensors:

- Wind profile
- Wind speed
- Wind direction
- Temperature and relative humidity
- Barometer
- Pyranometer
- Water temperature and salinity
- Conductivity, temperature, and depth
- Wave height and period
- Subsurface ocean.

For more information:
http://wind.pnnl.gov/lidarbuoyloanprogram.asp

ADDITIONAL FACILITIES WITH RESOURCE CHARACTERIZATION CAPABILITIES INCLUDE:

- Argonne National Laboratory's Atmospheric Radiation Measurement Southern Great Plains Site (see Field Testing, p. 22)
- National Renewable Energy Laboratory's Field Research Validation Sites (see Field Testing, p. 23)
- Sandia National Laboratories' Wake-Imaging Measurement System (see Field Testing, p. 25)



grid integration

TESTING FACILITIES HELP ENSURE RELIABLE INTEGRATION OF WIND ENERGY INTO THE ELECTRIC GRID

As the nation moves toward an energy system with higher wind energy penetration, grid operators must reliably integrate large quantities of wind energy into system operations and actively develop capabilities to improve the electric grid's power quality. The DOE Wind Energy Technologies Office works alongside electric grid operators, utilities, regulators, and industry to develop strategies for incorporating increasing amounts of wind energy into the power system while maintaining the economic and reliable operation of the grid. DOE-funded testing facilities investigate, verify, and validate new designs and strategies prior to final integration into the national grid infrastructure.

HARDWARE-IN-THE-LOOP GRID SIMULATOR HELPS SPEED NEW WIND ENERGY TECHNOLOGIES TO MARKET

***Clemson University's** Duke Energy eGrid*

Housed in the SCE&G Energy Innovation Center, the Duke Energy eGRID (Electrical Grid Research Innovation and Development) provides wind turbine manufacturers the ability to test both mechanical and electrical characteristics of their machines. The 15-megawatt (MW) hardware-in-the-loop grid simulator provides a well-controlled and calibrated environment capable of replicating many electrical scenarios that were previously only partially available through field demonstrations.

The Duke Energy eGRID speeds new wind energy technologies to market by providing industry the facilities to:

- Test multimegawatt equipment at full scale for grid-code compliance
- Validate electrical models
- Advance smart-grid technology
- Examine energy storage and converters
- Integrate distributed resources more efficiently into the power system.

For more information:
http://clemsonenergy.com/duke-energy-egrid/

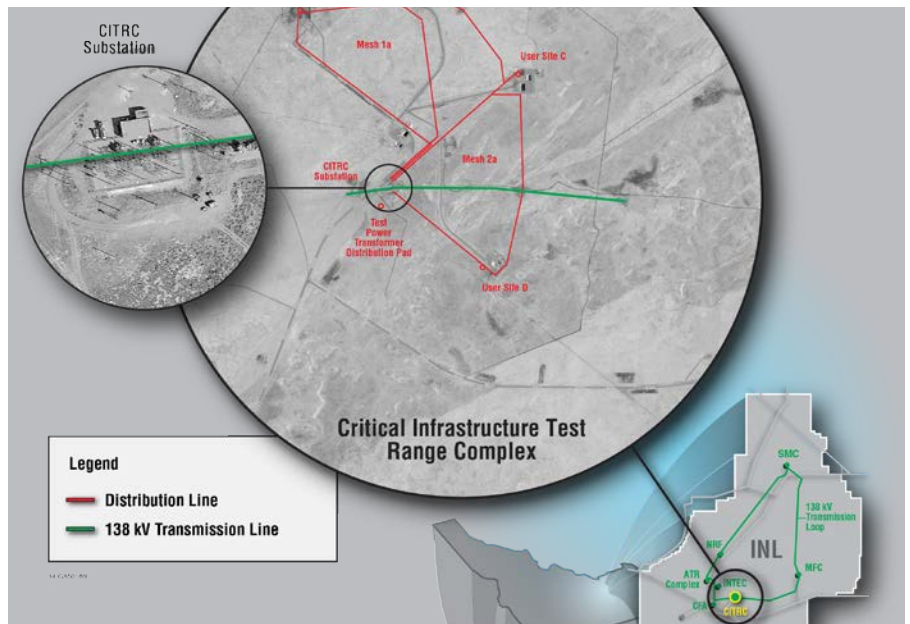
SPECIALIZED TEST FACILITIES HELP INDUSTRY USERS FIND GRID INTEGRATION SOLUTIONS

***Idaho National Laboratory's** Critical Infrastructure Test Range*

The Critical Infrastructure Test Range at the Idaho National Laboratory (INL) in Idaho Falls, Idaho, encompasses 890 square miles of specialized test beds and training where government agencies, utilities, and equipment manufacturers can work together to find solutions affecting many of the nation's most pressing security issues. The Critical Infrastructure Test Range includes:

- A dual-fed, 138-kilovolt transmission line in a 61-mile loop
- Seven substations
- Three commercial feeds
- A cyber security test bed
- The Scoville Light and Power Operational Control Center
- A national supervisory control and data acquisition test bed
- A smart grid transmission and distribution test bed (in development).

For more information:
https://www.inl.gov/research-program/critical-infrastructure-protection/



DIGITAL SIMULATION ENVIRONMENT SAFELY TESTS NEW TECHNOLOGIES BEFORE THEY ARE IMPLEMENTED

Idaho National Laboratory's *Human System Simulation Laboratory*

The Human System Simulation Laboratory (HSSL) at INL applies researchers' knowledge and experience of human performance in nuclear power operations to solving practical and emerging problems in the energy sector.

A reconfigurable virtual control center created to safely test new technologies before they are implemented builds on HSSL's original mission to simulate commercial nuclear reactor control rooms and improve their designs. The laboratory is also a virtual test bed for seamlessly integrating transmission line-dynamic line rating tools and data visualization (such as wind, solar, and temperature data) into electric utility control centers. The HSSL provides:

- A digital simulation environment compatible with all major control room designs and software platforms to aid in development of utility efficiency and asset management
- Industry-standard and customizable systems and protocols for operator training and evaluation
- High-fidelity task-simulated scenarios to evaluate control room designs that integrate dynamic line rating and accommodate operators' needs.

For more information:
http://bit.ly/INLHSSF

SIMULATION AND CONTROLS LAB FOR GRID INTEGRATION STUDIES OF HIGH-PENETRATION WIND

Idaho National Laboratory's *Power and Energy Real-Time Digital Simulation*

Advanced modeling capabilities can incorporate real-world data, hardware, and software into real-time simulations. The Power and Energy Real-Time Laboratory (PERL), located at INL, offers diverse expertise and the ability to co-simulate electrical, thermal, and mechanical systems.

