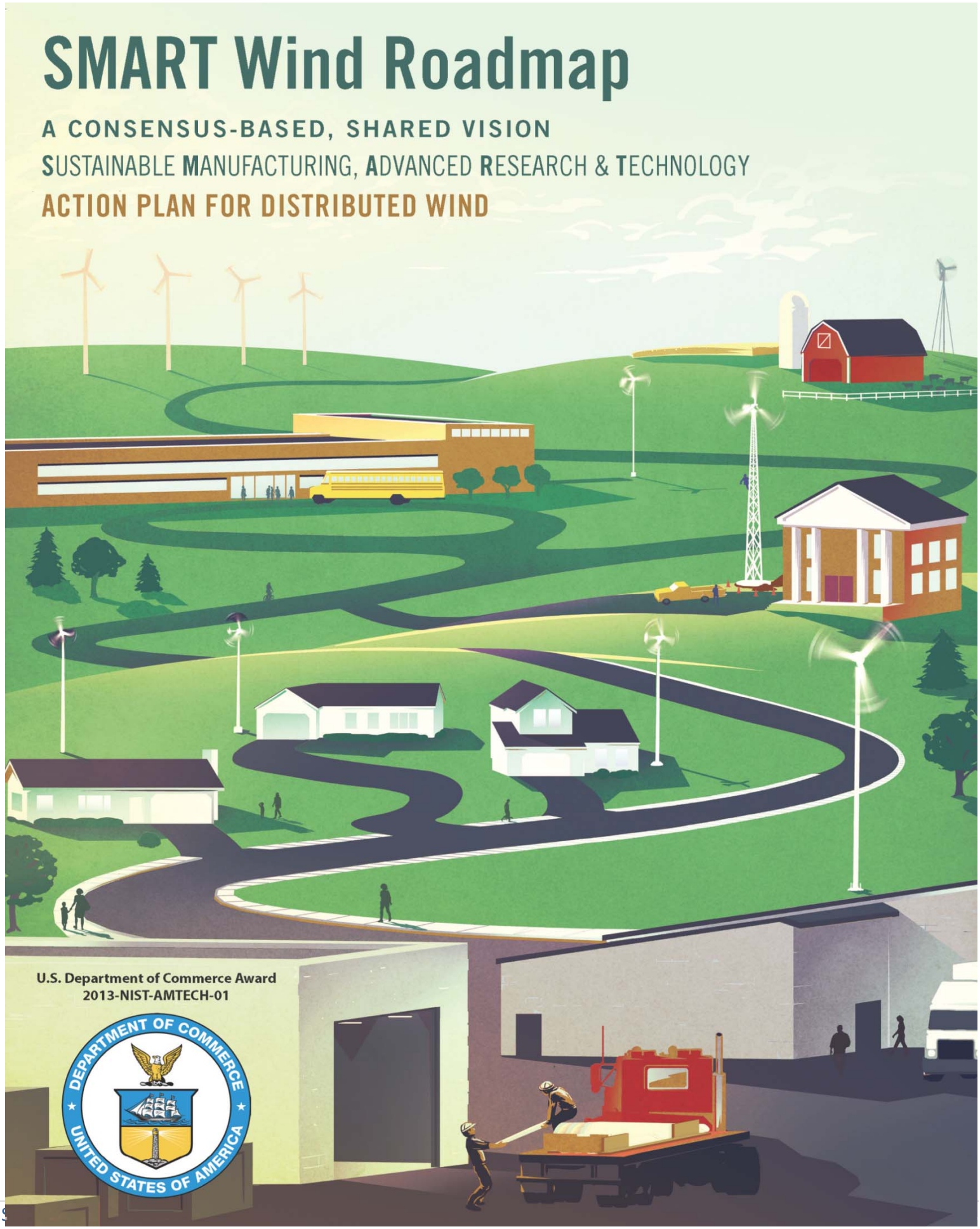
SMART Wind Roadmap

A CONSENSUS-BASED, SHARED VISION

SUSTAINABLE MANUFACTURING, ADVANCED RESEARCH & TECHNOLOGY

ACTION PLAN FOR DISTRIBUTED WIND



U.S. Department of Commerce Award
2013-NIST-AMTECH-01

CONSORTIUM FORMATION

The approach for forming the Sustainable Manufacturing, Advanced Research & Technology (SMART) Wind Consortium involved identifying U.S. Original Equipment Manufacturers (OEMs) that are currently producing distributed wind turbines, startups seeking to manufacture distributed wind turbines and components, and universities and laboratory researchers with the latest technology innovation and manufacturing approaches.

