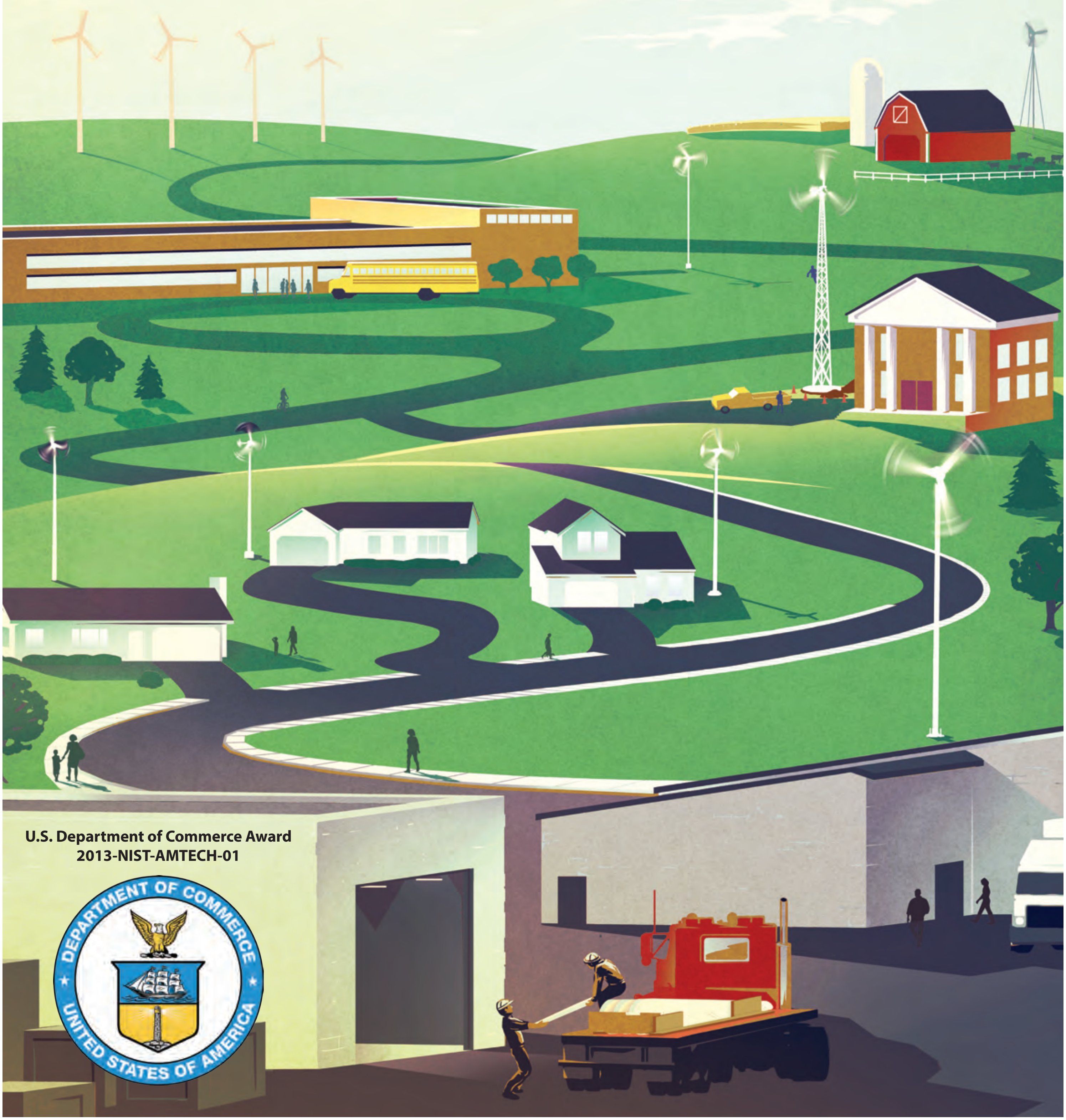
SMART Wind Roadmap

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

Abbreviations and Acronyms

AMTech	Advanced Manufacturing Technology
AWEA	American Wind Energy Association
BOM	bill of materials
CECET	Center for Evaluation of Clean Energy Technology
DWEA	Distributed Wind Energy Association
FAST	Fatigue, Aerodynamics, Structures, and Turbulence
FIT	feed-in tariff
GaN	gallium nitride
kW	kilowatt
GW	gigawatt
IACMI	Institute for Advanced Composites Manufacturing Innovation
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization for Standardization
LCOE	levelized cost of energy
MEP	NIST Manufacturing Extension Partnership
MW	megawatt
NIST	National Institute of Standards and Technology
NNMI	National Network for Manufacturing Innovation
NREL	National Renewable Energy Laboratory
NYSERDA	New York State Energy Research and Development Authority
OEM	original equipment manufacturer
PEIC	Power Electronics Industry Collaborative
PNNL	Pacific Northwest National Laboratory
SAMPE	Society for the Advancement of Material and Process Engineering
SiC	silicon carbide
SMART	Sustainable Manufacturing, Advanced Research and Technology
SNL	Sandia National Laboratories
SWCC	Small Wind Certification Council
TIA	Telecommunications Industry Association
UL	Underwriters Laboratories
U.S. DOE	U.S. Department of Energy
VFD	variable-frequency drive

Cover illustration designed by Ben Karis-Nix, www.benkn.com

SMART Wind Roadmap:

A Consensus-Based, Shared-Vision Sustainable Manufacturing, Advanced Research & Technology Action Plan for Distributed Wind

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May 2016

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

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Acknowledgments

DWEA wishes to thank Director Mike Molnar and Depurty Director Frank Gayle of the U.S. Department of Commerce National Institute of Standards and Technology (NIST) Advanced Manufacturing Office for providing funding to produce this Roadmap, along with our Project Manager Dr. Thomas Lettieri and Grants Specialists Elaine Nghiem and Eugene Ried for their guidance in launching the SMART Wind Consortium. The authors also thank team members who assisted with this Roadmap and supporters who provided valuable input and feedback on our NIST-Advanced Manufacturing Technology Consortia (AMTech) funding proposal: Matt Gagne and Kurt Sahl, eFormative Options; Mary Childress, DWEA Accountant and Financial Advisor; Lauren Glickman, WindyGlick Communications; Frank Marlowe and Robert Miller, Broadcast Wind; Lloyd Ritteer, Green Capitol, LLC; Karin Sinclair, National Renewable Energy Laboratory (NREL), which is funded by the U.S. Department of Energy (DOE) Wind and Water Power Technologies Office; Charles Newcomb, Endurance Wind Power; Mike Bergey, Bergey Windpower; Mick Sagrillo, Sagrillo Power & Light; Roger Dixon, Skylands Renewable Energy; and Roy Butler, Four Winds Renewable Energy.

The authors wish to thank the following for their help launching the Consortium and preparing this Roadmap: OEM Steering Group Members: Brian Kuhn, Aeronautica; Mike Bergey, Bergey Windpower; Bill Stein and Pat Quinlan, Black Island Turbines; Cris Somerville and Keith Monson, Dakota Turbines; Dr. David Laino and Charles Newcomb, Endurance Wind Power; Richard Legault, Martin Bissonette, Bouaziz Ait-Driss, and Claude Bourget, Eocycle; Diego Tebaldi and Chris McKay, Northern Power Systems; Ben Polito, Joshua Kauffman, Bill Hetzel, and Andrew Hickok, Pika Energy; Ken Portolese and Ken Kotalik, Primus Windpower; Tom Williams, Ventera Wind; John McCoury and Jay Yeager, Xzeres Wind Corp.; David Blittersdorf, AllEarth Renewables; Dr. Paul Migliore, AnemErgonics; Dr. Kyle Wetzel and Gary Kanaby, Wetzel Engineering. **SMART Wind Subgroup Leads - Mechanical**: Gary Harcourt, Great Rock Windpower; Dr. Patrick Lemieux, California Polytechnic State University; Robert Preus, NREL; **Electrical:** Dr. Ruth Douglas Miller, Kansas State University; Dr. Eduard Muljadi, NREL; Dr. Rob Wills, Intergrid; Dr. Greg Mowry, University of St. Thomas; **Composites:** Dr. Pier Marzocca, Clarkson University; Dr. Case van Dam, University of California-Davis; Paul Williamson, formerly with Maine Ocean & Wind Industry Initiative (MOWII); **Support Structures:** Roger Dixon, Skylands Renewable Energy; Dr. Rick Damiani, NREL; Gunes Demirbas, G-Tower; and other meeting participants listed in Appendix C. **Roadmap reviewers:** Bret Barker, advisor for distributed generation to the Wind Program at the U.S. DOE; Ian Baring-Gould, Dr. Eduard Muljadi, Robert Preus, and Dr. Suzanne Tegen, NREL; Alice Orrell and Nik Foster, Pacific Northwest National Laboratory (PNNL), which is funded by the U.S. DOE; Dr. Patrick LeMieux, Cal Poly; Gunes Demirbas, G-Tower; Dr. Rob Wills, Integrid; Joseph Spossey, Intertek; Dr. Jonathan Miles, James Madison University; David Wooley, Keyes, Fox & Wiedman; Dr. Ruth Douglas Miller; Kansas State University; Padma Kasthurirangan, Niagara Wind & Solar; Jim Duffy, Nixon Peabody LLP; Darrin Russell, formerly with Northern Power Systems; Mia Devine, Northwest Sustainable Energy for Economic Development; Dr. Pier Marzocca, RMIT/Clarkson University; Roger Dixon, Skylands Renewable Energy; Dr. Greg Mowry, St. Thomas University; Jay Yeager, Xzeres Wind Corp.

DWEA also thanks its Board members who have provided oversight for the SMART Wind NIST-AMTech grant project: Mike Bergey, Shawn Boudreau, Roger Dixon, Chris Diaz, Jim Duffy, Larry Flowers, Trudy Forsyth, Glenn Johnson, Wendy Langlais, Peter Mostow, Ben Polito, Heather Rhoads-Weaver, Haley Roberto, Kevin Schulte, Ryan Storke, Diego Tebaldi, Russell Tencer, and Mick Sagrillo.

DWEA thanks the following for speaking at Consortium events and virtual meetings: Dr. Frank Abdi, AlphaSTAR; Krent Aberle, Sherwin-Williams; Joe Banas, Hodge & Elyria Foundry, Inc.; Bret Barker, advisor for distributed generation to the Wind Program at the U.S. DOE; Bob Bechtold, Harbec Plastics; Tom Bell, Center for Economic Growth; Mike Bergey, Bergey Windpower; Derek Berry, NREL; Martin Bissonette, Eocycle; David Blittersdorf, AllEarth Renewables; Andy Bridge, Janicki Industries; Nick

Cannell, CAST Alloy Sales & Technology, Inc.; Dr. Xing Chen, Argonne National Laboratory; Dr. Rick Damiani, NREL; Gunes Demirbas, G-Tower; Roger Dixon, Skylands Renewable Energy; Dr. Ruth Douglas Miller and Dr. Asad Esmaeily, Kansas State University; Keith Evans, Kymatech; Ashley Hale, Kuntzsch Solutions; Gary Harcourt, Great Rock Windpower; Mark Higgins, U.S. DOE; D. DeWayne Howell, Peak Composites, Inc., SAMPE; Steve Huddle, University of Colorado-Denver; Michael Hudon, Intertek; Dr. Kerop Janoyan, Clarkson University; Jason Jonkman, NREL; Joshua Kauffman, Pika Energy; Dr. Keith Klontz, Advanced Motor Tech, LLC; Swad Komanduri, NextEnergy; Valeria La Saponara, University of California-Davis; Greg Lane, Low Volume Lean Center; Dr. Patrick Lemieux, Cal Poly; Dr. Thomas Lettieri, AMTech Program, NIST; Rick Lewandowski, Intertek, CECET; Ted Lynch, Strategic Marketing Innovations SAMPE; Dr. Pier Marzocca, Clarkson University; Dr. Paul Migliore, AnemErgonics; Jeff Minnema, Jeff Minnema Consulting; Dr. Greg Mowry, University of St. Thomas; Dr. Ed Muljadi, NREL; Dr. John Muth, NC State University; Dr. Brian Naughton, Sandia National Laboratories (SNL), which is funded by the U.S. DOE; Charles Newcomb, Endurance Windpower; Dr. Christopher Niezrecki, University of Massachusetts-Lowell; Stephen Nolet, TPI Composites; Tim Olsen, Advanced Energy Systems, LLC; Alice Orrell, PNNL; Joshua Paquette, SNL; Dr. Nathan Post, NREL; Robert Preus, NREL; Dr. Wei Qiao, University of Nebraska-Lincoln; Tara Rice, U.S. Department of Agriculture; Britton Rife, eFormative Options; Dr. Jacob Segil, University of Colorado; Jim Sims, Molycorp, Inc.; Scott Sklar, The Stella Group; Chris Storbeck, UL; Dr. Charles Sullivan, Dartmouth; Daniel Valyou, Clarkson University; Dr. Case van Dam, UC-Davis; Ben Vickery, NIST; Kelly Visconti, U.S. DOE; Dr. Qi Wang, NREL; Dr. Wenbin Yu, Purdue University; Dr. Kyle Wetzel, Wetzel Engineering; Paul Williamson, formerly with MOWII; Dr. Robert Wills, Intergrid; Dave Wixson, TMS Metalizing; Jay Yeager, Xzeres.

DWEA also thanks the following for providing letters supporting NIST funding proposals:
Industry members: Advanced Energy Systems; APRS World; Bregey Windpower; Chinook Wind; Dakota Turbines; Eaton; EWT B.V.; Endurance Wind Power; Ethos Distributed Solutions; Foundation Windpower; GBA Architects Engineers; G-Tower; Great Rock Windpower; Harbec Plastics; Harvest the World Network; Heartland Energy Solutions; Intergrid; Jeff Minnema Consulting; Juhl Energy; Keyes, Fox & Wiedman; Molded Fiber Glass Companies; Niagara Wind & Solar; Pika Energy; Rainbird; RightHand Engineering; Rohn Products; Sagrillo Power and Light; Skylands Renewable Energy; South Bay Risk Management; Sustainable Energy Developments; The Stella Group; TWN Wind Power; United Wind; Weaver Wind Energy; Wetzel Engineering/Wetzel Blade; WindAnalytics; and Windward Engineering.

Academia/National Laboratories/NGOs/Government: American Corn Growers Foundation; Advantage Kentucky Alliance, West Kentucky University Center for Research & Development; American Wind Energy Association; Appalachian State University-North Carolina Small Wind Initiative; Boise State University-Idaho Center for Advanced Energy Studies; Cal Poly; California Wind Energy Association; Cape & Islands Self-Reliance; Clean Energy States Alliance; Colorado State University; Illinois State University-Center for Renewable Energy; Intertek; Impact Washington; Iowa Wind Energy Association; Kansas State University-Civil Engineering and Electrical Engineering Departments; Long Island Power Authority; Manex; Minnesota Department of Commerce; NREL; NC Solar Center, North Carolina State University; Northern Arizona University Institute for Sustainable Energy Systems; Northwestern University; NW Sustainable Energy for Economic Development; PNNL; Pennsylvania State University; SNL; Small Wind Certification Council; Underwriters Laboratories; University of Maine-Advanced Structures and Composites Center; University of Nebraska-Nebraska Center for Energy Sciences; University of Northern Iowa-Center for Energy and Environmental Education and Sustainable Wind Energy and Environment Team; University of Oklahoma; Vermont Manufacturing Extension Center; Virginia Center for Wind Energy at James Madison University; Washington State Department of Commerce; West Texas A&M University; Western Illinois University-Wind Energy Program; WindSTAR Industry/University Cooperative Research Center, University of Massachusetts Lowell; and Windustry.

Foreword: SMART Wind Roadmap to Reach DWEA Vision

Americans have a strong desire to increase development of solar and wind resources (Center for American Progress 2016; CleanEdge 2015; Gallup 2015). Distributed wind is well positioned to help meet this demand as a rising star of American clean energy solutions.

Distributed wind energy systems offer clean and reliable “behind-the-meter” electricity generation in a wide variety of settings, including households, schools, farms, ranches, businesses, towns, communities, and remote locations. Distributed wind offsets local energy consumption near the point of end use (avoiding transmission system expansion), promotes more energy choices for Americans, and has substantial potential to increase private sector energy investment.

Distributed wind markets are primarily in rural and commercial areas with adequate space – an acre or larger lots. Customers typically want to reduce their utility bills and their exposure to rising electric rates. By the time they install wind energy systems, most have already invested in energy conservation to reduce their consumption. A wind turbine is their latest and largest investment in energy security.

The Distributed Wind Energy Association (DWEA) “30 GW by 2030” vision sets a goal of growing from 1 gigawatt (GW) in 2015 to 30 GW, or 30,000 megawatts (MW), of distributed wind capacity in the U.S. by 2030. By 2030, the distributed wind industry aims to reach annual revenues of $12.7 billion, employing over 150,000 people across America, and generating pollution-free electricity to power more than 5.8 million homes (DWEA 2015). DWEA believes that with the appropriate policy leadership it will take to achieve this growth, U.S. domestic content of distributed wind turbines in 2030 could exceed 80% of total installed costs.

DWEA has led this collaborative Sustainable Manufacturing, Advanced Research & Technology (SMART) Wind Roadmap development through our newly formed industry-academic Consortium to improve American distributed wind global competitiveness with shared-vision strategies for advanced research and technology. The project’s overall vision, to aid distributed wind industry growth and advance innovative manufacturing techniques by increasing production volumes and reducing lifecycle costs while maintaining high quality, dovetails nicely with DWEA’s primary mission and fundamental goals.

In order to achieve 30 GW of distributed wind by 2030, the industry will need to unite through advanced technology and a common policy platform, with the following Roadmap leading the way. Join us in taking the actions outlined below to help ramp up distributed wind’s contribution to American jobs and local clean energy.

Jennifer Jenkins, DWEA Executive Director

SMART Wind Roadmap:
A Consensus-Based, Shared-Vision Sustainable Manufacturing, Advanced Research & Technology Action Plan for Distributed Wind

Executive Summary

The distributed wind industry stands dedicated to advancing technology, lowering manufacturing costs, and providing a competitive electricity generation source for the U.S. to rely on for energy independence and expanded manufacturing opportunities. The Distributed Wind Energy Association (DWEA) has convened the targeted SMART Wind Consortium to develop a consensus-based, shared-vision Roadmap that identifies common distributed wind research and manufacturing gaps and barriers, prioritizes solutions to those gaps for today and for future scalability, and facilitates a rapid transfer of innovation into American-manufactured wind turbines. This initiative aims to open up new market opportunities and expand the number of distributed wind applications, thereby maintaining U.S. global competitiveness and leadership.

The SMART Wind Consortium identified and prioritized more than 170 potential action steps in the following priority-ranked areas:

1) Optimize and harmonize wind turbine designs to improve levelized cost of energy (LCOE) and achieve parity with U.S. retail electricity rates in more markets
2) Improve manufacturing parts, materials, and processes including incorporating lean manufacturing practices
3) Optimize standards and certification to enable technology evolution and maintain quality
4) Streamline installation and maintenance of wind turbine system
5) Sustain SMART Wind Consortium activities and partnerships

The SMART Wind Consortium's top priority action steps to address key gaps, barriers and opportunities include:

- Electrical Subsystems
    - Develop a common core modular inverter; utilize wide bandgap materials (advanced semiconductors)
    - 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 smart grid/resiliency requirements
    - Address impact of low voltage ride-through and high voltage ride-through requirements on induction machines
- Composites
    - Explore new efficient blade manufacturing materials, fixturing and tooling costs
    - Develop post-manufacturing non-destructive testing methods

- 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 the addendum for small wind turbines[1]
- Mechanical
  - Develop low-cost prognostic condition monitoring to provide a feedback loop on field performance to original equipment manufacturers (OEMs)
  - Develop a supplier directory for wind turbine parts, components, and designers
  - Research advanced casting and mold manufacturing techniques; develop new competitive partnerships
- Turbine System
  - 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
  - Encourage the development of common international requirements (e.g., U.S., U.K., Japan, building codes)
  - Explore new efficient manufacturing materials and processes
  - Improve/simplify the process for turbine re-certification
  - Educate developing markets on certification

These prioritized action steps will help fulfill the project's overall vision of aiding distributed wind industry growth and advancing innovative manufacturing techniques by increasing production volumes and reducing lifecycle costs while maintaining high quality. A follow-up study to understand the costs and quantifiable benefits of each of the priority actions identified could help maintain project momentum and further advance the goals of the SMART Wind Consortium. A thorough understanding of turbine reliability, lifetime, and O&M is needed to improve cost certainty, activate financiers, and stimulate new markets using different financial models, similar to utility-scale wind and solar markets.

Through the SMART Wind roadmapping process, dozens of additional actions were identified and evaluated. As reviewed and approved by the SMART Wind OEM Steering Group, the top ranked items are consistent with the high-priority R&D needs that Consortium members initially identified (listed in Section 2.2.2), confirming solid industry consensus.

As developing and industrialized nations seek strategies to address climate and economic challenges, the U.S. distributed wind industry is eager to provide cost-effective clean energy

[1] Telecommunications Industry Association (TIA) Engineering Committee TR-14 has developed an addendum for Small Wind Turbine Support Structures to Steel Antenna Tower Standard TIA-222. Small/residential wind turbines are typically grid-connected up to 20 kW; small/commercial wind turbines are typically 21 to 100 kW; and wind turbines above 100 kW are considered "mid-size." Off-grid wind turbines are generally considered "micro-wind" and sized less than 1 kW.

solutions and claim its share of the rapidly growing global distributed generation market. Maintaining their position as leading manufacturers and exporters of high-quality, reliable distributed wind turbines and improving competitiveness through advances in manufacturing technology will enable U.S. companies to thrive in a growing international market, with high payoffs in the form of increased employment and manufacturing output.

In contrast to large-scale centralized wind farms that feed power to the utility grid, distributed wind provides power directly near the end use or to support grid operations. Distributed wind turbines can be connected on the customer side of electric meters or to distribution or micro-grids, or the smaller wind turbines can supply power to off-grid applications. Due to its dispersed nature, distributed wind's technical challenges are substantial and distinct from those of utility wind. Utility-scale wind turbines have increased in size over the past decades and become more cost-effective in part due to increased investments in R&D. Many of those cost-effective concepts may be relevant and applicable for distributed wind technology.

Section 1 provides background on the importance of this Roadmap and an overview of SMART Wind Consortium participants and DWEA's sustainability plan. Section 2 provides an overview of the state of the distributed wind industry and market opportunities, including the expected impact of SMART Wind actions on the market. The major technology and manufacturing actions are discussed in Section 3 along with the complete list of actions identified as a unified plan to address industry barriers. Section 4 describes research and partnering opportunities. The key recommendations and next steps are reviewed in Section 5.

Key references and resources, including company-specific baselines and benchmarks, meeting agendas with links to presentation materials and recordings, and a directory of consortium participants, are included as appendices.

DWEA's SMART Wind Consortium seeks to support long-term industrial research[2] by creating this Roadmap for the next generation of technologies and transformational innovations needed in the distributed wind energy sector. Applying improved manufacturing techniques identified by the Consortium will lower installed turbine cost while maintaining higher product reliability, resulting in more competitive systems and greater market share for U.S. manufacturers. This will accelerate deployment of U.S. technology, helping to generate clean, renewable energy; increase employment in the sector; and bolster capabilities of this U.S.-led industry.

[2] The planned research or critical investigation performed by or for business aimed at the acquisition of new knowledge and skills for developing new products, processes or services or for bringing about a significant improvement in existing products, processes or services.

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1 Introduction

The U.S. distributed wind industry is poised for rapid growth with domestic installations and exports. Other distributed wind turbine markets, particularly grid-connected markets with 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. Without continued investments, American-made products will lose their global competitive advantage.

In 2013, the U.S. Department of Commerce's National Institute of Standards and Technology (NIST) launched the Advanced Manufacturing Technology (AMTech) Consortia, a "competitive grants program intended to establish new or strengthen existing industry-driven consortia that address high-priority research challenges impeding the growth of advanced manufacturing in the United States." In May 2014, NIST awarded DWEA, supported by eFormative Options and Wind Advisors Team, a 2-year AMTech grant to help manufacturers in the U.S. distributed wind turbine industry maintain their global leadership.

1.1 SMART Wind Consortium Project Vision

The NIST funding allowed the DWEA team to convene the Sustainable Manufacturing, Advanced Research & Technology (SMART) Wind Consortium, a first-of-its-kind targeted effort to form an industry-driven consortium of distributed wind turbine and component original equipment manufacturers (OEMs), academic researchers, NIST AMTech experts, representatives from federal laboratories, and stakeholders throughout the entire supply chain. The Consortium vision is to aid distributed wind industry growth and adoption of innovative manufacturing techniques, increasing production volumes and reducing costs throughout the technology lifecycle while maintaining high product quality and value, thereby sustaining U.S. global competitiveness and leadership, opening up new market opportunities, and expanding the number of distributed wind applications.

As a final product, SMART Wind Consortium leaders developed this consensus-based, shared-vision Roadmap that captures the feedback from industry stakeholders to help move the U.S. distributed wind industry into a more globally competitive stance. The document identifies common distributed wind research and manufacturing gaps and barriers. In early 2016, stakeholders prioritized all identified actions using an online ranking process. The following sections describe the SMART Wind Consortium organization and Roadmap design in more detail.

1.2 SMART Wind Consortium Overview

As shown in Figure 1-1, the SMART Wind Consortium is led by Core Team members:

- DWEA: Executive Director Jennifer Jenkins, providing project oversight
- eFormative Options: Heather Rhoads-Weaver and her team, providing project management oversight and reporting
- Wind Advisors Team: Trudy Forsyth and her team, providing technical leadership, facilitation of project meetings, and Roadmap development
- Summerville Wind and Sun: Brent Summerville, providing technical project co-leadership

U.S. distributed wind OEMs and other stakeholders participating in the SMART Wind Consortium were organized into four Subgroups based on common manufacturing techniques: mechanical and electrical subsystems, support structures, and composites. Industry experts served as Consortium Subgroup leaders to guide Subgroup progress and facilitate discussion and collaboration. Consortium members signed up for one or more Subgroups to participate in detailed dialogue and structured technical and process brainstorming during face-to-face and virtual meetings to discuss gaps and barriers and actions needed to address them.

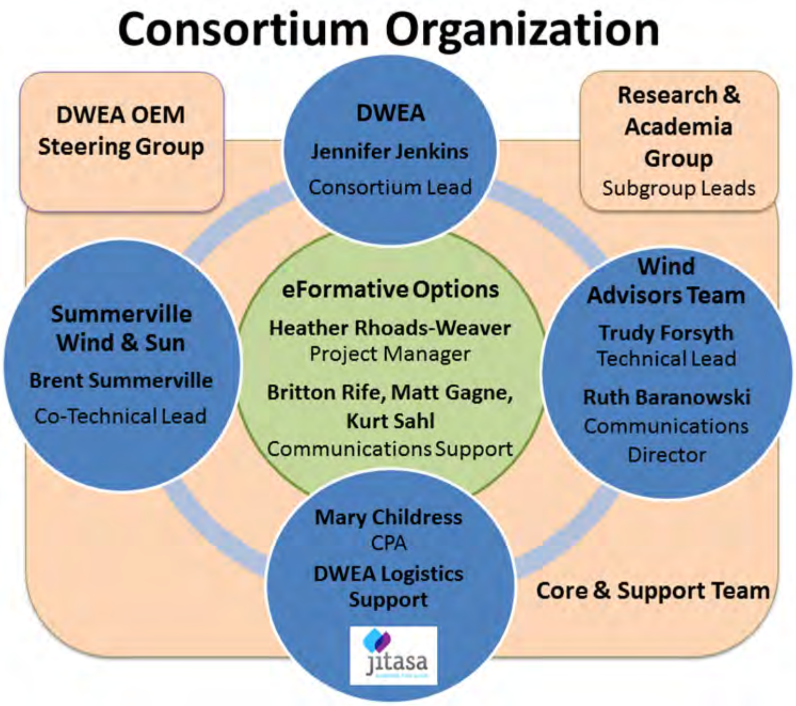

Figure 1-1. SMART Wind Consortium organization

The SMART Wind Consortium hosted seven face-to-face meetings from October 2014 to February 2016: a launch meeting, four Subgroup kick-off meetings, a Manufacturing Forum, and a final Roadmap meeting. At the beginning of the project, participants identified what they hoped the project would accomplish. A universal theme confirmed the importance of developing a long-term strategy for the distributed wind industry and reducing the installed cost of distributed wind turbines, thereby improving industry competitiveness and encouraging more people to install wind turbines.

Participants identified industry goals of:

- Empowering manufacturers with more knowledge about technical and manufacturing opportunities by:
    - Expanding the supply chain by connecting stakeholders (including OEMs, U.S. component suppliers, wind turbine researchers) with potential new supply chain vendors
    - Initiating a standing industry consortium with a wide variety of stakeholders to build good working relationships among stakeholders and foster future partnership opportunities
    - Presenting the latest major technological and related barriers that inhibit the growth of advanced distributed wind manufacturing and reaching consensus on advanced manufacturing opportunities
- Bringing the latest research/education and state-of-the-art technology to manufacturers, highlighting new technology that is near-term commercial
- Engaging the U.S. Department of Commerce and U.S. Department of Energy (DOE) in discussions of needed industry improvements and actions
- Developing a more reliable product over its lifecycle with lower cost-of-goods-sold and lower costs of installation, operation, and maintenance; facilitating safe installations and practices

- Improving turbine reliability and testing
- Allowing OEMs to cooperate and co-design system components
- Improving U.S. manufacturing capabilities in selected areas (incorporating NIST's National Network for Manufacturing Innovation[3])
- Bringing products made overseas back to being made in America
- Investigating new materials and new ways to manufacture

During an early Consortium meeting, participants discussed the project's two major, somewhat competing objectives of reducing component costs and encouraging technology development in the U.S. Bringing back manufacturing from overseas, even at a slight cost increase, is advantageous for maintaining U.S. leadership in the sector.

The Subgroups reviewed the common parts comprising different wind turbine systems and components and discussed ways in which multiple manufacturers could use the same parts, thereby increasing volume production and reducing costs.

Consortium participants agreed on the need for cost reduction targets and the importance of manufacturing in the U.S. Cost reduction for certain lighter weight materials like fiberglass may not be possible, and lower labor and manufacturing costs in Asia more than offset the cost of shipping compared to domestic manufacturing costs. Even though there is a preference for parts "made in America," honoring this preference presents a challenge in terms of retaining and reintroducing manufacturing in the U.S. while simultaneously striving to reduce costs. By automating processes to reduce labor costs, U.S. manufacturers can become more competitive. And even though funding for tool development is a tough sell for investors, U.S. manufacturers have found success in investing in additional tooling such as plastic injection mold development for wind turbine blade production and robotic welding equipment.

In combining the efforts of each company, participant, expert, and leader in the industry, the Consortium established a pledge from the industry to move forward. This document outlines this commitment and the goals to maintain the current dominance of U.S. manufacturing in the distributed wind sector. The distributed wind industry is dedicated to advancing technology, lowering manufacturing costs, and being a competitive source of energy for the U.S. to rely on for energy independence.

1.2.1 Consortium Formation, Domestic Content

The approach for forming the SMART Wind Consortium involved identifying U.S. OEMs that are currently producing distributed wind turbines and startups seeking to manufacture distributed wind turbines and components; universities and laboratory researchers with the latest technology innovation and manufacturing approaches; and other industry stakeholders.

Members of the four Consortium Subgroups attended face-to-face and virtual meetings from June 2014 through November 2015. Each of these Consortium Subgroups included academic researchers, U.S. distributed wind OEMs, U.S. component manufacturers, and manufacturing experts. The goal of the meetings was to become acquainted with the interested stakeholders and to brainstorm possible cost-reducing strategies that will lead to evolutionary product and manufacturing improvements.

[3] https://www.manufacturing.gov/nnmi/

At the launch meeting on October 16, 2014, in Albany, New York, the project scope, structure, and participants were identified. All U.S. companies, manufacturing experts, national laboratories, and universities were invited to attend and participate.

Consortium meetings accomplished the following goals:

- Brought together U.S. distributed wind turbine and component manufacturers with academic experts to identify new wind turbine component and system design opportunities that can be explored before streamlining wind turbine production
- Leveraged industry-academic research results to develop strategies to aid distributed wind industry growth through U.S. advanced manufacturing techniques
- Encouraged stakeholder dialogue to identify new opportunities for future partnerships that are specific for distributed wind turbines

1.2.2 OEM Steering Group and Foreign Participation Policy

A SMART Wind OEM Steering Group comprised of the industry's leading wind turbine manufacturers and component suppliers (profiled in Appendix C-2) focuses and strengthens the Consortium's objectives and efforts by identifying technical and manufacturing gaps, providing baseline and benchmark data, and offering guidance on the SMART Wind project.

DWEA targeted U.S. OEMs and academics to partner in the Consortium but was open to considering participation of non-U.S.-headquartered OEMs that are both DWEA members and have substantial U.S. domestic content (at least 40% of total installed costs with a goal of increasing above 60% through the project) to help open new opportunities and markets for U.S. component suppliers and installation and maintenance personnel.

