

U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

Testing Facilities and Capabilities at NWTCT Project ID # T1

Dave Simms

NREL



Photo by Dennis Schroeder, NREL 38270



FY17-FY18 Wind Office Project Organization

“Enabling Wind Energy Options Nationwide”

Technology Development

Atmosphere to Electrons

Offshore Wind

Distributed Wind

Testing Infrastructure

Standards Support and International
Engagement

Advanced Components, Reliability, and
Manufacturing

Market Acceleration & Deployment

Stakeholder Engagement, Workforce
Development, and Human Use Considerations

Environmental Research

Grid Integration

Regulatory and Siting

Analysis and Modeling (cross-cutting)

Project Overview

T1: Testing Facilities and Capabilities at NWTC

Project Summary

- Safely operate and maintain reliable performance of DOE's world-class research facilities and capabilities at the National Wind Technology Center (NWTC).
- Support fundamental research, development, experimentation, and validation of components and systems, and understand operation and failure modes.
- Support evolving DOE and industry research needs.

Project Objective & Impact

- Maintain mission readiness and operational expertise of specialized research facilities and capabilities, including highly-skilled staff, advanced state-of-the-art research methods, acquisition of research data, and development of data processing and analysis tools.
- Formal agreements with ~75 partner organizations annually with staff involved in projects that utilized NWTC research facilities.

Project Attributes

Project Principal Investigator(s)

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DOE Lead

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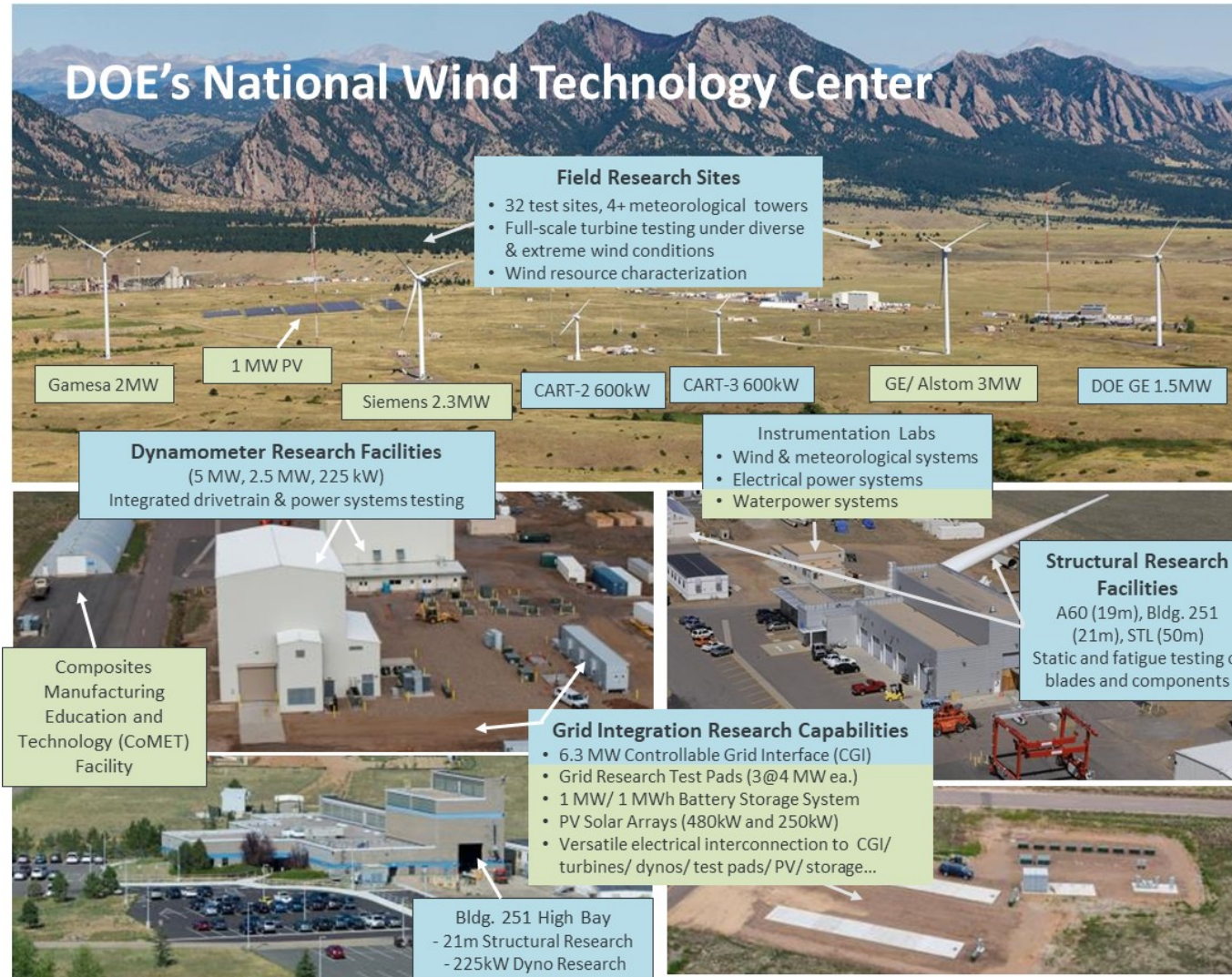
Project Partners/Subs