SMART Wind Consortium participants currently include:

- 25 OEMs
- 50 other vendors and industry supply chain members
- Researchers from 4 federal laboratories
- 30 academic stakeholders
- Nearly 20 nonprofit organizations, government representatives and other stakeholders

SMART Wind Consortium participants were organized into four Subgroups based on common manufacturing techniques:

- Mechanical Systems
- Support Structures
- Electrical Subsystems
- Composites

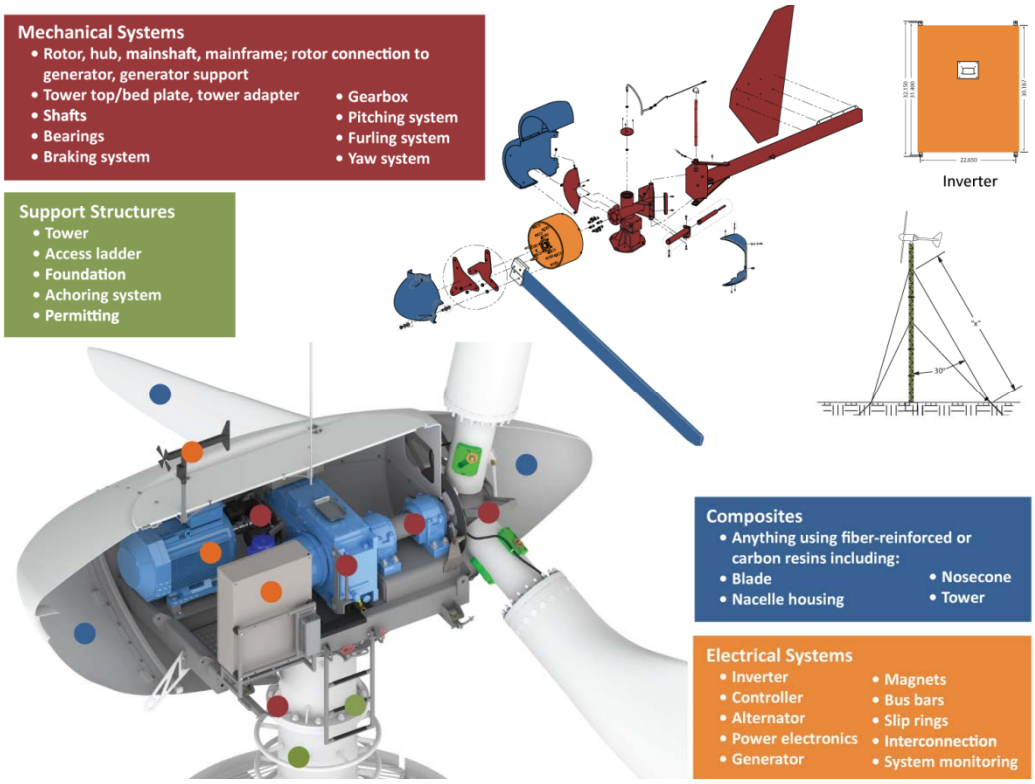
Industry, laboratory researchers, and academic experts served as SMART Wind Consortium Subgroup leaders who helped to guide and facilitate discussion and collaboration.

Consortium participants signed up for one or more Subgroups and volunteered to participate in both face-to-face and virtual meetings with specific, detailed, and technical dialogue, which were used as a basis for brainstorming actions needed.

The main goals of the meetings were to begin the development of the Consortium as an industry group and to identify possible cost-reducing actions that can lead to evolutionary product and manufacturing improvements.