Leading U.S.-based small wind turbine manufacturers have continued favoring U.S. supply chain vendors for most of their turbine components, ensuring more time-responsive suppliers and high-quality components, and maintaining domestic content levels of up to 85% (U.S. DOE 2015a). While more than 90% of small wind turbines installed in the U.S. in recent years were built in the U.S., the industry's challenge is to maintain its high level of American manufacturing and prevent following the path of solar modules, which are now more than 85% imported.

For most suppliers, U.S. content varies depending on the location of the system (within or outside the U.S.) since shipping, installation, commissioning, dealer/developer margins, and other soft costs represent a significant portion of the total installed costs seen by the end customer. DWEA is primarily concerned with domestic content of systems installed in the U.S. but would also like to see more parts sourced from the U.S. for projects installed overseas.

In considering national policies where a parent company is incorporated, in order to serve on the project's Steering Group, a foreign-owned company was required to demonstrate that its participation is in the economic interest of the U.S., including evidence that the foreign parent country provides U.S.-owned companies: 1) opportunities comparable to those provided to any other company to participate in programs similar to NIST's AMTech; 2) local investment opportunities in the foreign parent country comparable to those provided to any other company; and 3) adequate and effective protection of intellectual property rights.

1.3 Breakdown of Consortium Participants and Backgrounds

The SMART Wind Consortium has connected more than 120 collaborating companies and organizations and more than 250 individual stakeholders to form consensus on actions needed to increase cost competitiveness through the use of advanced manufacturing techniques. Shown in

Figure 1-2, SMART Wind collaborators include 25 OEMs and more than 50 other vendors and industry supply chain members; 4 federal laboratories and 30 academic stakeholders; and nearly 20 nonprofit organizations, government representatives and other stakeholders located in 33 states. By region, Consortium participants include 36 stakeholders in the Northeast; 34 in the Midwest; 16 in the Southeast; 37 in the West; and 5 international stakeholders.

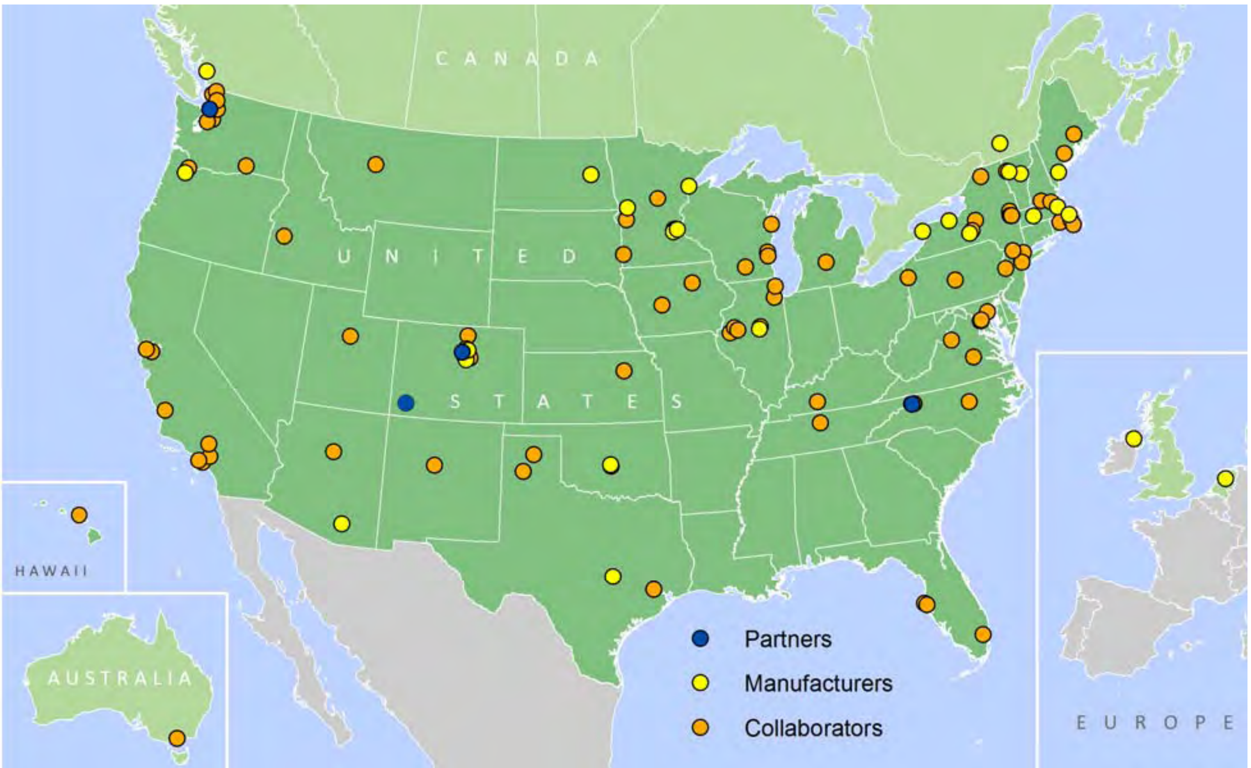

Figure 1-2. SMART Wind Consortium participants

1.4 SMART Wind Consortium Subgroups

Each SMART Wind Subgroup focused on specific aspects of wind turbine system designs, mechanics, and functions. As shown in Figure 1-3 and described further in the following sections, mechanical subsystems include the rotor, hub, main shaft, mainframe, rotor connection to generator, generator support, overspeed control/yaw mechanism (i.e., pitching, furling, yawing), tower top/bed plate, and tower adapter. Support structures include tower, bolts, foundation, rebar, guy wires, guy clamps, ground anchors, and lifting devices for tilt-down towers. Composite subsystems include anything using fiber-reinforced or carbon resins, including blades, nose cones, and nacelles. Electrical subsystems include generators, power electronics, and balance of system electrical components (all the way up to the electrical service: transformer, bus bars, slip rings, etc.).

1.4.1 Mechanical Subsystems

Distributed wind turbine mechanical components such as mainframes and shafts are typically fabricated parts and have great potential to benefit from innovative advances in manufacturing methods, processes, and systems. Mechanical systems range from bearings and gearboxes to complex blade pitching or furling systems and encompass myriad subcomponents and assemblies. In some cases, components are manufactured in-house while others are sourced from a diverse supply chain of vendors. Subgroup members discussed in-house strategies as well as efforts to reduce manufacturing gaps of suppliers to reduce costs and component price.

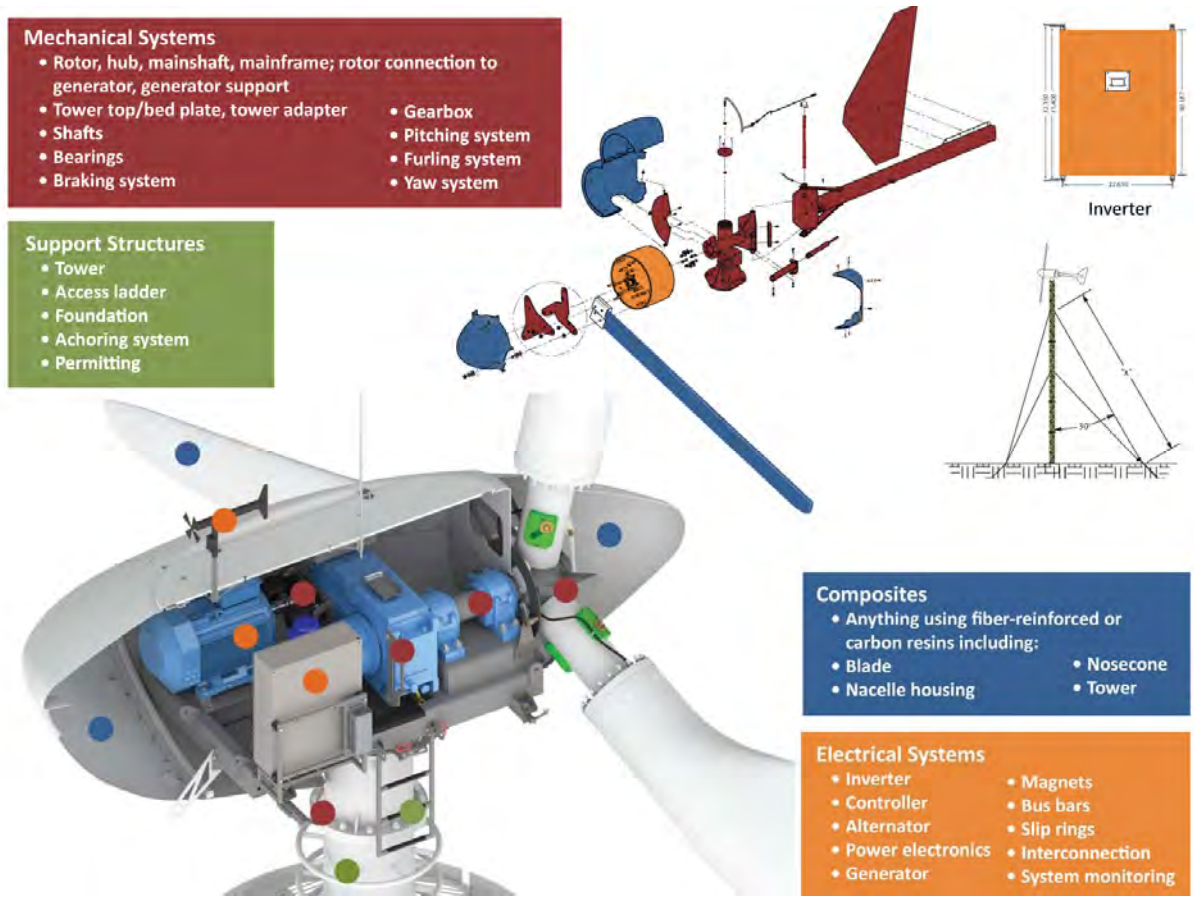

Figure 1-3. SMART Wind Subgroups breakdown

The Mechanical Subgroup met November 12-14, 2014, in Denver, Colorado (Figure 1-4). Subgroup leaders Dr. Patrick Lemieux, Cal Poly; Gary Harcourt, Great Rock Wind Power; and Robert Preus, National Renewable Energy Laboratory (NREL) gave presentations and led discussions on turbine design methods, FAST modeling, casting techniques, and 3-D printing.

Figure 1-4. Mechanical Systems Subgroup Kickoff Meeting (November 2014)

Recognizing that low-volume manufacturing is challenging, U.S. manufacturers expressed interest in improving castings, reducing labor and part costs, being flexible in manufacturing, and evolving designs to be more efficiently manufactured. Collaboration within the diverse SMART Wind Consortium has encouraged mechanical system suppliers and installers to learn about, adopt and implement lean principles, lean systems thinking, innovation engineering, and more advanced manufacturing concepts.

1.4.2 Support Structures

Tall towers help improve wind turbine performance since wind speeds increase with height and turbulence decreases with height. However, tower and foundation system design (including hardware, transportation, and installation considerations) are significant cost drivers for distributed wind technology, with self-supporting monopole towers accounting for as much as 50% of total installed costs for small wind turbines. Small wind systems are typically installed on 60- to 140-foot (18-43 m) towers. More installations would use towers in the 120- to 180-foot (37-55 m) range if the cost of towers and their installation could be reduced. A new generation of innovative, rapidly installed, self-supporting tall monopole systems or other novel low-cost, tall-tower concepts could significantly improve economics and increase distributed wind deployment.

The Support Structures Subgroup met January 13-14, 2015 in Golden, Colorado (Figure 1-5). Subgroup leaders Dr. Rick Damiani, NREL; Roger Dixon, Skylands Renewable Energy; and Gunes Demirbas, G-Tower gave presentations and led discussions on tower and foundation types, streamlining of foundations and safe installation practices, tower/foundation gaps and needs, support structure design optimization, tower design cost and material advances, support structure coatings, tower manufacturers, and foundation and anchoring systems.

Figure 1-5. Support Structures Subgroup Kickoff Meeting (January 2015)

The Support Structure meetings spurred industry collaboration to explore options for a family of tower designs that are not proprietary to either turbine or tower manufacturers. Deploying such a vision will decrease costs, including shipping, by utilizing local tower manufacturers in all parts of the country. Typical foundations are comprised of a substantial amount of concrete and rebar. Innovations in power-installed screw anchors as an alternative to concrete foundations have the potential to reduce distributed wind installation costs, decrease installation time, and utilize U.S.-manufactured products. This NIST-funded project brought the industry and academic researchers together to explore such ideas and Roadmap pathways for deployment.

1.4.3 Composite Subsystems

Modern wind turbines typically have three fiber-reinforced plastic rotor blades molded from e-glass and polyester resin. The rotor blades experience high peak loads and extremely high fatigue cycle counts, so their structural design is demanding. They must be protected from UV and leading-edge erosion at the tip. Carbon fiber is sometimes used to increase stiffness but is generally unaffordable in this application. Resin transfer molding is commonly used on smaller wind turbine blades, while hand lay-up with vacuum-infusion is preferred for larger distributed wind turbine blades.

Figure 1-6. Composites Subgroup Kickoff Meeting (February 2015)

The Composites Subgroup met February 16-18, 2015, in Boulder, Colorado (Figure 1-6). Subgroup leaders Dr. Pier Marzocca of Clarkson University, Dr. Case van Dam of University of California-Davis, and Paul Williamson, formerly of Maine Ocean and Wind Industry Initiative, gave presentations and led discussions on composites gaps and needs, OEM needs, possible partners, composite/blade research summary, blade design, structural blade testing, and tooling and coatings. The Composites Subgroup collaboration provided a link between industry needs for innovative rotor blade manufacturing solutions and university-based research efforts. To increase capacity factors and lower LCOEs, small wind turbine blades must become longer and stiffer. The advent of lower-cost pre-impregnated carbon fiber fabrics may allow for longer blades while also managing the cost of new materials. Thermoplastic and thermoset polyurethane resins can assist the design of more efficient structures with lower manufacturing costs. Solid polyurethane foam cores hold potential because they significantly increase stiffness without adding weight. Initial tooling costs can be significant and thus are a concern to distributed wind OEMs, so not all emerging composite fabrication materials techniques would be feasible at all wind turbine sizes and volume scales.

1.4.4 Electrical Subsystems

Many distributed wind turbines employ purpose-built direct-drive permanent magnet alternators using rare-earth magnets. Due to a recent global spike in rare-earth prices and dominance by Chinese suppliers, alternator designers have sought alternative technologies and magnet grades. This design shift is an opportune time for industry collaboration on a sustainable path forward for next-generation alternator designs. Most alternators are radial-flux machines with copper coils placed in lamination stacks of silicon steel stampings. Lamination costs can be reduced with very large stampings, armature costs can be reduced with automated coiling and placement machines, and assembly costs can be reduced with automated balancing. Identifying and prioritizing such opportunities through SMART Wind has encouraged efforts to advance solutions for reducing distributed wind turbine alternator costs.

Figure 1-7. Electrical Subgroup Kickoff Meeting (March 2015)

The Electrical Subgroup met March 25-26, 2015 in Washington, DC (Figure 1-7). Subgroup leaders Dr. Ruth Douglas Miller, Kansas State University; Dr. Greg Mowry, University of St. Thomas School of Engineering; Dr. Ed Muljadi, NREL; and Dr. Rob Wills, Intergrid Consulting, LLC presented and led discussions on the future of the grid, smart grids and distributed wind, the latest research in permanent magnet alternators, rare-earth magnets, opportunities in alternator design and manufacturing, coil winding, electrical safety and standards, energy storage, and power electronics.

The Electrical Subgroup discussed the harsh and demanding distributed wind energy environments and the need for field serviceable, rugged control hardware that can maintain reliability. Only a few U.S. OEMs offer wind-specific inverters; most inverters on the market today are adaptations from solar technology. Participants identified a need for a high-reliability, high efficiency, general-purpose inverter that also has diversion load capability to serve micro-grid and off-grid markets. In the near future, distributed wind turbine electronics will be expected to participate in evolving markets and grid technologies such as CO_2 trading where information and data may become as invaluable as kilowatt-hours.

New materials such as silicon nitride field effect transistors and nano-magnetic materials could improve efficiency. The cost of copper is expected to continue to rise, pushing medium wind to higher voltage alternators, 1,000 volt-plus inverters, and medium voltage utility connections. Considerable progress has been made developing direct-to-medium voltage inverters for use in solar technologies, which can now be applied to distributed wind. Delivering reliability and appropriate functionality at a competitive price is the challenge for suppliers of inverters and power conditioners. SMART Wind collaboration has identified technical opportunities for breakthroughs.

1.5 Sustainability Plan

DWEA recognizes that the collaboration fostered by the SMART Wind Consortium has value and should continue beyond the initial 2-year NIST funding period. Creating a Roadmap for future industry success is just a first step, and its implementation and ongoing prioritization of actions are equally vital. Moreover, economic, technical, and political environments can change rapidly, and the Roadmap will need to be updated to reflect those changes. While U.S. DOE support will likely be available to fund additional company-specific R&D under the Distributed Wind Energy Competitiveness Improvement Project (U.S. DOE 2015b) and other DWEA recommendations, SMART Wind leaders expect to seek follow-on funding through NIST and others for priority Roadmap actions.

DWEA is committed to extending the SMART Wind program past May 2016 and will ensure progress in implementing priorities identified and coordinating technology improvements, vision, and strategy after the NIST-AMTech planning grant ends. SMART Wind leaders will develop plans for periodic Roadmap updates, including data acquisition and aggregation, and maintain engagement of the SMART Wind OEM Steering Group and other participants.

2 State of Distributed Wind Industry and Market Opportunities

Distributed wind turbines are demonstrating the strong capabilities of American technology and manufacturing, providing affordable clean energy and supporting long-term sustainable jobs. While the U.S. market potential continues to be pursued, exports account for nearly 80% of the value of U.S.-based manufacturers' sales.

2.1 Why Distributed Wind?

The sheer number of sites with enough space and a productive wind resource has enabled distributed wind applications to contribute to the national energy infrastructure at the gigawatt (GW) scale.[4] DWEA recently published a Vision document outlining strategies to reach 30 GW of distributed wind in the U.S. by 2030 (DWEA 2015). Installed primarily where people live and work, distributed wind turbines are often the public's first exposure to wind energy and can help pave the way for additional wind installations.

Being connected "behind the meter" at a home, farm, business, or facility means that the wind turbine's output serves primarily to reduce the amount of electricity purchased from the utility company. Distributed wind also includes off-grid applications for battery charging; remote homes, cabins, and facilities; telecommunications; village power; and electrical-type water pumping. These applications account for a significant percentage of export sales, as the largest markets for off-grid wind systems are overseas. Foreign assistance and military applications are other examples of distributed wind's diverse market potential.

Along with the widely-recognized environmental, security, and price stability benefits shared by all clean energy technologies, distributed wind has a particularly attractive and unique benefit: it's made in America. Distributed wind has one of the highest domestic manufacturing content levels of any renewable energy technology. Providing added value of resource diversity and visibility promoting consumer awareness, distributed wind is an important part of the renaissance in

[4] Distributed wind cumulative capacity reached a total of 934 MW from over 75,000 wind turbines at 2015 year end (AWEA 2016).

domestic manufacturing. The industry already employs thousands of people from Maine to California, and it has very significant economic development potential in the years ahead.

U.S. manufacturers have been global leaders in distributed wind for decades and have a reputation for producing high-quality products, with numerous American small wind turbine designs replicated overseas. DWEA's 2030 Vision and the actions identified in this Roadmap will help reinvigorate American manufacturing with a resurgence of domestic clean energy jobs. The priorities align closely with Advanced Manufacturing Executive Actions to strengthen U.S. advanced manufacturing, spur innovation, and create new U.S. jobs and investment by enabling innovation, securing the talent pipeline, and improving the business climate (The White House 2014).

2.2 Where Are We Today?

The SMART Wind Core Team (described in Section 1.2) convened a steering group of U.S. distributed wind turbine OEMs in Fall 2014 to document industry baselines (public data specific to each OEM) and benchmarks (aggregated data) through questionnaires and interviews. After reviewing responses to an online questionnaire, the Core Team conducted one-on-one interviews with OEMs. The Technical Leads and OEMs discussed past roadmapping efforts (AWEA 2002), the purpose and importance of this project, and the distinction between public baseline and consolidated benchmark information. Responses are included in Appendix C-1.

2.2.1 Baselines

2.2.1.1 OEM and Turbine Information

Exploded diagrams of wind turbine components and photographs of manufacturing facilities provided by OEM Steering Group members helped guide the initial SMART Wind conversations and discussions to focus on specific components and sub-assemblies and identify near-term technology and manufacturing gaps. The core team also requested photos of the manufacturing process to gain an understanding of the existing processes. Figures 2-1 and 2-2 provide examples of the diagrams and photos submitted. Table C-1 in Appendix C summarizes company information for wind turbine OEMs involved in the SMART Wind Steering Group.

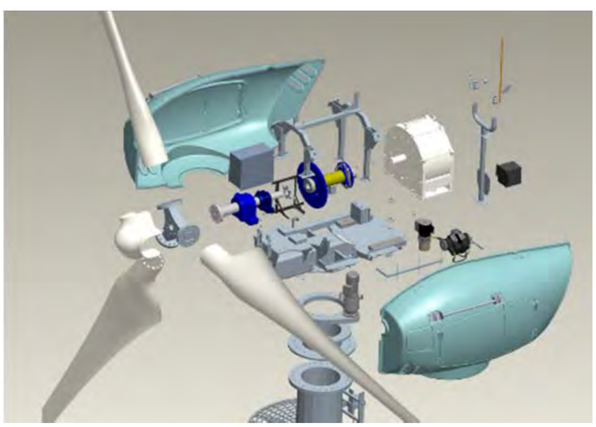

Figure 2-1. Sample exploded diagram, Eocycle

Figure 2-2. Northern Power Systems factory

2.2.1.2 Bill of Material and Cost Contributions

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, aggregated and shown as a representative BOM in Figures 2-3 and 2-4, with each component coded according to SMART Wind Subgroup. This study enabled the project team to focus on parts or subassemblies that contribute significantly to the total cost. Eight OEMs submitted BOM information. For mechanical subsystems, the gearbox and bedplate are the most expensive, particularly for larger turbines. Several mechanical parts can be castings, such as the mainframe and rotor hub. Blades are the focus for composites. For electrical subsystems, inverters, alternator/generators, and the controller are the top cost contributors. For support structures and overall, the tower and foundation contribute significantly.

Installation is not considered in the BOM, but it and other items such as turbine assembly, site development and preparation, zoning and permitting, transportation and logistics, and other non-hardware costs can contribute substantially to the overall system cost.

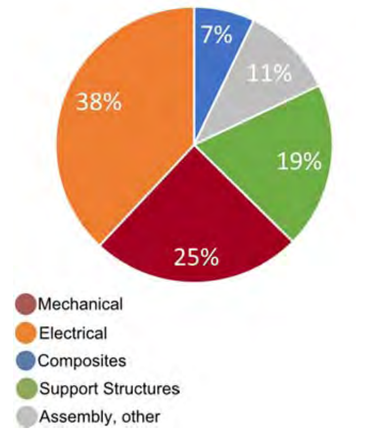

Figure 2-3. Aggregated cost by subsystem

Figure 2-4. Aggregated BOM for SMART Wind OEMs

2.2.1.3 Supply Chain

The following maps show the location of base operations for the 14 distributed wind OEMs that participated in the SMART Wind OEM Steering Group and their component suppliers. Figure 2-5 shows the SMART Wind OEM Steering Group members, half of which are located in the Northeast. Two are located in Canada.

Figure 2-6 shows the general country locations of SMART Wind OEM Steering Group members and their major component suppliers designated by subsystem. Many power electronics materials and processing facilities are currently located outside the United States. China manufactures much of the power electronics and support structure sub-components for distributed wind turbines. Asia has invested significantly in the infrastructure to produce these components, making it cheaper to establish power electronics manufacturing operations abroad, in close proximity to reliable component sources (PEIC 2015).

Figure 2-5. SMART Wind OEM Steering Group Member facility locations

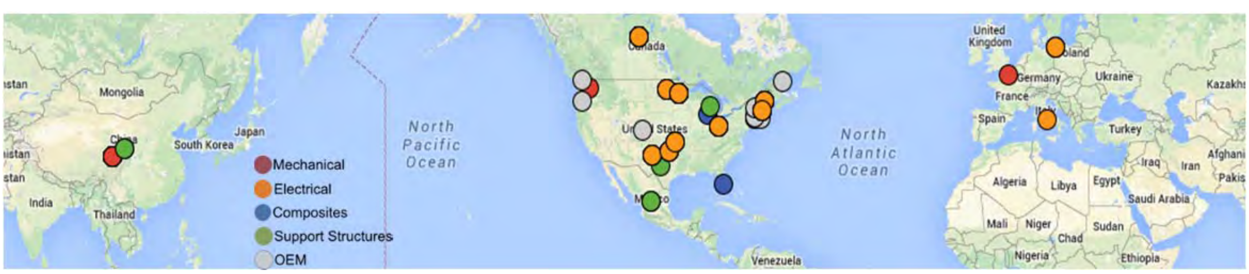

Figure 2-6. Supply chain of SMART Wind OEMs (note: not comprehensive of the global industry)

While Megawatt-scale wind turbine OEMs currently do not source electrical generators or associated electrical parts in the U.S., many distributed wind OEMs still manufacture their own electrical alternators, inverters, and controllers domestically. According to the Power Electronics Industry Collaborative (PEIC), the main opportunities for the U.S. lie within the wide bandgap materials for power electronics and maintaining domestic strength in design and engineering.

Figure 2-7 shows the top tier and dominant North American distributed wind suppliers in more detail, revealing a regional supply chain with a strong presence in the northeastern U.S. for mechanical parts.

2.2.1.4 Learning More about Manufacturing

SMART Wind OEMs are both system and component manufacturers and assemblers. In the initial Consortium OEM questionnaire, most indicated interest in learning more about lean manufacturing, developing new manufacturing partners (suppliers), and engaging with the NIST Manufacturing Extension Partnership (MEP).[5] Out of 24 OEMs who responded to the initial project questionnaire, one-third had already worked with NIST MEP centers, and nearly half stated they would like to work with MEPs in the future.

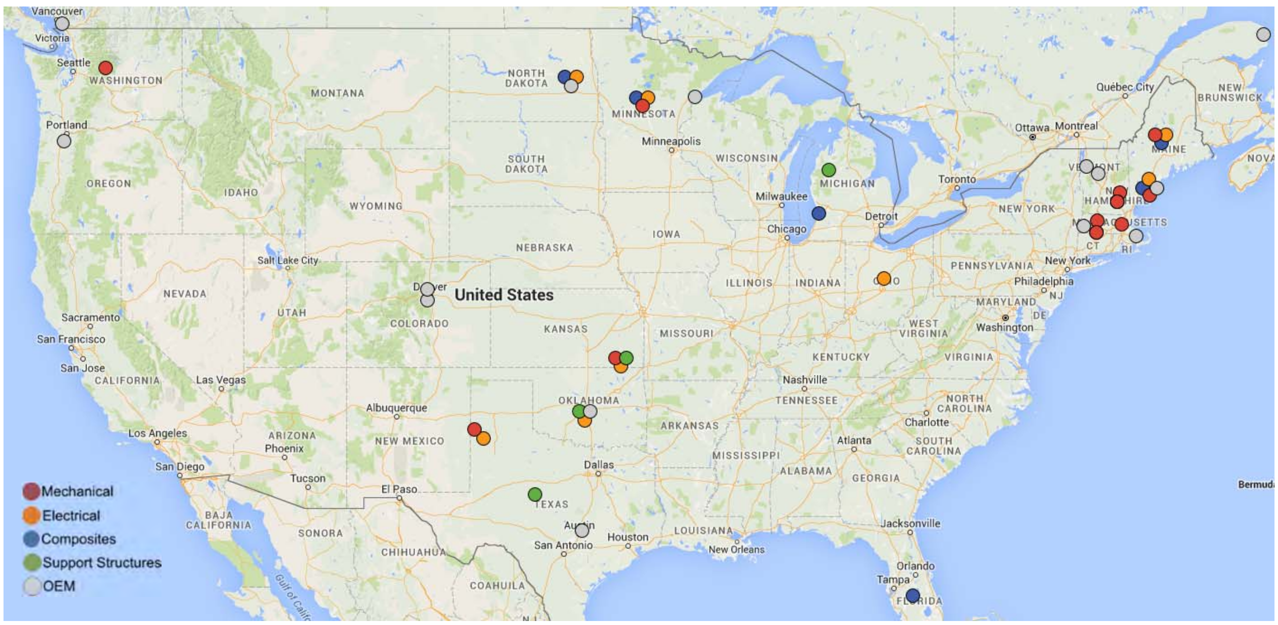

Figure 2-7. Top-tier/dominant distributed wind supply chain vendors (note: not comprehensive)

2.2.2 Benchmarks

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 the parts and complete final assembly in-house. At the start of the project in 2014, OEMs expressed interest in numerous R&D topics including:

- Electrical
  - Power electronics: inverters, lightning protection systems, programmable logic controllers, variable frequency drives, passive inverter components (e.g., capacitors, inductors)
  - Generator: stator/generator design, automation of stator winding, rare-earth magnets
  - Electrical balance-of-station: electrical storage systems, wiring, conduit, disconnects
- Mechanical
  - Load path and Fatigue, Aerodynamics, Structures, and Turbulence (FAST) modeling capabilities

[5] See Section 4.1.1 for more information on the NIST MEP.

- Advanced manufacturing techniques for mechanical systems such as near-net castings and additive manufacturing
  - Automation for low-volume manufacturing
  - Gearboxes, braking systems, lubricants and performance in cold climates
- Support Structures
  - Tower dynamics and loads
  - U.S. monopole tower supply
  - Foundation costs and installation times
  - Safety and training for tower climbing, turbine maintenance, and rescue
  - New tower coatings
  - Dynamic simulation of monopole towers
  - Standardization or tower designs
- Composites
  - Composite blade manufacturing options based on size, structural design, and dynamic behavior
  - New blade design and manufacturing optimization
  - Blade structural testing (static, fatigue, and dynamic)
  - Blade materials and coatings
- Other
  - No-/low-maintenance designs
  - Improvement opportunities in the supply chain
  - International certification requirements, impacts of design changes
  - Communication tools for turbine condition status prior to service visits

2.2.2.1 LCOE, Cost of Goods Sold

The price of wind turbines deployed in the U.S. varies by size, with smaller systems having higher relative costs. Leading small wind turbine models range from $4.60 to $10.60 per Watt installed; the average 2014 total installed consumer cost was $8,200/kilowatt (kW) for wind turbines less than 2.5 kW; $7,200/kW for wind turbines 2.5 kW to 10 kW; and $6,000/kW for wind turbines 11 kW to 100 kW (U.S. DOE 2015a, eFormative Options 2015). These systems typically operate at gross capacity factors[6] ranging from 15% to 35%, depending on site wind resource, terrain complexity, ground cover, and tower height. Over a 20-year period, a wind project at a site with an annual average wind speed of 6 m/s achieves an LCOE ranging from less than 10¢ to 20¢ per kilowatt-hour or higher before incentives. Small wind systems up through 100 kW qualify for a 30% federal investment tax credit that expires at the end of 2016. The most active U.S. markets for distributed wind turbines are in the Northeast and the West Coast, where retail residential and small business retail electric rates typically range from 12¢ to 30¢/kWh and are escalating at 2% to 5% per year. In contrast, solar energy costs have dropped dramatically following the $40 billion+ Chinese soft loans investment in mega-factories and a substantial drop in silicon prices (Perth Now 2015). Small-scale solar projects now typically cost less than $5 per Watt and operate at capacity factors of 12% to 20%, resulting in LCOEs over a 25-year operating life of 13¢ to 18¢ per kilowatt-hour before incentives (IRENA 2015).

[6] Capacity factor is defined as a measure of how often an electric generator runs during a specific time period. It compares how much electricity a generator produces with the maximum it could produce at continuous full-power operation during the same period.

LCOEs and internal rates of return from the U.S. DOE-funded Distributed Wind Policy Comparison Tool v3.2 (www.windpolicytool.com), which include incentives, are shown in Figure 2-8 for residential and commercial applications in selected states.[7] Positive rates of return were found in about two-thirds of the states for the commercial sector, but in less than half the states for the residential and non-taxed sectors. Even though some states and territories such as Hawaii, California, Vermont, Alaska, the Virgin Islands, and Puerto Rico have high LCOEs, distributed wind projects in those locations replace even higher electric retail rates and therefore also have strong internal rates of return. DWEA believes that all distributed wind turbine installed costs must decline dramatically and capacity factors must increase if distributed wind is to become a viable domestic energy source. In recent years, the dominant market for OEMs has been international. This market continues to expand and offers other points of sale for U.S. OEMs.

