U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Technology Innovation:

"Advanced Components, Reliability, and Manufacturing"

2019 Wind Program Peer Review

Brad Ring

April 30 – May 2, 2019

Wind Office Goals

Enabling Wind Options Nationwide

FY 2017–18 LCOE Targets

- The Office exceeded its Government Performance Reporting Act (GPRA) levelized cost of energy (LCOE) end of year targets for both land-based and offshore wind in Both FY 2017 and FY 2018.

FY 17-18 GPRA Targets

Land-Based Wind: Reduce the unsubsidized market LCOE for utility-scale land wind energy systems from a reference wind cost of $.074/kWh in 2012 to $.057/kWh by 2020 and $.042/kWh by 2030.

Offshore Wind: Reduce the unsubsidized market LCOE for offshore fixed-bottom wind energy systems from a reference of $.18/kWh in 2015 to $.15/kWh by 2020 and $.096/kWh by 2030.

Future Goals

- **LCOE targets:** The office works to achieve breakthroughs in reducing the LCOE for land-based wind by 50% from today's LCOE, to $.023/kWh without subsidies by 2030, and achieving a 50% reduction in offshore wind and distributed wind by 2030 from a 2015 benchmark.

- **Additional non-LCOE targets are under development by the office**

Wind Office Strategic Priorities

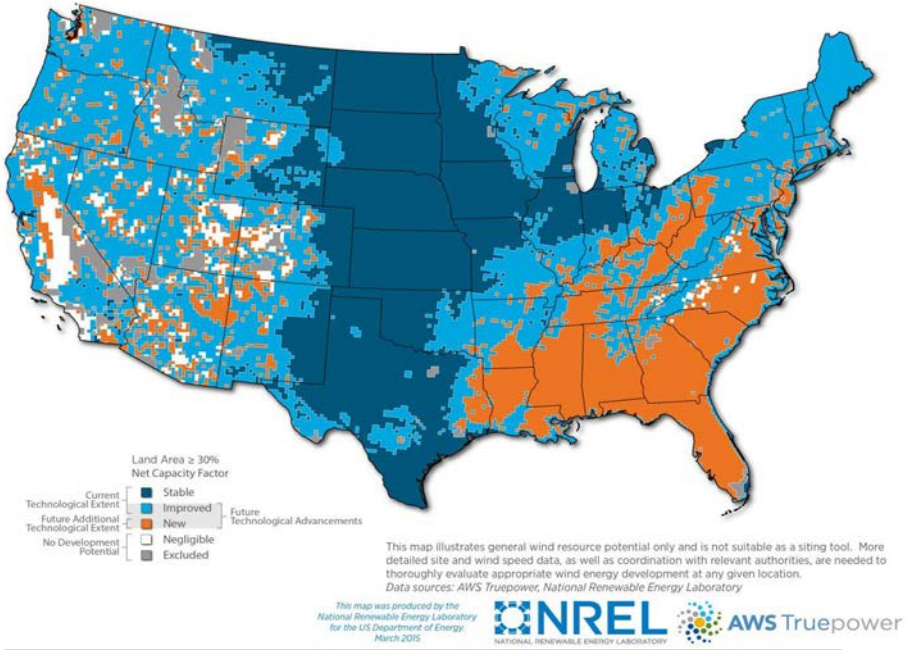
Clean, low-cost wind energy options nationwide