The laboratory can also integrate with microgrid test beds and simulation resources at other national laboratories. Real-time digital simulators and Opal-RT assets located at the INL campus augment PERL's real-time simulation capabilities. PERL features include:

- An on-site microgrid, including micropower sources controlled via power electronics that behave on the grid like a single controlled unit
- A Chroma 61850 grid emulator to mimic real-world events in the power grid
- Control hardware-in-the-loop and power hardware-in-the-loop simulations
- High-speed connectivity capability with NREL, demonstrating the feasibility of continental-scale power simulation investigations.

For more information:
http://bit.ly/INLPERL

THE FIRST U.S. FACILITY THAT CAN TEST WIND TURBINES UNDER BALANCED AND UNBALANCED VOLTAGE FAULT CONDITIONS

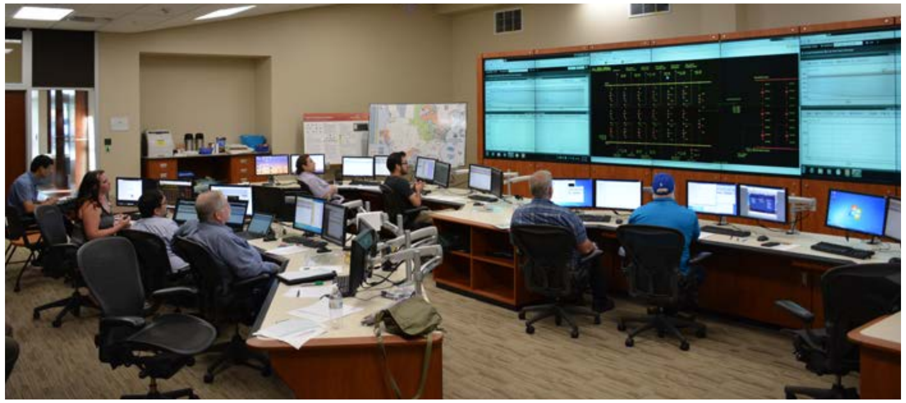
National Renewable Energy Laboratory's *Controllable Grid Interface*

The controllable grid interface (CGI), part of the NWTC at NREL, can test both the mechanical and electrical characteristics of wind turbines in a controlled grid environment by replicating many electrical scenarios that are only partially available in field testing.

The CGI can test frequency and voltage control under a variety of grid conditions and is the first U.S. facility that can test wind turbines under balanced and unbalanced voltage fault conditions. This platform ensures that wind turbines meet stringent national and international standards while testing the grid compliance of innovative electrical topologies and controls. The CGI can:

- Test wind turbines safely and isolated from the grid
- Support grid integration testing
- Remotely connect to power hardware-in-the-loop experiments at the Energy Systems Integration Facility on the NREL campus
- Fully integrate with two large dynamometers, wind turbines in the field, and a matrix of electronic and mechanical storage devices on-site at the NWTC.

For more information:
https://www.nrel.gov/wind/facilities-cgi.html



A SAFE SETTING FOR DEVELOPING AND REFINING TECHNOLOGY TO ACCELERATE GRID ADVANCEMENTS

Pacific Northwest National Laboratory's *Grid Systems Engineering Building: Electricity Infrastructure Operations Center*

The advancement of grid technologies in the face of an evolving energy landscape ensures a reliable, secure, and sustainable power system with limited service interruptions. The Systems Engineering Building at PNNL in Richland, Washington, provides researchers and industry with a safe setting to manage the iterative process of developing and refining the necessary technology to accelerate grid advancements.

Home to the Electricity Infrastructure Operations Center, the Systems Engineering Building is the hub for all power grid research at PNNL. The 24,000-square-foot facility includes:

- Three control centers (including the campus control center)
- Laboratories focused on power electronics and interoperability
- Outdoor testing pads
- Electric vehicle charging stations
- Data storage and computing capabilities
- Access to state-of-the-art industry software, real-time grid data, and advanced computation capabilities.

For more information:
http://systemsengineeringbuilding.pnnl.gov/

field testing

TESTING TURBINE DESIGNS IN THE NATURAL OPERATING ENVIRONMENT TO OPTIMIZE PERFORMANCE AND IMPROVE RELIABILITY AND EFFICIENCY

Private industry, public researchers, and academics use field testing facilities to drive new wind technology development—from designing more efficient blades to creating stronger, more durable drivetrains. Validating and demonstrating a complete turbine design requires testing the full system in the natural operating environment to help industry improve the performance of individual wind turbines and their components, while analyzing the interactions of multiple wind turbines in a wind farm allows researchers and developers to improve overall reliability and efficiency of entire wind plants.

METEOROLOGICAL INSTRUMENTATION FOR WIND FORECASTING AND PLANT OPTIMIZATION

Argonne National Laboratory's *Atmospheric Radiation Measurement Southern Great Plains Site*

Improving the accuracy of projected wind speeds in the environment is one way to further enhance a wind energy project's energy production potential. Operated by Argonne, the Atmospheric Radiation Measurement Southern Great Plains Site spans approximately 9,000 square miles in north-central Oklahoma and southern Kansas and provides access to meteorological instrumentation for wind forecasting and plant optimization.

The facility has placed more than 50 instrument platforms or suites at the Southern Great Plains Site observatory including:

- Radiometers
- Radars
- Lidars
- Surface meteorological instrumentation.

For more information:
https://www.arm.gov/capabilities/observatories/sgp

MICROGRID SYSTEMS INTEGRATE AND TEST DYNAMIC STORAGE AND LOAD-BALANCING OPTIONS

Idaho National Laboratory's *Microgrid Test Bed*

Energy storage systems and dynamic communication and controls can improve power system control and minimize threats such as brownouts or power surges.

At its Energy Systems Laboratory in Idaho Falls, INL researchers are integrating and testing dynamic storage and load-balancing options using microgrid systems and integrating wind, solar, natural gas, and diesel generation to maximize reliability and resiliency. In the process, the Microgrid Test Bed supports the field testing of distributed-scale wind turbines.

The facility features:

- A megawatt-scale laboratory with a microgrid incorporating wind and solar power and two flow batteries capable of storing 320 kilowatt-hours
- Advanced modeling capabilities for incorporating real-world data, hardware, and software into real-time simulations
- Load control capabilities and grid interaction algorithms
- The flexibility to operate connected to the grid or islanded, as needed
- A supporting infrastructure for grid component testing and validation.