The SMART Wind Consortium hosted seven face-to-face meetings from October 2014 to February 2016: a Launch meeting, four Subgroup meetings, a Manufacturing Forum, and a final Roadmap Review meeting.

SMART WIND SUBGROUPS



CHALLENGES

- The U.S. distributed wind industry stands poised for rapid growth with domestic installations and exports
- New international markets supported by policy incentives such as in Italy and the United Kingdom, have recently experienced significant growth
- Global competitors are developing new wind turbines that put cost-competitive pressure on U.S. distributed wind turbine manufacturers
- The challenge is how to make significant cost reductions in a micro-capitalized industry with a shifting market

OPPORTUNITIES

- The U.S. Department of Commerce's National Institute of Standards and Technology (NIST) funded a competitive grant program to establish new industry-driven consortia and to identify high-priority research challenges impeding the growth of advanced manufacturing in the U.S.
- NIST awarded DWEA, supported by eFormative Options and Wind Advisors Team, a 2-year grant in June 2014 to help U.S. distributed wind turbine manufacturers identify and prioritize actions to expand their global leadership.
- The SMART Wind Consortium has connected more than 120 collaborating organizations and 250 individual stakeholders to develop the SMART Wind Roadmap, identifying common short-term, mid-term and long-term R&D and manufacturing actions for distributed wind
- SMART Wind stakeholders prioritized all identified actions using an online ranking process in early 2016

AGGREGATED DISTRIBUTED WIND TURBINE INDUSTRY BILL OF MATERIALS

The SMART Wind Core Team convened a steering group of U.S. distributed wind turbine OEMs to ensure that project objectives aligned with their specific company needs.

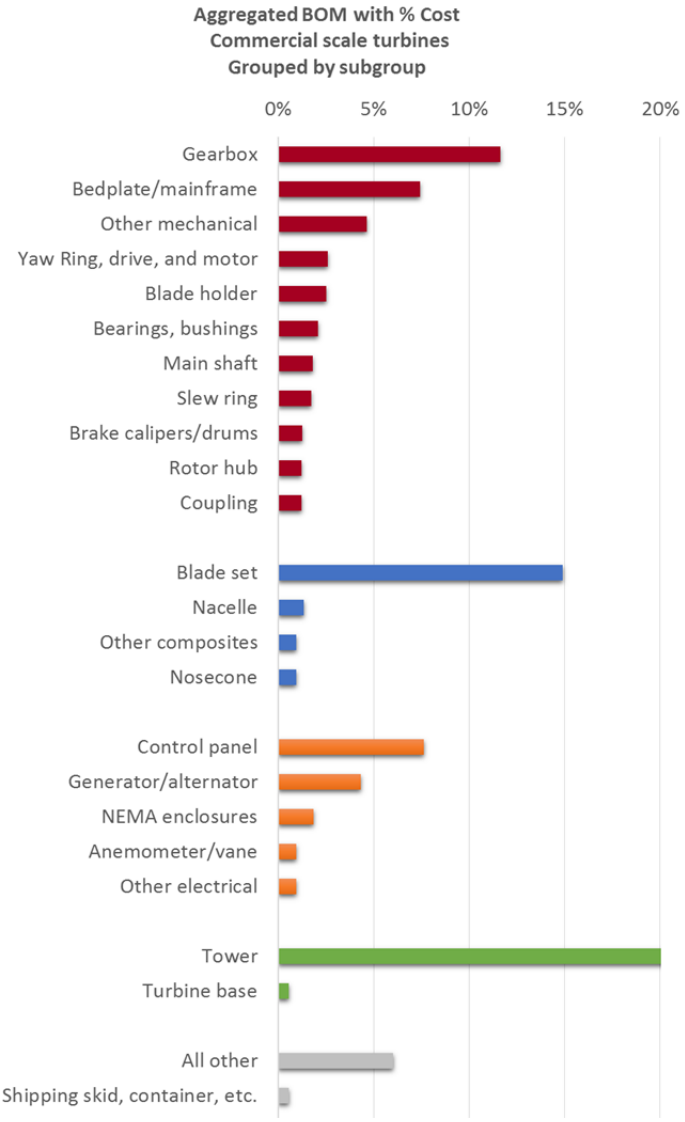
Each OEM Steering Group member was asked to provide a breakdown of its wind turbine top-level bill of materials (BOM) with a percentage of the total system costs for each component. These were aggregated and shown as representative BOMs for both micro/residential and commercial/mid-size sectors.