Many

Project Duration

Through FY19

Approach and Methodology



DOE Wind Energy Technology Office infrastructure

Infrastructure owned or operated by others (e.g. Industry partners, other DOE Programs, NREL Site Operations...)

- Wind technology since 1977
- Pioneers in turbine & component research validation methods, development of design & analysis codes
- Specialized research facilities & capabilities for use by DOE & industry
- Experiment design & execution to meet researcher needs (e.g. model validation, proof-of-concept research)
- Research validation to extremes, anticipate failures
- 305 acres
- Excellent DOE Wind & Water-Power Program stewardship
- Many partnerships
- Rigorous facility management per DOE requirements
- Exemplary safety record
- ISO 17025, A2LA accredited to many IEC Standards

Photos clockwise from top by Dennis Schroeder, NREL 22073, 19010, 19012, 22132, 25889

Approach and Methodology

Operations & Maintenance (O&M):

- **Specialized NWTC research facilities and capabilities, associated equipment and systems, qualified operators and technical experts**
 - To keep them “Mission Ready” for safe use by DOE researchers and industry partners
 - Maintained in a defined baseline configuration. Note that:
 - Enhancements (e.g., specific to supporting new research or customers) funded elsewhere
 - Customers pay NREL to install/set-up/take down their research projects and operate DOE equipment as needed to conduct their experiments
 - Includes associated research needs:
 - Control systems, data acquisition, instrumentation, calibrations, data analysis, and processing systems and tools.
- **Organized into the following areas:**
 1. Field: Turbines, met towers, sites
 2. Structural: blade static and fatigue loading
 3. Dynamometers: Drivetrains and components
 4. Grid Integration: Centered around Controllable Grid Interface (CGI)
 5. Overarching Safety, O&M



Approach and Methodology

Leverage WETO investments 2-4X

- Approximately \$15M–\$25M annual DOE, NREL, and industry funding associated with operating, maintaining, developing, improving, and utilizing specialized NWTC research facilities and capabilities
- Many projects underway concurrently, requires careful planning and scheduling, understanding of critical-path items, risk mitigation, and timeline to achieving desired outcomes:
 - Research validation projects and experiments (~30-60)
 - Sitewide projects including new capabilities, construction, renovation, and upgrade (~10-20)
 - Projects to inspect, maintain, and repair research facilities and equipment.

Ensure compliance with DOE requirements:

- Facility management, extensive rigorous integrated project planning, enables efficient sharing and optimization of resources (facilities, equipment, people)
- Develop and retain qualified workers, operators, cognizant system engineers and technicians, documentation and recordkeeping
- Safety per DOE, OSHA, NFPA
- Quality, security, environmental, property per applicable requirements
- Educate and support industry partners, especially smaller companies.