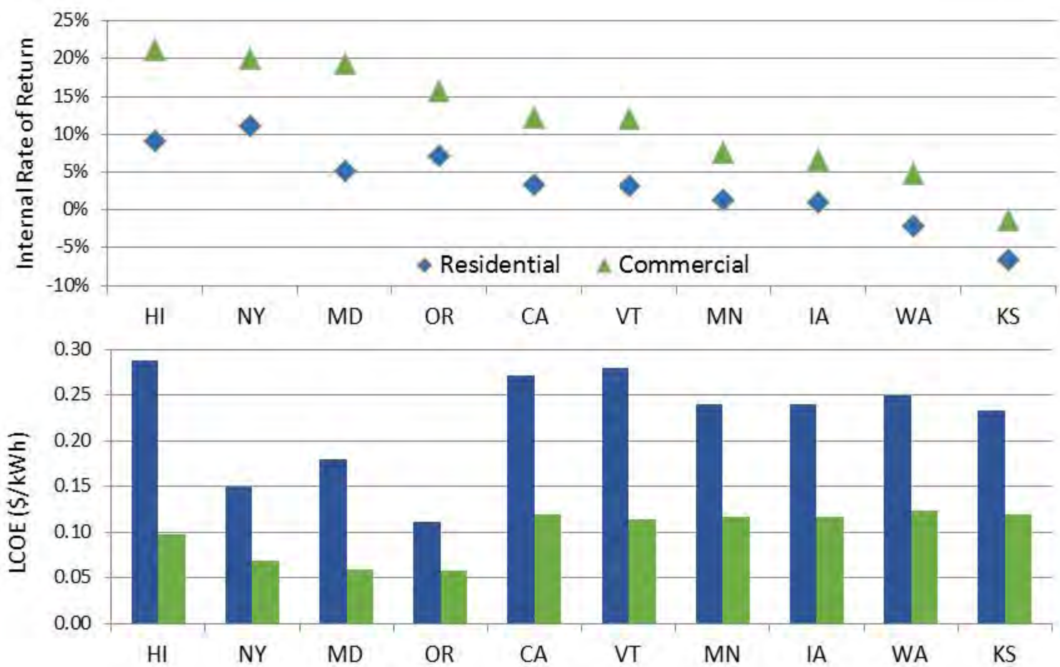

Figure 2-8. Distributed Wind Policy Tool results for selected states as of Fall 2015

2.2.2.2 Small Wind Turbine Cost Baseline

Representative costs for a typical 10-kW small wind installation are shown in Table 2-1. Installations on non-guyed, lattice towers are more expensive due to the heavier tower and much larger foundations. Table 2-2 shows the major component breakdown of a typical 10-kW wind turbine system with a guyed tower. The alternator and inverter are the most expensive pieces of the wind turbine, and the support structure is the most expensive component of the installed system. Equipment typically comprises 60% to 80% of the total installed cost, with the remaining 20% to 40% comprised of delivery, installation, and other soft costs (DWEA 2014).[8]

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[7] Results shown are for baseline wind resource values assigned in the Distributed Wind Policy Tool as follows: Mid Class 3 for Kansas (6.7 m/s for residential 37-m tower and 7 m/s for commercial 42-m tower); Low Class 3 for Minnesota and Iowa (6.3 m/s for residential and 6.5 m/s for commercial); and Mid Class 2 for all other states shown (5.8 m/s for residential and 6 m/s for commercial).

[8] Soft costs include non-hardware balance-of-system costs such as permitting, interconnection, shipping, and installation. The focus of this project is primarily hardware but turbine installation is also addressed.

Table 2-1. Typical installation costs for 10-kW wind turbine, two tower options

	10-kW Wind Turbine, 31-Meter Guyed Tower	10-kW Wind Turbine, 37-Meter Self-Supporting Lattice Tower
Turbine (incl. dealer markup)	$ 31,770	$ 31,770
Tower	$ 14,145	$ 26,995
Wiring kit, wire run	$ 4,325	$ 4,440
Foundation(s)	$ 3,280	$ 14,000
Setup/crane	$ 2,000	$ 2,800
Shipping & delivery	$ 1,800	$ 2,000
Electrical contractor	$ 1,375	$ 1,375
Permit & misc.	$ 750	$ 1,000
Total cost	**$ 59,445**	**$ 78,530**

Table 2-2. Typical portion of distributed wind system cost per major component (Example: 31-meter guyed tower from Table 2-1)

Consortium Subgroup	Component	Average Share of System Cost
Mechanical Systems	Mainframe	**12%**
Mechanical Systems	Tail	**4%**
Composites	Rotor	**10%**
Electrical Systems	Alternator	**22%**
Electrical Systems	Inverter	**22%**
Support Structure	Tower & Foundation	**30%**

2.2.2.3 Volumes and Jobs

DWEA SMART Wind OEM Steering Group members reported sales of 3,254 distributed wind turbines in 2013, which represents nearly 60% of 2013 domestic and exported units sold and about 40% of 2013 global unit sales reported by small wind manufacturers with a U.S. sales presence. DWEA estimates that the entire U.S. small, mid-size, and utility-scale distributed wind industry employed a 5,500-strong full-time equivalent workforce in 2012 (the latest data available), averaging 30 jobs per MW sold and $410 million in annual investment (DWEA 2013). Considering direct and indirect jobs in the U.S. distributed wind sector, a 50-fold increase is envisioned to meet DWEA's 2030 vision, as shown in Figure 2-9 (DWEA 2014).

2.2.3 Domestic Market

The 934 MW of cumulative U.S. distributed wind capacity is comprised of more than 75,000 wind turbines installed in all 50 states, Puerto Rico, and the U.S. Virgin Islands providing local energy, serving on-site electricity needs and local grids. In 2015, the U.S. added 28 MW of new distributed wind capacity, including more than 4.3 MW using turbines with a capacity rating up to 100 kW which represent 1,695 units and over $21 million in investment (AWEA 2016). Distributed wind industry jobs include local installers, a domestic sales force, engineering/technical teams, and manufacturing jobs.

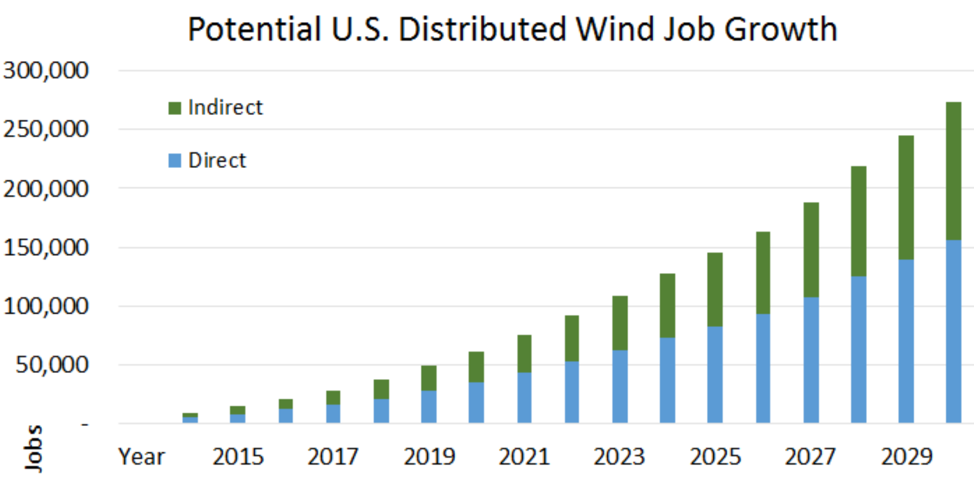

Figure 2-9. Distributed wind job growth under DWEA's 30 GW by 2030 Vision

DWEA estimates that in 2030 there will be 23.7 million homes and buildings suitable for distributed wind in the U.S., together representing a theoretical potential for 1,100 GW of generating capacity.[9] DWEA also estimates that other related market segments, such as community wind, wind gardens, and virtual metered systems, could boost the potential for non-windfarm wind energy to 1,400 GW. Federal and state programs play a major role in market development. While the U.S. Investment Tax Credit is due to sunset in 2016, DWEA continues to pursue an extension for customer-owned wind turbines and expansion to larger projects. The U.S. Department of Agriculture's Rural Energy for America Program helps fund renewable energy projects in rural markets. The New York State Energy Research and Development Authority's (NYSERDA's) On-Site Wind Turbine Incentive Program supports a large portion of installations. Renewable portfolio standard carve outs, net metering, and tax incentives are expected to grow the domestic distributed wind market in Colorado, Minnesota, Vermont, and other states.

The most active U.S. markets are in states that provide robust incentives and have above-average electric rates. Within those states, markets are concentrated in areas with stronger wind resources. A prime example is Wyoming County in New York, which saw 300% growth in distributed wind installations during 2015 due to NYSERDA incentives, electric rates 80% above the national average, along with good wind resources. Sales of distributed wind systems tend to develop in clusters, as visible working wind turbines drive consumer interest. New York, Iowa, Alaska, Minnesota, California, Texas, and Illinois are among the most active states.

Investment in distributed wind companies and the leasing model appear to be opening doors for growth opportunities. An option previously available only to small-scale solar customers, third-party leasing of wind turbines to energy consumers dramatically decreases the upfront costs and provides equity investors with dependable cash flow. Along with guaranteeing predictable energy production, leasing companies handle the wind project development for potential owners, including

[9] To estimate this theoretical potential, DWEA used available statistics or best estimates of the number of common categories of buildings, estimated their growth to 2030, applied exclusions for wind resource and other unsuitability factors, and estimated the average turbine size that would best fit the category. This upper range contrasts with the approach to establish DWEA's 30 GW goal, based on 30% average annual growth through 2030.

paperwork and permitting, processes that are often fraught with hurdles and delays. Leasing companies have attracted significant investment capital in recent years and have strong potential to stimulate the distributed wind market (GearBrain 2016).

Other markets of interest include the wind-diesel, islanded-grid market where electricity rates are high, and commercial end-users who enjoy the “green” marketing benefits of having a distributed wind system on-site as wind turbines are iconic symbols of environmental stewardship. And finally, the educational market continues to grow as educators enlist on-site wind to teach not only the next generation but the surrounding community that clean, local energy is affordable and reliable.

2.2.4 International Market

U.S.-manufactured distributed wind turbines have been installed in more than 130 countries. As the worldwide demand for cleaner energy continues to grow, particularly in developing countries with weak transmission infrastructure or no centralized utility grids, distributed wind energy has a vital role to play in generating on-site electricity. A strong export market for U.S.-manufactured distributed wind turbines supports domestic manufacturing and supply chain jobs across the country. As of 2016, the two largest global distributed wind markets are China and the U.S., accounting for 41% and 30% of the global distributed wind installed capacity (WWEA 2016). The U.S. faces competitive pressure from China in particular displacing US manufactured wind turbines.

U.S.-based small wind turbine manufacturers claimed strong exports to countries across the globe over the past 5 years, particularly to Europe, Asia, and the Americas as shown in Figure 2-10. Exports accounted for more than 80% of the value of 2015 U.S.-based distributed wind manufacturers’ sales, with a total estimated value of $122 million primarily to Italy, the United Kingdom, and Japan (AWEA 2016). The U.K., Italy, and Japan were the largest U.S. export markets in 2015 due to lucrative feed-in tariff (FIT) policies[10] that encourage renewable electricity deployment.

Figure 2-10. U.S. small wind turbine exports
Source: PNNL (U.S. DOE 2015a)

Italy’s FIT “revolutionized” the country’s small wind market. A previous Italian FIT began in January 2008 and expired in December 2012. It provided a tariff of 300 Euros per megawatt-hour for 15 years for wind turbines rated between 1 and 200 kW. The new FIT, which began in January 2013 and ended in December 2015, divides power classes from 1 kW to 5 MW. It was limited to 60 MW each year with the maximum annual spending expected to be 5.8 billion Euros. According to the World Wind Energy Association, in 2015 Italy ranked fourth in installed small wind capacity, behind China, the U.S., and the U.K., respectively (WWEA 2016).

As seen with large wind and solar, robust domestic markets help manufacturers leverage export sales through increased cost competitiveness and market development resources. Growing the U.S. distributed wind market will also grow exports (DWEA 2015).

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[10] FITs are policies used to encourage deployment of renewable electricity. In areas with FITs, customers who own an eligible renewable electricity generation system receive a set price from their utility for the electricity they generate and provide to the grid (EIA 2013). FITs are limited in the U.S. but are more common in the rest of the world (including Denmark, Canada, Greece, Cyprus, Israel, Lithuania, and other countries) (WWEA 2014).

2.2.5 Impact of Standards, Testing, and Certification

The global distributed wind community has developed technical standards for testing and design of distributed wind turbines and has established certification systems that provide a mechanism for assessing the quality and functionality of wind turbines and provide end users with performance data enabling informed purchasing decisions. The distributed wind industry has invested considerable resources in third-party certification over the past 10 years. In 2009, the American Wind Energy Association (AWEA) led an industry effort to create the AWEA Small Wind Turbine Performance and Safety Standard, and the U.S. DOE Wind and Water Power Technologies Office funded the launch of the Small Wind Certification Council (SWCC). In 2014, the SWCC created new certification criteria for "medium" wind turbines,[11] representing an important growing sector.

On behalf of U.S. DOE, NREL has consistently supported standards development, modeling, and field testing. In 2014, DOE issued a memorandum to 17 federal agencies (U.S. DOE 2014) stressing the importance of distributed wind turbine certification and recommended "the use of public funds be provided only for wind turbines that have been tested and certified for safety, function, performance, and durability." The memo further recommends "certification requirements ensure taxpayer monies are only made available to products with dependable performance estimates and demonstrated compliance with nationally recognized standards." In 2015, the U.S. Internal Revenue Service required certification for wind turbines claiming the federal Investment Tax Credit.

In producing this Roadmap, SMART Wind Consortium participants considered the technology evolution of wind turbine designs. Wind turbine designers have expressed concerns about impacts of such changes on wind turbine certifications. U.S. distributed wind turbine suppliers will secure a competitive global presence by maintaining this commitment to certification. The reporting of all wind turbine design changes to the bodies that grant certification and the subsequent "change management" is essential for maintaining the validity of certifications. As wind turbine suppliers evolve their designs, working closely with their certification bodies will help ensure that technology evolution is coordinated with the conformity assessment process.

2.3 Growth Potential

Distributed wind's potential is on par with the 1,100 GW potential the U.S. DOE has estimated for offshore wind for water depths up to 30 meters, as well as the existing total U.S. generation capacity of all types (DWEA 2015). With policy support comparable to that already provided to other clean energy technologies, distributed wind is primed to be part of the next clean tech boom.

DWEA's estimate does not include special-purpose loads such as pumps and irrigation systems. Nor does it include community wind projects, wind gardens, or additional projects made feasible by virtual net metering, which several states are implementing. DWEA estimates that these additional market segments could boost distributed wind's potential by 25% (DWEA 2015). Navigant Research recently published a report predicting the worldwide distributed wind market for small and medium wind turbines up to 500 kW at 3.2 GW worldwide by 2023 (Navigant 2015). These projections assume a business-as-usual scenario, while DWEA's goal accounts for a larger portion of distributed wind's theoretical potential to be attained if favorable policies are implemented and the priority actions identified in this Roadmap are executed, resulting in substantial cost reductions.

[11] Wind turbines up to 100 kW are eligible for the 30% federal Investment Tax Credit through 2016. For certification purposes, international standards apply to "small" wind turbines with rotor-swept areas up to 200 square meters (approximately 50 to 65 kW) and "medium" wind turbines greater than 200 square meters.

2.3.1 SMART Wind's Impact on the Market

Distributed wind's future lies in areas with grid parity in large enough markets to allow the industry to grow and thrive. State and federal subsidies are a bridge to that future by enabling the industry to reach volumes and apply advanced manufacturing techniques that reduce the total project costs. The SMART Wind Roadmap shows how to create that bridge and make distributed wind a significant long-term contributor to America's clean energy future.

Key steps include:

- Addressing major technological and related barriers that inhibit the growth of advanced distributed wind manufacturing through the industry-based SMART Wind Consortium
- Connecting more than 120 existing and new collaborators to take action on near-term, mid-term, and long-term plans needed to increase cost competitiveness through the use of advanced manufacturing techniques, as documented in the SMART Wind Roadmap
- Accelerating university-based research to develop innovative technology solutions and facilitate deployment to support advanced U.S. manufacturing, increasing the number of American jobs throughout the distributed wind supply chain
- Substantially reducing LCOEs of installed distributed wind turbines near-term (as shown in Figure 2-11 for example residential and commercial wind turbines over a range of typical wind resources) and achieving parity with U.S. retail electricity grid rates in more markets
- Integrating NIST work with other federal and state government opportunities to unite strategies and complement the U.S. DOE's distributed wind efforts

SMART Wind actions prioritize technical breakthrough opportunities for cost reduction of U.S.-manufactured goods sold, leading to substantial job growth and strengthening the capacity and success of U.S. distributed wind supply chain members.

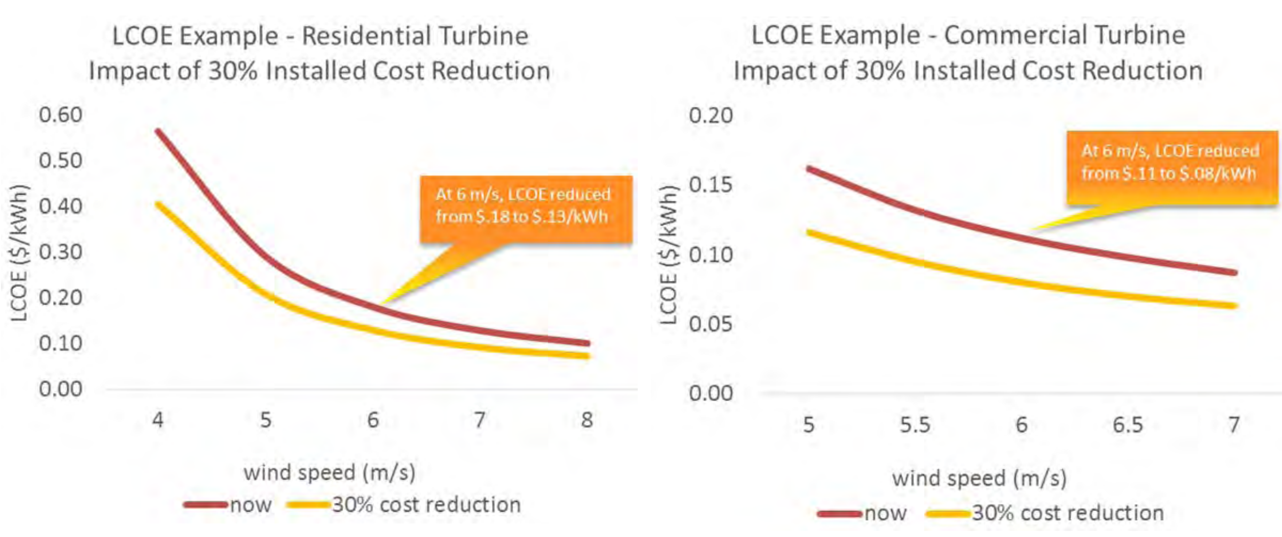


Figure 2-11. Examples of LCOE impact from 30% reductions in installed cost

3 Distributed Wind Turbine Technology, Manufacturing Opportunities, and Actions

U.S. OEMs of distributed wind turbines and key components are typically small enterprises, and thus resource-constrained financially and in terms of available staff. Many of the skills used to manufacture and assemble distributed wind turbines are similar to skills required in the oil and gas industry, such as welding. Recent increases in domestic oil and gas development have increased labor and employee turnover rates for at least two SMART Wind OEMs.[12] Many distributed wind OEMs also experience non-steady production and low-volume production, which are further aggravated by frequent changes and sunsets of financially supporting policies. Most North American OEMs are pursuing more lucrative international export markets to stabilize and build production volume.

As part of initial SMART Wind research, OEMs were asked which turbine components are most difficult to produce or procure. The responses revealed that blades, towers, castings, inverters, and alternators top the list, as highlighted in the weighted "word cloud" in Figure 3-1. Since machine topologies differ depending on the wind turbine technology size, SMART Wind's approach is to focus on parts and areas with wide interest.

Figure 3-1. Most challenging distributed wind components

The SMART Wind Consortium launch questionnaire also asked OEMs to identify their main technology gaps and opportunities. Details are included in Appendix C-1; responses include:

- Aeronautica sees opportunities in castings; domestic sourcing of large castings presents cost issues while non-domestic sources have quality issues
- AllEarth Renewables sees opportunities in improving ISO 9000 quality system and Telecommunications Industry Association (TIA) tower standards; expressed interest in using machines to increase volumes and drive down the price of parts
- Bergey Windpower sees opportunities in blade material advances, process improvements, and automation; expressed interest in bringing some vendor-produced components in-house
- Black Island Turbines sees opportunities in blades, generators, and castings; interested in small-volume automation and professional development for the industry
- Endurance Wind Power is focused on reducing LCOE and finding less expensive ways to manufacture parts (entailing lower cost and/or higher reliability); sees opportunities in tower supply and manufacturing, with interest in just-in-time manufacturing
- Eocycle sees opportunities with blades and power electronics; low-volume manufacturing is a challenge for quality and/or cost competitiveness
- Northern Power is interested in automation and in-process testing; sees opportunities in blade manufacturing, reducing labor, flexibility, and just-in-time manufacturing

[12] As reported by SMART Wind OEM Steering Group members through Consortium correspondence, 2014-2015.

- Pika Energy sees opportunities with castings, blade manufacturing, U.S.-made towers, foundations, and power electronics; low-volume manufacturing is challenging in terms of capital investments and suppliers
- Primus Windpower reports that U.S. sourcing sometimes involves design changes, and thus tooling costs; challenges with micro-wind turbines may differ from larger wind turbines (e.g., towers can quickly increase system costs)
- Ventera Wind is interested in improvements in the whole process, raw material to final product, including training and reliability monitoring; sees opportunities in castings, U.S.-made hydraulic or screw-jack erected towers, blades, inverters, and controllers

SMART Wind Subgroups met individually (face-to-face kickoff meetings with each, and then virtually) to learn about new research results, understand which may have near-term commercial opportunities, and examine advanced manufacturing techniques that may apply to wind turbine production. Some of these opportunities have existing barriers that require action in order to be fully realized, and these actions are embedded within this Roadmap.

This section reviews actions identified and recommended by the four subgroups (Mechanical, Support Structure, Composite, and Electrical Subsystems) and at the system level to account for the full lifecycle of a distributed wind turbine and the needs for operation and maintenance after its installation. While most of the actions are broadly applicable for distributed wind technology, some address specific manufacturers' concerns. The end goals of the actions are to reduce distributed wind turbine life-cycle costs, increase product and market competitiveness, and maintain quality and U.S. leadership in manufacturing.

3.1 Electrical Subsystems Barriers and Actions

The primary focus of the SMART Wind Electrical Subgroup is power electronics (inverters, lightning protection systems, programmable logic controllers, phase converters, controller electronics) and alternators/generators. Through Subgroup meetings and partnering with the PEIC, participants learned that the field of power electronics has challenges in education and competition with foreign supply chains while having opportunities in next-generation components and potential collaboration with the growing transportation sector. About half of the SMART Wind OEMs are manufacturing custom, permanent-magnet alternators in-house, so opportunities exist in coil winding and placement optimization.

Other barriers and actions identified for electrical subsystems include:

- Investigate power electronics
    - Develop a common core modular inverter; utilize wide bandgap materials
    - Apply VFDs
    - Research emerging/innovative power electronics; how have other industries standardized their product offerings?
    - Encourage trade schools and universities to focus on and offer training for the growing power electronics industry

Figure 3-2. Pika Energy Stator Coil Assembly

- Collaborate with the electric vehicle industry on power electronics
    - Incorporate new wide bandgap switching materials (e.g., silicon carbide [SiC] and gallium nitride [GaN]) into power electronics
    - Research VFDs in distributed wind applications; continue to partner with VFD manufacturers such as ABB and Schneider Electric, expressing the need for development and successful implementation in this type of application
- Investigate potential cost reduction in inverters
    - Develop high-frequency inverters with SiC for increased efficiency, reduced audible noise, reduced cost, and a solution for increased ripple currents experience with VFDs; need low-loss magnet materials
    - Design inverters with fewer parts
    - Leverage latest research results on new magnetic and capacitive components; utilize thermal management simulations (e.g., Argonne National Laboratory)
    - Develop a core inverter module that is Underwriters Laboratories (UL)/ Institute of Electrical and Electronics Engineers (IEEE)-compliant, can be built in volume, and utilizes wide bandgap switching and higher bus voltages
    - Collaborate with PV inverter manufacturers to explore higher-volume manufacturing and bulk pricing opportunities
- Improve alternators
    - Design and improve manufacturing processes of alternators/generators
    - Address impact of low voltage ride-through and high voltage ride-through requirements on induction machines
    - Collaborate with electric-vehicle industry on generator/motor development
    - Research improved technology for stator laminations (helical winding, notching)
    - Use robots for coil placement as opposed to custom insertion machine; collaborate with printed circuit board or automotive industry on this approach
    - Explore better ways to automate stator winding
    - Investigate how to meet new IEEE 1547 requirements with induction generators
    - Collaborate with micro-hydro industry on generator and power converter; collaborate with marine hydrokinetic generation industry (market expansion)
    - Leverage dynamometer testing facilities at NREL (10 kW-5 MW)
    - Leverage electromagnetic and thermal design capabilities at NREL to develop new generators for wind turbines (low cogging, high efficiency, robust generators)
- Improve the supply chain
    - Research bulk purchase opportunities (wire, switching, semiconductors, disconnect boxes, fuses, fuse holders, connectors, relays, anemometers and tail vanes, rare-earth magnets)
- Improve smart grid integration
    - Incorporate micro-grids and storage; examine existing and proposed small-scale solutions (Tesla, Enphase)
    - Validate electrical design through component testing to standard and smart grid/resiliency requirements

- Integrate all renewable energy and tie systems together so that distributed wind turbines become part of the "Internet of Everything"[13] (interoperability is important: resiliency, reliability, power management)
- Develop more sophisticated grid control and monitoring capabilities
- Leverage power system simulators at NREL to test grid compatibility and system integration aspects of distributed wind generators (1-4 MW) at the Energy Systems Integration Facility and National Wind Technology Center

3.2 Composite Subsystem Barriers and Actions

Composites include structural (blades and towers) and non-structural (nosecones, nacelles, etc.) wind turbine parts. SMART Wind Consortium Composites Subgroup discussions have focused on blades due to their high costs, sensitivities to low volume, and lack of use by multiple OEMs. Blades in some ways are the most visible part of the wind turbine, and some OEMs do not want to use a common blade design because the lack of design uniqueness will make each OEM's product more difficult to market.

At the same time, tremendous growth in blade materials and processes is occurring (e.g., in the aerospace and automotive industries). Are there new production processes that can duplicate the current fleet of strong, productive blades at a reduced cost and improved availability? Tapping into other sectors to identify possible candidates and working with the Institute for Advanced Composites Manufacturing Innovation (IACMI) and other partners will be critical in reducing composite part costs. The SMART Wind Composite Subgroup identified numerous barriers and actions unique to the distributed wind industry, including:

Figure 3-3. Endurance Wind Power wind turbine blades

- Material advances
  - Explore new efficient blade manufacturing materials, fixturing, and tooling costs (carbon-fiber, thermoplastics, H-glass, sustainable products such as bamboo, natural cellulose fibers for reinforcement and bio-based resins) to obtain high strength, stiffness, toughness, and adhesion
  - Identify and/or engineer new materials that can lead to an increase in tensile strength in the fiber direction, increase in shear strength in the out-of-plane direction, and increase in a compressive strength; identify and apply advanced composites
  - Develop coatings and systems that resist erosion and icing, along with fiber treatment to minimize hydrophobic matrix and hydrophilic fiber issues
  - Develop materials with longer life cycles
  - Investigate composites for towers
  - Work with Sandia National Laboratories (SNL) and Montana State University to build on materials database and blade design

[13] "IoE" is the evolving ecosystem of devices, software and services that are network-connected.

- Blade design optimization
  - Develop airfoils less sensitive to surface roughness; test them in wind tunnels
  - Develop a better open source design and analysis tools for composites in blade structures; more capabilities are required than are currently available
  - Address the fact that XFoil, Navier-Stokes (may need fundamental research) do not predict roughness, and that in-flow conditions are not well understood
  - Develop an integrated, iterative approach between design and blade manufacturing
  - Develop a new solution to improve blade stiffness without weight penalty
  - Investigate ways to work with manufacturers of other products and share information (e.g., surfboard manufacturers)
  - Develop a new blade design based on blade manufacturing technique; develop a blade that can be incorporated into multiple turbine designs
  - Explore whether 13-m to 27-m modular space frame blades are possible; they would not require molds
  - Develop practical approaches for achieving a damage-tolerant design; review composite blade structural design and dynamic behavior
  - Explore the possibility of modular space-frame blade design
- Blade reliability
  - Develop post-manufacturing non-destructive testing methods for blades to identify defects and/or to examine cycled blades for wear patterns that develop over time
  - Develop better blade reliability information
  - Develop methodologies for manufacturing process control
  - Validate blade design through blade structural testing
  - Research experimental mechanics for load determination in small blades; real-time loading of blades during testing
    - Opportunity to take direct measurement of loads in situ, then bring into the lab, calibrate, place on the turbine, and measure loads
    - This is not possible with large blades, so the distributed wind industry could provide a blade research opportunity for the Megawatt-scale wind industry to identify a promising new blade material/process and try it on sub-scale blades
  - Develop practical approaches for considering uncertainty qualification in design to address robustness in aerodynamic loading and environmental conditions
  - Develop a spectrum load testing methodology for small wind turbine blades (most failures may occur at low-cycle fatigue; small turbine blades may respond better to spectral loading, depending on manufacturing technique and materials)
  - Develop an approach for IEC 61400-2 that addresses blade fatigue
- Blade performance improvements
  - Develop joint proposals to work with U.S. DOE/IACMI technology demonstration
  - Explore possibilities of monitoring blade degradation while in service to predict remaining lifetime and support development of better damage models
  - Identify low-cost and reliable prognostic condition and usage monitoring systems for blades that can be used to evaluate the effect of lightning strikes, ice, and hailstorms

- Cost reduction
    - Develop long-term contracts, orders of materials and parts large enough to drive costs down
- Blade manufacturing process
    - Develop methodologies for manufacturing process control
    - Explore new efficient manufacturing solutions, including microwave bonding and joining, automated fabric and tape laying, pultrusion, injection and additive manufacturing processes
    - Develop tools that integrate manufacturing, quality testing, and design results
    - Develop methods and models that describe effects of production defects

3.3 Support Structure Barriers and Actions

Wind turbines' support structures include the towers and foundations, which carry wind turbine loads to the ground, and accessories such as electrical connections, lightning protection, and hardware. The support structure also includes related equipment and hardware used to install, operate, and maintain the wind turbine system. While the wireless and utility-scale wind industries have solid U.S. tower supply (self-support, galvanized, slip joints, step bolts), the majority of distributed wind turbine towers are currently outsourced from China. Composite towers and foundations may or may not be directly cost competitive, but may offer cost savings in installation and service.

Figure 3-4. Ventera Wind tilt-up monopole tower

3.3.1 Towers

Barriers related to support structures involve reducing the costs of and increasing the quality of the tower supply. Actions identified for towers include:

- Ensure high-quality towers
    - Develop a distributed wind turbine support structure design standard with the guidance of IEC 61400-2, ASCE 48-05, ASCE 48-11 ASCE 72, and TIA-222
    - Improve U.S. monopole design and supply for base diameters above 80"
    - Explore hot rolled, 60-degree angle, 3-leg lattice towers
    - Identify how to reduce cost and ensure flatness of tower flanges; consider mass sourcing
    - Explore a standard industry tower with flange attachments
    - Conduct a design review, test for at least a 6-month period, and complete third-party certification of each new support structure and foundation design and concept prior to commercialization
    - Understand turbine-tower dynamics well enough to propose new fatigue requirements for upcoming IEC standards
    - Develop tower certification strategy
    - Explore a range of standard industry towers for economies of scale

- Better understand tower dynamics and loads to refine designs
    - Refine TIA-222-G Addendum 4; develop an alternative or improve the small wind turbine addendum
    - Conduct modal analysis and create Campbell diagrams[14] for a number of tower cases with soil variations and interactions for the turbine and towers; use results as input to technical discussions on fatigue for IEC 61400-2
    - Model and explore the use of slip-fit, tapered compared to mechanically coupled towers from a loads and dynamic perspective
    - Understand tower dynamics and how other tower industries can address the needs of the distributed wind turbine industry
- Quantify the effect of slip-joints
    - Gather test data to validate turbine dynamic models; develop models that capture the turbine-tower coupling effects
    - If using slip-fit towers, determine how installers climb
- Increase U.S. content of distributed wind towers
    - Adapt distributed wind towers to have higher U.S. manufacturing content, similar to utility and wireless (self-support, galvanized, slip joints, step bolts)
    - Examine HS Code: 7308.20 / Custom duty on poles made in China
    - Collaborate with partner organizations to build cost-competitive domestic structural support supply chain
- Develop a more robust supply of U.S. monopole towers from multiple suppliers
    - Design, build, and test a family of towers that could be used by several OEMs
    - If there is interest from multiple OEMs, work together to negotiate as a cooperative with component suppliers (possible better terms)
    - Examine custom duty on poles manufactured in China (HS Code: 7308.20) for ways to make U.S. manufactured products more competitive
    - Increase U.S. tower supply by adapting approaches used in the utility and communications industries
- Increase safety for tower installation, climbing, turbine maintenance, and rescue
    - Determine how to enable time-efficient work platforms, tie-off points, and better climbing and safety approaches
    - Validate turbine design for operations and maintenance (O&M) procedures that maximize human safety
- Develop new partnerships
    - Determine what can be learned from other industries about tower building and lifting approaches; NREL could offer a workshop on how dynamic loads differ between wind turbines and transmission towers to educate tower manufacturers
    - Develop new competitive partnerships with U.S. pole manufacturers

[14] The Campbell diagram represents the natural frequencies of a wind turbine system versus the rotation speed of the turbine rotor, useful in understanding the dynamic behavior of the turbine system.