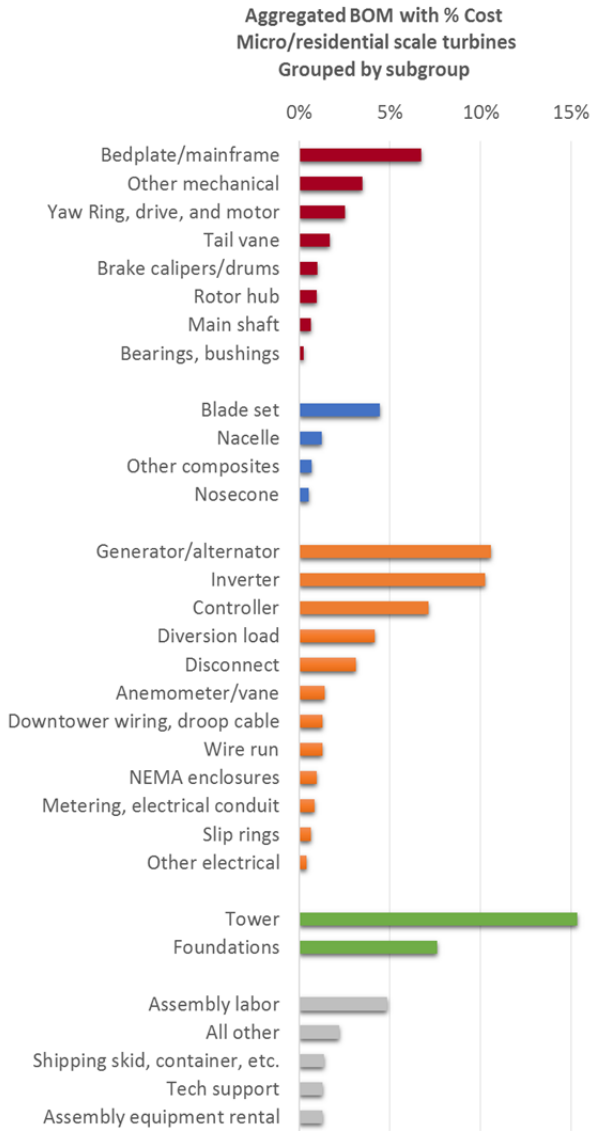
KEY POINTS ABOUT BOMS INCLUDE:

- For mechanical subsystems, the bedplate/mainframe is the most expensive; gearboxes were identified as the most expensive for the commercial sector
- Blades are the dominant focus for composites
- Under electrical subsystems, the control panel (for the commercial sector), generator/alternators, and inverters (for the micro/residential sector) are the top cost contributors
- For support structures and overall, the tower contributes significantly to system cost

OTHER MANUFACTURING POINTS

- Lean manufacturing and innovation engineering and other manufacturing improvement philosophies can be deployed to increase the competitiveness of distributed wind equipment manufacturers
- While some of the SMART Wind OEMs manufacture many of their own parts (including controllers, inverters, and wind turbine blades), most OEMs purchase the majority of parts and complete final assembly in-house
- The strategy for the distributed wind industry's continued growth is to increase manufacturing process improvements incrementally while addressing shifting production levels, taking individual steps that will reduce manufacturing costs but not become an undue financial burden
- While OEMs are learning about lean manufacturing, they can also develop new manufacturing processes around technologically enhanced wind turbines





TOP PRIORITY ACTIONS

At the launch meeting, SMART Wind participants identified what they hoped the project would accomplish. A universal theme confirmed the importance of developing long-term strategies and reducing the installed cost of distributed wind turbines, thereby improving industry global competitiveness. The table below shows the top priority actions selected out of more than 170 items ranked in an online poll by 80 respondents, including 16 OEMs, sorted by Subgroup and by the timeframe identified as appropriate for each, and as reviewed and approved by the SMART Wind OEM Steering Group.