Approach and Methodology

1. Field Research Facilities and Capabilities O&M:

- DOE-owned research wind turbines:
 - DOE 1.5 (1.5 MW, Site 4.0), CART-2 (600 kW, Site 4.3), CART-3 (600 kW, Site 4.2), NW-100 (100 kW, Site 1.2), Skystream (3 kW, Site entrance).
- Instrumented meteorological research towers:
 - 135 m (2, Site 4.0 & 4.4) , 80 m (Site M2, includes interactive display and archive), upwind of each CART machine (Sites 4.2 & 4.3).
- Also supports A2e, Reliability, Environmental R&D, Grid Integration, Solar Program.



Approach and Methodology

2. Structural Research Facilities and Capabilities O&M:

- 3 structural research facilities with test stands:
 - STL: up to 50-m length test articles
 - 251: up to 21 m
 - A60: up to 19 m.
- Also supports Advanced Manufacturing Office, Water Power Program



Approach and Methodology

3. Dynamometer Research Facilities and Capabilities O&M:

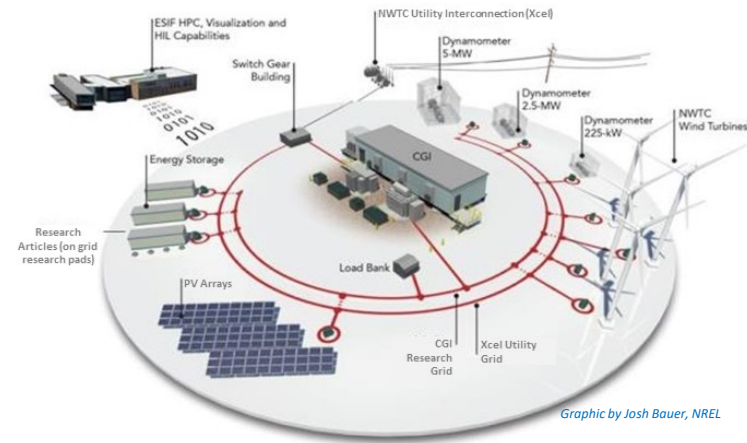
- 3 dynamometer research facilities
 - 225 kW
 - 2.5 MW
 - 5 MW with nontorque loading system
- Also supports Water Power Program



Approach and Methodology

4. Grid Integration Research Facilities and Capabilities O&M:

- 6.3-MW Controllable Grid Interface (CGI) grid simulator
 - Expose power device(s) to precisely created and controlled grid power anomalies (e.g., grid faults, transients, frequency fluctuations) under safe conditions on research grid isolated from utility
- Electrical interconnections to all plausible configurations of grid integration research assets (e.g., loads, generators, storage)
- Also supports Water Power, Solar, and Grid Modernization Programs



NWTC Grid Integration Research Assets

- DOE-owned turbines:
 - DOE 1.5
 - 2 600-kW CARTs
- Industry-owned turbines:
 - Siemens 2.3 MW
 - Gamesa 2 MW
 - GE/Alstom 3 MW (research completed, removed FY18)
- Dynos:
 - 2.5 MW
 - 5 MW
- “Grid-friendly” ancillary service control capabilities of DOE 1.5
- Research pads (3@4 MW each, for power, storage devices, NREL-funded)
- Industry-owned PV Solar arrays (480 kW and 250 kW, new FY18)
- 1-MW/1-MW-hr Battery Energy Storage System (new FY17, NREL-funded)



Approach and Methodology

5. Overarching Safety, O&M

- Research operations in accordance with DOE Integrated Safety Management System, comprehensive project planning and scheduling
- Qualified operation and scheduled preventative maintenance of general use equipment
- Specialized training and mentoring
- Quality assurance (accreditation, audits, procedure revisions, software validation, etc.)
- Government property management, inventory, equipment database
- Site-wide environmental compliance and reporting, assessments, NEPA, etc.