    - Pole manufacturers exist in almost every state, but many of them may be unaware of the small and distributed wind turbine industries; determine whether they could be open to new business/industries (e.g., highway signs, power transmission and distribution structures, lighting poles, wireless towers, hydraulic tilt-up oil drilling towers, etc.)
- Work with the NIST MEP to transition highway sign manufacturers to turbine tower manufacturers
- Improve tower coatings
    - Develop new approaches to hot-dip galvanization, including cost-effective coatings
    - Work with interested coating companies (explore latest research) to identify tower coatings that can replace hot-dipped galvanized and other coatings
    - Research sound-deadening material for application inside the tower and at tower base grout
    - Investigate research in sub-surface corrosion protection methods and materials; find U.S. small batch/tailored galvanizing partner (perhaps through the MEP)
- Material advances
    - Investigate the use of composite towers
- Reduce costs
    - Collaborate with partner organizations to build cost-competitive domestic structural support supply chain
- Reduce maintenance needs
    - Develop turbine design for ease of maintenance
    - Account for human safety and safe installation requirements in future designs, including:
        - Increase the number of anchor points for rescue
        - Address spacing of climbing pegs so that they are not too far apart
        - Ensure clip-off points at the top and round cross-sections for a better grip
        - Require an interactive monitoring system
        - Develop standards for a safety ladder system (the Occupational Safety and Health Administration has ladder requirements)
        - Identify parts requiring frequent replacements and plan for ease of serviceability (components/modules that are easily removed and replaced)
        - Develop a best-practice document on installations

3.3.2 Foundations

Wind turbine support structures have evolved toward more use of pre-fabricated foundations, which have the potential to increase manufacturing volume when used by multiple wind turbine OEMs.

Barriers and actions identified for foundations include:

- Reduce foundation costs
    - Design cost-efficient foundations for a range of tower configurations and soil conditions
    - Develop common, pre-fabricated foundations for multiple turbines. Consider less expensive materials. Perhaps design for worst-case soil conditions (avoids cost of site-specific soil tests/drawings created just for specific site)

- Fiber-reinforced concrete may have significant cost-saving potential for turbine foundations; explore technical limitations and opportunities. Also work to reduce reinforcing steel costs and reduce form costs for concrete
- Facilitate international forum to identify specific countries' structural and electrical requirements and expertise (e.g., Japan)
- Investigate commercial viability of other earth-anchor systems (e.g., helical anchors); leveling of towers, foundations, and mechanical fasteners, including earth anchor and helical anchors, is critical for successful long-term turbine operation
- Investigate the function and commercial viability of spread-leg foundations
- Investigate embedded sections with or without sleeve and tar coating in pole support structures used in power transmission and distribution pole steel structures

Figure 3-5. Prefabricated foundation installed by Skylands Renewable Energy

- Reduce maintenance needs
  - Identify new ways to reduce the amount of concrete needed for distributed wind turbine foundations

3.4 Mechanical Subsystem Barriers and Actions

Mechanical systems include cast and fabricated parts such as the rotor, hub, main shaft, mainframe, and bedplate. Other mechanical assemblies include bearings, braking systems, gearboxes, pitching systems, furling systems, and yaw systems. The Mechanical Subgroup identified opportunities in castings, which can contribute significantly to system cost and weight. New casting partnerships can benefit from these process improvements and impacts from lean manufacturing techniques. Procuring these mechanical systems at low volumes poses challenges in maintaining steady supply. Consequently more manufacturing is done in-house, and it is costly to understand manufacturing processes at such a low volume; yet it is critical to streamline and improve manufacturing processes for long-term cost-effective production. A challenge exists in finding cost-effective incremental approaches to manufacturing improvements such as automation, design optimization, and labor/waste reduction.

SMART Wind participants would like to see the effort empower manufacturers to make improvements, educate OEMs and component suppliers on state-of-the-art technology, communicate the benefits of new technology not currently utilized in the distributed wind industry, and determine which research topics are applicable. Processes identified as "expensive" include manual welding, assembly, controls assembly, and application of non-corrosive finishes.

Other barriers and actions identified for mechanical systems include:

- Optimize the supply chain
  - Develop a supplier directory for wind turbine parts, components, and designers; provide information on component supplier capabilities; pool knowledge of who can supply what at the best price

- o Research the standardization of some components and group ordering
  - o Identify regional manufacturer expertise and encourage entry/conduct meetings with such component suppliers to enter wind turbine sector
  - o Work with machining companies on manufacturability


Figure 3-6. Aeronautica Windpower mainframe assembly

- Optimize castings
  - o Research advanced casting and mold manufacturing techniques; enable more functionality from fewer parts; develop new competitive partnerships
  - o Explore best practices for computer numerical-controlled machining of near-net-shape castings
  - o Research a reliable method for galvanizing large ductile iron castings
- Improve gearboxes
  - o Develop low-cost prognostic condition monitoring
  - o Develop a siphon tube in the gearbox for pump/vacuum oil removal (cleaner and faster)
  - o Investigate hydrostatic transmissions for small and medium wind turbines
  - o Monitor progress on mechanical innovations, e.g. intensive quench for gears, and improvements to gear life through surface treatments
  - o Develop methods for accelerated life testing
  - o Position industry as a test bed for large wind drive train concepts
- Improve lubricants
  - o Increase performance and replacement interval for lubricants
  - o Research materials, lubricants, and gear oil for use in cold climates
- Improve moving surfaces
  - o Develop information on brake materials with good life and consistent brake torque
  - o Understand and refine bushing materials for long life and low maintenance in sliding fit applications such as centrifugal pitching systems
- Additive manufacturing
  - o Research additive manufacturing for prototyping, molds, and real parts
- Manufacturing
  - o Conduct research on carbon shaft manufacturing (short-term)
  - o Implement automation and robotics

3.5 Turbine System Barriers and Actions

To reduce the overall cost of energy, both upfront capital cost and ongoing O&M expenses need to be reduced. Low-maintenance designs enable reduced O&M expenses. SMART Wind OEMs identified opportunities with modeling of wind turbine systems such as a limited familiarity with FAST modeling and absence of dynamic aspects of design and loads analysis. FAST v7 includes tail geometry and aerodynamics but does not include high-fidelity tower modeling. FAST v8 includes tower wind load modeling but not tail geometry and aerodynamics. Fixing this (and validating FAST predictions) would facilitate manufacturing improvements because component designs could be adequate but not overdesigned. Actions identified for wind turbine modeling include:

- Optimize component designs
    - Update aerodynamic models in FAST v8 to include towers and tails
    - Provide educational courses on computer-aided engineering tools (e.g., FAST, Crunch[15]) for industry, college students
    - Address accuracy of performance modeling of distributed wind turbines

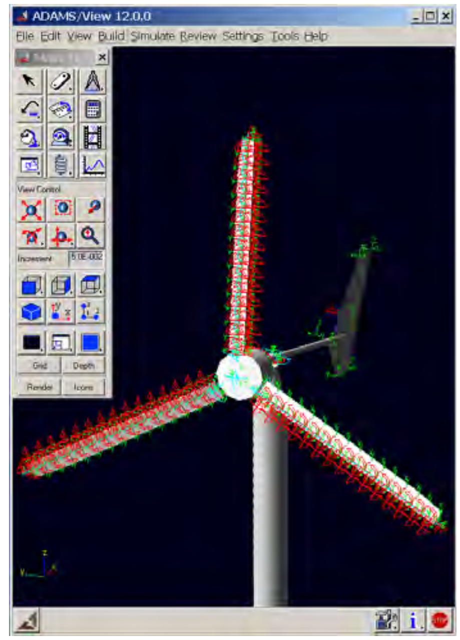


Figure 3-7. FAST wind turbine model Source: NREL

SMART Wind OEMs also identified the following actions to expedite low-maintenance designs:

- Reduce maintenance needs
    - Ensure training opportunities for small wind installers to erect, maintain, and operate distributed wind turbines (especially needed for installers who climb non-tilting towers)
    - Eliminate excavation with screw-in anchors, which need to be installed at an angle (What are the limitations of this approach? Could re-tensioning be part of maintenance?)
    - The utility-scale wind industry may be able to offer lessons from designing, installing, and maintaining met towers, which are sometimes left in the field for 6 to 7 years; aviation requirements for taller towers should be researched
    - Identify new ways to reduce the amount of concrete needed for distributed wind turbine foundations
    - Develop installation processes with an emphasis on safety and cost reduction (see Section 3.3.1 above for full list)
    - Fund development of standardized condition monitoring and remote debugging modules for an industry of varied hardware, particularly to help installers reduce the time they spend maintaining turbines; hardware is not expensive, the expense results from getting something useful from cheap hardware (development of code/system/modules to handle data; library of modules/hardware)
- Manufacturing
    - Explore new efficient manufacturing materials and processes incorporating lean manufacturing practices
    - Many OEMs cannot afford a high-quality process engineer to implement process

[15] https://nwtc.nrel.gov/FAST and https://nwtc.nrel.gov/Crunch

    - improvements; explore funding independent auditors to provide expertise for advanced manufacturing specific for wind; provide a neutral, unbiased roving process engineer
    - Connect NIST MEP centers and OEMs
    - Assist OEMs with tooling and part handling for low-volume manufacturing, and fixturing to reduce labor
    - Partner with vendors to identify and adjust high-cost specifications
    - Pursue lean manufacturing
- Increase U.S. content of distributed wind turbines and towers
    - Initiate a new "Made-in-America" effort to address dumping of steel and determine how common OEM design and supply (e.g., tower flange) could boost volume
- Certification
    - Encourage the development of common international requirements (e.g., U.S., U.K., Japan, building codes)
    - Conduct a gap analysis for certification requirements for various global markets (i.e., what is the scope of work to certify a turbine for both the domestic market and the most vibrant international markets?); educate and promote certification to maintain quality
    - Assess how changing a turbine design impacts certification requirements
    - Certify small wind and medium wind hardware (challenging due to costs)
    - Obtain better understanding of fatigue for IEC61400-2.

SMART Wind participants also identified the importance of additional market expansion and workforce development efforts, including:

- Export markets
    - Conduct trade missions and other match-making events in key international markets; match U.S. firms' travel funds for foreign missions
    - Coordinate American distributed wind pavilions at key global trade shows
    - Conduct trainings on technology selection, site evaluation, installation, and maintenance in key export markets
    - Pursue Market Development Cooperator Program Export Awards to promote sales of U.S.-made distributed wind turbines and components in growing international markets
- Inspiring innovation
    - Work with U.S. DOE to include relevant themes in Collegiate Wind Competitions, inviting projects focusing on advanced manufacturing for distributed wind-scale technology

3.6 Overall Industry Actions

Other industry actions identified outside the scope of the initial SMART Wind Subgroups include:

- Encourage mentorship and outreach programs to increase workforce diversity
- Establish/support national zoning and interconnection rules
- Review advances in non-rare-earth magnets
- Encourage public education initiatives to educate about permitting and zoning, as well as refuting myths about wind energy
- Monitor utility-scale wind technology development for distributed wind applications

4 Research and Partnering Opportunities

U.S. manufacturers of distributed wind turbines have opportunities to partner with supportive programs such as the NIST MEP to enhance growth, improve productivity, reduce costs, and expand capacity. Lean manufacturing, innovation engineering,[16] and other manufacturing improvement philosophies can be deployed to increase the competitiveness of small distributed wind equipment manufacturers. Partnerships can increase profits and expand markets when new products are developed, new manufacturing technology is introduced, and improvements are made to existing processes. Competitive solicitations through the U.S. DOE Competitiveness Improvement Project, the multi-agency Small Business Innovation Research program, the National Science Foundation, and other funding initiatives can be pursued to undertake these projects.

The SMART Wind Consortium has explored opportunities to partner with other AMTech awardees focusing on power electronics and composites. Through collaboration with partners committed to similar missions, project efforts will be farther-reaching and can provide opportunities for future growth and development beyond the initial funding. DWEA also sees great opportunities for continued collaboration between U.S. DOE and the distributed wind industry in addressing priorities for improving and advancing distributed wind technologies. Working with research and testing laboratories, universities and technical colleges, economic development agencies, and other partners, U.S. distributed wind manufacturing leaders can energize and enhance the industry's involvement in key initiatives and timely opportunities, helping to capture more business, grow market share, and build global competitiveness.

4.1 U.S. Department of Commerce

To further its mission to create the conditions for economic growth and opportunity, the U.S. Department of Commerce works with businesses, universities, communities, and the nation's workers to promote jobs creation, economic growth, sustainable development, and improved living standards for Americans. Its diverse workforce of nearly 47,000 employees includes economists, Nobel-winning scientists, foreign service officers, patent attorneys, law enforcement officers, and specialists in everything from international trade to aerospace engineering. Its 12 bureaus work together to drive progress in five key goal areas: trade and investment, innovation, environment, data, and operational excellence. Partnership opportunities of interest to the distributed wind industry under the "America is Open for Business" Strategic Plan include the International Trade Administration's Market Development Cooperator Program, which supports projects that help U.S. companies generate exports that create or sustain U.S. jobs.

Founded by Congress in 1901 to address U.S. industrial competitiveness and now a bureau of the U.S. Department of Commerce, NIST is one of the nation's oldest physical science laboratories. NIST measurements support technologies ranging from nanoscale devices to global communication networks. NIST's Advanced Manufacturing Office is responsible for administering:

- NNMI Institutes with common goals where industry, academia, and government partners are leveraging existing resources, collaborating, and co-investing to nurture manufacturing innovation and accelerate commercialization

[16] Innovation engineering provides a reliable, scientific system for profitable growth by creating a culture of ongoing innovation within organizations that delivers increased innovation speed and decreased risk. It is a new multi-disciplinary field of academic study and industrial practice based on a body of knowledge comprised of 48 skills blending humanities, engineering, business, and patent law, described at www.innovationengineering.org.

- The interagency Advanced Manufacturing National Program office, which convenes the whole-of-government NNMI program, funded by the Departments of Commerce, Defense, and Energy, creating a competitive research-to-manufacturing infrastructure for U.S. industry and academia to solve industry-relevant problems
- The AMTech program, which has funded the SMART Wind Consortium and 31 other industry-driven technology consortia establishing technology roadmaps to address long-term U.S. industrial research needs

Launched in 2013, AMTech funds broad participation across the value chain through competitive grants to solve high-priority technology challenges and to accelerate the growth of advanced manufacturing in the U.S. As of January 2016, AMTech activities have been merged into NNMI as directed by the Consolidated Appropriations Act of 2016 (H.R. 2029). Technology roadmaps and related AMTech-enabled outputs were to help guide pre-competitive, infrastructural research, some of which will be supported by AMTech in future years through funding for university and government laboratory research. The NNMI was to make use of technology roadmaps in determining which R&D projects to pursue. While the AMTech program will not hold a competition in 2016, decisions regarding possible future competitions will be posted on the AMTech webpage.[17]

4.1.1 Manufacturing Extension Partnership Centers

The vision of the NIST MEP is to serve as a catalyst for strengthening American manufacturing – accelerating its ongoing transformation into a more efficient and powerful engine of innovation, driving economic growth and jobs creation. Public and private resources are leveraged to focus on meeting manufacturers' short-term needs in the context of overall company strategy. MEP centers, shown in Figure 4-1, work regionally to provide engineering services for specific products and processes, apply lean manufacturing principles to eliminate non-value-added activities and waste, improve and streamline quality systems, strategize around sustainability, and assist in workforce development. MEP centers have worked with 31,000 manufacturers on more than 10,000 projects.

Figure 4-1. Manufacturing Extension Partnership Centers across the U.S. (www.mep.nist.gov)

[17] http://www.nist.gov/amo/amtech/index.cfm

Some members of the SMART Wind OEM steering group reported that they had worked with MEP centers on projects including automation equipment design and selecting a new enterprise resource planning package. They reported having positive experiences and would work with the MEP again with a specific request or project to focus on. Others had not worked with their local MEP centers but expressed a desire to receive assistance with specific challenges in low-volume, in-house manufacturing; they noted that the cost of the MEP service could be a barrier.

Action steps that OEMS can undertake with manufacturing and MEP experts include:

- Decreasing inventory and operating expense
- Increasing throughput and revenue
- Improving profitability

4.1.2 Power Electronics Industry Collaborative

The PEIC is a national, industry-driven membership-based consortium comprised of OEMs, component suppliers, researchers, and other stakeholders working to advance the U.S. power electronics industry. The PEIC's vision is to position the U.S. as a global center of power electronics research, design, and manufacturing.

The PEIC has identified three key goals to achieve its vision:

- Industry analyses: Analyze the state of the power electronics industry to understand gaps and opportunities to advance power electronics innovation and manufacturability
- Investment: Advocate for targeted public and private investment in power electronics to accelerate the speed, scale, and development of the U.S. power electronics supply chain
- Workforce development: Develop a highly skilled, competitive domestic workforce to support design and manufacturing needs of the power electronics industry in the U.S.

Since 2012, the PEIC grew from an informal collaboration of four companies in the automotive sector to a fully established 501(c)(6) nonprofit with a diverse and growing membership of 21 organizations including industry, national laboratories, and academia representing a diverse array of technologies used in current and future power electronics.

The PEIC's April 2015 study of the power electronics supply chain concluded that "the supply chain and manufacturing ecosystem for applications that have left the United States will not come back," and that the U.S. needs to focus on emerging applications such as wide bandgap semiconductor materials and components (e.g., SiC and GaN). As shown in Figure 4-2, while Asia is dominating silicon-based materials (SI; large orange blocks at bottom left of graphic), currently there is no dominant supplier of wide bandgap semiconductor materials, leaving an opportunity for the U.S. to lead. The distributed wind industry will benefit from continued collaboration with the PEIC, leveraging its expertise in the power electronics ecosystem.

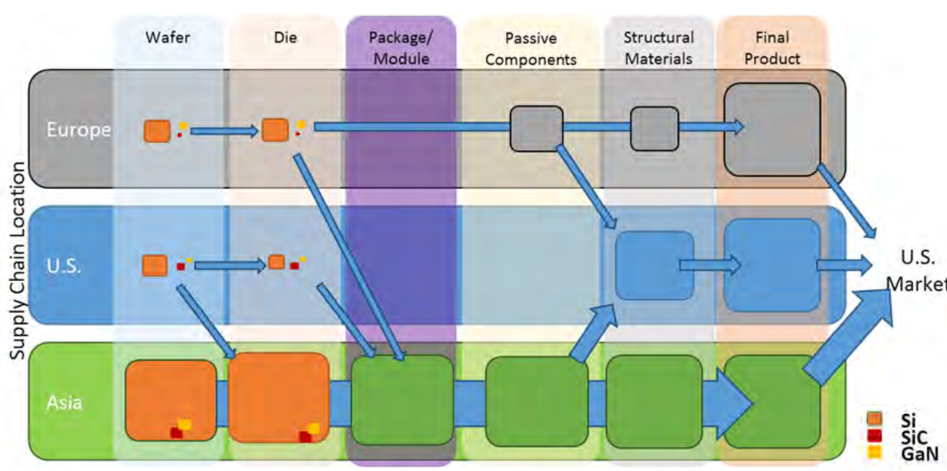


Figure 4-2. PEIC power electronics supply chain, materials (PEIC 2015)

4.1.3 FIBERS Composites Project

The Facilitating Industry by Engineering, Roadmapping and Science (FIBERS) Consortium strives to strengthen U.S. composites manufacturing and innovation by forming a consortium of composites manufacturers and suppliers, government laboratories, academics, and non-profit organizations. The FIBERS Consortium is developing a roadmap to identify the challenges and gaps in the composites manufacturing industry, identify research and development priorities, and create a network of stakeholders prepared to foster solutions.

The main challenges that the FIBERS Consortium is addressing include modeling; automation; new fibers and resins; repeatability of processes (high volume); workforce development for composite design; and disconnect among material suppliers, manufacturing engineers, and technicians. The project aims to identify pre-competitive research and demonstration projects and software and hardware tools to facilitate the advancement of composites manufacturing processes. The end goal of the project is to promote sustained interaction among industry, academia, and government laboratories in the area of composites.

4.2 U.S. Department of Energy

The U.S. DOE's Wind and Water Power Technologies Office has supported distributed wind as part of its mission to enable U.S. deployment of clean, affordable, reliable, and domestic wind and water power to promote national security, economic growth, and environmental quality. U.S. DOE aims to accomplish this by improving the performance, lowering the costs, and accelerating the deployment of innovative wind and water technologies. The Distributed Wind Program's goals include increasing the number of small and medium wind turbine designs certified to performance and safety standards, and reducing the LCOE of wind turbine technology used in distributed applications to be competitive with retail electricity rates and other sources of distributed generation.

In 2014, the U.S. DOE solicited feedback from industry, academia, research laboratories, government agencies, and other stakeholders to help shape future activities on the acceleration of distributed generation from wind energy systems under a formal request for information. Numerous stakeholder responses confirmed strong support for advanced manufacturing research to reduce hardware costs and advanced rotor design development for small and mid-size wind turbines. More than 30 DWEA members submitted letters reinforcing U.S. DOE's role and highlighting the following recommendations, which the Wind Program is working to address. U.S. DOE's ongoing support for distributed wind advanced manufacturing initiatives and turbine technology evolution aligns well with SMART Wind Consortium goals.

1. New or expanded cost-shared programs to support developing advanced components and advanced manufacturing: Launched in 2013, the Competitiveness Improvement Project aims to expand and revitalize U.S. leadership in domestic and international distributed wind markets by helping U.S. manufacturers lower the cost of energy from their turbines and increase their market competitiveness. With its current focus on component and manufacturing process improvements and turbine testing, cost-shared Competitiveness Improvement Project awards help distributed wind turbine companies improve their system designs and earn certification that shows they have met performance and safety standards. SMART Wind Consortium members including Bergey Windpower, Endurance Wind Power, Intergrid, Northern Power Systems, Pika Energy, Primus Wind Power, and Ventera Wind have received Competitiveness Improvement Project awards to reduce hardware costs, improve efficiency, and earn certification from accredited third-party certification bodies, and future funding is anticipated to support additional similar efforts. In the future, project funding could be used to support a variety of technology and manufacturing improvements as directly relevant in supporting the industry in achieving actions identified in this Roadmap.

In addition, as part of its Testing, Manufacturing, and Component Development Project, U.S. DOE is improving the performance, reliability, and time-to-market of components through advanced testing, manufacturing, and development initiatives. The program works with U.S. manufacturers to develop advanced component designs, fabrication techniques, and automation processes that will enable wind turbines to capture more energy and help manufacturers increase their component production capabilities. The Clean Energy Manufacturing Initiative is a U.S. DOE effort focused on strengthening U.S. competitiveness by boosting energy productivity and leveraging low-cost domestic energy resources. For the wind industry, the initiative focuses on additive manufacturing, which distributed wind manufacturers have significant potential to incorporate. U.S. DOE's Small Business Vouchers Pilot program aims to connect clean energy innovators with leading scientists and engineers at select federal laboratories to bring next-generation clean energy technologies to the market faster. SMART Wind Consortium collaborators NREL, Pacific Northwest National Laboratory (PNNL), and SNL are among those selected to lead the pilot, providing access to expertise and tools that can help distributed wind OEMs test, validate, and introduce new products.

2. A substantial initiative to address "soft costs," particularly permitting: As U.S. DOE's platform for disseminating credible information about wind energy, WINDExchange helps communities weigh the benefits and costs of wind energy, understand the deployment process, and make wind development decisions supported by the best available information. U.S. DOE continues its support of the OpenEI Small Wind Guidebook[18] by enhancing its content, services, and data offerings. The Guidebook provides recommendations to potential system owners regarding estimates of costs and best practices gleaned from national resources.

The DOE is funding a "soft costs" project with the goal of reducing non-hardware costs for distributed wind systems. These costs include zoning, permitting, installation, incentives, and other costs that installers and project owners incur. DOE tasked NREL and PNNL with creating a distributed wind taxonomy to clarify categories of costs (e.g., labor for permitting, hardware costs). The taxonomy was developed along with industry, and stakeholders provided comments at the Fall 2015 and Spring 2016 DWEA meetings as well as by email. PNNL and NREL are now gathering data from 10 installers to proof-test a database that will serve to collect baseline information for 2016. After making improvements to the database, it will serve as the repository for regular distributed wind data collection efforts in the future. Having baseline information will allow DOE and industry to track cost and labor trends and be able to make informed decisions on future projects that can bring down the soft costs of distributed wind, enabling more turbines to be deployed.

3. Improved wind maps and performance predictions, with emphasis on active markets: WINDExchange also provides wind maps and data to help homeowners, communities, states, and regions learn more about their available wind resources and plan wind energy projects. The Wind Forecast Improvement Project, while primarily concerned at present with providing reliable wind forecasts for utility wind farms, can inform future decision making in providing better resource predictions, especially for smaller utilities serving large concentrations of distributed wind turbines.

4. Continued support of certification and standards activities: U.S. DOE's Wind Program supported development of technical standards that are now used to test small wind turbines to performance

[18] http://en.openei.org/wiki/Small_Wind_Guidebook

and safety criteria and helped establish the SWCC, which provides accredited third-party verification of test results in accordance with internationally adopted technical standards. To increase the availability of small wind turbine testing and share field expertise, U.S. DOE and NREL initiated the Regional Test Center project in 2009. Test Center partners are located in Utah (Windward Engineering), New York (Intertek), Texas (UL), and Kansas (K-State University/Colby Community College). NREL provided technical assistance as needed during the testing process. The project goal is for the centers to be self-sustaining, independent entities that are capable of providing certification testing services to the small wind turbine industry.

5. Development of an industry roadmap and market forecast: Published by U.S. DOE and produced by PNNL, the annual Distributed Wind Market Report analyzes industry trends that are unique to distributed wind applications, detailing costs, numbers of deployments, performance, capacity factors, types of turbines used, application types, domestic and international markets, and market drivers and barriers. As a compendium of yearly activity, it serves as the industry's trusted source for benchmarking progress and identifying potential obstacles on the way to achieving U.S. DOE industry-sector goals.

NREL has also developed the "dWind" model as part of its larger Distributed Generation Market Demand (dGen) toolset. This new capability provides quantitative intelligence on future diffusion of distributed wind generators. The model decision-making framework relies on broad-based national datasets for wind resource, retail electricity rates, local policy conditions, and other factors to ascertain project level economics. These data are then coupled to consumer-purchasing behavior data to estimate future adoption and deployment. NREL's current work scope is focused on understanding key drivers, market sensitivities, and opportunities at various timeframes out to 2050 (Sigrin et al. 2016).

4.2.1 Institute for Advanced Composites Manufacturing Innovation

The fifth Institute in the National Network of Manufacturing Innovation, supported by the US Department of Energy's Advanced Manufacturing Office, IACMI, is committed to delivering a public-private partnership to increase domestic production capacity, grow manufacturing and create jobs across the US composite industry. IACMI's collaboration of industry, research institutions and state partners is committed to accelerating development and adoption of cutting-edge manufacturing technologies for low-cost, energy-efficient manufacturing of advanced polymer composites for vehicles, wind turbines, and compressed gas storage. IACMI's research, development, and demonstration programs are driven by major industry participation with a focus on reducing technical risk and developing a robust supply chain to support a growing advanced composites industry. Encouragement and development of small- and medium-enterprise industry participants and long term sustainability are key objectives of the Institute.

4.2.2 Power America

Led by NC State University, PowerAmerica, also called the Next Generation Power Electronics National Manufacturing Innovation Institute, is working to make wide bandgap semiconductor technologies cost-competitive with the silicon-based power electronics that are currently used. The Institute is establishing a collaborative community that will create, showcase, and deploy new power electronic capabilities, products, and processes that can impact commercial production, build workforce skills, enhance manufacturing capabilities, and foster long-term economic growth in the region and across the nation.

4.3 Research and Testing Laboratories

As part of efforts to improve performance, lower costs, and accelerate deployment of innovative wind technologies, U.S. DOE provides funding to several national laboratories. In addition to the Labs described below, Idaho National Laboratory's Wind Energy program, Lawrence Berkeley National Laboratory's Electricity Markets and Policy Group, Oak Ridge National Laboratory's Innovations in Manufacturing program, and others may offer opportunities for collaboration.

4.3.1 Argonne National Laboratory

Argonne's wind power technology and analysis program is investigating the root cause of failures to wind turbine drivetrain components, such as bearings and gears, and conducting research on magnetic and nanostructured materials fabrication.

4.3.2 Lawrence Livermore National Laboratory

Lawrence Livermore National Laboratory uses its tools and expertise, including building new partnerships and additive manufacturing, to support renewable energy and smart grid goals.

4.3.3 National Renewable Energy Laboratory

NREL's National Wind Technology Center is the nation's premier wind energy technology research facility, offering the necessary infrastructure, experienced staff, and state-of-the-art equipment needed for research and development of innovative wind energy technologies. The National Wind Technology Center is also home to NREL's Distributed Energy Resources Test Facility, a working laboratory for interconnection and systems integration testing.

4.3.4 Pacific Northwest National Laboratory

PNNL conducts distributed wind market research and analysis and produces the annual Market Report on Wind Technologies in Distributed Applications. As a Lab partner on the industry-led DOE-funded Distributed Wind Policy Comparison Tool project, PNNL developed and helps maintain the pro forma model tool that quantitatively determines how state policies and incentives impact the cost of energy of distributed wind turbines 100 kW in size and smaller.

4.3.5 Sandia National Laboratories

SNL conducts applied research related to improving wind turbine performance and reliability and reducing the cost of energy, specializing in all aspects of wind turbine blade design, manufacturing, and system reliability. SNL researchers work to advance the state of knowledge in materials, structurally efficient airfoil designs, active-flow aerodynamic control, and sensors.

4.4 Universities and Technical Colleges

SMART Wind participants identified establishing internship programs with universities and technical colleges as a priority, particularly focusing on engineering, sales, and marketing.

4.4.1 Appalachian State University

The Sustainable Technology program at Appalachian State conducts hands-on distributed wind energy work at the Small Wind Research & Demonstration Facility at Beech Mountain where students and faculty conduct research, lead workshops, and operate the latest wind technology in a Class 5 wind regime. AppState also serves as a Wind for Schools Application Center and offers Bachelor and Master's degrees in Sustainable Technology and Renewable Energy Engineering.

4.4.2 California Polytechnic State University

The Department of Mechanical Engineering at the California Polytechnic State University, San Luis

Obispo, has developed a wind power research facility focused on the study of blade manufacturing processes, nacelle design and fabrication, wind resource assessment, and novel rotor balance techniques. The facility's goal is to prepare the next generation of wind power mechanical engineers by studying and developing systems according to a design philosophy relevant to utility-scale wind turbines but implemented in small machines suitable for research and teaching. SMART Wind Mechanical Subgroup Leader Dr. Patrick Lemieux's research focuses on the aerodynamic design and control of wind turbine blades, as well as prognostic condition monitoring of rotor systems and the turbine assembly and structure as a whole.

4.4.3 Clarkson University

Clarkson University's Blade Test Facility has supported the SMART Wind Consortium while conducting testing and developing new instrumentation for testing as well as monitoring the performance, operational loads, and structural health of small, distributed wind turbines. Co-directed by Dr. Kerop Janoyan and Daniel Valyou, the facility has conducted an IEC 61400-23 Blade Certification Test on two 7-m wind turbine blades, an IEC 61400-2 certification on one 2-m blade, and is preparing for two IEC Operational Loads tests (one scheduled to last 6 months and the other a full year), as well as its largest IEC 61400-23 blade test to date that will stretch the limits of its blade testing capabilities. Dr. Pier Marzocca, SMART Wind Composites Subgroup Leader, former Co-Director of Clarkson's Blade Test Facility and currently an Associate from RMIT University, focuses his research efforts on aeroelasticity, unsteady aerodynamics, composite structures, structural dynamics and controls of advanced aerospace and wind turbine technologies, including active flow and aeroelastic controls of flexible structures, structural health monitoring and damage progression in composites, and development of reduced order models and computational tools.

4.4.4 James Madison University

The Small Wind Training and Testing Facility at James Madison University was designed and is equipped for installer training and field testing of small wind turbines. The facility features a Bergey 10 kW (de-rated to 7.5 kW) XL-R wind turbine and is prepared to receive two Skystream 2.4-kW turbines and a Gaia 11-kW turbine, as well as updated monitoring systems that enable performance comparisons between turbines and online access to data. The Skystream turbines are deployable and intended primarily for installer training purposes. The lattice tower that supports the Bergey is equipped with 12 mechanical and ultrasonic sensors at three elevations. The facility is sufficiently flexible to support performance verification, prototype testing, and research intended to improve existing designs. The facility was designed to provide a resource to students and those in the business community who wish to become educated on small wind turbine design, deployment, operation, and maintenance. The facility's underlying goals are to provide a unique resource to the region; train a future wind workforce; provide hands-on, experiential teaching of K-12 students; engage interested stakeholders; and emphasize the importance of safety, appropriate resource assessment, and the benefits of wind power.