	Land-Based Wind	Offshore Wind	Distributed Wind
Technology Development & Scientific Research	Atmospheric Science & Wind Plant Systems Engineering	Atmospheric Science & Wind Plant Systems Engineering	Atmospheric Science
	Standards and Certification	Standards and Certification	Standards and Certification
	Technology Innovation	Technology Innovation	Technology Innovation
	World Class Testing Facilities	World Class Testing Facilities	
	Tech to Market Commercialization	Tech to Market Commercialization	
	Integrated Systems Design	Integrated Systems Design	
		Offshore Specific R&D	
		Advanced Technology Demo Projects	
Market Acceleration & Deployment	Advanced Grid Integration	Advanced Grid Integration	Advanced Grid Integration
	Workforce and Education Development	Workforce and Education Development	Workforce and Education Development
	Stakeholder Engagement	Stakeholder Engagement	Stakeholder Engagement
	Environmental Research	Environmental Research	
	Siting & Wind Radar Mitigation	Siting & Wind Radar Mitigation	
Analysis & Modeling	Evaluate and Prioritize R&D	Evaluate and Prioritize R&D	Evaluate and Prioritize R&D
	Model Development and Maintenance	Model Development and Maintenance	Model Development and Maintenance
	Techno-economic Analysis	Techno-economic Analysis	Techno-economic Analysis
	Electricity Sector Modeling	Electricity Sector Modeling	Electricity Sector Modeling

Motivation: Enabling Wind Nationwide

The combined land-based and offshore domestic wind resource potential is more than 10 times greater than the total U.S. electricity demand

- Untapped Wind Market Potential in All 50 States: Land-based utility-scale wind (LBW), Offshore wind (OSW) and Land-based distributed-scale wind
- Barriers: **Wind Turbine Design, Reliability,** Wind plant optimization, **Cost reduction**, Grid integration, and Mitigation of environmental impacts and human use impacts such as radar interference.



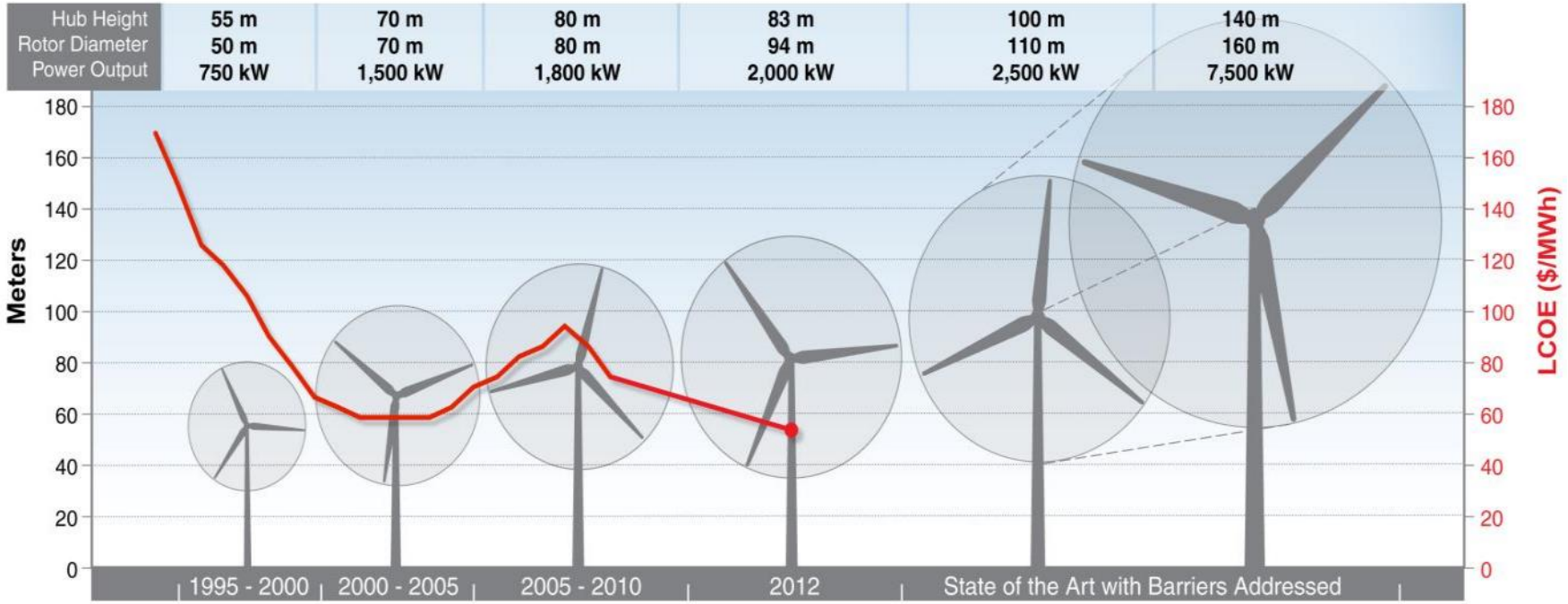
Land area achieving a minimum 30% net capacity factor, based on current technology, increased rotor diameter and a 140-m hub height. Areas of expanded access to wind power are highlighted in orange.