Photos by Dave Jager, NREL



Accomplishments and Progress

- Exemplary safety record
- All DOE milestones completed on time and within budget
- Maintained steady queue of 2.5-MW and 5-MW dyno research projects, and CGI/grid integration research projects
- Supported A2e:
 - Developed and verified turbine instrumentation systems (e.g., loads, LIDARs) prior to wind farm deployment
 - Supported Sandia colleagues at the SWiFT facility in Lubbock, TX with field testing and instrumentation expertise
- Supporting upgrade of NWTC electrical utility interconnection (Xcel) from 10-MW distribution grid to 19.9-MW transmission infrastructure
- Maintained ISO 17025 accreditation by A2LA to many IEC standards
- Worked with DOE to establish process to use UASs (drones) to support R&D



Photo by Jerry Hur, NREL



Photo by Werner Slocum NREL 51763



Photo by Steve Nixon, NREL

NWTC R&D Project Examples

DOE 1.5-MW research wind turbine at NWTC retrofitted with highly instrumented gearbox to support DOE's Drivetrain Reliability Program.

- Field experiments are now underway to provide researchers and industry partners with research data needed to better understand drivetrain physics and develop improved drivetrain models.



Photo by Dennis Schroeder, NREL 49409



Photo by Dennis Schroeder, NREL 49413



Photo by Jon Keller, NREL

NWTC experts install specialized instrumentation on gearbox components prior to factory assembly

The DOE 1.5-MW turbine's OEM gearbox is replaced with new research gearbox.

NWTC R&D Project Examples

DOE's two 600-kW research wind turbines (CART-2 and CART-3) utilized to conduct full-scale aerodynamics research experiments in partnership with:

- **Rensselaer Polytechnic Institute (RPI)**
 - CART-3 retrofitted with customized blade tip configured with RPI's active synthetic jet blowing devices designed to control blade loading fluctuations:
<http://cefpac.rpi.edu/research/projects/smart-blades-enhance-wind-turbine>
- **DLR**
 - CART-3 retrofitted with three innovative "Smartblades" designed to adapt to wind conditions using bending-torsion coupling in accordance with the objectives of the German Aerospace Center (DLR) research project:
https://www.dlr.de/dlr/en/desktopdefault.aspx/tabid-10501/826_read-25338/#/gallery/29286
- **ARPA-e**
 - CART-2 retrofitted with two highly flexible "Segmented Ultralight Morphing Rotor" (SUMR) blades that were designed in accordance with the objectives of the University of Virginia's ARPA-e research project:
<https://arpa-e.energy.gov/?q=slick-sheet-project/ultra-large-wind-turbine>
To enable this research, the CART-2 will be operated downwind



NWTC Transition

- Supported transition of NWTC from single program to multiprogram to address anticipated future needs (called NWTC 2.0) :
 - Due to NWTC synergies of capabilities to support other EERE Programs
 - Especially Water Power, Solar, Advanced Manufacturing, Grid Modernization
 - Significant grid integration investments generated new work and interest, benefits to EERE and industry
 - Providing NWTC 2.0 planning and analysis for NREL and DOE management, including:
 - 2nd CGI
 - 3 additional grid research pads
 - MW-scale load bank and other assets for microgrid R&D
 - Electrical infrastructure upgrades to support new Distributed Wind MIRACL project



Water Power Research

NWTC dynamometer research facilities and staff technical expertise support DOE's Water Power Technologies Office (WPTO)

- Research validation of Columbia Power Technology's large prototype wave energy device was conducted in the NWTC 5-MW dynamometer. In addition, a water power instrumentation laboratory has been established where research measurement systems are to be built and verified prior to deployment on field experiments.