4.4.5 Kansas State University

Kansas State University operates the High Plains Small Wind Test Center, which completed testing its first wind turbine and started testing its second in 2015, after the manufacturer completed a controller redesign. The site is open for at least 3 more turbines, and distributed wind turbine testing is expected to continue. Research activities in improved inverter design are being pursued primarily by Dr. Behrooz Mirafzal; he is interested in increasing fault-tolerance in power electronics leading to inverters that gracefully continue operation upon loss of grid signal and gracefully reconnect to the grid when the signal is re-established. The latter is difficult to complete in practice, as disconnect switches that can re-connect without manual intervention are difficult to design. Other innovations under investigation include assessing generator health through easily measured variables such as temperature of conductors and harmonics in the generated power signal. SMART Wind Electrical Subgroup leader Dr. Ruth Douglas Miller has recently focused efforts on making data from Wind for Schools Project wind turbines widely and reliably available; she hopes to develop tools to analyze the resulting large body of wind data for both educational purposes and wind energy prediction.

4.4.6 University of California-Davis

The University of California-Davis Mechanical and Aerospace Engineering Department examines blade aerodynamic design and has recently focused on the following new concepts: high lift-to-drag outboard section shapes, blunt trailing edge inboard section shapes, swept blades, vortex generators, serrated trailing edges, and active load control. Wind turbine rotor aerodynamics have evolved considerably in the past 30 years, and some of the main developments include improved computational tools for design and analysis, a shift from National Advisory Committee for Aeronautics airfoil sections to custom designed section shapes, and the use of iterative concurrent blade design. The effect of surface soiling and erosion on performance has been a recurring problem, and aeroacoustic sound now plays a critical role in blade design. Active aerodynamic load control is also receiving significant attention. Research efforts of SMART Wind Composites Subgroup leader Dr. Case van Dam have recently focused on wind tunnel testing of airfoils and wind energy conversion systems, computational fluid dynamic analysis of airfoils and rotors, full-scale aerodynamic testing of various systems, and active control of the aerodynamic loads acting on wind turbine blades.

4.4.7 University of Massachusetts Lowell

The Wind-Energy Science, Technology, and Research (WindSTAR) Industry/University Cooperative Research Center is a collaboration between UMass Lowell and the University of Texas at Dallas that performs research in composites and blade manufacturing; foundations and towers; manufacturing and design; structural health monitoring; non-destructive inspection and testing; control systems, energy storage, and grid integration; and wind system planning, siting, and O&M . Dr. Christopher Niezrecki, WindSTAR Director and SMART Wind collaborator, conducts research in structural dynamics, non-destructive inspection, structural health monitoring, acoustics, smart structures and materials, active vibration control, and blade testing. His work is focused on developing encapsulated self-healing solvent or epoxy-amine chemistries applicable to blade material systems to improve the fatigue life in fiber-reinforced materials, increase blade reliability, and extend service life while minimizing manual inspection and intervention. Access to an easy-to-use virtual design tool that considers the mechanical behavior of the fabric is also a top priority to reduce the potential for defects during blade design and manufacturing processes.

4.5 State Agencies and Other Partners

Some state and local economic development agencies offer support for local manufacturing, such as the Michigan Accelerating Technologies program. NextEnergy maintains listings of active and upcoming funding opportunities, a helpful resource for SMART Wind participants to monitor.[19] The Clean Energy States Alliance is a national nonprofit coalition of public agencies and organizations working together to advance clean energy, which manages the Interstate Turbine Advisory Council

[19] https://www.nextenergy.org/active-funding-opportunities/

(ITAC), an alliance of clean energy programs and utility incentive providers working jointly to tackle the challenges and promotes the potential of the small and mid-scale wind market.

Launched in March 2015, the White House Supply Chain Innovation Initiative focuses on public-private partnerships and federal efforts to strengthen U.S. manufacturing by closing gaps between large and small-scale manufacturers. The initiative presents unique opportunities for OEMs to partner with small businesses in supply chains to accelerate technology adoption, strengthen domestic linkages, and improve product design and process engineering.[20]

5 Strategy Summary and Conclusions

Distributed wind is poised to play a valuable role in building America's clean energy economy and modernizing our electric power grid to incorporate climate and consumer-friendly technology innovations. SMART Wind activities advance wind turbines sited near their end users, which provide numerous unique economic, technical, environmental, and social benefits to individuals, businesses, utility companies, and communities.

Distributed wind has great potential to serve increasing demands for distributed generation and can provide a cost-effective solution for many homes, farms, schools, and other end-users. Distributed wind is an important part of the changing U.S. energy portfolio, and offers increased security of energy supply as well as community awareness of clean energy options. A strong distributed wind industry encourages domestic manufacturing and innovation, furthers energy independence, reduces emissions from electricity generation, and reduces dependence on expanded transmission. Distributed wind energy encourages active participation in generating electricity and evolving the U.S. energy market. DWEA's SMART Wind efforts are influencing that evolution.

5.1 Key Recommendations and Next Steps

An online poll ranking more than 170 action items identified by SMART Wind Consortium participants helped to shape the following action plan to address top industry barriers and increase global sales, OEM profitability, and U.S. jobs. Table 5-1 below shows a summary of action items ranked as top priority by 80 respondents, including 16 OEMs, sorted by Subgroup and by the timeframe identified as appropriate for each (near-term, mid-term, and long-term), and as reviewed and approved by the SMART Wind OEM Steering Group.

Many conclusions can be drawn from the detailed poll results. The poll questions were divided into two sectors: micro/residential and commercial/mid-size; most actions are included for both, but often the timeframes differ between the sectors. The top and medium priorities are summarized below. The intent is to cover an installed turbine system and seek actions that will reduce the LCOE through changes in manufacturing processes as well as evolution of the hardware and software designs. The challenge is in how to make significant cost reductions in a micro-capitalized industry with a shifting market, which is currently dominated by exports.

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.

[20] https://www.whitehouse.gov/blog/2015/08/17/invented-america-made-america

Table 5-1. Summary of Top Priority Actions by Subgroup and Timeframe

	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 smart grid/resiliency requirements • Address impact of low voltage ride-through and high voltage ride-through requirements on induction machines • 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 over time • Explore possibility of 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 the small wind turbine addendum • Increase U.S. tower supply by adapting approaches used in the utility and communications industries • Gather test data to validate turbine dynamic models • Design, build, and test family of towers that could be used by several OEMs • Develop U.S. monopole tower supply • Develop tower certification strategy	• Model and explore the use of slip-fit, tapered tower to address loads and dynamics • Understand tower dynamics, how other tower industries can address distributed wind industry needs • Develop turbine and tower design to ease maintenance • Explore a standard industry tower with flange attachments • Investigate commercial viability of other anchoring systems • Develop common, pre-fabricated foundations for multiple OEMs • Investigate functional/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

	Short-Term (0-3 years)	Mid-Term (3-7 years)	Long-Term (7-10 years)
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/real parts • Work with machining companies on manufacturability • Research materials, lubricants, and gear oil for 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 to account for full turbine dynamics and control • Address accuracy of performance modeling of distributed wind turbines • Provide public education and economic tools, refute 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

The solutions to balance manufacturing and technology improvements will likely be specific to each OEM, so what makes sense for one may not make sense for another. This is particularly evident given the wide size range of wind technologies, from hundreds of Watts to just under 1 MW. Grouping the two wind turbine size sectors helps to clarify the poll data, but it does not account for specific turbine topology and needs for manufacturing and technical support.

The sections below are organized into topical areas of needed actions. Sometimes an action can fit in multiple sections, but it is only mentioned once here for the purpose of brevity. These items are a list of actions the industry can take; they are not directed at anyone or any specific OEM in particular. Section 4 lists distributed wind industry partners who have a vested interest in developing these actions. It is hoped that partners will work together to address these needed actions and move the industry forward.

5.1.1 Optimize Wind Turbine Design

Priority actions to optimize wind turbine design, achieve higher efficiency, and lower costs include:

Near-term for both micro/residential and commercial/mid-size sectors

- Refine FAST to account for full turbine dynamics and control
- Innovate blade design with advanced materials, and manufacturing methods and overspeed control (aerodynamics, pitch, other)
- Develop post-manufacturing non-destructive testing methods; verify new blade designs through testing to estimated lifetimes

- Explore the possibility of modular, space-frame blade design
- Validate electrical designs through component testing, ensuring that the designs meet UL/IEEE 6142, 6141, and NEC and will have capabilities to meet Smart Grid opportunities and requirements
- Work with NREL staff on the latest research on new generator concepts

Near-term for the commercial/mid-size sector only

- Develop new blade design based on blade manufacturing technique; develop blade that can be incorporated into multiple turbine designs
- Leverage power system simulators to test grid compatibility and system integration aspects
- Research VFDs for distributed applications
- Work with SNL and others to:
    - Develop open source design and analysis tools for blade design that consider structural and aerodynamic design and material selection
    - Survey OEMs and developers on blade reliability to determine top issues and build on materials database

Mid-term for the micro/residential sector

- Work with SNL and others to:
    - Develop open source design and analysis tools for blade design that consider structural and aerodynamic design and material selection
    - Survey OEMs and developers on blade reliability to determine top issues
- Leverage electromagnetic and thermal design expertise at NREL to:
    - Support the development of new efficient inverters, robust generators, and other electrical components
    - Integrate the wind turbines into the "Internet of Everything"
- Leverage latest research results on new magnetic and capacitive components; utilize thermal management simulations (e.g. Argonne National Laboratory)

Mid-term for the commercial/mid-size sector

- Develop more sophisticated grid control and monitoring capabilities
- Incorporate micro-grids and storage; examine existing and proposed small-scale solutions (Tesla, Enphase)

Mid-term for both sectors

- Research additive manufacturing for prototyping, molds, and real parts

5.1.2 Improve Manufacturing Parts, Materials, and Processes

Domestic wind turbine manufacturing can be a complex, expensive endeavor, especially as technology improves and OEMs make higher-quality products. The distributed wind industry can benefit by increasing collaboration with other industries and by standardizing components for use by multiple OEMs. The main manufacturing parts, materials, and processes actions include:

Parts

- Develop a supplier directory for wind turbine parts, components, and designers
- Initiate a new "Made-in-America" effort that could focus on U.S. companies to:

    - Identify potential U.S. regional manufacturing supply, participate in their industry meetings, and introduce the possibility of working with the distributed wind OEMs
    - Prioritize those subsystem/components that are currently in short supply (casting, mechanical subsystems, etc.)
    - Develop a targeted campaign to find a new U.S. tower supply (utility-scale wind suppliers, streetlight pole manufacturers, electric utility pole manufacturers, other), particularly monopole towers with base diameters above 80” but also smaller towers
    - Improve power electronics by using advanced magnetic/wide bandgap materials to achieve higher reliability of smaller, more efficient, and faster switching power conditioning units that can operate at higher bus voltages with greater prognostic condition monitoring capabilities – very limited U.S. supply provides opportunity to develop power electronics for multiple OEMs using a standard core and modules unique to specific turbine models

Materials

- Identify new materials for long-life brakes, carbon shaft materials (the commercial/mid-size sector only), bushing materials for sliding applications, new lubricants, etc.
- Find new, reliable methods for galvanizing (near-term for commercial/mid-size, mid-term for micro/residential sector)
- Develop blade coatings and systems that resist erosion and icing, along with fiber treatment to minimize hydrophobic matrix and hydrophilic fiber issues (micro/residential sector)
- Research moving fluids and gear box oils for cold climates (commercial/mid-size sector only)
- Explore new efficient blade manufacturing materials, fixturing, and tooling costs (carbon-fiber, thermoplastics, H-glass, sustainable products such as bamboo, natural cellulose fibers for reinforcement and bio-based resins) to obtain high strength, stiffness, toughness and adhesion

Processes

- Improve understanding of existing U.S. manufacturing process expertise and the advanced materials that can be used
- Provide targeted manufacturing process support to OEMs that is specific to their companies (streamlined processes, semi-automation, use of robotics, etc.)
- Have a roving “process engineer” that could work on providing focused, tailored advice on how to streamline the manufacturing/assembly processes for each OEM
- Lower fixturing and tooling costs to reduce the per-unit costs
- Link directly with machining companies to streamline the design for ease of manufacturability
- Research additive manufacturing for prototyping, molds, and real parts (near-term for micro/residential sector)
- Identify better ways to automate stator windings
- Research advanced casting and mold manufacturing techniques; develop new competitive partnerships
- Develop post-manufacturing non-destructive testing methods for blades to identify defects and/or to examine cycled blades for wear patterns that develop over time

5.1.3 *Optimize Standards and Certification*

Safety and performance certifications improve distributed wind credibility and are now recognized as industry best practices in addition to being required for qualification for many federal and state incentives. Standards and certification actions prioritized by SMART Wind participants include:

Near-term

- Conduct a gap analysis for certification requirements for various global markets; educate and promote certification to maintain quality
- Assess how changing a turbine design impacts certification requirements
- Refine TIA-222-G Addendum 4; develop an alternative or improve the small wind turbine addendum to better reflect turbine loads, deflections, and dynamics. One approach could be developing a better understanding of turbine dynamic and static loads through measurements
- Tower certification methodology could be developed that would allow for variations in tower height, size, and supply
- Improve international standard IEC 61400-2 to account for better understanding of structural and aeroelastic modeling capabilities, fatigue, and safety factors
  - Update FAST and collect measurements to validate dynamics and towers, and key model assumptions to be used in refining the code
  - Develop improved and verifiable fatigue life prediction methods through blade structural testing and modeling
- Encourage international consolidation of standards and requirements, specifically for the commercial/mid-size sector

Mid-term

- Determine how to enable safe work operations through turbine platforms, lifting eyes, tie-down points, etc. in consideration of human limitations
- Develop an approach to certify towers, including standards development and setting up testing laboratories and certification bodies
- Present and discuss technical research findings from improved, validated models and test results to be considered by the expert standards-making committees for incorporation into future international standards

5.1.4 *Streamline Installation and Maintenance of Turbine System*

To drive down LCOEs, reductions are needed in OEMs' cost-of-goods sold, installation, and O&M while improving reliability and safety. SMART Wind participants prioritized the following actions to reduce overall installation and O&M costs with more effective and proactive service:

- Develop low-cost prognostic condition monitoring to give the installer and OEM more information about the turbine system
- Design turbines for ease of installation and maintenance
- Design concrete-efficient foundations
- Investigate commercial viability of other anchoring systems
- Develop an integrated system with other renewable and dispatchable technologies
- Develop training for micro/residential installers to install, operate, and maintain distributed wind turbine systems, with emphasis on tower climbing and safety

- Conduct a time-motion installation study to find ways to reduce time and labor
- Explore possibilities of monitoring blade degradation (erosion, blade cracking, lightning, etc.) while in service to predict remaining lifetime and support development of better damage models (near-term for micro/residential sector)

5.1.5 Expand Partnerships

- Collaborate with energy storage industry on storage approaches involving distributed wind
- Collaborate with the electric vehicle and micro-hydro industries to co-design motor/generator and power electronics solutions. The electric vehicle industry offers a new marketing opportunity for commercial/midsize turbines: charging vehicle fleets and micro/residential turbines for consumers' electric vehicles
- Look for new composite blade partners, such as the surfboard industry

5.1.6 Continue Sustainable Consortium Activities

SMART Wind Consortium participants agreed on the importance of sustaining momentum with collaborative actions, including:

Near-term

- Continue as a SMART Wind OEM steering committee, building stronger relationships among industry leaders. Future support could include developing a joint supplier directory, screening and selecting targeted U.S. suppliers, etc.
- Research bulk purchase by multiple OEMs for electrical parts for micro/residential wind turbines
- Develop a joint tapered tower with flange attachment design with manufacturing stakeholders, starting with the micro/residential sector

Mid-term

- Build on work in micro/residential sector to develop a joint tapered tower with flange attachment design with manufacturing stakeholders for the commercial/mid-size sector
- Research slip-fit tapered tower options for both distributed wind turbine size sectors
- If there is convergence on blade materials and parts, develop long-term supplier contracts for increased supply at competitive costs

5.1.7 Overall Industry

The SMART Wind action ranking poll allowed respondents to write in additional comments; the following were viewed to be outside the scope of initial SMART Wind Subgroups but worth noting:

- The industry is experiencing a shortage of educated power electronics engineers
- Trainings are needed in key export markets on technology selection, site evaluation, installation, and O&M
- Industry involvement with future U.S. DOE Collegiate Wind Competitions is needed to ensure distributed wind themes are included and projects that focus on advanced manufacturing for distributed wind-scale technology are invited
- There are numerous public education opportunities, especially in refuting myths and providing support for permitting and zoning needs
- Training on computer-aided engineering tools is needed

- Improved site assessment of complex terrain and turbulence modeling are needed to better reflect actual turbine production
- Mentorship and outreach programs should be developed to increase workforce diversity
- National utility interconnection zoning rules should be established
- Shared industry-wide reliability and materials databases (what works, what does not) should be developed
- Opportunities should be identified to cross-train people to prepare for scaling up
- A thorough understanding of turbine reliability, lifetime, and O&M is needed to improve cost certainty, activate financiers, and stimulate new markets using different financial models (similar to utility-scale wind and solar markets)

5.2 DWEA Sustainability Plan: Next Steps

A follow-up study to understand the costs and quantifiable benefits of each of the priority actions identified could help maintain project momentum and further advance the goals of the SMART Wind Consortium. DWEA leaders and members have pledged to sustain the SMART Wind private/public collaboration, working to implement Roadmap priority actions and facilitating technology transfer from R&D to manufacturing. At the conclusion of the formal NIST-funded Consortium activities, SMART Wind's leadership is committed to continuing a standing collaborative open to all DWEA members focused on advanced manufacturing and driving down costs.

DWEA plans to host revenue-generating events addressing SMART Wind topics such as OEM strategy meetings and manufacturing and supply chain workshops or webinars to continue to grow membership and organizational funding for related efforts. DWEA's Board of Directors recognizes the value in continuing to convene industry leaders and representatives from academic institutions leading research and design, public entities providing funding and having an interest in certification and standards, as well as other suppliers, vendors, and partners in the private sector who develop projects and install equipment.

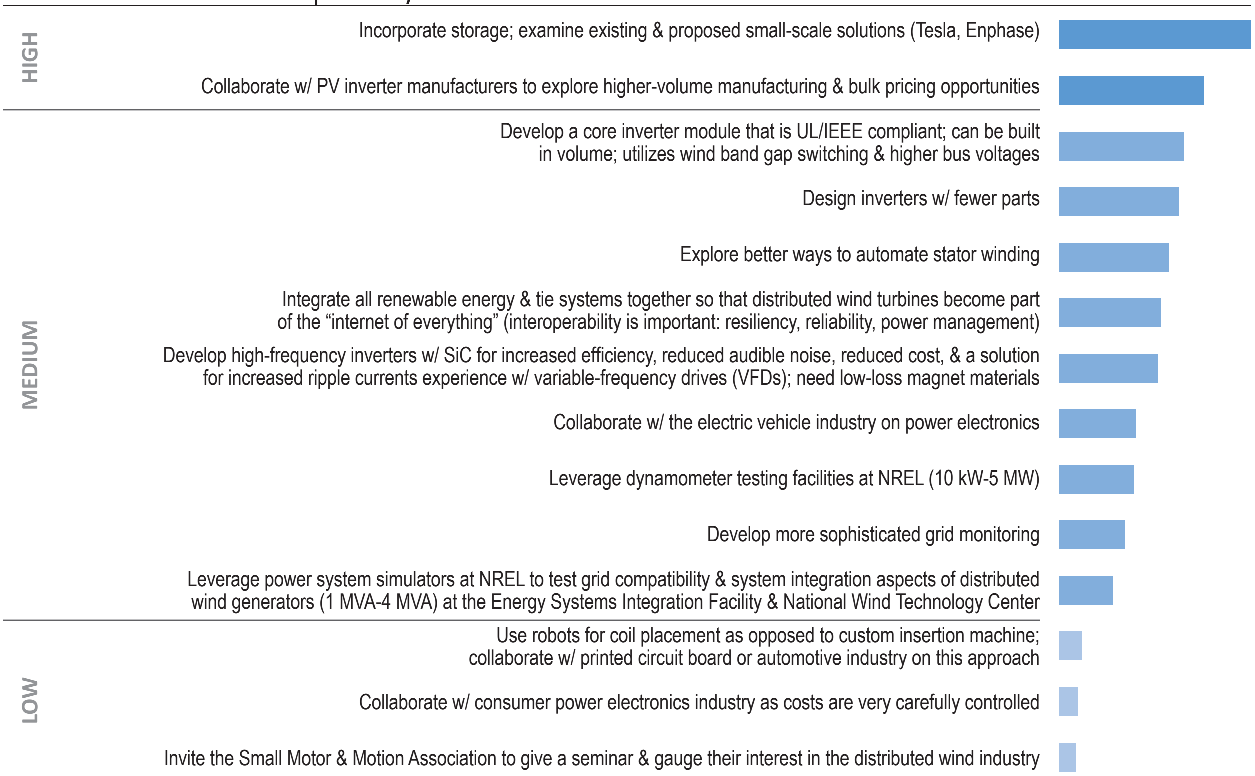
More than four dozen Consortium participants have pledged ongoing support by: helping plan future SMART Wind events; serving as speakers and sponsors; assisting with preparing funding applications to pursue SMART Wind actions; renewing or initiating DWEA membership; financially supporting SMART Wind-led competitions; serving as mentors for newcomers to distributed wind; spreading the word through social media; advising and instructing university students, and participating in the Collegiate Wind Competition; specifying inverters and storage systems for distributed wind applications; and providing legal and policy support; and promoting distributed wind best practices.

Because improving wind turbine designs, components, and manufacturing processes and validating wind turbine performance and safety are critical for ensuring long-term sustainability of the distributed wind industry, DWEA will encourage continued federal funding and investigate new sources to support R&D, testing, and certification efforts. The SMART Wind Consortium will continue facilitating innovation into American-manufactured wind turbines, improving U.S. global competitiveness and supporting a dramatic scale up of distributed wind.

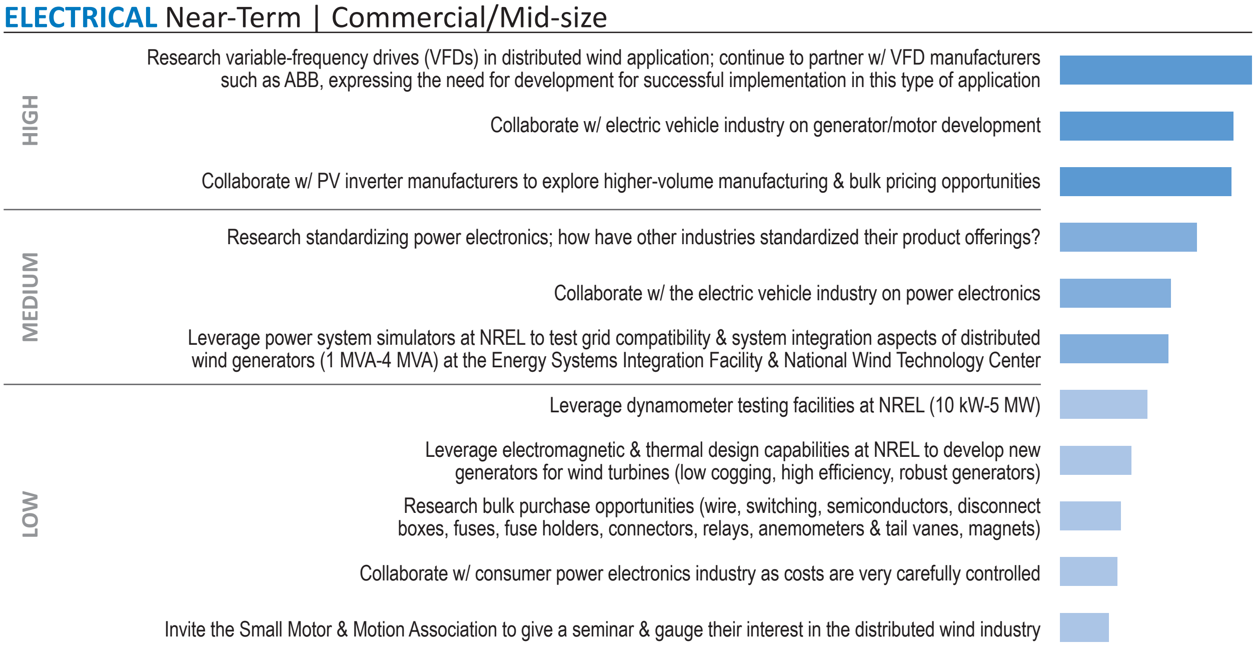
Appendix A. Near-Term, Mid-Term, and Long-Term Actions

The charts below reflect the results of the online poll of action item rankings from 80 respondents, weighted to balance OEMs and non-OEMs. These results were reviewed and adjusted through a consensus process with Consortium leaders to reach the final recommended priorities.

ELECTRICAL Near-Term | Micro/Residential



ELECTRICAL Near-Term | Commercial/Mid-size



ELECTRICAL Mid-Term | Micro/Residential

HIGH

- Research variable-frequency drives (VFDs) in distributed wind application; continue to partner w/ VFD manufacturers such as ABB, expressing the need for development for successful implementation in this type of application
- Leverage electromagnetic & thermal design capabilities at NREL to develop new generators for wind turbines (low cogging, high efficiency, robust generators)

MEDIUM

- Collaborate w/ electric vehicle industry on generator/motor development
- Research bulk purchase opportunities (wire, switching, semiconductors, disconnect boxes, fuses, fuse holders, connectors, relays, anemometers & tail vanes, magnets)
- Research improved technology for stator laminations (helical winding, notching)
- Incorporate new wide band gap switching materials (e.g. Silicon Carbide, SiC, & Galium Nitride, GaN) into power electronics
- Encourage trade schools & universities to focus on & offer training for the growing power electronics industry

LOW

- Research the use of smaller inductors for inverters using wind bandgap magnetic materials
- Pursue the commercialization of Litz wire for use in inverter inductors

ELECTRICAL Mid-Term | Commercial/Mid-size

HIGH

- Integrate all renewable energy & tie systems together so that distributed wind turbines become part of the "internet of everything" (interoperability is important: resiliency, reliability, power management)
- Incorporate storage; examine existing & proposed small-scale solutions (Tesla, Enphase)

MEDIUM

- Develop a core inverter module that is UL/IEEE compliant; can be built in volume; utilizes wind band gap switching & higher bus voltages
- Develop more sophisticated grid monitoring
- Investigate how to meet new IEEE 1547 requirements w/ induction generators
- Collaborate w/ micro-hydro industry on generator & power converter (market expansion)

LOW

- Design inverters w/ fewer parts
- Develop high-frequency inverters w/ SiC for increased efficiency, reduced audible noise, reduced cost, & a solution for increased ripple currents experience w/ variable-frequency drives (VFDs); need low-loss magnet materials
- Research improved technology for stator laminations (helical winding, notching)
- Explore better ways to automate stator winding
- Incorporate new wide band gap switching materials (e.g. Silicon Carbide, SiC, & Galium Nitride, GaN) into power electronics
- Use robots for coil placement as opposed to custom insertion machine; collaborate w/ printed circuit board or automotive industry on this approach
- Develop magnetics & capacitive components w/ national labs; utilize thermal management simulations (e.g., Argonne National Lab)

ELECTRICAL Long-Term | Micro/Residential

HIGH

- Research standardizing power electronics; how have other industries standardized their product offerings?

MEDIUM

- Investigate how to meet new IEEE 1547 requirements w/ induction generators
- Develop magnetics & capacitive components w/ national labs; utilize thermal management simulations (e.g., Argonne National Lab)
- Collaborate w/ micro-hydro industry on generator & power converter (market expansion)

LOW

- Collaborate w/ marine hydrokinetic generation industry (market expansion)

ELECTRICAL Long-Term | Commercial/Mid-size

HIGH

- Encourage trade schools & universities to focus on & offer training for the growing power electronics industry

MEDIUM

- Collaborate w/ marine hydrokinetic generation industry (market expansion)

LOW

- Research the use of smaller inductors for inverters using wind bandgap magnetic materials
- Pursue the commercialization of Litz wire for use in inverter inductors

COMPOSITES Near-Term | Micro/Residential

HIGH

- Explore new materials & processes for blades (carbon-fiber, thermoplastics, H-glass, sustainable products such as natural cellulose fibers for reinforcement & bio-based resins) to obtain high strength, stiffness, toughness, & adhesion
- Explore new efficient manufacturing solutions, including microwave bonding & joining, automated fabric & tape laying, pultrusion, injection & additive manufacturing processes
- Develop improved & verifiable fatigue life prediction methods to support IEC61400-2 standards

MEDIUM

- Validate blade design through blade structural testing
- Develop spectrum load testing methodology for small wind turbine blades (most failures may occur at low cycle fatigue; small turbine blades may respond better to spectral loading, depending on manufacturing technique & materials)
- Determine need for &, if warranted, develop techniques) for post-manufacturing testing of blades to identify defects by non-destructive means &/or to examine cycled blades to examine for wear patterns that develop over time
- Develop joint proposal for DOE Composites Manufacturing Institute technology demonstration
- Develop new solution to improve blade stiffness without weight penalty

LOW

- Develop families of blades w/ common bolt patterns that could be used in part or in whole by multiple OEMs

COMPOSITES Near-Term | Commercial/Mid-size

HIGH

- Develop families of blades w/ common bolt patterns that could be used in part or in whole by multiple OEMs
- Develop long-term contracts, enough materials & parts to drive costs down
- Develop improved & verifiable fatigue life prediction methods to support IEC61400-2 standards
- Determine need for &, if warranted, develop techniques) for post-manufacturing testing of blades to identify defects by non-destructive means &/or to examine cycled blades to examine for wear patterns that develop over time

MEDIUM

- Develop coatings & systems that resist erosion, icing, along w/ fiber treatment to minimize hydrophobic matrix & hydrophilic fiber issues
- Work w/ Sandia & Montana State to build on materials database & blade design
- Develop better open source design & analysis tools for composites in blade structures; more capabilities are required than are currently available
- Develop integrated, iterative approach between design & blade manufacturing
- Develop airfoils that are not so sensitive to surface roughness; test them in wind tunnels

LOW

- Document research results on composite blade structural design & dynamic behavior
- Develop methodologies for manufacturing process control
- Validate blade design through blade structural testing
- Develop spectrum load testing methodology for small wind turbine blades (most failures may occur at low cycle fatigue; small turbine blades may respond better to spectral loading, depending on manufacturing technique & materials)
- Conduct a study to evaluate aeroacoustics w/ vortex generators

COMPOSITES Mid-Term | Micro/Residential

HIGH

- Develop coatings & systems that resist erosion, icing, along w/ fiber treatment to minimize hydrophobic matrix & hydrophilic fiber issues
- Develop better open source design & analysis tools for composites in blade structures; more capabilities are required than are currently available
- Explore possibilities of monitoring blade degradation while in service as to predict remaining lifetime & to support the development of better damage models

MEDIUM

- Develop materials w/ longer life cycles
- Identify low cost & reliable health & usage monitoring systems (HUMS) for blades that can be used to evaluate the effect of lightning strikes, ice, & hailstorms
- Develop airfoils that are not so sensitive to surface roughness; test them in wind tunnels
- Develop methodologies for manufacturing process control
- Research experimental mechanics for load determination in small blades; real-time loading of blades
- Address the fact that XFoil, Navier-Stokes (may need fundamental research) don't predict roughness, & that in-flow conditions are not well understood
- Document research results on composite blade structural design & dynamic behavior
- Work w/ Sandia & Montana State to build on materials database & blade design
- Develop practical approaches for achieving damage tolerant design
- Develop methods & models that describe production defects effects during production
- Develop better blade reliability information
- Investigate ways to work w/ manufacturers of other products, share info (e.g., surfboard manufacturers)

LOW

- Conduct a study to evaluate aeroacoustics w/ vortex generators
- Encourage development of 13-m, 14-m blade for Sandia SWIFT program that might also be commercialized; could be part of technology demonstrator

COMPOSITES Long-Term | Micro/Residential

HIGH

- Identify and/or engineer new materials that can lead to an increase in tensile strength in the fiber direction, increase in shear strength in the out-of-plane direction, & increase in a compressive strength

MEDIUM

- Develop integrated, iterative approach between design & blade manufacturing
- Develop long-term contracts, enough materials & parts to drive costs down

LOW

- Explore whether 13-m to 27-m modular space frame blades are possible; they would not require molds

SUPPORT STRUCTURES - TOWERS Near-Term | Micro/Residential

HIGH

- Determine how to refine TIA 222 for more wind turbine tower loads & deflections
- Adapt distributed wind turbine towers to have higher US manufacturing content similar to utility & wireless (self-support, galvanized, slip joints, step bolts)
- Use test data to validate better dynamic simulation capability for monopole towers; develop models that capture the turbine-tower coupling effects
- Pole manufacturers are in almost every state, but many may be unaware of the small & distributed wind industries; determine whether they could be open to new partnerships (e.g., highway signs, transmission lines, etc.)
- Design, build, & test a family of towers for different OEMs

MEDIUM

- Explore the possibility of creating an industry-standard, tapered tower design w/ flange attachments
- Collaborate w/ partner organizations to build cost-competitive domestic structural support supply chain
- If there is interest from multiple OEMs, work together to negotiate as a cooperative w/ suppliers (possible better terms)

LOW

- Develop automated methods or better tools to ensure higher quality, repeatable tower welds
- Conduct modal analysis & create Campbell diagrams for a number of tower cases w/ soil variations & interactions for the turbine & towers; use results as input to technical discussions on fatigue for IEC 61400-2
- Conduct dedicated finite element analysis to verify the effect of uncertain positioning & friction on modal performance for slip joints

SUPPORT STRUCTURES - TOWERS Near-Term | Commercial/Mid-size

HIGH

- Improve U.S. monopole design & supply for base diameters above 80”
- Pole manufacturers are in almost every state, but many may be unaware of the small & distributed wind industries; determine whether they could be open to new partnerships (e.g., highway signs, transmission lines, etc.)