Increasing hub heights from 86 to 140 meters would expand technical potential by 67% and unlocks an additional 1/5th of U.S. land area of wind power resource potential in the U.S. (~1800 GW)

Motivation: Larger Turbines

Enabling Wind Power Nationwide

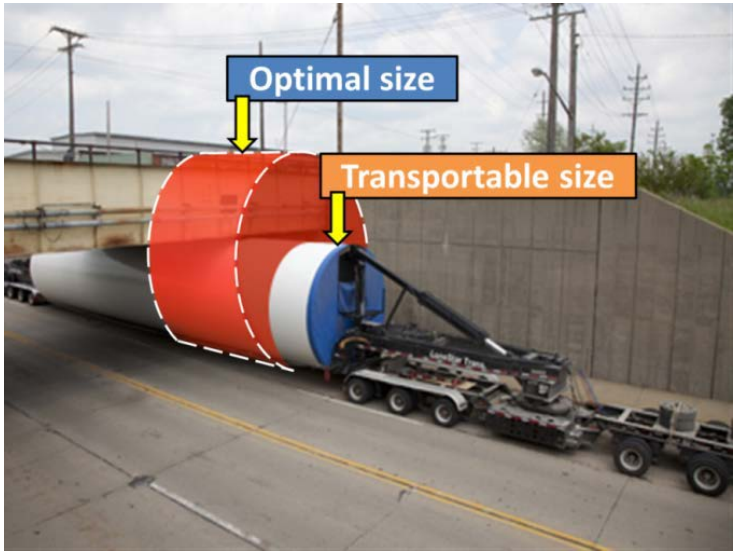
- **Taller towers and longer blades (60+ m) access stronger, more consistent winds**
- **Bigger turbines (with longer blades and taller towers) will require continued investment in component R&D to allow larger blades, drivetrains, towers, while keeping the cost of energy low**



Motivation: Transportation & Logistics Barriers

- Transportation challenges have slowed further economies of scale for larger turbines
- Increases in rotor diameter and hub height create increased costs for most components of turbine and drive higher transportation and installation costs

Photo credit: SSP Technology



Motivation: Domestic Manufacturing & Economic Value

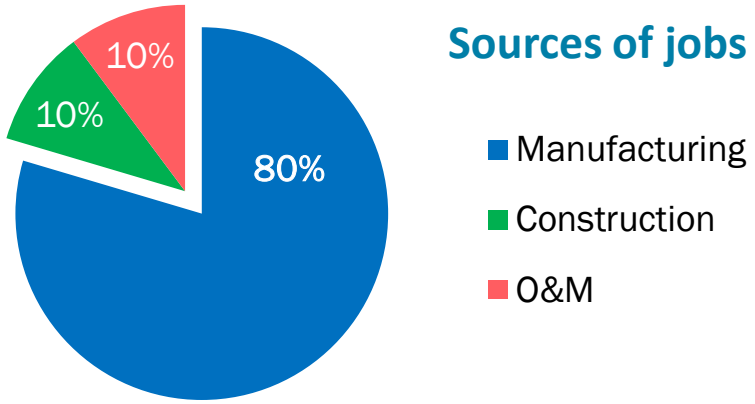
Domestic Manufacturing is Key to a Sustainable U.S. Wind Industry