For more information:
https://www.inl.gov/research-program/critical-infrastructure-protection/

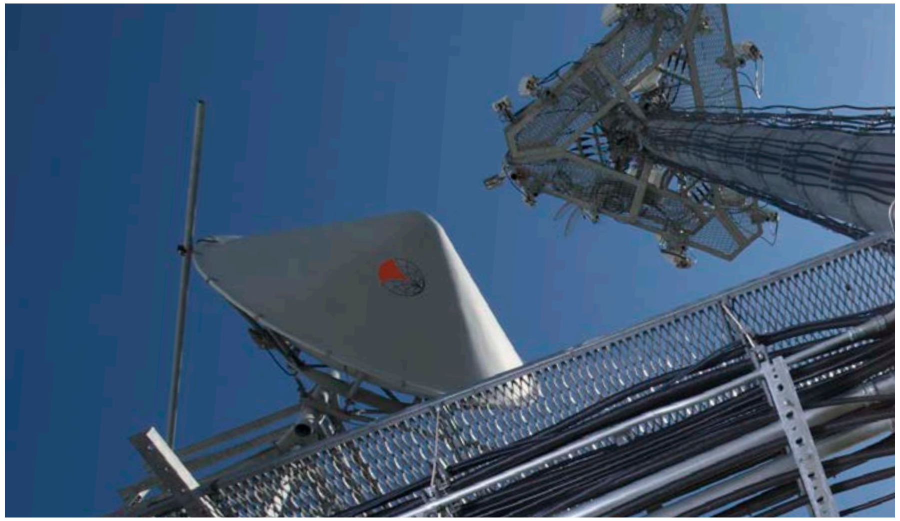
A LOW-NOISE ENVIRONMENT SUITABLE FOR TESTING AN ARRAY OF DEVICES AND HARDWARE

Idaho National Laboratory's *Wireless Test Bed*

INL operates a comprehensive wireless test bed spread across 890 square miles of federally owned land. Situated in a low-noise environment, this area allows engineers to test devices and hardware ranging from high- to ultra-high-frequency and including cellular, satellite, microwave, and everything in between. The Wireless Test Bed features:

- Access to research and testing capabilities across TCP/IP, ATM, 802.11, GSM, and modem communication signals
- Approximately 170 miles of fiber; OC-3, OC-12 fiber links over a SONET/ATM backbone
- Testing capabilities for two-way radio systems, cell phones, and hard-wired systems
- Testing capabilities for intranet systems, intrusion detection, firewalls, and secure communications.

For more information:
https://www.inl.gov/research-programs/wireless-research/



DIVERSE FACILITIES ACCREDITED TO PERFORM COMPREHENSIVE RESEARCH VALIDATIONS

National Renewable Energy Laboratory's *Field Research Validation Sites*

NREL's National Wind Technology Center offers industry partners the use of three wind turbines and two meteorological towers. The test turbines include a DOE-owned GE 1.5-MW wind turbine, which is used for research and education, and two 600-kilowatt (kW) experimental Controls Advanced Research Turbines, which are used to test advanced control systems.

The NWTC also features two highly instrumented meteorological towers: a 135-m and an 80-m tower that perform research-grade inflow measurements at multiple heights and also record wind speed, direction, temperature, humidity, and pressure. The NWTC is accredited to perform the following research validations:

- Acoustic noise
- Power performance
- Mechanical loads
- Power quality
- Duration testing
- Safety and function.

For more information:
https://www.nrel.gov/wind/facilities-research.html

WIND TURBINE BLADES WITH RADAR-ABSORBING MATERIALS REPRESENT AN INNOVATIVE APPROACH

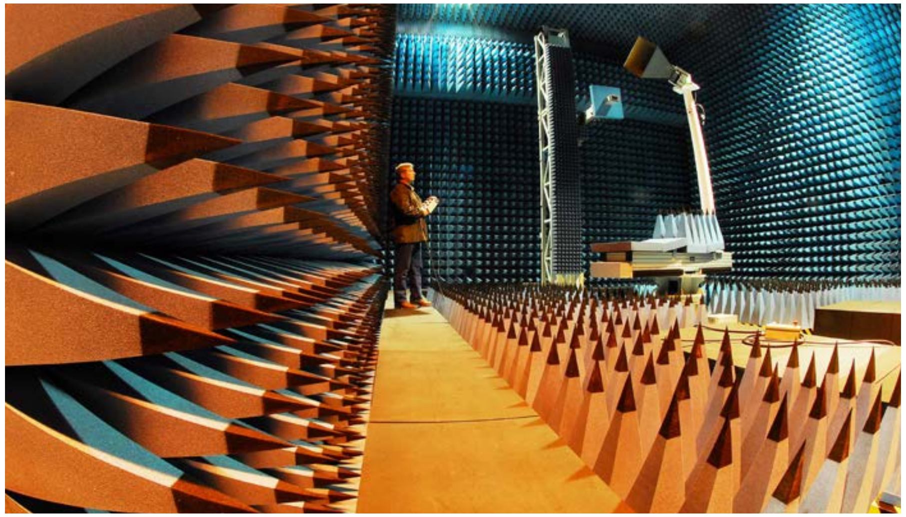
Sandia National Laboratories' *Facility for Antenna and Radar Cross-Section Measurement*

Minimizing the impact of wind turbine and radar interactions can unlock high-risk locations that were previously deemed undevelopable because of national defense, homeland security, and/or air safety concerns. Sandia National Laboratories (Sandia) has taken a different approach to address this issue by researching the manufacture of wind turbine blades with radar-absorbing materials.

The Facility for Antenna and Radar Cross-Section Measurement in Albuquerque, New Mexico, features the following capabilities:

- A near-field measurement system
- A broadband, high-isolation measurement chamber for characterizing radio frequency transmission properties
- A precision Gaussian-beam measurement system for characterizing millimeter-wave properties of engineered materials.

For more information:
http://bit.ly/SNLRCSM



REPLICATING NATURE TO HELP INDUSTRY CREATE MORE DURABLE COMPONENTS AND REDUCE REPAIR DOWNTIME

Sandia National Laboratories' *Lightning Simulator*

Understanding the impact to wind turbine components of various weather phenomena can help the wind energy industry develop components that can lead to more durable machines with less downtime for repairs. One of the most common and expensive problems is damage caused by lightning strikes on wind turbines.

To study this problem and mitigate the costly effects of lightning damage, Sandia's Lightning Simulator can be used to conduct research related to turbine blade damage caused by lightning strikes. Test configurations of the Lightning Simulator include:

- Direct-attachment lightning (simulator is connected to or arcs to the test object)
- Burn-through (continuing current)
- Nearby magnetic fields resulting from the simulated strokes.