Photo by Dennis Schroeder, NREL 48856

Columbia Power Technology's wave energy device generator installation in NWTC 5-MW dynamometer facility

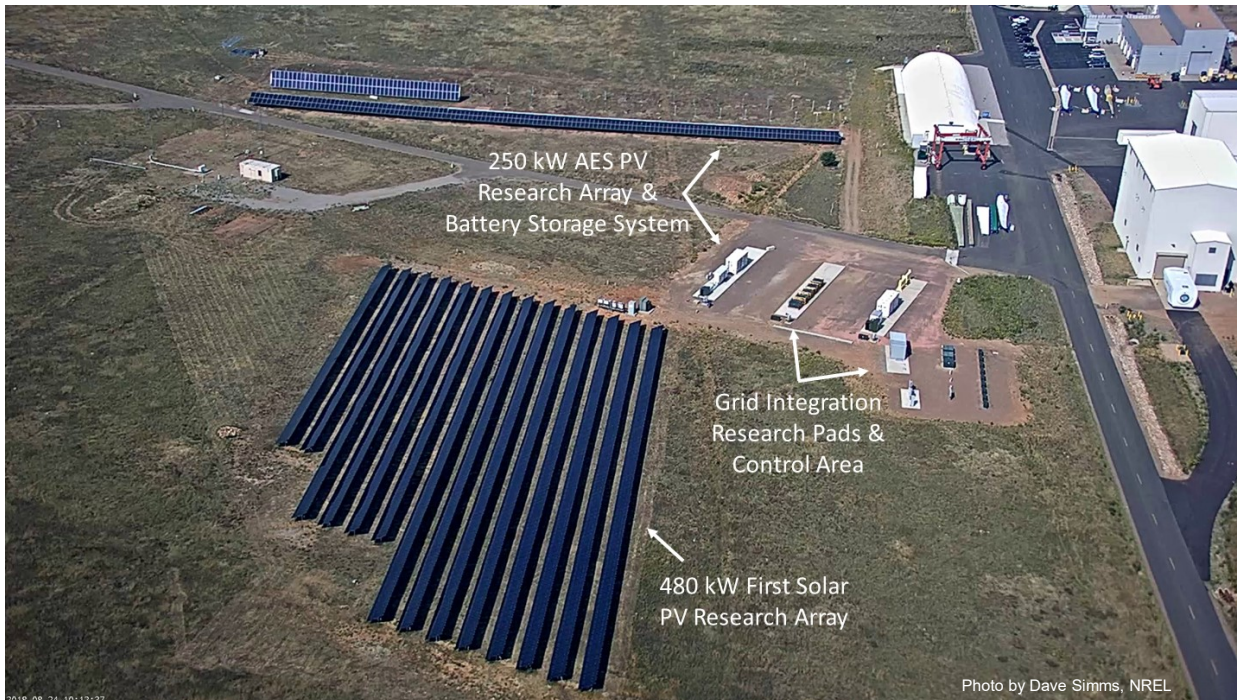


Photo by Mark McDade, NREL 44103

Photovoltaic Research

NWTC grid integration research facilities and staff technical expertise support DOE's Solar Energy Technologies Office (SETO):

- Installation of two PV research systems at NWTC:
 - First Solar 480-kW PV array and power conversion system
 - AES 250-kW PV array with an integrated battery storage and power conversion system
- Both partners utilize the NWTC's Controllable Grid Interface to expose their systems to a wide range of grid anomalies (in combination with other load, generation, and storage devices) and obtain resulting detailed electrical voltage and current response data.



NWTC PV Research Arrays and Grid Integration Research Pads

Communication, Coordination, and Commercialization

Communication and outreach strategies:

1. NWTC visitors and tours:

- Hosted tours for over 1,000 visitors and VIPs from around the world in FY18

2. NWTC-hosted conferences, events, presentations, and published information:

- Hosted DOE's Collegiate Wind Competition (at NWTC and AWEA). Designed/built/stored/transported/operated wind tunnels
- Many technical presentations describing NWTC facilities, capabilities, and accomplishments to stakeholder groups
- Fact sheets associated with each of the major NWTC research facilities and capabilities.

3. Staff researcher interaction with the U.S. and international R&D community:

- All NWTC personnel are important emissaries and communicators of DOE research facilities and capabilities when they attend conferences, meetings, and trainings with colleagues, including participation in IEA and IEC activities.