Enable next-generation turbine scaling

- The next generation of turbines (particularly > 3 MW) and higher towers (> 100m) face daunting logistical challenges in manufacturing, transport and installation

Manufacturing is where the jobs are

- 80% of wind industry jobs are related to manufacturing and supply chain activities
- Wind generation now provides the third largest share of Electric Power Generation employment - 101,738 workers[1]



Enabling innovation to ensure domestic supply chain

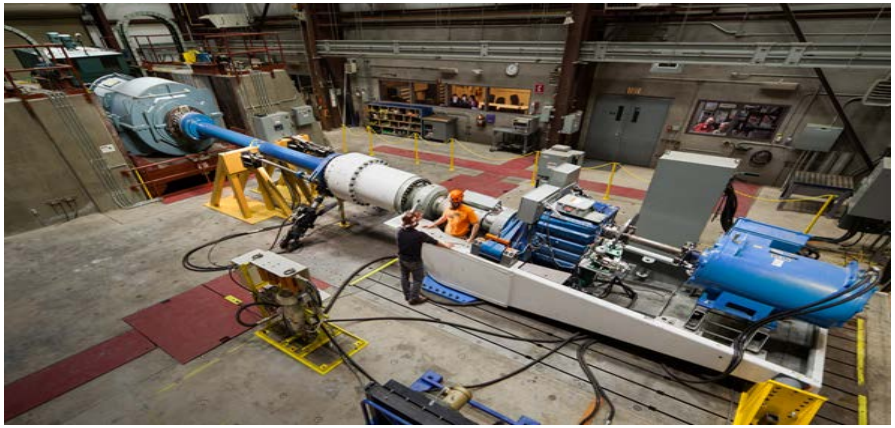
- **Manufacturing** - logistics and new techniques
- **Advanced Components** - LCOE reduction & larger components
- **Reliability** - mitigate wind project O&M costs

Motivation: Wind Turbine Reliability

Conduct material and mechanical testing and analysis to improve reliability, availability, reduce wind plant O&M costs & create opportunities for further LCOE reduction

With increasing turbine size & aging plants, turbine reliability has been adversely affected, increasing O&M costs for new turbines and existing fleet

- Component repair and replacement are a large portion of these costs
- Modeling & decision tools on remaining useful life and whether to repair, replace, or repower not available
- Conditioning monitoring is not standardized or effectively implemented
- Difficulties of sharing of reliability and cost data



GRC 750 kW

Technology Innovation: Challenges, Goals, & Approach

Strategic Area	Challenges	Goals	Approach
Manufacturing	Improvements require advancements in composite materials, automation, and manufacturing processes	Enable rapid prototyping, improve design flexibility, and develop innovative construction techniques to keep high-paying jobs in the U.S. to decrease LCOE	• Additive manufacturing R&D programs • Investigate on- or near-site manufacturing
Advanced Components	New large rotor and tall tower designs must be able to scale up in size while remaining low cost	Innovative designs, advanced materials, that enable low cost advanced components, and decrease LCOE	• Drivetrain R&D • Big Adaptive Rotor • Optimized Carbon Fiber • SBV: Tower Technologies & Sentient Science projects
Reliability	It remains difficult to predict direct operation and maintenance (O&M) costs or to avoid unplanned maintenance and replacements costs.	Reduce performance uncertainty, prevent premature component failures, reduce project risk, and increase overall project financial performance to decrease LCOE	• Drivetrain Reliability Collaborative: • White Etching Cracks • Characterize predominant and unaccounted failure mode mechanisms and develop mitigation strategies • Blade Reliability Collaborative: • Advanced Non-destructive Inspection Techniques & damage repair methods • Durable and Damage Tolerant Design

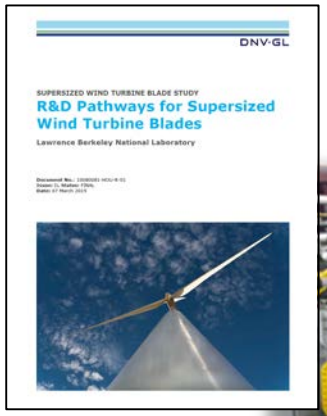
Manufacturing: Accomplishments

- AM mold for 13-m research blades – Manufacturing by Big Area Additive Manufacturing (BAAM)
- Demonstrated efficacy of AM in manufacturing of Wind Components and Tooling
- Identified a target structural nacelle component for direct AM production; Ided 3 separate methodologies utilizing large scale AM: reinforced composite print, foam print for lost foam casting, and direct metal print.