For more information:
http://bit.ly/SNLLightning

RAPID, COST-EFFICIENT TESTING AND DEVELOPMENT OF TRANSFORMATIVE WIND ENERGY TECHNOLOGIES

Sandia National Laboratories' *Scaled Wind Farm Technology Facility*

To improve wind plant performance and test new wind turbine components, Sandia's Scaled Wind Farm Technology (SWiFT) facility provides industry and academia access to a research and development test facility for transformative wind energy technologies.

Located at Texas Tech University's National Wind Institute Research Center in Lubbock, Texas, SWiFT features:

- Three turbines
- Atmospheric observation tools
- A reconfigurable network
- State-of-the art equipment specifically designed for wind research.

For more information:
http://bit.ly/SNLSWiFT

WAKE IMAGING SYSTEM ENHANCES WIND FARM ENERGY CAPTURE AND REDUCES OVERALL COST OF ENERGY

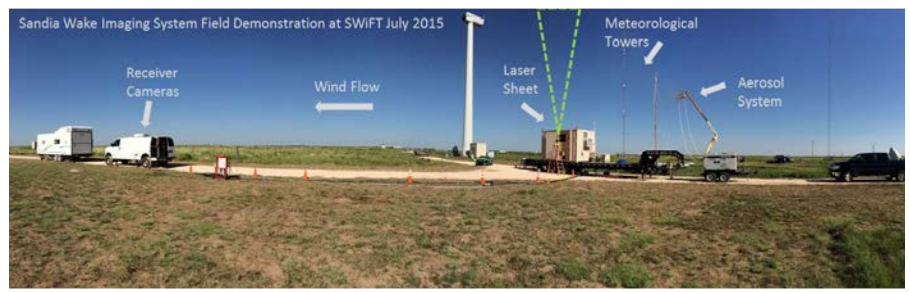
Sandia National Laboratories' *Wake Imaging Measurement System*

Wakes produced from upstream turbines in wind plants lead to lower power production and increased loads on downstream turbines—resulting in lower energy capture and higher maintenance costs. Computational simulation and design tools can improve wind plant design to realize cost of energy reductions.

Sandia's Wake Imaging Measurement System goes beyond scanning lidar or particle image velocimetry by producing a velocity image of the measurement field. Using specialized cameras and software, the Wake Imaging Measurement System measures the wind turbine wake phenomena researchers need to develop solutions to wind plant underperformance. Deployed at the SWiFT facility in Lubbock, Texas, Sandia's Wake Imaging Measurement System can lead to:

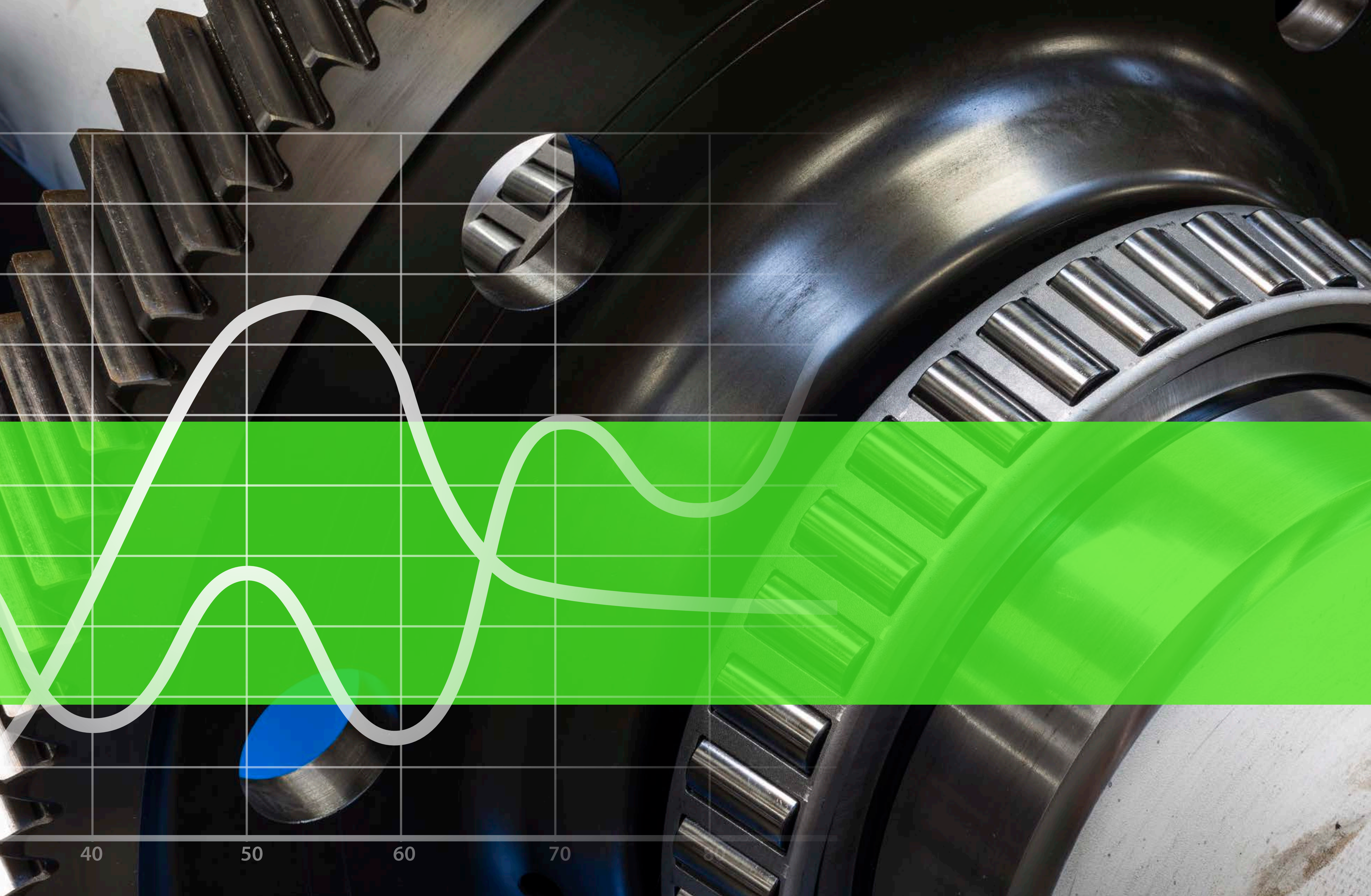
- Enhanced energy capture in a wind farm
- Decreased maintenance costs
- A reduction in overall cost of energy.