MEDIUM

- Determine what can be learned from other industries about tower building & lifting approaches; NREL could offer workshop on how dynamic loads differ between wind turbines & transmission towers to educate tower manufacturers
- Conduct design review, testing for at least a 6-month period, & 3rd-party certification of each new support structure & foundation design & concept prior to commercialization
- Determine how to refine TIA 222 for more wind turbine tower loads & deflections
- Collaborate w/ partner organizations to build cost-competitive domestic structural support supply chain
- Identify how to reduce cost & ensure flatness of tower flanges

LOW

- Investigate hot dip galvanizing options including cost-effective coatings
- Conduct modal analysis & create Campbell diagrams for a number of tower cases w/ soil variations & interactions for the turbine & towers; use results as input to technical discussions on fatigue for IEC 61400-2
- Develop performance specifications in the distributed wind industry for tower coatings
- Develop automated methods or better tools to ensure higher quality, repeatable tower welds
- Examine HS Code: 7308.20 / Custom duty on Chinese poles

SUPPORT STRUCTURES - TOWERS Mid-Term | Micro/Residential

HIGH

- Determine what can be learned from other industries about tower building & lifting approaches; NREL could offer workshop on how dynamic loads differ between wind turbines & transmission towers to educate tower manufacturers
- Determine how to enable time-efficient work platforms, tie-off points, & better climbing & safety approaches

MEDIUM

- Explore slip-fit, tapered compared to mechanically coupled towers from a loads & dynamic perspective
- Investigate hot dip galvanizing options including cost-effective coatings
- Examine HS Code: 7308.20 / Custom duty on Chinese poles

LOW

- Research sound-deadening material for application inside the tower
- Identify how to reduce cost & ensure flatness of tower flanges
- Improve U.S. monopole design & supply for base diameters above 80”
- Find U.S. small batch/tailored galvanizing partner (perhaps through MEPs)
- Develop performance specifications in the distributed wind industry for tower coatings
- Develop tower coatings for touching up nicks (e.g., from shipping) using kits/cartridges application
- Explore different welding methods & develop inexpensive scalability strategies (i.e., spiral welding in the field, robotic welding, etc)
- Conduct design review, testing for at least a 6-month period, & 3rd-party certification of each new support structure & foundation design & concept prior to commercialization

SUPPORT STRUCTURES - TOWERS Mid-Term | Commercial/Mid-size

HIGH

- Explore slip-fit, tapered compared to mechanically coupled towers from a loads & dynamic perspective
- Explore the possibility of creating an industry-standard, tapered tower design w/ flange attachments

MEDIUM

- Design, build, & test a family of towers for different OEMs
- Adapt distributed wind turbine towers to have higher US manufacturing content similar to utility & wireless (self-support, galvanized, slip joints, step bolts)
- Account for human safety & safe installation requirements in future designs, such as increase the number of anchor points, address spacing of climbing pegs, ensure clip-off points (see Roadmap for full list of recommendations)
- Use test data to validate better dynamic simulation capability for monopole towers; develop models that capture the turbine-tower coupling effects
- If there is interest from multiple OEMs, work together to negotiate as a cooperative w/ suppliers (possible better terms)

LOW

- Research sound-deadening material for application inside the tower
- Explore different welding methods & develop inexpensive scalability strategies (i.e., spiral welding in the field, robotic welding, etc.
- Work w/ MEPs to transition highway sign manufacturers to turbine tower manufacturers
- Develop tower coatings for touching up nicks (e.g., from shipping) using kits/cartridges application
- Investigate research in sub-surface corrosion protection methods & materials
- Find U.S. small batch/tailored galvanizing partner (perhaps through MEPs)
- Conduct dedicated finite element analysis to verify the effect of uncertain positioning & friction on modal performance for slip joints
- If using slip-fit towers, determine how installers climb

SUPPORT STRUCTURES - TOWERS Long-Term | Micro/Residential

HIGH

- Account for human safety & safe installation requirements in future designs, such as increase the number of anchor points, address spacing of climbing pegs, ensure clip-off points (see Roadmap for full list of recommendations)

MEDIUM

- Investigate research in sub-surface corrosion protection methods & materials
- If using slip-fit towers, determine how installers climb

LOW

- Work w/ MEPs to transition highway sign manufacturers to turbine tower manufacturers
- Investigate composites for towers (no huge cost advantage; fiberglass still expensive compared to steel)

SUPPORT STRUCTURES - TOWERS Long-Term | Commercial/Mid-size

HIGH

- Investigate composites for towers (no huge cost advantage; fiberglass still expensive compared to steel)

MEDIUM

- Determine how to enable time-efficient work platforms, tie-off points, & better climbing & safety approaches

SUPPORT STRUCTURES - FOUNDATIONS Near-Term | Commercial/Mid-size

HIGH

- Identify new ways to reduce the amount of concrete needed for distributed wind turbine foundations

MEDIUM

- Investigate commercial capability of other earth-anchor systems, e.g. helical anchors
- Fiber-reinforced concrete may have significant cost-saving potential for turbine foundations; explore technical limitations & opportunities

LOW

- Investigate use of embedded angular steel stud sections rather than anchor bolts which are used in utility lattice tower steel structures
- Form team of foundation installation experts to perform time-motion study of installation, w/ the goal of reducing labor hours
- Work w/ crane manufacturer for hydraulic tower design for erection & maintenance
- Develop performance specifications in the distributed wind industry for tower coatings

SUPPORT STRUCTURES - FOUNDATIONS Mid-Term | Micro/Residential

HIGH

- Identify new ways to reduce the amount of concrete needed for distributed wind turbine foundations
- Investigate commercial capability of other earth-anchor systems, e.g. helical anchors

MEDIUM

- Develop common, pre-fabricated foundations for multiple turbines. Consider cheap materials such as cheap steel. Perhaps design for worst-case soil conditions
- Fiber-reinforced concrete may have significant cost-saving potential for turbine foundations; explore technical limitations & opportunities

LOW

- Investigate spread leg foundations commercial & functional viability for distributed wind turbines
- Develop helical foundation specific for this industry
- Form team of foundation installation experts to perform time-motion study of installation, w/ the goal of reducing labor hours
- Work w/ crane manufacturer for hydraulic tower design for erection & maintenance
- Facilitate forum to identify specific countries' structural requirements & expertise (e.g., Japan)
- Investigate use of embedded angular steel stud sections rather than anchor bolts which are used in utility lattice tower steel structures
- Develop performance specifications in the distributed wind industry for tower coatings

SUPPORT STRUCTURES - FOUNDATIONS Mid-Term | Commercial/Mid-size

HIGH

- Develop common, pre-fabricated foundations for multiple turbines. Consider cheap materials such as cheap steel. Perhaps design for worst-case soil conditions
- Investigate spread leg foundations commercial & functional viability for distributed wind turbines
- Facilitate forum to identify specific countries' structural requirements & expertise (e.g., Japan)

MEDIUM

- Develop helical foundation specific for this industry

MECHANICAL Near-Term | Micro/Residential

HIGH

- Research advanced casting techniques, get more functionality out of fewer parts
- Identify regional manufacturer expertise & encourage entry/conduct meetings w/ such suppliers to enter wind turbine sector
- Explore best practices for computer numerical controlled (CNC) machining of near-net-shape castings

MEDIUM

- Research the standardization of some components & group ordering
- Investigate hydrostatic transmissions for small & medium wind turbines

LOW

- Quantify the cost required for QA management & effects of poor quality from imported castings
- Find cost-effective condition monitoring of gearboxes
- Research fluids in cold climates

MECHANICAL Near-Term | Commercial/Mid-size

HIGH

- Develop a supplier directory for wind turbine parts & components; provide information on supplier capabilities; pool knowledge of who can supply what at the best price

MEDIUM

- Develop information on brake materials that give good life & consistent brake torque
- Identify regional manufacturer expertise & encourage entry/conduct meetings w/ such suppliers to enter wind turbine sector
- Research parts & assemblies that can be redesigned w/ additive manufacturing in mind, such as advanced 3D metal printing for prototyping structural components

LOW

- Conduct research on carbon shaft manufacturing
- Quantify the cost required for QA management & effects of poor quality from imported castings
- Explore best practices for computer numerical controlled (CNC) machining of near-net-shape castings

MECHANICAL Mid-Term | Micro/Residential

HIGH

- Develop a supplier directory for wind turbine parts & components; provide information on supplier capabilities; pool knowledge of who can supply what at the best price
- Research parts & assemblies that can be redesigned w/ additive manufacturing in mind, such as advanced 3D metal printing for prototyping structural components
- Speak directly w/ machining companies that manufacture product, streamline design for easy manufacturability

MEDIUM

- Understand & refine bushing materials for long life & low maintenance in sliding fit applications such as centrifugal pitching systems
- Increase performance & replacement interval for lubricants
- Develop information on brake materials that give good life & consistent brake torque

LOW

- Research intensive quench for gears, improvements to gear life through surface treatments
- Research a reliable method for galvanizing large ductile iron castings
- Develop a siphon tube in gearbox for pump/vacuum oil removal (cleaner & faster)

MECHANICAL Mid-Term | Commercial/Mid-size

HIGH

- Find cost-effective condition monitoring of gearboxes
- Research fluids in cold climates

MEDIUM

- Increase performance & replacement interval for lubricants
- Research a reliable method for galvanizing large ductile iron castings
- Understand & refine bushing materials for long life & low maintenance in sliding fit applications such as centrifugal pitching systems
- Investigate hydrostatic transmissions for small & medium wind turbines

LOW

- Speak directly w/ machining companies that manufacture product, streamline design for easy manufacturability
- Research advanced casting techniques, get more functionality out of fewer parts
- Research the standardization of some components & group ordering

MECHANICAL Long-Term | Commercial/Mid-size

HIGH

- Research intensive quench for gears, improvements to gear life through surface treatments

MEDIUM

- Develop a siphon tube in gearbox for pump/vacuum oil removal (cleaner & faster)

TURBINE SYSTEMS Near-Term | Micro/Residential

HIGH

- Conduct a gap analysis for certification requirements in most compelling markets, i.e. what is the scope of work for certifying a turbine for not only the domestic market bur for the most vibrant international markets at the same time
- Assess how changing wind turbine system may impact machine certification
- Encourage international & foreign standards/codes/licensing that allow access to export markets

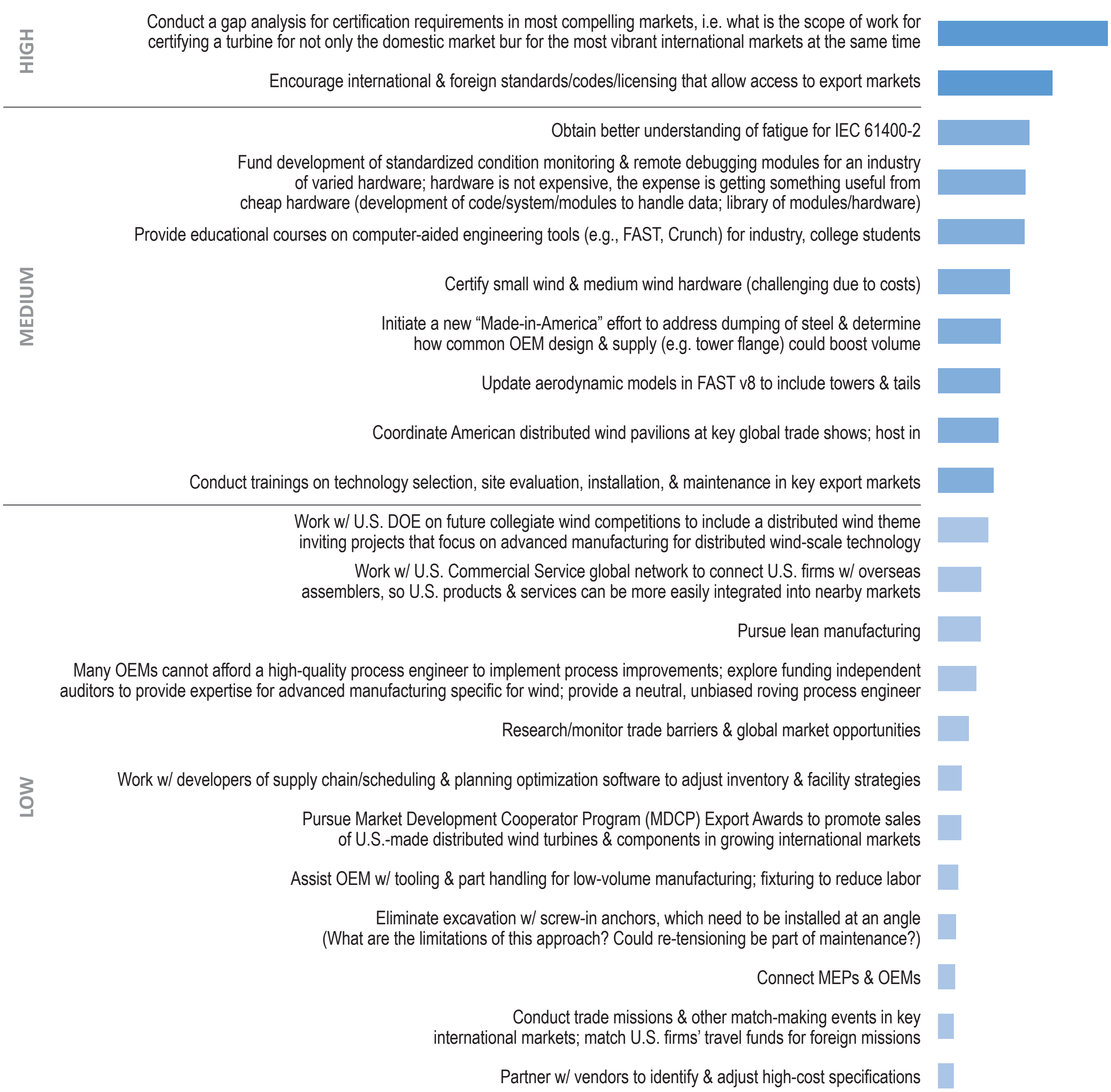
MEDIUM

- Update aerodynamic models in FAST v8 to include towers & tails
- Certify small wind & medium wind hardware (challenging due to costs)
- Obtain better understanding of fatigue for IEC 61400-2
- Pursue lean manufacturing
- Conduct trainings on technology selection, site evaluation, installation, & maintenance in key export markets
- Conduct trade missions & other match-making events in key international markets; match U.S. firms' travel funds for foreign missions
- Coordinate American distributed wind pavilions at key global trade shows; host in
- Pursue Market Development Cooperator Program (MDCP) Export Awards to promote sales of U.S.-made distributed wind turbines & components in growing international markets
- Provide educational courses on computer-aided engineering tools (e.g., FAST, Crunch) for industry, college students
- Assist OEM w/ tooling & part handling for low-volume manufacturing; fixturing to reduce labor
- Eliminate excavation w/ screw-in anchors, which need to be installed at an angle (What are the limitations of this approach? Could re-tensioning be part of maintenance?)
- Partner w/ vendors to identify & adjust high-cost specifications

LOW

- Connect MEPs & OEMs
- Work w/ developers of supply chain/scheduling & planning optimization software to adjust inventory & facility strategies
- Research the use of "hot wire" anemometers

TURBINE SYSTEMS Near-Term | Commercial/Mid-size



TURBINE SYSTEMS Mid-Term | Micro/Residential

Priority	Action
HIGH	Ensure training opportunities for small wind installers to erect, maintain, & operate distributed wind turbines (training is especially needed for installers who climb non-tilting towers)
MEDIUM	Many OEMs cannot afford a high-quality process engineer to implement process improvements; explore funding independent auditors to provide expertise for advanced manufacturing specific for wind; provide a neutral, unbiased roving process engineer
MEDIUM	Initiate a new “Made-in-America” effort to address dumping of steel & determine how common OEM design & supply (e.g. tower flange) could boost volume
MEDIUM	Work w/ U.S. DOE on future collegiate wind competitions to include a distributed wind theme inviting projects that focus on advanced manufacturing for distributed wind-scale technology
MEDIUM	Fund development of standardized condition monitoring & remote debugging modules for an industry of varied hardware; hardware is not expensive, the expense is getting something useful from cheap hardware (development of code/system/modules to handle data; library of modules/hardware)
LOW	Research/monitor trade barriers & global market opportunities
LOW	Work w/ U.S. Commercial Service global network to connect U.S. firms w/ overseas assemblers, so U.S. products & services can be more easily integrated into nearby markets
LOW	Research robotics, low-cost automation techniques for the volumes in the distributed wind industry; robotics could be mobile & multi-purpose (molding, winding, welding, painting, etc)
LOW	The utility-scale wind industry may be able to offer lessons from designing, installing & maintaining met towers, which are sometimes left in the field for 6 to 7 years; aviation requirements for taller towers should be researched

TURBINE SYSTEMS Mid-Term | Commercial/Mid-size

Priority	Action
HIGH	Assess how changing wind turbine system may impact machine certification
MEDIUM	The utility-scale wind industry may be able to offer lessons from designing, installing & maintaining met towers, which are sometimes left in the field for 6 to 7 years; aviation requirements for taller towers should be researched
MEDIUM	Ensure training opportunities for small wind installers to erect, maintain, & operate distributed wind turbines (training is especially needed for installers who climb non-tilting towers)
LOW	Research robotics, low-cost automation techniques for the volumes in the distributed wind industry; robotics could be mobile & multi-purpose (molding, winding, welding, painting, etc)
LOW	Research the use of “hot wire” anemometers

Appendix B. SMART Wind Consortium Events and Meetings

The following face-to-face and virtual Consortium meetings were held from June 2014 – February 2016. Meeting recordings and presentations are available at: http://distributedwind.org/smart-wind-past-meetings/

- Meet & Greet: June 17, 2014, Stevens Point, WI
- First OEM Steering Group Meeting: June 19, 2014, Stevens Point, WI
- Monthly Core Team Phone Meetings: June 2014-May 2016
- SMART Wind Consortium Intro Webinar: July 23, 2014
- First Full OEM Steering Group Web-based Meeting: September 15, 2014
- SMART Wind Consortium Launch: October 15-16, 2014, Albany, NY
- SMART Wind Mechanical Subgroup Meeting: November 12-14, 2014, Boulder, CO
- SMART Wind Support Structures Subgroup Meeting: January 13-14, 2015, Denver/Golden, CO
- SMART Wind Composites Subgroup Meeting: February 16-18, 2014, Boulder, CO
- Distributed Wind 2015 and SMART Wind Electrical Systems Subgroup Meeting: March 25-26, 2015, Washington, DC
- SMART Wind Manufacturing Forum: September 30, 2015, Sacramento, CA
- Final Roadmap Review Meeting: February 22, 2016, Washington, DC
- A series of follow-up virtual meetings for each subgroup helped to maintain project momentum. Virtual meeting dates and topics include:
    - Condition/Health Monitoring (January 7, 2015)
    - Rare-Earth Magnets (April 29, 2015)
    - Reducing Installation Costs (May 27, 2015)
    - PEIC Joint Virtual Meeting (June 24, 2015)
    - Composite Materials & Process Opportunities (July 29, 2015)
    - Inverters & Variable Frequency Drives (August 26, 2015)
    - Blade Design (October 28, 2015)
    - Support Structures Virtual Meeting (November 18, 2015)

All meetings included GoToMeeting connections for virtual participation; meeting recordings and slides are available at www.distributedwind.org/smart-wind-past-meetings/.

Attachment B-1. Launch Meeting Program

SMART WIND CONSORTIUM LAUNCH

Albany, New York
October 15 - 16, 2014

National Institute of Standards and Technology
U.S. Department of Commerce

Upcoming SMART Wind Events

SMART Wind: Mechanical Systems Subgroup Meeting
November 12-14, 2014
Denver/Boulder, CO

SMART Wind: Support Structures Subgroup Meeting
January 13-14, 2015
Denver/Golden, CO

SMART Wind: Composites Subgroup Meeting
February 16-18, 2015
Denver/Boulder, CO

Distributed Wind 2015 and SMART Wind: Electrical Systems Subgroup Meeting
March 24-27, 2015
Washington, DC

Distributed Wind 2016 and SMART Wind: Roadmap Prioritization Meeting
March, 2016 (Specific Dates TBD)
Washington, DC

DWEA
DISTRIBUTED WIND ENERGY ASSOCIATION

www.distributedwind.org

Agenda

Wednesday, October 15

5:30 PM - 7:30 PM **Welcome Reception**
Hosted presentations:
Daniel Valyou
Facility Manager, CECET Blade Test Facility, Clarkson University
Gary Kanaby
Director of Marketing and Sales, Wetzel Engineering Inc

OBJECTIVE
For distributed wind manufacturers, supply chain members, academic researchers and other Consortium participants to meet each other, to establish expected outcomes, and learn about NIST resources available. Identify opportunities, expertise and distributed wind knowledge.

Thursday, October 16

7:30 AM **Registration and Coffee**

8:00 AM **Self-Introductions by Consortium Participants**
What do you hope this project to accomplish? What are your areas of expertise?
Jennifer Jenkins - facilitator
Executive Director, Distributed Wind Energy Association
Heather Rhoads-Weaver - facilitator
Market, Policy & Development Consultant, eFormative Options LLC

8:30 AM **Welcome and Opening Remarks**
Dr. Tom Lettieri - U.S. Department of Commerce NIST Programs in Manufacturing Innovation
Project Manager, AMTech Program, National Institute of Standards & Technology
Bret Barker - U.S. Department of Energy Distributed Wind Engagement
Distributed Wind Analyst, New West Technologies

9:00 AM **Manufacturing Related Federal Activities: Opportunities for Distributed Wind**
Ben Vickery
Senior Analyst, Manufacturing Futures Group, National Institute of Standards & Technology
Tom Bell
Project Director, Center for Economic Growth
Tara Rice - Rural Council "Made in Rural America" Initiative
Special Assistant, Office of the Secretary, U.S. Department of Agriculture

10:00 AM **Networking Break**

10:30 AM **Overview of Project Plans, Advisors & Core/Support Team Roles**
Expectations for Participants
Jennifer Jenkins
Executive Director, Distributed Wind Energy Association
Heather Rhoads-Weaver
Market, Policy & Development Consultant, eFormative Options LLC

11:00 AM **Overview of DWEA OEM Steering Group Members, Top-Level Manufacturing Gaps & Opportunities**
Technology, skill sets, tooling, facilities, vendor relationships, QA, etc.
Trudy Forsyth
Managing Director, Wind Advisors Team
Brent Summerville, PE
Principal Engineer and President, Summerville Wind & Sun

12:00 PM **Lunch: Informal Table Discussions by Subgroups**
Composites, Support Structures, Mechanical & Electrical Systems

Agenda

STEERING GROUP MEMBERS

Thursday, October 16 continued

1:00 PM **Identifying Steering Group Advisors and Subgroup Leaders**

Mechanical:

Robert Preus
Technical Lead for Distributed Wind, National Renewable Energy Laboratory

Gary Harcourt
Manager and Co-owner, Great Rock Windpower
Commissioning Engineer, Endurance Windpower Inc.

Dr. Patrick Lemieux
Associate Professor of Mechanical Engineering, CalPoly

Composites:

Dr. Pier Marzocca
Associate Professor of Mechanical & Aeronautical Engineering, Clarkson University

Dr. Case van Dam
Department Chair, Mechanical & Aerospace Engineering, UC Davis

Paul Williamson
Director and Principal Coordinator, Maine Ocean and Wind Industry Initiative (MOWII)

Electrical:

Dr. Ruth Douglas Miller
Associate Professor of Electrical & Computer Engineering, Kansas State University

Dr. Wei Qiao
Associate Professor of Electrical Engineering
Director of Power and Energy Systems Laboratory, University of Nebraska-Lincoln

Dr. Rob Wills, PE
Principal Engineer, forENGics

Support Structure:

Dr. Asad Esmaeily
Professor of Structural Engineering, Kansas State University

Dr. Rick Damiani
Senior Engineer, National Renewable Energy Laboratory

Roger Dixon
Owner, Skylands Renewable Energy

3:00 PM **Networking Break**

3:30 PM **Latest Distributed Wind Research at U.S. DOE National Labs**

Robert Preus, PE
Technical Lead for Distributed Wind, National Renewable Energy Laboratory

Joshua Paquette
Task Leader for Laboratory & Field Testing of Wind Turbine Blades, Sandia National Laboratories

Alice Orrell, PE
Energy Analyst, Pacific Northwest National Laboratory

4:30 PM **Other NIST AMTech Projects and Related Efforts**

Dr. Christopher Niezrecki
Professor of Mechanical Engineering, University of Massachusetts Lowell

5:00 PM **Participant Closing Remarks: Next Steps**
Roundtable: How do you see yourself contributing to this project?

5:30 PM **Adjourn**

6:30 PM **DWEA OEM Steering Group Dinner**
(Invitation only)

SMART WIND CONSORTIUM

Mechanical Systems Subgroup
Denver/Boulder area, Colorado • November 12-14

Agenda

Wednesday, Nov. 12 - Group Dinner Romano's Macaroni Grill • 10411 Town Center Dr, Westminster, CO

6-8 PM	"Dutch Treat" Group Dinner

Thursday, Nov. 13 - Mechanical Subgroup Meeting National Wind Technology Center • 18299 W. 120th Ave, Louisville, CO

7:30 AM	**Registration and Full Breakfast**
8:00 AM	**Welcome and Opening Remarks**
8:15 AM	**Overview of SMART Wind Consortium and Mechanical Subgroup** Brent Summerville, Summerville Wind & Sun, SMART Wind Technical Co-lead, Mechanical Subgroup Chair Trudy Forsyth, Wind Advisors Team, SMART Wind Technical Lead, Mechanical Subgroup Co-chair Ruth Baranowski, Wind Advisors Team, Co-facilitator
8:45 AM	**Introduction of Subgroup Leaders** Dr. Patrick Lemieux, CalPoly Gary Harcourt, Great Rock Robert Preus, NREL (unable to attend)
9:00 AM	**Self-introductions by Subgroup Participants** What do you hope this project to accomplish? What are your areas of expertise?
9:15 AM	**Discussion of Barriers and Gaps from survey/interviews** Facilitated by Subgroup Leaders and Brent Summerville
10:30 AM	**Break**
11:00 AM	**Turbine design panel: Design methods, FAST Modeling** Rick Damiani – NREL: Design methods Jason Jonkman – NREL: FAST Jeff Minnema – Jeff Minnema Consulting: Experience with FAST, loads
12:30 PM	**Lunch**
1:30 PM	**Overview of US Casting Industry** Nick Cannell – Cast Alloy Sales & Technology, Inc. Joe Banas, Hodge & Elyria Foundries, Inc.
2:45 PM	**3D printing, State-of-the-art** Jacob Segil, Ph.D. – Integrated Teaching and Learning Laboratory (ITLL), University of Colorado Steve Huddle – University of Colorado Lab Manager
3:30 PM	**Break**
3:45 PM	**Report from Rapporteur** Ruth Baranowski – Communications Director, Wind Advisors Team
4:45-5 PM	**Next (virtual) meetings & close of meeting**

OBJECTIVE

For participants of the SMART Wind Mechanical subgroup to meet each other, Identify gaps and opportunities, learn about state-of-the-art manufacturing methods and technologies and capture information for Roadmap.

Friday, November 14 - Half Day Wrap-up Meeting (Invitation only for Subgroup Leaders, OEM Steering Group and Core Team)

8:45 AM	**Coffee and Welcome**
9:00 AM	**Debrief Mechanical Subgroup Meeting** Brent Summerville, Summerville Wind & Sun, SMART Wind Technical Co-lead, Mechanical subgroup chair Trudy Forsyth, Wind Advisors Team, SMART Wind Technical Lead, Mechanical subgroup Co-chair
9:30 AM	**Thoughts from Subgroup Leads** Dr. Patrick Lemieux (CalPoly) Gary Harcourt (Great Rock)
10:00 AM	**Break**
10:15 AM	**Discussion on what worked, what could be better, next steps, lessons learned**
11:30 AM	**Summary of action items and next steps**
12:00 PM	**Close of meeting**

SMART WIND CONSORTIUM

Support Structures Subgroup
NREL, RSF - Golden, Colorado • January 13-14, 2015

Agenda

Tues., Jan. 13 – Support Structures Subgroup Meeting – NREL, RSF – Beaver Creek B & C

11:30a **Registration and Lunch**

1:00p **Overview and Status of SMART Wind Consortium and Project**
Trudy Forsyth, Wind Advisors Team, SMART Wind Technical Lead, Support Structure subgroup chair
Brent Summerville, Summerville Wind & Sun, SMART Wind Technical Co-lead, Support Structure subgroup co- chair

1:20p **Introduce Subgroup Leaders**
Dr. Rick Damiani, NREL
Roger Dixon, Skylands Renewable Energy
Dr. Asad Esmaeily, Kansas State University

Objective: For participants of the SMART Wind Support Structures Subgroup to meet each other, identify gaps and opportunities, learn about state-of-the art manufacturing methods and technologies, and capture information for Roadmap.

1:30p **Self-Introductions by Subgroup Participants**
What do you hope this project will accomplish? What are your areas of expertise?

1:50p **Overview of Different Tower and Foundation Types**
Roger Dixon, Skylands Renewable Energy, LLC
Streamlining of foundations and safe installation practices

2:30p **Tower/Foundation Gaps and Needs**
Trudy Forsyth, Wind Advisors Team, SMART Wind Technical Lead, Support Structure subgroup chair

3:00p Break

3:30p **Support Structure Technical Panel**
Dr. Rick Damiani, NREL – Support Structure Design Optimization
Gunes Demirbas, P.E., G-Tower – Cost and Material Advances in Tower Design

4:30p **Support Structure Coatings**
Krent Aberle, Sherwin Williams – Protective Coatings for Wind Energy
Dave Wixson, TMS Metalizing – Corrosion Coating Metalizing Overview (presentation given by Brent Summerville)

5:15p Adjourn

6:00p **"Dutch Treat" Dinner for All Participants – Mimi's Café, 14265 West Colfax Avenue, Golden, CO 80401**

Wed., Jan. 14 – Support Structures Subgroup Meeting – NREL, RSF – Beaver Creek B & C

8:00a Welcome Back, Any New Ideas?

8:15a **Panel of Tower Manufacturers, Overview of Other Tower Manufacturers**
Paul Migliore, AnemErgonics (virtual)
Mike Bergey, Bergey Windpower

9:30a Break

10:00a **Panel on Foundation and Anchoring Systems**
David Blittersdorf, AllEarth Renewables (virtual)
Tim Olsen, Advanced Energy Systems LLC
Charles Newcomb, Endurance Wind Power

11:30a **Report from Rapporteur**
Ruth Baranowski, Wind Advisors Team
Review of compiled ideas/actions
Brainstorm and refine actions

12:30p **Close of Meeting, Box Lunch Provided**

Wed., Jan. 14 – Wrap-Up Meeting, Invitation Only for Subgroup Leaders & DWEA OEM Steering Group

1:00p Debrief Support Structure Subgroup Meeting
1:30p Thoughts from DWEA OEM Steering Group Members
2:45p Thoughts from Subgroup Leads
3:15p Break
3:30p Next (virtual) meetings – topics, month, speakers
4:00p Adjourn

DWEA DISTRIBUTED WIND ENERGY ASSOCIATION

SMART WIND CONSORTIUM

Composites Subgroup
NREL/NWTC Boulder, CO • February 16-18, 2015

Agenda

Monday, February 16th

6:00p **"Dutch Treat" Dinner for All Participants**
Gordon Biersch Brewing Company, 1 West Flatiron Circle, Flatiron Crossing, Broomfield, CO

Tuesday, February 17th – Composites Subgroup Meeting – NWTC 18299 W 120th Ave, Louisville, CO

7:30a Registration and Breakfast

8:00a **Overview and Status of SMART Wind Consortium and Project**
Trudy Forsyth, Wind Advisors Team, SMART Wind Technical Lead, Composites subgroup chair
Brent Summerville, Summerville Wind & Sun, SMART Wind Technical Co-lead, Composites subgroup co- chair
Ruth Baranowski, Wind Advisors Team, co-facilitator

8:15a **Introduce Subgroup Leaders**
Dr. Pier Marzocca, Clarkson University
Dr. Case van Dam, University of California-Davis
Paul Williamson, Maine Ocean and Wind Industry Initiative (virtual)

8:20a **Self-Introductions by Subgroup Participants (Introductions will also occur during the Feb 16 dinner)**
What do you hope this project to accomplish? What are your areas of expertise?