Collaborators: Oakridge National Lab, NREL, Vestas

Advanced Components: Accomplishments

- "R&D Pathways for Supersized Wind Turbine Blades"- BAR workshop: over 60 participants from labs, academia, and industry
- Concept catalogue of innovative technologies to enable future low SP rotors
- Optimized Carbon Fiber (CF) -Material selection (heavy-tow, low-cost carbon fiber materials)
- Carbon Fiber: Pultrusion cost model developed, mechanical testing, optimization tools & models developed to assess material demand at low wind resource sites & material property cost relationships
- SBV new tower model development by WTT to compare costs of traditional wind tower and erection tech to SECT



Source: Dacotrans with Goldhofer ETV

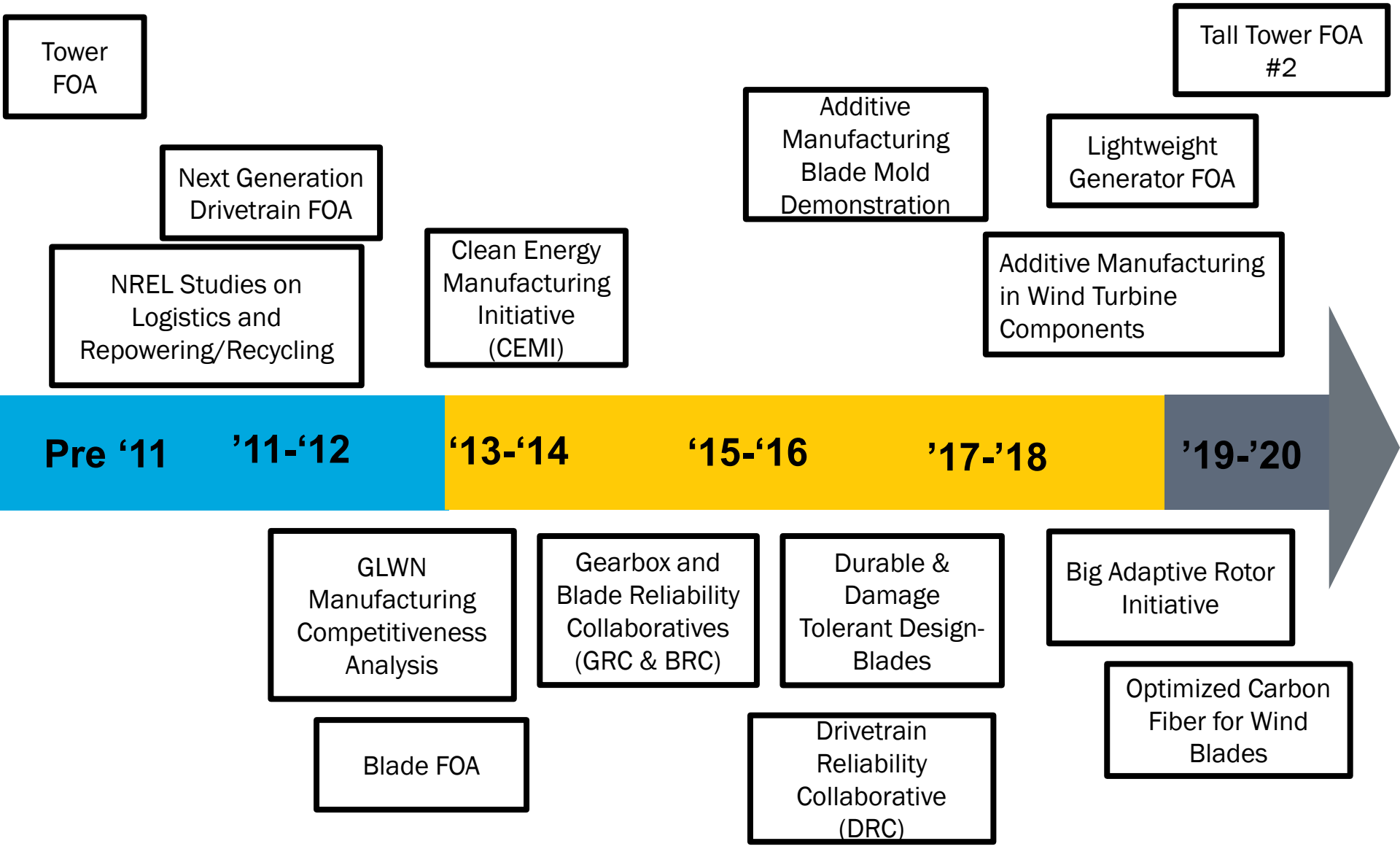
Collaborators: NREL, SNL, LBNL, ORNL; DNVGL; Domestic & International Industry; Small Businesses: Wind Tower Technologies, Sentient Science