For more information:
http://bit.ly/SNLWIMS



ADDITIONAL FACILITIES WITH FIELD TESTING CAPABILITIES INCLUDE:

- Idaho National Laboratory's Human System Simulation Laboratory (see Grid Integration, p. 17)
- Lawrence Livermore National Laboratory's Mobile Observational Instruments (see Resource Characterization, p. 11)
- Lawrence Livermore National Laboratory's Site 300 (see Resource Characterization, p. 11)
- National Renewable Energy Laboratory's Controllable Grid Interface (see Grid Integration, p. 18)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drivetrain testing

DYNAMOMETERS VALIDATE WIND TURBINE DRIVETRAINS TO REDUCE DOWNTIME, IMPROVE RELIABILITY, AND LOWER COSTS

Containing the gearbox, generator, and main shaft or bearing, wind turbine drivetrains undergo tremendous rotational and off-axis loading during normal operation. By replacing the rotor and blades of a turbine with a powerful motor, dynamometers help optimize drivetrain designs and increase turbine reliability. And from a research perspective, modeling techniques can emulate rotor, tower, pitch, and yaw systems with computer simulations operating in real time. Operated at a steady state, these dynamometers can determine a turbine's power curve—that is, how its electrical production relates to the input mechanical energy. Dynamometers can also determine a turbine's useful operating lifetime by intentionally overloading the turbine.

DRIVETRAIN SYSTEM SUBCOMPONENT TESTING TO EXTEND DRIVETRAIN LIFE AND REDUCE THE COST OF WIND POWER

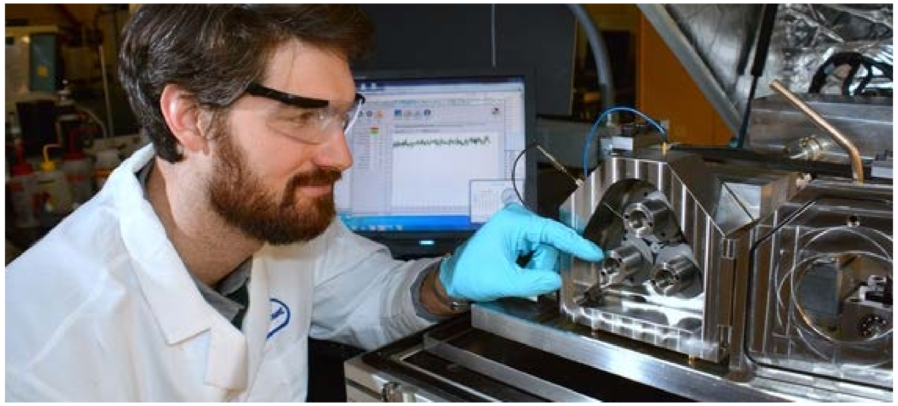
Argonne National Laboratory's *Tribology Laboratory*

Wind turbine reliability issues are often linked to failures of contacting parts, such as bearings, gears, and actuators. Argonne's Tribology Laboratory in Argonne, Illinois, can help prolong the life of these components through accelerated testing of the materials that experience surface damage (such as micropitting, fatigue pitting, scuffing, and wear).

The Tribology Laboratory is equipped with:

- A full range of coating development capabilities
- Friction and wear testing capabilities
- Characterization facilities.

For more information:
https://www.anl.gov/energy-systems/facilities/tribology-laboratory



HIGH-ENERGY X-RAY SYNCHROTRON ENABLES GREATER UNDERSTANDING OF PREMATURE COMPONENT FAILURES

Argonne National Laboratory's *Advanced Photon Source Technical Facility*

The maintenance of wind turbine components represents a major element of the cost of wind energy. A thorough understanding of component failure can provide turbine manufacturers with the knowledge necessary to develop the next generation of durable components that will reduce maintenance time and overall cost of energy. Wind-related research at Argonne's Advanced Photon technical facility allows for better understanding of premature failures by using a high-energy x-ray synchrotron to look deep inside the material of failed turbine components to locate microscopic cracks inside the steel bearings. The high-energy hard x-ray beams of the Advanced Photon Source enable unique scientific observation and experimentation for various materials and engineering applications at high-fidelity length and timescales. These techniques include:

- Imaging at the nanoscale level
- Scattering for solid material atomic structure characterization
- Spectroscopy to determine chemical bonding and material elemental analysis.

For more information:
https://www1.aps.anl.gov/

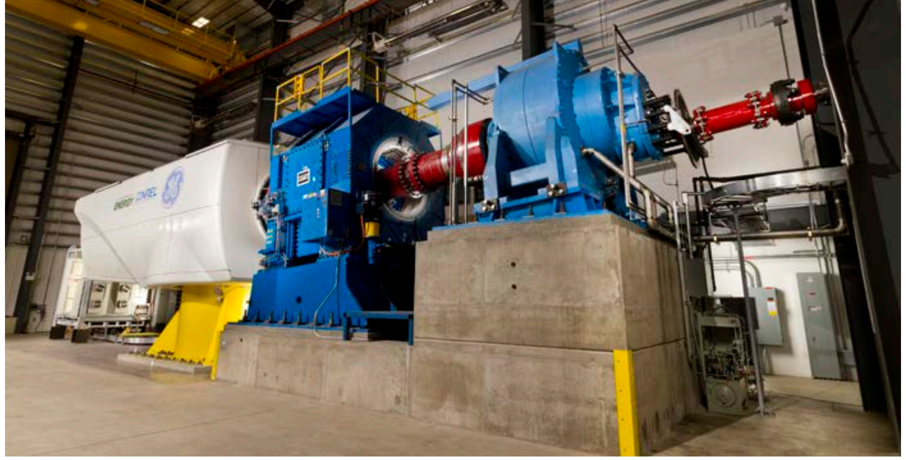
FACILITIES SPECIFICALLY DESIGNED FOR LARGE-COMPONENT TESTING AND UTILITY-SCALE VALIDATION

Clemson University's *SCE&G Energy Innovation Center*

Supported through a $45 million DOE grant awarded in 2009, Clemson University's Wind Turbine Test Beds in North Charleston, South Carolina, provide high-value, high-quality, and cost-competitive testing and validation services to advance wind technology and reduce the cost of energy. Capabilities at Clemson's Energy Innovation Center include:

- A 7.5-MW test bench for endurance and acceptance testing
- A 15-MW test bench focused on multimegawatt offshore and land-based nacelles
- A 15-MW Duke Energy electrical grid research innovation and development to model real-world conditions on the grid to test multimegawatt devices at the utility scale
- A sophisticated infrastructure with a waterfront for deep-water, rail, and road access and a natural deep port to shipping channels only 10 miles from open sea.