Communication, Coordination, and Commercialization

NWTC Partnering Expertise: 80 Partner Organizations** Utilized NWTC Research Facilities and Capabilities in FY17

Industry-funded WFO & Funds-in CRADAs

1. Alstom Power Inc.*
2. Anemergonics (SBIR)
3. Clarkson University
4. Collaborative Composite Solutions
5. Colorado Office of Economic Dev.
6. Dow Aska
7. Gamesa*
8. Genuine Wind
9. Google Incorporated
10. Laufer Wind
11. Micatu, Inc.
12. Michigan Aerospace (CART)
13. Mitsubishi Heavy Industries
14. PASL Wind Solutions Pvt. Ltd.
15. RPI/ XC Associates, Inc.
16. Siemens Energy & Automation Inc.*
17. Verdant Power
18. Xpeed Turbine Technology, LLC
19. Xzeres Wind

Cooperative Research Agreements

20. Clemson University*
21. Columbia Power Technologies
22. Garrad-Hassan (CART)
23. GE Wind*
24. Massachusetts WTTC
25. Ocean Renewable Power Co., LLC
26. RES Americas
27. Sentient Science Corporation

Other AOP Collaborations (NDA, MOU, Government, University)

28. SKF GmbH and SKF USA*
29. TU, Netherlands (CART)
30. Winergy Drive Systems Corporation*
31. INL
32. ORNL
33. SNL
34. PNNL
35. NASA
36. NOAA
37. AES Wind Generation (GRC)
38. Ansol (GRC)
39. AGMA (GRC)
40. Argonne (GRC)
41. Bosch-Rexroth (GRC)
42. Brad Foote Gearing (GRC)
43. Duke Energy Renewables (GRC)
44. EDF Renewable Services (GRC)
45. EDP Renewables (GRC)
46. Gearbox Express (GRC)
47. GEARTECH (GRC)
48. Iberdrola (GRC)
49. Infigen (GRC)
50. Invenergy (GRC)
51. KU Leven (GRC)
52. LMS International (GRC)
57. Schaeffler (GRC)
58. SIMPACK (GRC)
59. Terra-Gen Power LLC (GRC)
60. The Gear Works (GRC)
61. The Ohio State University (GRC)
62. The Timken Company (GRC)
63. AXYS Technologies Inc.
64. Colorado School of Mines (CART)
65. DNV-GL
66. DTU, Denmark (CART)
67. ECN Netherlands (CART)
68. Glosten
69. Leosphere
70. National Instruments
71. Next Era*
72. Romax Technology*
73. Texas Tech University
74. Univ of Colorado (CART)
75. Univ of Maryland
76. Univ of Stuttgart (CART)
77. UMass
78. Vattenfall
79. Xcel Energy
80. Zephyr Wind (CART)

* Also Gearbox Reliability Collaborative GRC partner

** Partner organizations with staff involved in projects that utilized specialized NWTC research facilities (e.g., dynos, field test sites, and turbines, CGI, structural). Does not include "office-only" research partnerships, e.g., modeling, cost studies.

Summary

- NREL works closely with WETO to ensure NWTC research facilities and capabilities meet the needs of DOE, industry, and stakeholder groups:
 - Focused on advancing the state of the art and enabling other important technical advances, innovations, and research results
 - Based on a cohesive and realistic strategy including:
 - Detailed project planning, understanding of critical path items, risk mitigation, and timeline-produced results meeting all expectations and/or obligations relative to project plans and schedules
 - Sound technical principles, with a credible pathway to technical success and/or meeting the other stated goals of the project
 - High degree of scientific rigor conducting experiments and other key tasks
 - Significant partnering and collaboration with industry, universities, other research organizations
- Successfully adapted to continually evolving technical and programmatic challenges
- Widespread support across all WETO program activity areas (e.g., Technology Development, Market Acceleration & Deployment)
- Transitioning to support other EERE Technology Offices (Water Power, Solar, Advanced Manufacturing, Grid Modernization)