	Short-Term (0-3 years)	Mid-Term (3-7 years)	Long-Term (7-10 years)
Electrical	• Develop a common core modular inverter; utilize wide bandgap materials • Apply variable-frequency drives (VFDs) • Incorporate micro-grids • Design and improve manufacturing processes of alternators/generators • Validate electrical design through component testing to standard and resiliency requirements • Address impact of LVRT/HVRT requirements • Collaborate with electric vehicle industry	• Leverage electromagnetic and thermal design capabilities at NREL • Integrate wind turbines into "Internet of Everything" • Leverage latest research results on new magnetic and capacitive components	• Research emerging/innovative power electronics • Encourage power electronics training at trade schools/universities
Composites	• Explore new efficient blade manufacturing materials, fixturing and tooling costs • Develop post-manufacturing non-destructive testing methods • Develop new blade design based on blade manufacturing technique • Develop blade that can be incorporated into multiple turbine designs	• Develop coatings and systems that resist erosion, icing, etc. • Develop better open-source blade design and structural analysis tools • Explore ways to monitor blade degradation • Explore modular space-frame blade design • Identify and apply advanced composites and new materials	• Develop tools that integrate production processes with blade design, performance analysis and tests • Develop a shared industry-wide materials database
Support Structures	• Develop new approaches to hot-dip galvanization • Explore a range of standard industry towers for economies of scale • Design cost-efficient foundations for a range of tower configurations and soil conditions • Refine TIA 222-G Addendum 4; develop an alternative or improve small wind addendum • Increase U.S. tower supply by adapting approaches used in utility and communications industry • Gather test data to validate turbine dynamic models • Design, build, and test a family of towers that could be used by several OEMs • Develop U.S. monopole tower supply • Develop tower certification strategy	• Model and explore use of slip-fit, tapered tower to address loads and dynamics • Understand tower dynamics and how other tower industries can address distributed wind industry needs • Develop turbine/tower design to ease O&M • Explore a standard industry tower with flange attachments • Investigate commercial viability of other anchoring systems • Develop common, pre-fabricated foundations for multiple OEMs • Investigate the functional and commercial viability of spread-leg foundations • Facilitate international forum on differing local requirements (soil/structural, other)	• Validate turbine and tower design for O&M procedures that maximize human safety • Investigate the use of composite towers
Mechanical	• Develop low-cost prognostic condition monitoring • Develop a supplier directory for wind turbine parts, components, and designers • Research advanced casting and mold manufacturing techniques; develop new competitive partnerships • Identify regional manufacturer expertise	• Research additive manufacturing for prototyping, molds, and real parts • Work with machining companies on manufacturability • Research materials, lubricants, and gear oil in cold climates • Monitor progress on mechanical innovations, e.g. intensive quench for gears	• Develop methods for accelerated life testing • Position industry as a test bed for utility-scale wind drive train concepts • Implement automation and robotics
Overall System/Industry	• Conduct a gap analysis for certification requirements for various global markets; educate and promote certification to maintain quality • Assess how changing turbine design impacts certification requirements • Explore new efficient manufacturing materials and processes • Refine FAST for full turbine dynamics and control • Address accuracy of performance modeling of distributed wind turbines • Provide public education and economic tools, especially refuting myths; permitting support	• Train installers for small wind O&M • Develop installation processes with an emphasis on safety and cost reduction • Encourage the development of common international requirements (e.g., U.S., U.K., Japan, building codes) • Develop a shared industry-wide reliability database	• Establish/support national zoning and interconnection rules • Encourage mentorship and outreach to increase and support workforce diversity • Monitor utility-scale wind technology development for distributed wind applications