For more information:
http://clemsonenergy.com/wind-turbine-test-beds/



THREE DYNAMOMETERS OFFER RESEARCH VALIDATION FOR DRIVETRAINS OF DIFFERENT SIZES

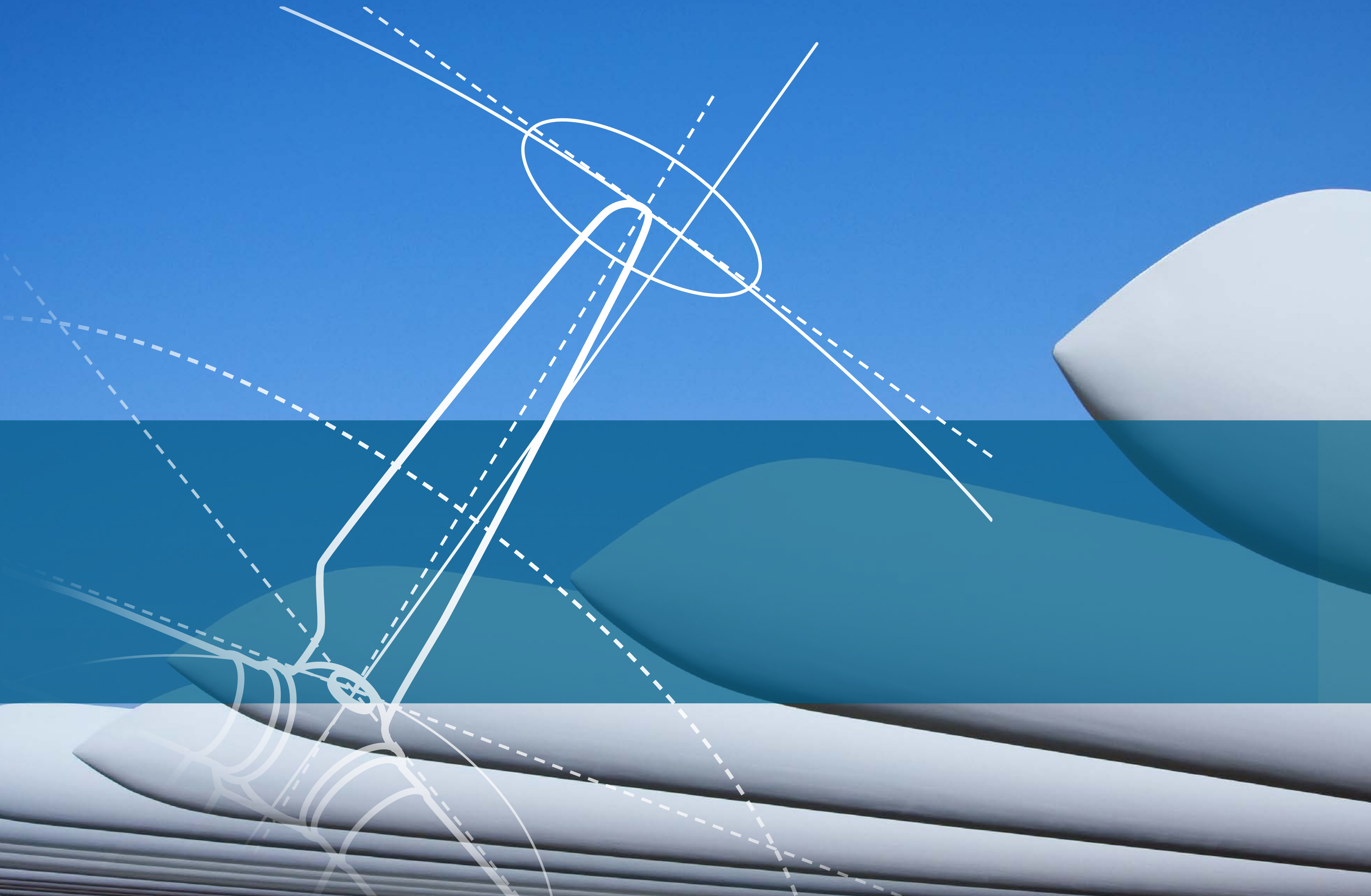
National Renewable Energy Laboratory's *Dynamometers*

The NWTC at NREL near Boulder, Colorado, features three dynamometers that can perform research validation on wind turbine systems from 1 kW to 5 MW. The dynamometers mimic realistic operational conditions to validate drivetrain designs and increase the technical readiness of innovations.

The NWTC offers 225-kW, 2.5-MW, and 5-MW dynamometers with the following capabilities.

- The 2.5-MW and 5-MW dynamometers can apply nontorque loads, including radial and thrust forces
- The 5-MW dynamometer can apply yaw or pitch moments of up to 7.2 meganewton-meters
- The 2.5-MW and 5-MW dynamometers can connect to NREL's controllable grid interface to provide a better understanding of how wind turbines react to grid disturbances.

For more information:
https://www.nrel.gov/wind/facilities-dynamometer.html



blade testing

VALIDATING WIND TURBINE ROTOR BLADE DESIGN, PERFORMANCE, AND DURABILITY REQUIRES RESEARCH, TESTING, AND CERTIFICATION

Longer turbine blades improve energy capture efficiency and, once certified, allow developers to use fewer turbines, thus reducing their operation and maintenance costs. Capabilities at U.S. wind turbine blade testing facilities include static and fatigue testing, blade materials testing, and hands-on workforce training that meets International Electrotechnical Commission (IEC) standards.

FIRST U.S. COMMERCIAL LARGE-BLADE TESTING FACILITY CAN TEST BLADES AS LONG AS 300 FEET (90 METERS)

Massachusetts Clean Energy Center's *Wind Technology Testing Center*

Located near the Port Authority in Boston Harbor, the Massachusetts Clean Energy Center's Wind Technology Testing Center is in close proximity to substantial offshore wind resources and a 1,200-foot (360-m) dock for handling blades. The facility, which received a $25 million grant from DOE in 2009 along with funding from other sources, is ideal for certifying the larger blades and higher-capacity turbines that enable offshore developers to use fewer turbines, reducing operation and maintenance costs.

Providing the tools necessary to evaluate and support the next generation of wind turbine blade developments and meet international standards that reduce technical and financial risk for developers, the facility's capabilities include:

- A full suite of static and fatigue tests per IEC 61400-23 standard
- Three test stands and 100-ton overhead bridge crane capacity
- Blade material testing
- Dual-axis static or fatigue testing
- Prototype development and blade repair capabilities
- A convenient location on a deep-water port to accept all blade sizes.