8:50a **Composite Gaps and Needs – Trudy Forsyth**

9:10a **Specific OEM needs**
Martin Bissonette, Eocycle
Others

9:40a **Break**

Objective: For participants of the SMART Wind Composites Subgroup to meet each other, identify gaps and opportunities, learn about state-of-the art manufacturing methods and technologies, and capture information for Roadmap.

10:00a **Possible Partners**
Kelly Visconti, PE, DOE IACMI (virtual), Institute for Advanced Composite Manufacturing Initiative (IACMI) Overview
D. DeWayne Howell, Peak Composites, Inc., Society for the Advancement of Material and Process Engineering (SAMPE)
Rick Lewandowski, Intertek (virtual), Center for Evaluation of Clean Energy Technology (CeCET)
Paul Williamson, MOWII (virtual), Composite Engineering Research Lab – Southern Maine CC, University of Massachusetts-Amherst, Structures and Composite Center-University of Maine

11:20a **Sandia National Laboratories (SNL) Composite/Blade Research Summary**
Dr. Brian Naughton, SNL

12:20p Lunch

1:05p **Blade Design**
Dr. Pier Marzocca, Clarkson University, Design and Testing of Composite Wind Turbine Technologies
Dr. Qi Wang, NREL and Dr. Wenbin Yu, Purdue University (virtual), Efficient High-fidelity Modeling of Composite Wind Turbine Blades
Dr. Case van Dam, University of California-Davis, What is new in blade aerodynamic design?
Dr. Frank Abdi, AlphaSTAR (virtual), Why blades break under static and fatigue?

2:30p **Structural Blade Testing**
Dr. Kerop Janoyan, Clarkson University (virtual), Condition monitoring systems and sensing needs
Dr. Nathan Post, NREL, Blade structural fatigue testing – technical aspects
Daniel Valyou, Clarkson University Blade Test Facility, Blade structural testing – practical aspects

3:40p Break

DWEA DISTRIBUTED WIND ENERGY ASSOCIATION

4:00p **Panel of Blade Manufacturers, Tooling and Coatings**
Stephen Nolet, TPI Composites
Dr. Kyle Wetzel, Wetzel Engineering
Krent Aberle, Sherwin-Williams
Andy Bridge, Janicki Industries

5:10p **Report from Rapporteur – Ruth Baranowski**
Review of compiled ideas/actions
Brainstorm and refine actions

6:30p Meeting adjourned

7:00p Dinner and further discussion, Tillers Kitchen & Bar, Westminster Marriott, 7000 Church Ranch Blvd

Wednesday, February 18th – Half Day Wrap-Up Meeting, Invitation Only for Subgroup Leaders & OEM Steering Group at NREL/NWTC

9:00a Debrief Composites Subgroup Meeting
Next (virtual) meetings – identify topic, month, speakers

10:00a DWEA OEM Steering Group, and Invited Expert Post-Meeting Input

12:00p Meeting adjourned

SMART WIND CONSORTIUM

Electrical Subgroup JW Marriott
Washington, DC March 25-26, 2015

Sponsors

Agenda

Wednesday, March 25

5:30-7p **Cocktails on the Hill, all are welcome**
Rayburn House Building B-354, 45 Independence Ave SW, Washington, DC

7:30-9:30p **"Dutch Treat" *cash-only* group dinner, all are welcome**
Bullfeathers of Capitol Hill, 410 First St SE, Washington, DC

Thursday, March 26 Electrical Systems Subgroup Meeting
Senate Room, JW Marriott, 1331 Pennsylvania Ave NW Washington, DC

7:30a Registration and Breakfast

8:00a **Welcome and Opening Remarks**
Heather Rhoads-Weaver, eFormative Options, SMART Wind Project Manager
Trudy Forsyth, Wind Advisors Team, SMART Wind Technical Lead

8:05a **Electrical Subgroup Opportunities and Gaps**
Brent Summerville, Summerville Wind & Sun, SMART Wind Technical Co-lead

8:35a **Self-Introductions by Subgroup Participants**
(Introductions will also occur during the March 25th dinner.)
What do you hope this project to accomplish? What are your areas of expertise?

Introduce Subgroup Leaders
Dr. Ruth Douglas Miller, Kansas State University
Dr. Greg Mowry, University of St. Thomas, School of Engineering
Dr. Ed Muljadi, NREL
Dr. Rob Wills, Intergrid Consulting, LLC

9:00a **Future of the Grid:**
Smart Grid and Distributed Wind
Scott Sklar, The Stella Group, Ltd
Robert Preus, NREL
Q&A, Discussion

10:00a **Break**

10:30a **Alternator Panel Discussion**
10-15 minutes each followed by discussion

Overview in Latest Research in PM Alternators, Dr. Ed Muljadi, NREL
Rare Earth Magnets, Jim Sims, Molycorp, Inc.
Opportunities in Alternator Design and Manufacturing, Dr. Greg Mowry, University of St. Thomas
Coil Winding, Dr. Keith Klontz Ph.D., Advanced Motor Tech, LLC

Objective: For participants of the SMART Wind Consortium Electrical Systems Subgroup to meet each other, identify gaps and opportunities, learn about state-of-the art technology and manufacturing methods and capture information for the final Roadmap.

OEM Steering Group

12:00p **Lunch**

1:00p **Shock and Fire: Electrical Safety and Standards**
Electrical testing and certification, Mike Hudon, Intertek (virtual)
UL6142, Chris Storbeck, UL
Energy Storage and NEC, Dr. Rob Wills, Intergrid

2:00p **Power Electronics Panel Discussion**
10-15 minutes on latest greatest followed by discussion

A 20 kW power electronics setup using variable speed drive front end and Power One inverter, Dr. Rob Wills, Intergrid

A Novel Single-phase Inverter with Distribution Static Compensator Capability for Wind Applications, Dr. Ruth Douglas-Miller, Kansas State University

Cost Effective Power Electronics for Low Volume Production, Joshua Kaufman, Pika (virtual)

Power America and Distributed Wind, Dr. John Muth, NC State University, Department of Electrical & Computer Engineering

3:30p **Break**

4:00p **Report from Rapporteur**
Ruth Baranowski, Wind Advisors Team
Refine the list of gaps and opportunities
Brainstorm actions regarding listed gaps
List next (virtual) meetings

5:00p **Close of Meeting**

5:30-7:30p **Invitation-Only for OEMs, Subgroup Leaders & Core Team**
Discussion on next steps, thoughts, feedback

SMART WIND CONSORTIUM

Attachment B-6. Manufacturing Forum Program

Manufacturing Forum
Hyatt Regency Sacramento, CA | Sept. 30, 2015

OUR WIND OUR POWER OUR FUTURE

Agenda

Wednesday, September 30

1:00p Welcome & Introductions, Focus on Scaling Up Domestic Distributed Wind Jobs
Jennifer Jenkins, DWEA

1:15p Manufacturing and the Smart Grid: Partnering for Successful Scale-Up
Keynote Speaker: Patrick Dempsey, LLNL & CNMI

1:45p Low Volume Lean Leadership Improves Costs within All Departments & the Entire Supply Chain
Featured Speaker: Greg Lane, Low Volume Lean Center

2:30p Process Improvement, Automation and Case Study on Distributed Wind Turbine Tower Fabrication
Mike Bergey, Bergey Windpower and George Chao, Manex

3:00p "Show & Tell" Break – UC Davis instrumented small wind turbine blade
Valeria La Saponara, UC Davis

3:30p When, How & Why Distributed Wind OEMs Should Scale Up
Moderator: Jay Yeager, Xzeres Wind Corp
Dialogue with panelists and all participants

4:15p Addressing Gaps & Barriers / Actions by SMART Wind Subgroup
Trudy Forsyth, Wind Advisors Team
Britton Rife, eFormative Options
Round-robin on Critical Actions for SMART Wind Roadmap

4:40p Wrap up on Next Steps, Process for SMART Wind Roadmap
Heather Rhoads-Weaver, eFormative Options

4:50p Closing Remarks: SMART Wind and DOE Looking Forward
Mark Higgins, U.S. Department of Energy Wind & Water Program

5:00p Adjourn

5:30p-6:30p All-States Summit Opening Reception

7:30p Invite-only OEM Steering Group Dinner

Objective:
For participants of the SMART Wind Consortium to meet each other, identify gaps and opportunities, learn about state-of-the art technology and manufacturing methods and capture information for the final Roadmap.

Thank you to SMART Wind Forum Sponsors

SMART WIND CONSORTIUM

Attachment B-7. Roadmap Review Meeting Program

Final Roadmap Meeting
JW Marriott, Washington, DC | Feb. 22, 2016

Final Roadmap Review Meeting Agenda – *JW Marriott Congressional Room*

Link to view screen and join meeting virtually: *https://global.gotomeeting.com/join/519028589*
Phone dial-in if needed: (646) 749-3122, Access Code: 519-028-589

Monday, February 22

1:00p Welcome & Introductions, "What have you gained from the Roadmapping process?"
Jennifer Jenkins, DWEA

1:15p Overview of TOC, Methods & Ground Rules for Consensus
Heather Rhoads-Weaver & Matt Gagne, eFormative Options
- *One response/position per company, balance OEMs and other stakeholders*
- *Mark detailed edits on hard copy or redline Word file by March 4*

1:40 Presentation & Discussion of Action Plan to Address Industry Barriers (Section 5)
Trudy Forsyth, Wind Advisors Team & Brent Summerville, Summerville Wind & Sun
- *Anything critical missing from top level executive summary bullets, table, or "baskets"?*

2:30p Break

2:45p Continue Discussion of Action Plan to Address Industry Barriers
Trudy Forsyth & Brent Summerville
- *Major areas of agreement, any major objections?*

3:30p Future of Consortium: "Where would you like to see SMART Wind go?"
Heather Rhoads-Weaver & Trudy Forsyth
- *What's next for Consortium? Near-term opportunities?*

4:00p Opportunity for Feedback on Front Matter, Exec Summary, and Cover Graphics
Jennifer Jenkins & Heather Rhoads-Weaver

4:30p Opportunity for Feedback on Section 4: Partnering Opportunities
Britton Rife, eFormative Options
- *Anyone missing?*

4:50p Opportunity for Feedback on Sections 1-3, References and Consortium Directory

5:10p Wrap up on Next Steps & Dissemination Efforts, Future Funding Opportunities

5:30p Adjourn

6:30p Dutch treat dinner at The Hamilton, 600 14th St NW, Washington, DC 2005

Meeting Objective:
For SMART Wind Consortium leaders to provide final substantive feedback on scope and findings of the 2016 SMART Wind Roadmap and confirm accuracy of priority actions ranked online by 80 participants.

Thank you to SMART Wind funders!

Appendix C. SMART Wind Consortium Directory

Appendix C-1. Baseline and Benchmark Detailed Information

The SMART Wind team asked distributed wind turbine OEMs the following questions through an online questionnaire and follow-up interviews:

- How many years has your company been in business?
- In what year did you sell your first wind turbine or wind turbine component?
- Who is in your supply chain (i.e., number of suppliers, number of states in the U.S., number of countries)?
- Are you interested in finding new manufacturing partners (i.e., new, lower-tier suppliers or component manufacturers)?
- Are you interested in identifying and working with lean manufacturing experts, manufacturing experts, NIST MEP experts, or others?
- Have you worked with your local MEP on improvements to your manufacturing (lean, plant layout/flow, etc.)? Briefly describe that experience
- Would you be interested in evolving a part/subsystem design in partnership with manufacturing expertise?
- What would it take to source imported components/parts in the U.S.?
- Are there opportunities for manufacturing automation that make sense given a low production volume?
- Are there opportunities for bulk purchasing of raw materials such as magnets, copper, composites, or other metal stock?
- Besides bolts and fasteners, are there other components that could be purchased in bulk with other DWEA OEMs?
- Are there specific component/part technology evolutions we should explore (i.e., something from an academic/applied research perspective)?
- How can we help you get the most out of this manufacturing-focused project? What are your manufacturing gaps and challenges that this project could help address?
- Would you want to invite your existing lower-tier suppliers to participate in this project? Would a general letter of invitation be helpful?
- Do you have any thoughts on how to best identify common manufacturing gaps, prioritize actions to close these gaps, and foster rapid transfer of solutions?

Baseline information to be made public:

- Can you provide an exploded diagram with photos of the turbine and parts/turbine being manufactured?
- Can you provide a top-level bill of material with percent cost for each component and where manufactured (template provided)?
- Can you identify your hard-to-produce (manufacture or inspect for quality) or procured piece parts or assemblies?

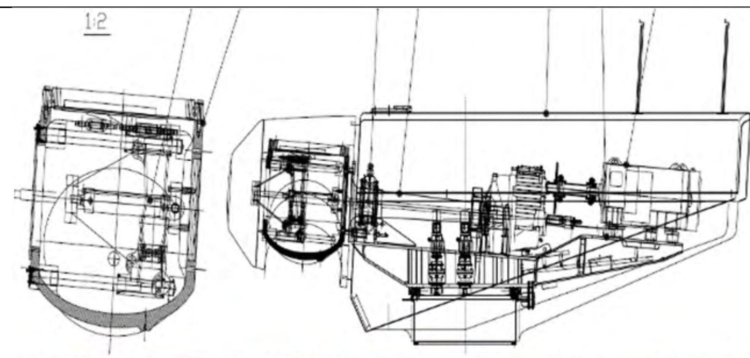
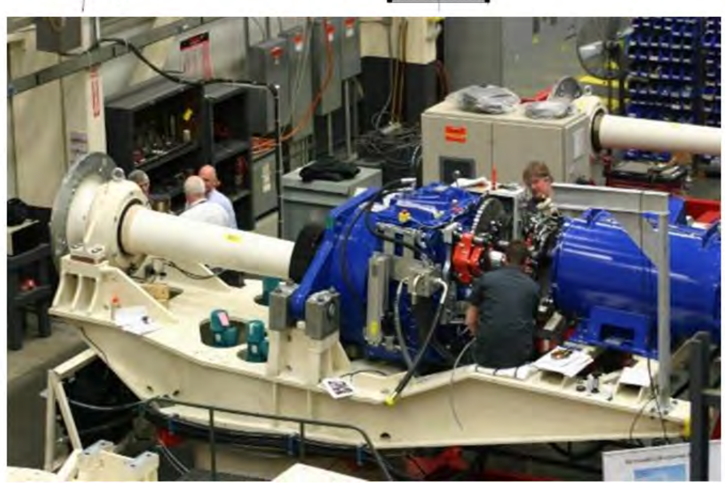
- Are you familiar with the Great Lakes organization for sourcing suppliers? Are there components with quality/delivery problems that could be re-sourced in the U.S.?
- Please describe your experience working with the MEP centers

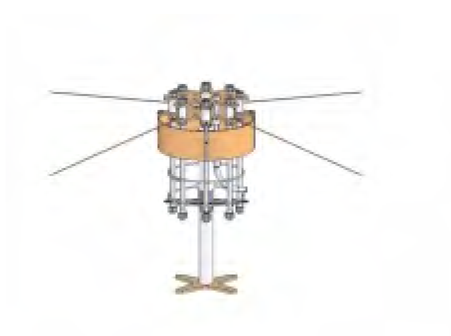
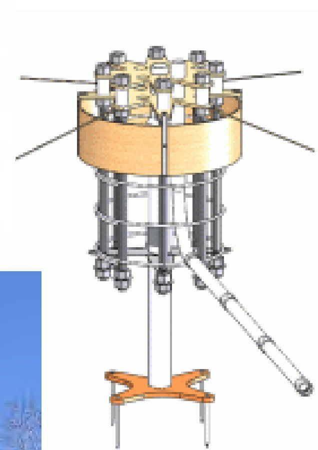
Benchmarks to be aggregated:

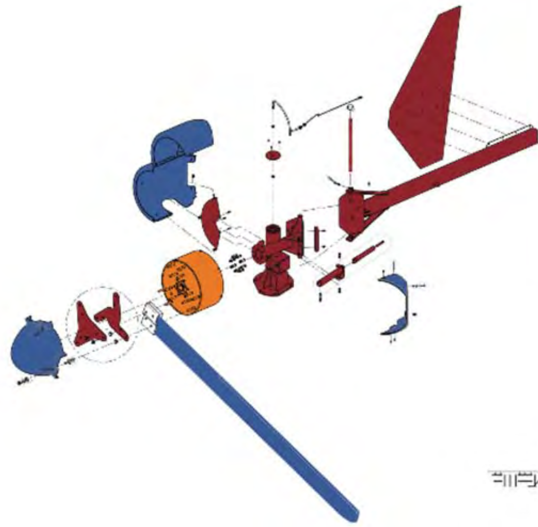
- Can you share the LCOE for your installed turbines and cost of goods sold?
- Can you provide a lower-level bill of materials with percent costs, down to raw materials, focusing on assemblies/areas that may have opportunities for improvement?
- Can you provide volumes: turbines manufactured per year, current and near-term forecast?
- Can you quantify U.S. jobs created by the manufacturing and installation of your wind turbine?

Background information and exploded diagrams provided by OEMs are included in Table D-1 below. The support structure typically rises to the top of the chart for percent of system cost (the only exception is the largest wind turbine, Aeronautica, with its significant mainframe structure). Other top contributors for all models include the alternator, gearbox, blades, inverters and power electronics, and nacelle mainframes.

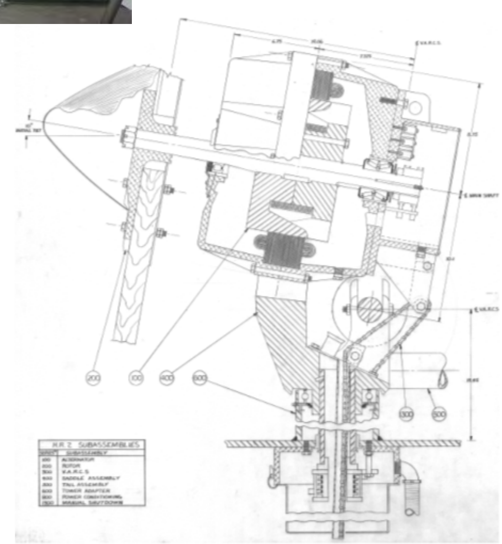
Table C-1. OEM and Wind Turbine Information

Manufacturer, Products, Company Info, Product Photo	Exploded Diagram and Manufacturing Photo(s)
Aeronautica Windpower Turbine: AW750 (47-m and 54-m rotors), Danish (Norwin) design In business 7 years, started with refurbishing, first 750 kW in 2011 AERONAUTICA WINDPOWER www.aeronauticawind.com 	 

AllEarth Renewables Product: AllEarth dual-axis tracker In business since 2005, originally developed 2.5-kW direct-drive residential wind turbine before switching gears to design and manufacture grid-tied solar PV tracking systems www.allearthrenewables.com	
AnemErgonics Products: SMarT Foundations™ and SMarT Towers™ from 8 m to 20 m for wind turbines up to 5 kW Commercial sales began in 2013 after considerable laboratory and field testing www.anemergonics.com 	

<table>
<tr>
<td>Bergey Windpower Company
Turbines: Excel 6 and 10, both AWEA certified by SWCC
In business 37 years, first turbine in 1980
www.bergey.com
</td>
<td>

Inverter

</td>
</tr>
<tr>
<td>Black Island Wind Turbines
Turbine: HR3, tested at AEI facility in Canyon, TX. Originated from 1978 U.S. DOE contract to develop a high-reliability small wind turbine
Founded 2011, first turbine in 2013
www.blackislandwindturbines.com
</td>
<td>
</td>
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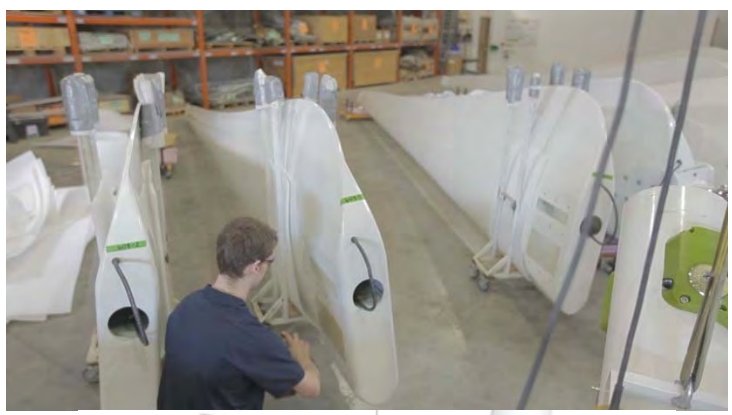
</table>

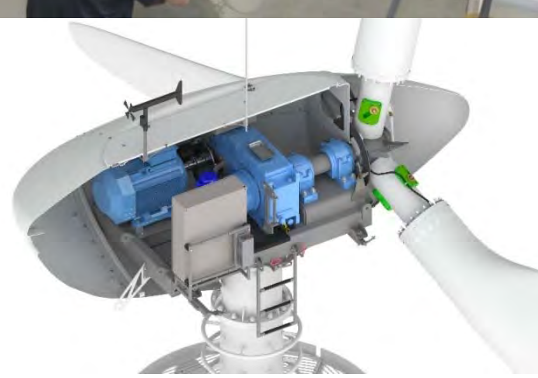
Dakota Turbines
Turbine: 30-kW DT30, under test at High Plains Small Wind Test Center for AWEA certification by SWCC
In business 8 years, first turbine in 2011

www.dakotaturbines.net

Endurance Wind Power
Turbine: E-3120, granted SWCC Performance Certification
In business 7 years, first E-series in 2009

www.endurancewindpower.com





<table>
<tr>
<td>
Eocycle Technologies
Turbine: EOCYCLE 25, pursuing AWEA and BWEA certifications with Intertek
In business 13 years, first turbine in 2010
EOCYCLE TECHNOLOGIES
www.eocycle.com

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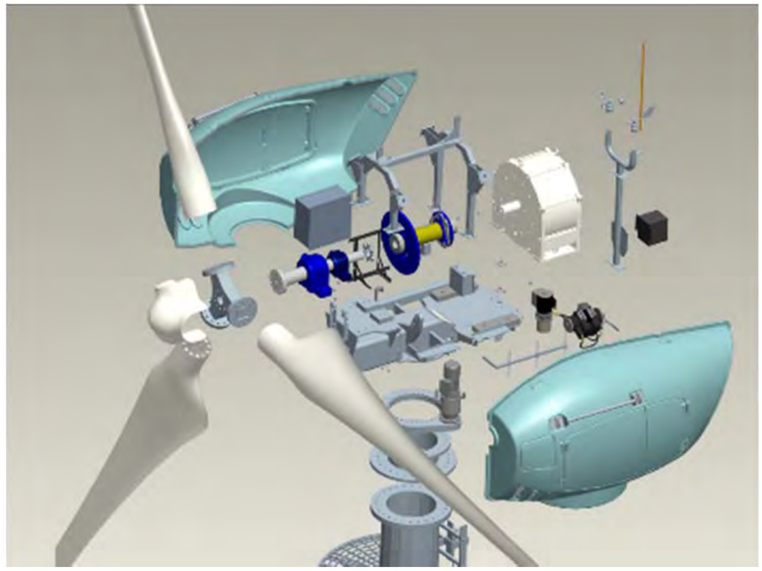
<td>



</td>
</tr>
<tr>
<td>
Northern Power Systems
Turbine: NPS 100C
In business 40 years, first turbine in 1978
Northern POWER SYSTEMS
www.northernpower.com
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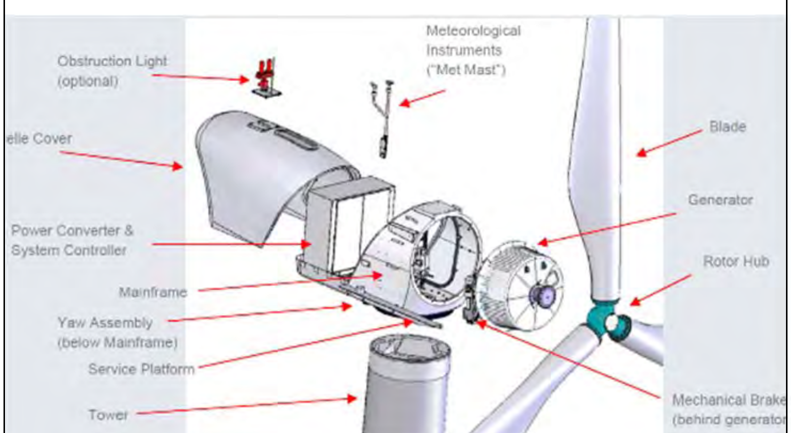

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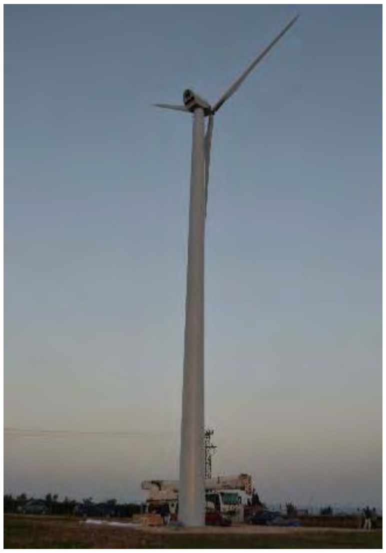
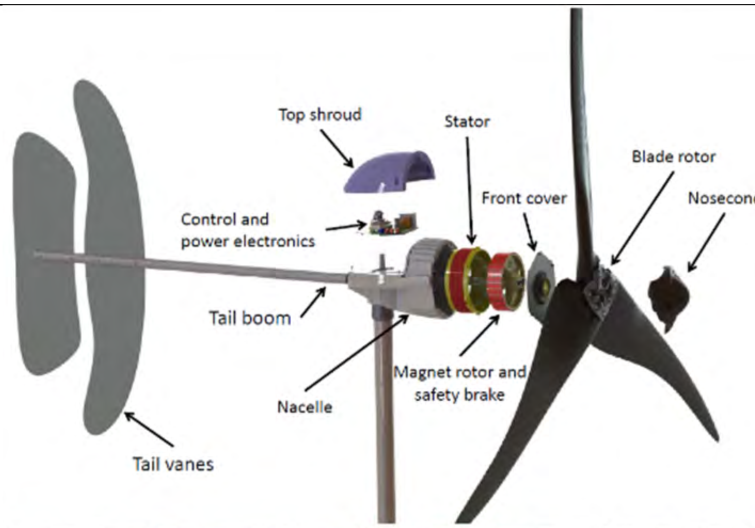
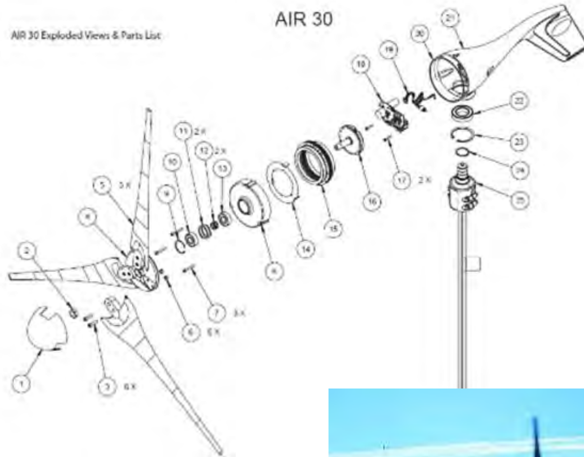
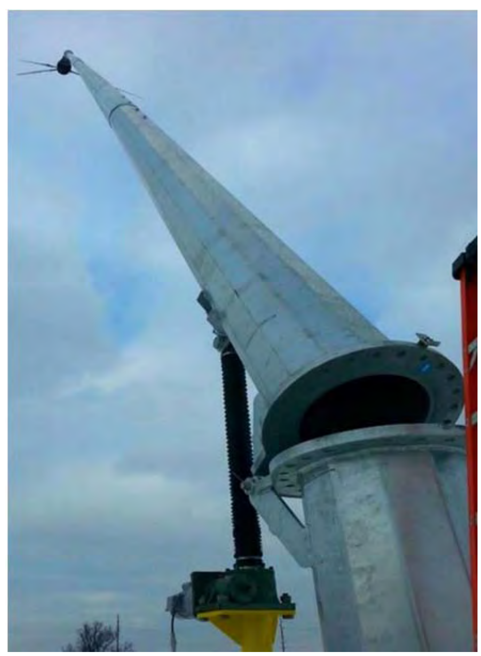
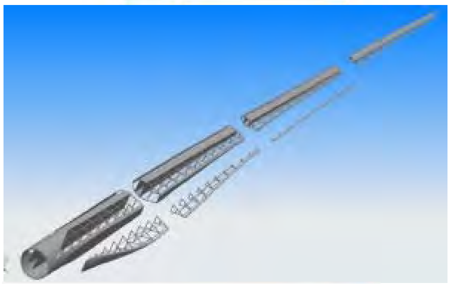
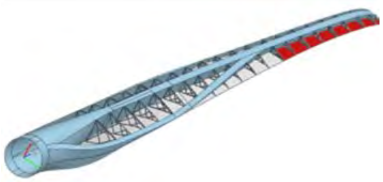
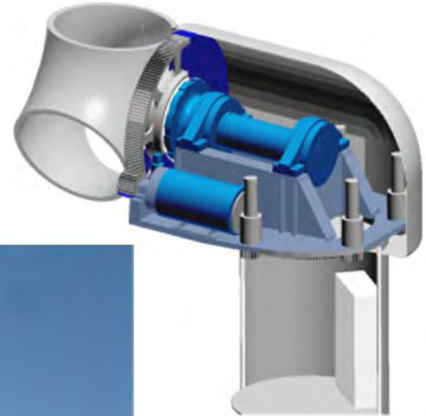


Pika Energy
Turbine: Pika T701, under test at High Plains Small Wind Test Center for AWEA certification by SWCC
In business 4 years, first turbine in 2013

www.pika-energy.com



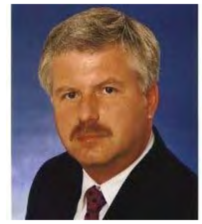
Primus Windpower Turbines: Air 30, 40, Breeze, X Typically paired with PV, hybrid In business 2 years, first turbine in 1995; part of larger Primus Aerospace www.primuswindpower.com 	 
Ventera Wind Turbine: VT10 In business 3 years, first turbine in 2007 www.venterawind.com 	

Wetzel Engineering Products: Model W-35 blade, Model W-83 blade Has offered state-of-the-art engineering services since 2001  	 
Xzeres Wind Turbines: 442SR (under test in Texas for AWEA certification with SWCC), Skystream (SWCC certified) In business 5 years, first turbine in 2010 www.xzeres.com   	 

Appendix C-2. SMART Wind Consortium OEM Steering Group

Aeronautica Windpower, LLC | Plymouth, MA | www.aeronauticawind.com

Aeronautica Windpower is a sales, marketing, manufacturing, and O&M service company that builds and markets mid-scale commercial and industrial (225- to 750-kW) wind turbines primarily for behind-the-meter and net-metered applications.



Brian Kuhn is Aeronautica's founder and a principal member of a number of renewable energy companies. Mr. Kuhn offers the perspective of more than 30 years of project, product, and service development in the fields of wind, solar, heat recovery, real estate development and permitting, and general marketing.

AllEarth Renewables |Williston, VT | www.allearthrenewables.com

AllEarth Renewables believes that having experience does not mean you should not look for new answers. It has built two 25-acre, 382-tracker, 2.1-MW solar farms in its own backyard in order to fine-tune every aspect of its product, services, and delivery for its customers.

David Blittersdorf founded NRG Systems in 1982, and over the next 22 years he developed the company into a global leader in wind measurement technology. He stepped down as CEO of NRG Systems in 2004 to launch his second company, AllEarth Renewables, which originally developed a 2.5-kW direct-drive residential wind turbine before switching gears to design and manufacture grid-tied solar PV tracking systems.

AnemErgonics |Arvada, CO| www.anemergonics.com

AnemErgonics strives to keep its products simple and believes modular components—specialized, mass-produced, and interchangeable—improve flexibility and lower costs. AnemErgonics uses the term SMarT (Simple Modular Technology) to describe its products, including SMarT Foundations™ and SMarT Towers™.

Dr. Paul Migliore has 35 years of experience in virtually all aspects of wind energy, including research and teaching in academia, wind farm development, engineering design, manufacturing, consulting, and project management. Since retiring from NREL in 2005, he has consulted for numerous wind turbine manufacturers, primarily in the areas of aerodynamics, aeroacoustics, foundations, and tower design. As a consultant to NREL, he assisted with the implementation of computational aeroacoustics projects, wind tunnel aerodynamic and aeroacoustic tests, and wind tunnel tests of low-noise blade tips for small wind turbines.

Bergey Windpower Co. | Norman, OK | www.bergey.com

Bergey Windpower is the oldest manufacturer of residential-size wind turbines in the world. Thirty years ago, Bergey pioneered the radically simple "Bergey design" that has proven to provide the best reliability, performance, service life, and value of all of the hundreds of competitive products that have come and gone in that time. With only three moving parts and no scheduled maintenance necessary, the Bergey 10-kW has compiled a service record that no other wind turbine can match. Bergey backs it up with the longest warranty in the industry.