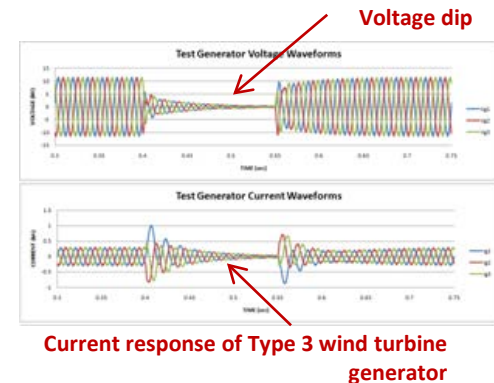
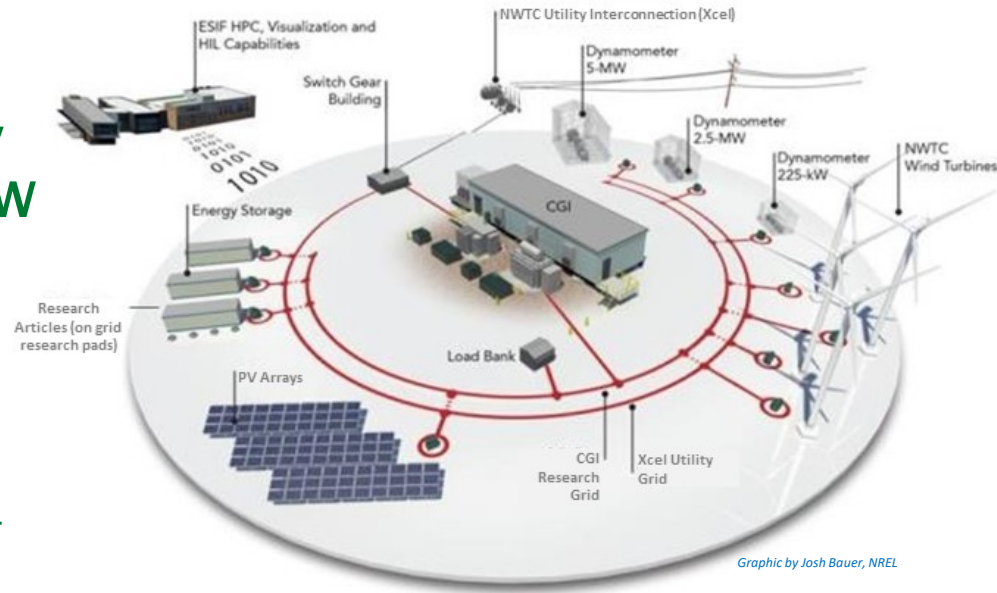


Photo by Dennis Schroeder, NREL 47220

NWTC Controllable Grid Interface

Grid Integration Research Versatility Centered Around the NWTC's 6.3-MW Controllable Grid Interface (CGI):

- **Research validation of MW-scale grid power devices and systems:**
 - Energy generation and storage (e.g., wind turbines, solar arrays, batteries), loads (e.g., lighting, HVAC, battery charging), power converters, and control systems
 - Located within facilities, on research pads, and in the field
 - Individual research articles or integrated systems; DOE infrastructure or customer supplied
 - Any combination of interconnected devices that respond directly to electrical grid conditions
- **Expose power device(s) to precisely created and controlled grid power anomalies from the CGI (e.g., grid faults, transients, frequency fluctuations) under safe conditions isolated from utility**



NWTC Controllable Grid Interface (continued)

- Resulting research data enables DOE, NREL, and industry to characterize full range of device and system behavior, associated impact on grid, and interaction among devices (i.e., harmonics)
- Used to:
 - Develop and validate computer simulation models of the grid and grid devices
 - Inform evolution of standards, certification, safe operating procedures
 - Validate and demonstrate grid recovery and restoration procedures after disasters, cyber, and physical grid attacks

Grid Research data acquisition:

- Customized Medium-Voltage Data Acquisition System (MV-DAS):
- ~20 real-time GPS-synchronized modular measurement nodes
- Located at all power devices and strategic interconnection points
- Research-grade power quality and energy flow measurements (e.g., 3-phase voltage, current), each at 40 kHz rate to central location