For more information:
http://www.masscec.com/wind-technology-testing-center

SERVO-HYDRAULIC EQUIPMENT AND DATA ACQUISITION SYSTEMS FOR SMALLER BLADES AND COMPONENTS

National Renewable Energy Laboratory's *Structural Testing Laboratories*

The NWTC offers three structural research laboratories that can validate blades and components smaller than 1 m to more than 50 m in length, performed to the IEC 61400-23 standard.

These world-class facilities are capable of simulating the extreme operating loads experienced by blades during field operation and accelerated fatigue lifetime loading. In addition, modal, acoustic emission, thermography, and surface characterization systems are available. General types of rotor blade research performed at the NWTC include:

- Property validation
- Static strength research validation
- Fatigue research.

For more information:
https://www.nrel.gov/wind/facilities-structural-research.html

INSPECTION SPECIMENS AND TECHNOLOGY SPECIFICALLY SUITED TO WIND BLADES

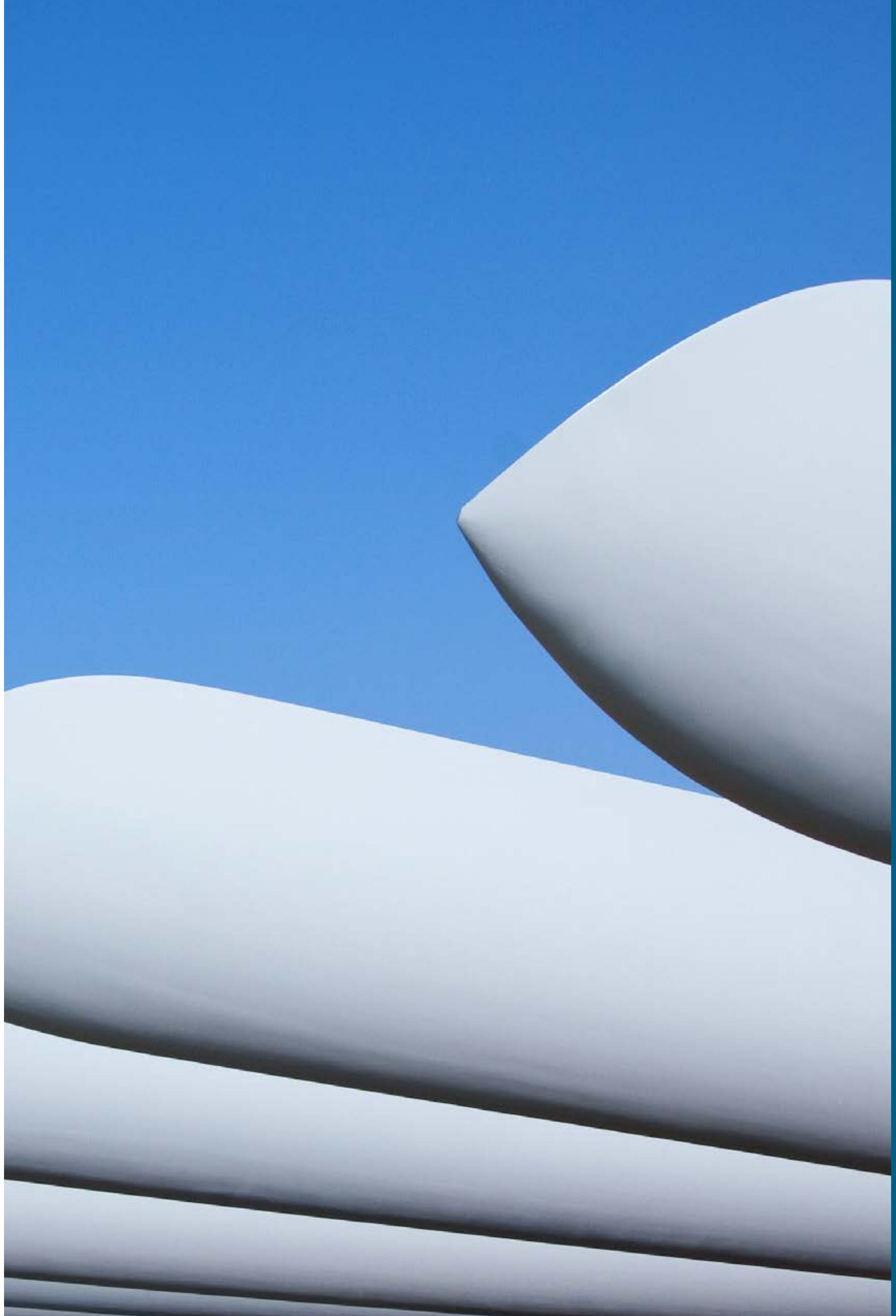
Sandia National Laboratories' *Infrastructure Assurance and Non-Destructive Inspection Facility*

Sandia's Infrastructure Assurance and Non-Destructive Inspection Facility features real and engineered wind blade inspection specimens that include all flaws and damage types that are commonly found in wind blades in both manufacturing floor and field settings.

The Wind Blade Non-Destructive Inspection Center provides the following capabilities and expertise:

- Nondestructive inspection
- Automated and robotic inspection deployment
- Structural health monitoring and sensor development
- Composite fabrication and structural repair
- Structural mechanics and damage tolerance analysis
- Fatigue, fracture, and strength mechanical testing
- Reliability and probabilistic analysis.

For more information:
http://energy.sandia.gov/energy/renewable-energy/wind-power/materials-reliability-standards



Facility	Advanced Manufacturing	High-Performance Computing	Resource Characterization	Grid Integration	Field Testing	Drivetrain Testing	Blade Testing	Page Number
Argonne National Laboratory's Advanced Photon Source Technical Facility						✔		30
Argonne National Laboratory's Atmospheric Radiation Measurement Southern Great Plains Site			✔		✔			22
Argonne National Laboratory's Leadership Computing Facility		✔	✔					10
Argonne National Laboratory's Tribology Laboratory						✔		30
Argonne National Laboratory's Wind Resource Instrumentation			✔					10
Clemson University's Duke Energy eGrid				✔				16
Clemson University's SCE&G Energy Innovation Center						✔		31
Idaho National Laboratory's Critical Infrastructure Test Range				✔				16
Idaho National Laboratory's Human System Simulation Laboratory				✔	✔			17
Idaho National Laboratory's Microgrid Test Bed					✔			22
Idaho National Laboratory's Power and Energy Real-Time Digital Simulation		✔		✔				17
Idaho National Laboratory's Wireless Test Bed					✔			23
Lawrence Livermore National Laboratory's High-Performance Computing Innovation Center		✔						6
Lawrence Livermore National Laboratory's Mobile Observational Instruments			✔		✔			11
Lawrence Livermore National Laboratory's Site 300 Testing Facility			✔		✔			11
Massachusetts Clean Energy Center's Wind Technology Testing Center							✔	34
National Renewable Energy Laboratory's Composites Manufacturing Education and Technology Facility	✔							2