Reliability: Accomplishments

- Developed gearbox failure database; Design and testing of gearbox improvements
- Gearbox Bearing Axial (White Etching Crack) -failure analysis, developed new benchtop testing method to replicate WECs, discovered frictional energy criteria for WEC , initial testing completed on mitigation technologies, up-tower testing
- Complete full-scale, high-speed shaft benchtop test validating the performance of shaft, bearing cage and roller speed instrumentation for 1.5 MW gearbox parts
- Install and instrumented 1.5 MW gearbox in the GE 1.5 SLE turbine
- Drivetrain Reliability Collaborative- over 150 participants; Blade Reliability Collaborative
- NDI evaluation and testing for wind turbine blades- “Probability of Detection Study to Assess Performance of Nondestructive Inspection Methods for Wind Turbine Blades”
- Damage modeling to develop & assess predictive tools for OEM/wind plant operators

Collaborators: NREL, SNL, ANL ; Montana State University; Domestic and international industry;

Technology Innovation: Key Projects Over Time



Tech Innovation: Future Priorities (FY19 and beyond)

Approach: Innovation in **material science and mechanical engineering** R&D to develop next generation technologies that maximize energy capture and decrease LCOE.

Sample Strategic Areas	Future Priorities	Collaborators
Scaling/Light-weighting (e.g. Tall Wind for LBW)	• **Goal: Enable access to better wind resources and continue economies of scale for *land-based wind* turbines** • Low-specific power rotors 150 W/m^2(BAR Initiative) • 35-50% lighter drivetrain (Lightweight Generator FOA) • Taller Towers 140m+ (Tall Tower FOA) • Logistics: Transportation & On-site Assembly	• National Labs: SNL, NREL, ORNL, LBNL • Industry Partners
Next Generation Design	• **Goal: Next Generation and Enabling Technologies for *LBW & OSW*, decrease LCOE, and improve future turbine reliability** • Advanced manufacturing techniques, Advanced materials (e.g. carbon fiber, additive manufacturing) • AI/robotics, advanced sensors • Design innovation and design tools • Floating for OSW	• National Labs • Academia • Industry Stakeholders • Advanced Manufacturing Office • Institute for Advanced Composites Manufacturing Institute
Turbine Reliability	• **Goal: A) Decrease unplanned maintenance for existing fleet and B) and inform next generation design for reliability** • Drivetrains: Id material, design, and operational root causes to drivetrain failures; design, control, material, coating, and lubricant solutions; • Novel sensing techniques, life data analysis tools, algorithms, • Blade Reliability- Leading edge erosion, lightning damage & protection	• National Labs • Industry • Academia