Facility	Advanced Manufacturing	High-Performance Computing	Resource Characterization	Grid Integration	Field Testing	Drivetrain Testing	Blade Testing	Page Number
National Renewable Energy Laboratory's Controllable Grid Interface				✔	✔			18
National Renewable Energy Laboratory's Dynamometers						✔		31
National Renewable Energy Laboratory's High-Performance Computing Center		✔						6
National Renewable Energy Laboratory's Field Research Validation Sites			✔		✔			23
National Renewable Energy Laboratory's Structural Testing Laboratories							✔	34
Oak Ridge National Laboratory's Carbon Fiber Technology Facility	✔							2
Oak Ridge National Laboratory's Institute for Advanced Composites Manufacturing Innovation: Composite Materials and Process Technology Area	✔							3
Oak Ridge National Laboratory's Manufacturing Demonstration Facility	✔							3
Pacific Northwest National Laboratory's Coastal Wind Profiling Radars			✔					12
Pacific Northwest National Laboratory's Grid Systems Engineering Building: Electricity Infrastructure Operations Center				✔				18
Pacific Northwest National Laboratory's Lidar Buoy Loan Program			✔					12
Sandia National Laboratories' Facility for Antenna and Radar Cross-Section Measurement					✔			24
Sandia National Laboratories' Advanced Simulation and Computing		✔						7
Sandia National Laboratories' Infrastructure Assurance and Non-Destructive Inspection Facility							✔	35
Sandia National Laboratories' Scaled Wind Farm Technology Facility					✔			25
Sandia National Laboratories' Wake Imaging Measurement System			✔		✔			25
Sandia National Laboratories' Lightning Simulator					✔			24

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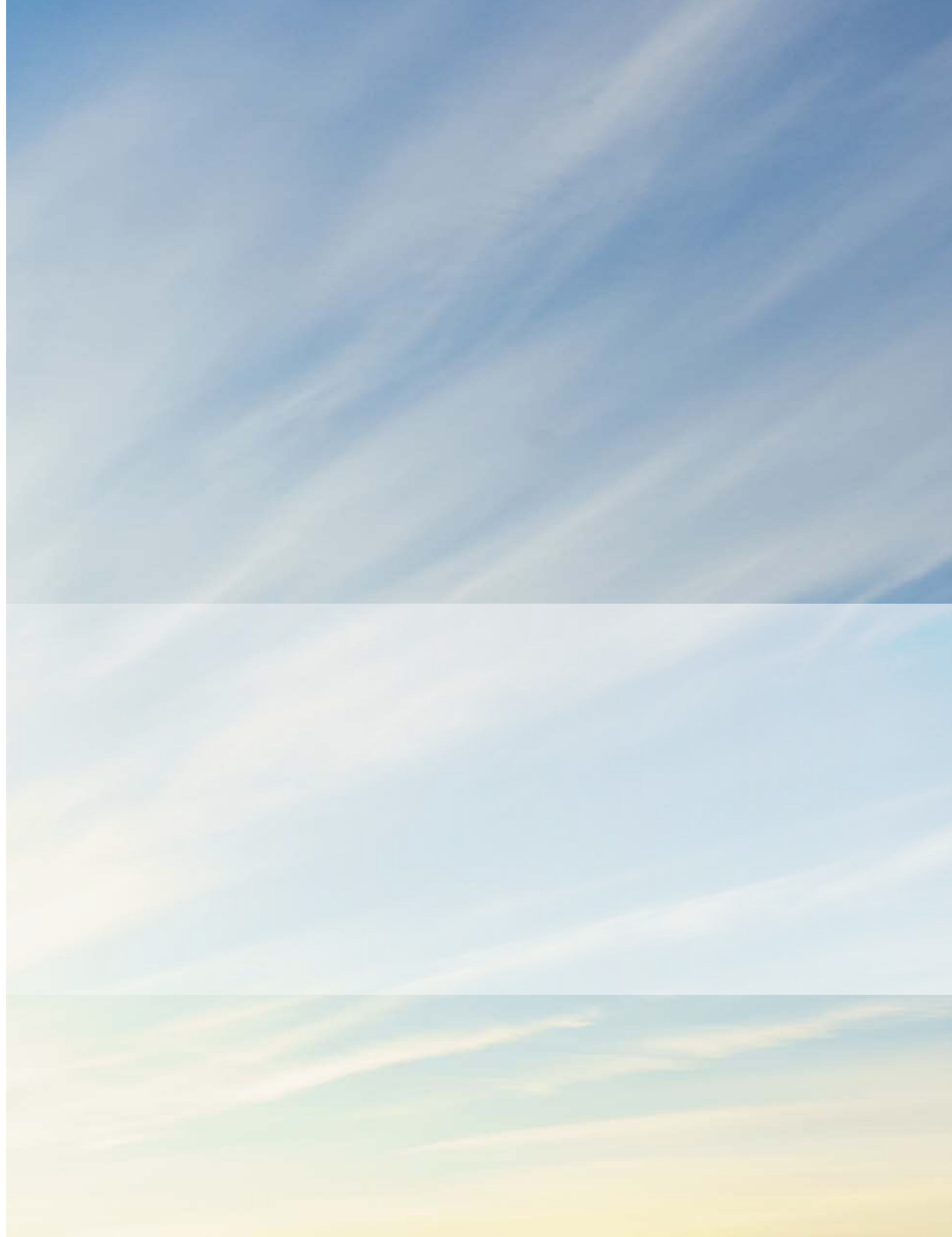

DOE's Wind Energy Technologies Office facilities support research and certification of wind technologies at the component, turbine, and wind plant levels. In addition, resource assessment and grid integration facilities help industry accurately define, measure, and forecast land-based and offshore wind resources and enable new wind installations to actively improve the quality of the electric grid.

wind.energy.gov

The U.S. Department of Energy (DOE) Wind Energy Technologies Office is committed to developing and deploying a portfolio of innovative technologies for domestic power generation to support an ever-growing industry and economic development.

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

WIND ENERGY TECHNOLOGIES OFFICE

DOE/GO-102017-4941 • February 2017