Mike Bergey is a mechanical engineer and an internationally recognized expert in the field of small wind turbines, distributed generation, and rural electrification. A co-founder of Bergey Windpower and president since 1987, he holds one patent in the wind energy field. He served two terms as president of DWEA, twice served as president of AWEA, and served on the AWEA Board of Directors from 1981 to 2007. He is a past chairman of the U.S. Export Council for Renewable Energy, member of the U.S. Department of Commerce Environmental Technology Trade Advisory Committee, and a past president of the Oklahoma Renewable Energy Council.

Black Island Wind Turbines | Hadley, MA | www.blackislandwindturbines.com

Black Island, Antarctica is one of the harshest wind turbine installations in the world with routine Category 5 hurricane winds, top speeds reaching 200 mph, temperatures falling to minus 70 degrees F, marine environments, and super-critical loads. One wind turbine prevails: the ***HR3***, a high-reliability, 3-kW wind turbine that **Black Island Wind Turbines** will soon offer for commercial sales to satisfy the most difficult site and customer demands around the world.

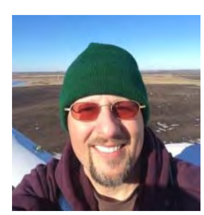
Pat Quinlan is the CEO of Black Island Wind Turbines, the former associate director of the U-Massachusetts Wind Energy Center and a former Senior Analyst at NREL. Mr. Quinlan worked for Paul MacCready, world-class inventor and designer, and served as a Science Fellow in Congress for the Chair of the House Science Committee and Technology Fellow in the White House for the President's Science Advisor. He holds an M.Sc., Mechanical Engineering; is a U-Wisconsin Solar Energy Lab Professional Engineer; and is licensed in California.

Bill Stein is Black Island's founder and CTO, building wind turbines that can survive winds up to 197 mph and -57˚ F. Black Island has evolved from principally refurbishment of legacy equipment to complete new systems in 2013, resulting in growing sales to U.S. agencies, military, and private commercial customers. Mr. Stein continues his work in developing cutting-edge solutions to technical problems as well as managing and mentoring enthusiastic younger developing engineers.

Dakota Turbines | Cooperstown, ND | dakotaturbines.net

Dakota Turbines Inc., based in Cooperstown, North Dakota, builds compact, efficient, rugged wind turbines made almost entirely from parts manufactured in the Upper Midwest. With capital from parent company Posilock Puller Inc. and the ND Industrial Commission, Dakota Turbines began developing design concepts for its turbines in 2006 and completed its first commercial installation in 2011. The company has worked to develop innovative technologies to enhance production from wind turbines. Its unique configuration of ironless coils and magnets affixed to the turbine's rotor eliminates cogging and enables generation at very low wind speeds. Dakota Turbines has developed a highly efficient blade design and a tailored inverter. Its design also includes fail-safe coil springs on each blade shaft that can quickly bring the turbine to a gentle stop in the event of any electrical or mechanical disruptions. The company has acquired and is working to acquire several patents for its technologies.

Cris Somerville has 25 years of experience working with and developing hydraulic, pneumatic, and mechanical systems. He is credited with 6 patents, two of which are for Dakota Turbines, and an additional 2 patents pending also for Dakota Turbines. He has extensive knowledge and experience with 3-D modeling and design software. Taking on difficult projects and providing innovative solutions is something that Mr. Somerville takes great pride in.



Endurance Wind Power | Surrey, BC, Canada | endurancewindpower.com

Endurance Wind Power manufactures advanced wind turbines designed for distributed wind power applications. Endurance's line of modern, induction-based wind turbines brings efficient, reliable, safe, and quiet renewable energy to homeowners, businesses, and institutions across Europe, North America, and an expanding global market.

Dr. David Laino was a co-founder of Windward Engineering in 1999 and a lead designer on the original Endurance S-Series turbine. He previously worked at NREL, where he developed wind turbine computer modeling capabilities to analyze innovative designs and evaluate proposed safety standards. He also analyzed and compared test and simulation data in validation studies. He is an active member of DWEA and Co-Administrator of the U.S. Technical Advisory Group to IEC Technical Committee for Wind Turbine Standards.

Charles Newcomb serves as the Director of Technical Strategy for Endurance to align the company's technical solutions with business strategies. He brings more than 15 years of experience in nearly all aspects of the wind industry, from sales and project development to procurement and implementation strategies. He works with Endurance's technical team on the company's future product roadmap and business models. Prior to joining Endurance, Mr. Newcomb held several senior engineering roles at NREL.

Eocycle Technologies | Gaspé, Québec, Canada | eocycle.com

Eocycle Technologies Inc. develops, manufactures, and commercializes worldwide the Eocycle 25, a state-of-the-art, 25-kW direct-drive wind turbine for distributed wind energy applications. Capitalizing on more than 12 years of internal R&D and prototyping, Eocycle Technologies stands out from its peers by being an integrated technology and manufacturing company.

Bouaziz Ait-Driss is the Chief Innovation Officer at Eocycle Technologies Inc. He holds a Masters in Renewable Energies and has more than 25 years of experience in the development of energy systems in Africa, Europe, and North America. His experience in the energy sector stems from designing, implementing, and operating a multitude of wind and solar power projects and mandates. Before he joined Eocycle, he led teams of engineers at GL Garrad Hassan and research and development organizations, including academia. He has managed projects totaling more than 20 GW of planned capacity. At Eocycle, he leads the development and implementation of cutting-edge energy conversion solutions.

Northern Power Systems | Barre, VT | www.northernpower.com

Northern Power Systems has been delivering innovative energy solutions in a changing landscape for more than 40 years. Around the globe, Northern's installed base of permanent magnet direct drive wind turbines and grid-friendly power technology components have logged millions of kilowatt-hours of operation to date, demonstrating the company's commitment to performance and reliability.

Diego Tebaldi is Northern's Global Head of Business Development & Product Management. He is a focused and driven leader with 20+ years of international experience in corporate divisions as well as start-ups, leading and growing in complex markets worldwide and running field operations with a diverse global footprint.

Chris McKay has more than 20 years of experience in the energy industry with specialties in product development, product management, and program management. He currently leads Northern's Product Life-Cycle Management team, driving the development and commercialization of new products from wind turbine and power electronics product platforms using stage-gate methodology.

Pika Energy | Westbrook, ME | www.pika-energy.com

Pika Energy manufactures high-efficiency, bi-directional inverters and charge controllers, small wind turbines, and substring solar optimizers. All Pika products are powered by the REbus™ DC nanogrid and provide grid-optional clean power that enables buildings to collect, store, and self-consume energy from solar and wind sources. Pika believes that renewable energy will power the future, bringing that future closer for homeowners and businesses. Pika's vision is the result of years of experience designing, building, and using renewable energy. Pika is committed to making reliable, high-performance products that customers will be proud to use and recommend.

Ben Polito has been building clean energy technology since his days on an island farm in Maine, beyond the reach of grid power. Mr. Polito was lead mechanical engineer for the groundbreaking Skystream wind turbine. Prior to launching Pika Energy, he built the East Coast office of GreenMountain Engineering, a design consulting firm serving clean technology startups, and served on the founding team of 1366 Technologies, where he developed texturing methods for high-efficiency silicon solar cells. He holds patents and patents-pending on technology ranging from implantable medical devices to solar cells. Mr. Polito earned a mechanical engineering degree from MIT, where he developed 3D printers, built autonomous submarines, and worked on Eink, the display technology of the Amazon Kindle.

Bill Hetzel, Pika's Director of Operations, started his career as a management consultant for Oliver Wyman, then moved to Merck & Co., where he engineered global chemical plant capacity for active pharmaceutical ingredients. For the next 13 years, Mr. Hetzel worked at Tom's of Maine as leader of Procurement, Supply Chain, and then as Plant Manager, responsible for all operations of the Sanford, Maine facility. Mr. Hetzel holds a BS in chemistry from Yale, as well as an MS in chemical engineering and an MS in management from MIT.

Primus Wind Power | Lakewood, CO | www.primuswindpower.com

Primus Wind Power is a global leader of off-grid, portable small wind turbines and maker of the Air Breeze Turbine, Air 30 Turbine, and Air 40 Turbine with more than 150,000 units installed since 1995 and installations in more than 100 countries and on seven continents. Purchased from Southwest Windpower in January 2013, the AIR product line continues to achieve nearly 100% reliability, resulting in the lowest warranty rate in the market. Primus continues its global reach with sales offices in Arizona, Colorado, and Germany. Authorized service dealers are also located in the U.S., Canada, Brazil, U.K., Netherlands, Australia, and New Zealand.

Primus Wind Power has common ownership and shared facilities, equipment, and management with Primus Aerospace. Established in 1989, the company is a privately held leading provider of high-precision, high-complexity machined components, kits, and subassemblies for the aerospace, defense, and space industries. Primus Aerospace serves aerospace customers in North America, Europe, and Asia with diversified and complex machined products, assembly services, and engineering support. Customers include industry leaders such as Lockheed Martin, Parker Hannifin, United Technology Corporation, Eaton Corporation, and the U.S. Department of Defense. The company focuses on core principles of increased automation, unique capability, and extraordinary flexibility to customers.

Ken Kotalik, Director of North American Sales, Primus Wind Power, works out of the Primus Flagstaff, Arizona office. Mr. Kotalik has a bachelor's degree in Science from Northern Arizona University. He has worked in and around the renewable energy field for 15 years in various roles including technical sales, sales engineering, installation, and training. Prior to his work with Primus Wind Power, he was a sales manager and training facilitator for Southwest Windpower. He built his own passive and active solar straw bale house in Flagstaff, Arizona.

Ventera Wind | Duluth, MN | www.venterawind.com

Ventera Energy Corporation was formed in January 2004 by designer and inventor Elliott Bayly, a Duluth native. After 3 years of design, prototyping, and field testing, Ventera Energy Corp. was proud to present to the world its new 10-kW VT10 Wind Turbine in 2007. Ventera Energy Corp. ceased operations in July 2011, and Ohio-based North Coast Wind & Power, LLC, purchased the technology. Ventera Wind, Inc. was formed in September 2011 with Dr. Bayly as part of the new team. The new Ventera Wind team set out to continue providing high quality for consumers, improving the turbine over the years with top-quality parts to minimize maintenance, eliminate rusting issues, and improve performance.

Thomas A. Williams, Jr. is the CEO of Ventera Wind, Inc**.** and has served as the managing director for North Coast Wind & Power, LLC for 9 years, developing small to mid-size utility-grade wind generation facilities for publicly owned power providers and commercial and institutional distributed wind installations. Mr. Williams has also acted as a renewable energy finance consultant.

Wetzel Engineering, Inc. | Pflugerville, TX| www.wetzelengineering.com

Wetzel Engineering, Inc., headquartered in Pflugerville, Texas, has been offering state-of-the-art engineering services since 2001 to manufacturers in wind energy, aviation, and heavy industry. The company maintains a network of associated consultants with internationally recognized expertise in aerospace materials and manufacturing, gas turbine engines, advanced controls systems, aircraft design, mechanical systems engineering, and electrical systems engineering.

Dr. Kyle Wetzel has engineered state-of-the-art energy, aerospace, and defense systems since 1993 in a variety of capacities, including as a consultant and researcher through two of his own companies, as Technical Manager of New Product Development at Enron Wind Energy (now part of GE Energy), as Executive VP of Aerotech Engineering & Research Corp., and as a university researcher. He has served as an adjunct professor in the Department of Aerospace Engineering at the University of Kansas since 2005. He has served as Principal Investigator and/or manager on 14 government-funded R&D contracts worth more than $30 million and has consulted to more than 60 private-sector clients. Dr. Wetzel holds an M.S. in Aeronautical and Astronautical Engineering from the University of Illinois at Urbana-Champaign and a Ph.D. in Aerospace Engineering from the University of Kansas.

XZERES Corp. | Wilsonville, OR | www.xzeres.com

XZERES Wind designs, manufactures, and distributes high-quality distributed small wind turbines (2.5 kW – 10 kW). XZERES grid-connected and off-grid wind turbine systems are utilized for electrical power generation for applications and markets such as residential; micro-grid-based rural electrification; agricultural; small business; rural electric utility systems; as well as other private, corporate infrastructure, and government applications.

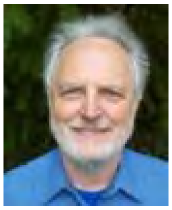
Jay Yeager, Senior Applications Engineer at XZERES Corp., is a wind industry veteran with extensive background and experience in small wind turbine technologies, manufacturing, field testing, wind turbine certification, product development and design, project management, and distributed wind systems development around the world. He has focused on village electrification in underserved and remote locations with full-cycle involvement from resource assessment to siting to modeling and system design, funding, deployment, installation, and commissioning.

Appendix C-3. SMART Wind Consortium Subgroup Leads

Mechanical Systems

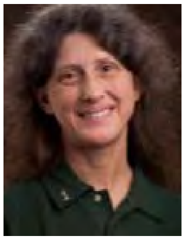
Gary Harcourt – Founder, manager and co-owner of Great Rock Windpower is on a mission to promote distributed wind energy through the installation and maintenance of safe and cost-effective small wind systems. Along with his partners, he installed and maintains a small fleet of turbines in Massachusetts. Mr. Harcourt also travels for Endurance Wind Power as a commissioning engineer, training installers and technicians throughout North America and Europe. Serving on the North American Board of Certified Energy Practitioners *(*NABCEP) small wind exam committee, Mr. Harcourt helped craft the first installer certification exam and was certified as a NABCEP Level III small wind installer. He has served on the DWEA Planning and Zoning committee and is a board member for the Small Wind Certification Council. He received the 2014 installer of the year award at the small wind conference in Wisconsin. Mr. Harcourt is also a customer and turbine owner, operating a 5-kW turbine at his woodshop on Martha's Vineyard in Massachusetts.

Dr. Patrick Lemieux – Associate Professor of Mechanical Engineering, California Polytechnic State University is a Bently Professor who has been involved with wind power research for more than 20 years. Over the past 6 years, he developed Cal Poly's Wind Power Research Facility and presented progress made at national AWEA conferences as well as in a federal congressional panel on energy issues. The facility's goal is to prepare the next generation of wind power mechanical engineers by studying and developing systems according to a design philosophy relevant to utility-scale wind turbines but implemented to small machines suitable for university research and teaching. His prime area of research focuses on the aerodynamic design and control of wind turbine blades; his interests include the turbine system assembly and structure as a whole. Dr. Lemieux is also concerned with global energy sustainability and climate change issues.



Robert W. Preus, PE – Technical Lead for Distributed Wind at NREL is the founder of Advanced Renewable Technology, which provided training, engineering, and certification support to small wind manufacturers. He has 27 years of wind energy experience. Mr. Preus has extensive experience in wind energy systems design and led the successful development of 2.5-kW to 300-kW wind generators. He has trained many dealers in the installation of distributed wind systems and served on the committees that developed NABCEP installer certification task list, applicant experience requirements, and the exam. He was the co-chair of the group that wrote a section for small wind in the National Electrical Code. In 2010, Mr. Preus received the Small Wind Advocate award from the U.S. DOE's Wind Powering America initiative.

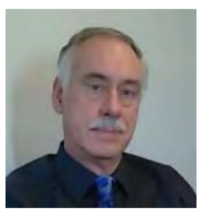
Electrical Systems



Dr. Ruth Douglas Miller – Associate Professor of Electrical and Computer Engineering at Kansas State University has directed K-State's Wind Application Center, which runs the state's Wind for Schools project, since 2007. In the program, K-12 schools receive small wind turbines to educate students about wind energy and interest them in careers in the field. The project has installed more than 20 turbines. The Wind Application Center also runs the High Plains

Small Wind Test Center in partnership with Colby Community College; under a grant from DOE/NREL, the center is testing two small turbines for certification under the AWEA Small Wind Standard. Dr. Douglas Miller is a member of IEEE, Tau Beta Pi, and Eta Kappa Nu, and has more than 25 academic publications. Dr. Douglas Miller earned her doctorate and master's at the University of Rochester and her bachelor's at Lafayette College.

Dr. Eduard Muljadi – NREL received his Ph. D. in Electrical Engineering from the University of Wisconsin, Madison. From 1988 to 1992, he taught at California State University in Fresno, and he joined NREL in June 1992. His current research interests are in the fields of electric machines, power electronics, and power systems in general with emphasis on renewable energy applications. He is a member of Eta Kappa Nu and Sigma Xi and is a Fellow of the IEEE. He is involved in the activities of the IEEE Industry Application Society, Power Electronics Society, and Power and Energy Society. He is an editor of the IEEE Transactions on Energy Conversion and holds two patents in power conversion for renewable energy.



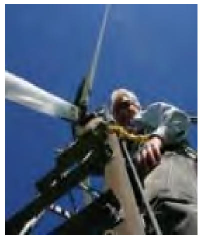
Dr. Robert Wills – Intergrid has been involved in the U.S. solar industry for 32 years and wind for 15 years. He has designed inverters ranging in power from 250 W to 250 kW and was co-designer of the inverter for the Skystream wind turbine. Dr. Wills currently represents the wind community on the U.S. National Electrical Code (Article 694) and also sits on a number of related UL and IEEE standards committees. He is chair of the NEC task group that is writing a new article on micro-grids. Dr. Wills is a consulting engineer whose current clients include wind turbine, energy storage, and utility companies.

Composites

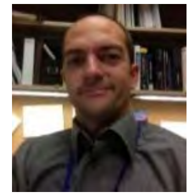
Dr. Pier Marzocca – Clarkson University Dr. Pier Marzocca – Clarkson University / RMIT University has been a faculty member in the Mechanical and Aeronautical Engineering Department at Clarkson University since 2003. He is currently the Deputy Head of the School for Aerospace and Aviation at RMIT University. He received his doctorate in Aerospace Engineering from Politecnico di Torino, Italy, and worked as a Postdoctoral Researcher and Visiting Assistant Professor in Engineering Science and Mechanics at Virginia Tech before joining Clarkson in 2003 and RMIT University in 2015. Dr. Marzocca has been working in aerospace engineering since 1996 and specializes in multi-physics modeling and characterization of advanced materials and structures, with interactions among advanced structures and fluids, magnetic, electric, and thermal fields. He leads/co-leads several research projects with funding from government agencies, including National Science Foundation, U.S. Air Force Office of Scientific Research, U.S. Army Armament Research, Development and Engineering Center, DOE, EPA, NYSERDA, DST Group, Australian Defence Science Institute; private foundations, such as MDA and Syracuse CoE; and industries, including GE, Pratt & Whitney, and Intertek. He is an AIAA Associate Fellow, Chair of SAE Unmanned Aircraft System Technical Committee, International Journal of Aeronautical and Space Sciences Deputy Editor, and Associate Editor of ASCE Journal of Aerospace Engineering and the Journal of Thermal Stresses.

C.P. "Case" van Dam – Chair of Mechanical and Aerospace Engineering, University of California at Davis heads the California Wind Energy Collaborative, a partnership among industry, the University of California, and the California Energy Commission. Before joining UC Davis in 1985, Dr. van Dam was employed as a National Research Council post-doctoral researcher at the NASA Langley Research Center and as a research engineer at Vigyan Research Associates in Hampton, Virginia. His current research includes wind energy engineering, aerodynamic drag prediction and reduction, high-lift aerodynamics, and active control of aerodynamic loads. He has extensive experience in computational aerodynamics, wind-tunnel experimentation, and flight testing. He teaches industry short courses on aircraft aerodynamic performance and wind energy; has consulted for aircraft, wind energy, and sailing yacht manufacturers; and has served as a reviewer for government agencies and research organizations.

Support Structures



Roger Dixon – Owner of Skylands Renewable Energy, energy vendors for the New Jersey Farm Bureau. Mr. Dixon has been involved with the evolution of wind electric for 38 years. He is a charter member of the New Jersey Small Wind Working Group (NJSWWG), chairing the NJSWWG Highlands Committee, Economics Committee, and the Small Wind Model Zoning Ordinance and Siting Committee. He has participated in the New Jersey Board of Public Utilities (NJ BPU) Renewable Energy committee meetings and sat on the NJ BPU Solar Alternative Compliance Payment/Alternative Compliance Payment Advisory Committee representing small wind developers. He is a founding DWEA member, serves as Board Secretary, and is past co-chair of the Permitting & Zoning and Installer Committees.



Dr. Rick Damiani – Senior Engineer, NREL, has been a consultant to the wind industry for the past 15 years. He focuses on aeroelastic modeling of turbines and structural design and analysis of blades and support structures. For NREL's National Wind Technology Center, Dr. Damiani supports various technical projects, from offshore wind to distributed wind. He holds a PhD in Aeronautical Engineering and is a Licensed Professional Engineer.

Gunes Demirbas – G-Tower has more than 10 years of engineering and project management experience in the tower business, including wind towers (< 1.5 MW), electric transmission and distribution towers (< 600 kV), telecommunication towers, and lighting poles. Prior to starting G-Tower, he worked for tower manufacturers Valmont Industries, Falcon Steel, and Mitas Energy. He holds M.Sc. (Geotechnical) and B.Sc. degrees in Civil Engineering from Middle East Technical University. He received an MBA from the University of Alabama at Birmingham. He is a licensed professional engineer in Texas and Alabama.

Appendix C-4. SMART Wind Consortium Collaborating Companies and Organizations

ACE NY – Alliance for Clean Energy New York, Inc.
Albany, NY | aceny.org

Advanced Energy Systems
Denver, CO | windtechnology.com

Advanced MotorTech
Pinellas Park, FL
www.advancedmotortech.com

Advantage Kentucky Alliance
Bowling Green, KY
orgs.wku.edu/advantageky

Aeronautica Windpower
Plymouth, MA
www.aeronauticawind.com

allEarth Renewables
Williston, VT
www.allearthrenewables.com

AlphaSTAR
Long Beach, CA |
alphastarcorp.com

Alternative Energy Institute
Canyon, TX
www.windenergy.org

Amberg Renewable Energy
Alberta, MN
ambergrenewableenergy.com

Ambor Structures
St. Paul, MN |
amborstructures.com

American Corn Growers Foundation
Washington, DC | www.acgf.org

AnemErgonics
Arvada, CO
anemergonics.com

Appalachian State University
Boone, NC | www.appstate.edu

Argonne National Laboratory
Lemont, IL | www.anl.gov

Bergey WindPower
Norman, OK | www.bergey.com

Black Island Wind Turbines
Hadley, MA
blackislandwindturbines.com

BluePacificEnergy
Paia, HI | bluepacificenergy.com

BlueSkyWind
White Plains, NY
blueskywind.com

Boise State University
Boise, ID | boisestate.edu

Cal Poly Wind Power
San Luis Obispo, CA
www.calpoly.edu

Cascade Community Wind Company
Bellingham, WA
cascadecommunitywind.com

CAST, Inc.
Cast Alloy Sales & Technologies, Inc.
Randolph, OH | www.cast-inc.net

cec energy
A Division of
Cazenovia Equipment Company
Cazenovia, NY | cec-energy.com

cecet
Center for Evaluation of Clean Energy Technology
Cortland, NY | www.cecet.com

Mary Childress, CPA
Washington, DC

Chinook Wind
Everson, WA | chinookwind.net

Clarkson University
Potsdam, NY | www.clarkson.edu

CohnReznick
New York, NY | cohnreznick.com

Colorado Energy Office
Denver, CO
www.colorado.gov/energyoffice

Colorado State University
Wind Application Center
Department of Mechanical Engineering
Fort Collins, CO | colostate.edu

Dakota Turbines
Cooperstown, ND
www.dakotaturbines.com

DWEA
Distributed Wind Energy Association
Durango, CO | distributedwind.org

eFormative options LLC
Vashon, WA
eformativeoptions.com

Energy Options
Palmdale, CA
www.energyoptions-wind.com

EnergyTrust of Oregon
Portland, OR | energytrust.org

Endurance wind power
we power the future
Surrey, BC
www.endurancewindpower.com

Eocycle Technologies
Anjou, Quebec | eocycle.com

EWT
Amersfoort, Netherlands
www.ewtdirectwind.com

Extol Wind
Cambridge, MA
www.extolwind.com

forENGics™
Engineering Forensics
Temple, NH | forengics.com

Borger, TX | www.fpctx.edu

Houston, TX | www.g-tower.com

Vineyard Haven, MA
www.greatrockwindpower.com

Ontario, NY | www.harbec.com

Greenville, PA
www.elyriafoundry.com

Boulder, CO | homerenergy.com

Macomb, IL | www.iira.org

Normal, IL
renewableenergy.illinoisstate.edu

Temple, NH | intergrid.org

Glen Burnie, MD | intertek.com

Harrisonburg, VA | jmu.edu

Sedro-Woolley, WA | janicki.com

Pipestone, MN | juhlenergy.com

Manhattan, KS | www.k-state.edu

Manhattan, KS | wac.ece.ksu.edu

Random Lake, WI
www.kettleviewre.com

Oakland, CA |kfwlaw.com

Denver, CO
keystonetowersystems.com

Cavan, Ireland | kingspan.com

Portland, ME
www.mainewindindustry.com

San Ramon, CA
www.manexconsulting.com

Arlington, WA | midnitesolar.com

St. Paul, MN
mn.gov/commerce/energy

Helena, MT | deq.mt.gov

Richmond, VA |
www.nano.vcu.edu

Boulder, CO | www.nrel.gov

Raleigh, NC
nccleantech.ncsu.edu

Niagara Wind & Solar
Niagara Falls, NY
www.niagarawind.com

Nixon Peabody
Albany, NY
nixonpeabody.com

Northern Arizona University
Flagstaff, AZ | nau.edu/cefns

Northern Power Systems
Barre, VT | northernpower.com

Northwest S.E.E.D — Sustainable Energy for Economic Development
Seattle, WA | www.nwseed.org

nyserda — Energy. Innovation. Solutions.
Albany, NY | nyserda.ny.gov

owpi — Oklahoma Wind Power Initiative
Norman, OK | www.ou.edu

Orchid International
Mt Juliet, TN
www.orchidinternational.com

Pacific Northwest National Laboratory — Proudly Operated by Battelle Since 1965
Richland, WA | www.pnnl.gov

Penn State
State College, PA | www.psu.edu

Pika Energy
Westbrooke, ME
www.pika-energy.com

PowerAmerica
Durham, NC
www.ncsu.edu/power

PEER — Power & Electrical Energy Resources
Hubertus, WI
www.linkedin.com/in/david-feider-1b313610

PEIC — Power Electronics Industry Collaborative
Grand Ledge, MI | peic-us.org

primus windpower
Lakewood, CO
www.primuswindpower.com

QED Wind Power — Quiet Economical Dependable
Tucson, AZ
www.qedwindpower.com

Renewtech, LLC
Elbow Lake, MN
renewtechllc.com

RHE — Experts in Renewable Energy Monitoring — www.RightHandEng.com
Ellensburg, WA
www.righthandeng.com

RMIT University
Melbourne, Australia
www.rmit.edu.au

Rohn Products LLC
Peoria, IL | www.rohnnet.com

RUTE Foundation Systems
Portland, OR
www.rutefoundations.com

Sagrillo Power & Light
Forestville, WI

SAMPE
Covina, CA | www.sampe.org

Sandia National Laboratories
Albuquerque, NM |
www.sandia.gov

SecondDesk
Weston, FL | www.2nddesk.com

Self-Reliance
Cataumet, MA
www.selfreliancefuelcoop.org

Seminole Financial Services, LLC — The operating company for The Seminole Companies
Belleaire Bluffs, FL
seminolefinancialservices.com

Hampton, NJ
skylandsrenewableenergy.com

Torrance, CA | sbrmins.com

Clifton Park, NY
smallwindcertification.org

Brainerd, MN
www.smallwindturbines.us

Washington, DC | strategicmi.com

Arlington, VA
www.thestellagroupltd.com

Ontario, NY |sed-net.com

Boone, NC
summervillewindandsun.com

Scottsdale, AZ
tpicomposites.com

Northbrook, IL | ul.com

Brooklyn, NY | unitedwind.com

University of Colorado Denver
Denver, CO | ucdenver.edu

Orono, ME | umaine.edu

Lowell, MA | www.uml.edu

University of Minnesota
Minneapolis, MN
twin-cities.umn.edu

Cedar Falls, IA | www.uni.edu

St. Paul, MN | www.stthomas.edu

Randolph, VT | www.vmec.org

Duluth, MN | venterawind.com

Harrisonburg, VA | wind.jmu.edu

Freeville, NY
weaverwindenergy.com

Madison, WI
www.wesengineering.com

Canyon, TX | www.wtamu.edu

Macomb, IL | www.wiu.edu

Pflugerville, TX
www.wetzelengineering.com

Seattle, WA | www.wsgr.com

Broomfield, CO
windadvisorsteam.com

Spanbroek, Netherlands
www.windenergysolutions.nl

Jamaica, IA

Wind-Energy Science, Technology, and Research Industry/University Cooperative Research Center
Lowell, MA
www.uml.edu/WindSTAR

Minneapolis, MN | windustry.org

Spanish Fork, UT
www.windwardengineering.com

Wilsonville, OR |www.xzeres.com

Appendix C-5. SMART Wind Consortium Participants

Frank Abdi, AlphaSTAR Corporation
Krent Aberle, Sherwin-Williams
Stuart Adler, United Wind
Bouaziz Ait-Driss, Eocycle Technologies Inc.
Roy Amberg, Amberg Renewable Energy
Megan Amsler, Self-Reliance
Vladimir Antikarov, Verea Group
Trevor Atkinson, Northern Power Systems
Dominique Bain, Northern AZ University
Meredith Baker, Ogin Energy
Mark Bakke, AWEA
Greg Balko, SAMPE
Joe Banas, Hodge & Elyria Foundries
Kurt Bankord, Xzeres Wind
Ruth Baranowski, Wind Advisors Team
Ian Baring-Gould, NREL
Bret Barker, U.S. DOE
Ryan Barnhart, Wetzel Engineering
Bob Bechtold, Harbec
Tom Bell, Albany MEP
Dan Bergey, Bergey Windpower
Mike Bergey, Bergey Windpower
Derek Berry, NREL
Aditya Bhatnagar, Extol Wind
Jarod Bishop, EWT
Martin Bissonnette, Eocycle
Steve Black,

Moog Components Group
David Blittersdorf, AllEarth Renewables
Nick Bock, Rohn Products
John Bosche, Chinook Wind
Shawn Boudreau, Endurance Wind Power
Claude Bourget, Eocycle Technologies
Andy Bridge, Janicki
Scott Broughton, Advantage KY Alliance
Malcolm Brown, Catskill Mountain Institute
Tom Bugnitz, Manufacturer's EDGE
Dave Burgess, Endurance Wind Power
Doug Cairns, Montana State University
Nick Cannell, Cast Alloy Sales & Technologies, Inc.
Josh Carlson, Ambor Structures
Everett Carpenter, Nanofoundry
David Carr, Frank Phillips College
Ethan Case, NC Clean Energy Technology Center
Donald Cassil, Sherwin Williams
George Chao, Manex Consulting
Jackie Chelemedos, Renewtech
Xing Chen, Argonne Nat'l Lab
Mary Childress, CPA
Mark Cironi,

Green Energy Technologies
Charlton Clark, U.S. DOE
David Cregg, Kingspan Environmental
Habib-J Dagher, University of Maine Advanced Structures & Composites Center
Rick Damiani, NREL / RRD Engineering
Lisa Daniels, Windustry
Dean Davis, Endurance Wind Power
Chris Dearth, Energy Trust of Oregon
Keith DeGraff, United Wind
Gunes Demirbas, G-Tower
Patrick Dempsey, LLNL
Mia Devine, Northwest SEED
Chris Diaz, Seminole Financial Services
Roger Dixon, Skylands Renewable Energy
Ruth Douglas Miller, K-State University
James Duffy, Nixon Peabody
John Dunlop, Renewable Energy Services
Asad Esmaeily, Kansas State University
Keith Evans, PEIC
Randy Faller, Kettle View RE
Shane Flansburg, MBA
Larry Flowers, G4 Wind
Trudy Forsyth, Wind Advisors Team
Nik Foster, PNNL

Scott Fouts, QED Wind Power
Michael Frazee, CEC Energy
Josh Gange, NOAA
John Gardner, Boise State University
Helmuth Geiser, Scaled Energy LLC
Jake Gentle, U.S. DOE
Jeff Gilman, NIST
Patrick Gilman, U.S. DOE
David Gower, Clarkson University
Elias Greenbaum, GTA, Inc.
Scott Greene, University of Oklahoma
Daniel Griffith, SNL
Elliot Haag, ATA Engineering
Rob Hach, Anemometry Specialists
Alex Hagen, Weaver Wind Energy
Ashley Hale, PEIC
Christopher Hansen, UMass Lowell
Gary Harcourt, Great Rock Windpower
Mark Harris, PUC of Nevada
Jenny Heinzen, MREA
Dean Henderson, Infineon
Troy Hewitt, Intertek
Bill Hetzel, Pika Energy
Andrew Hickok, Pika Energy
Pat Higby, UNI Center for Energy & Environmental Education

Mark Higgins, U.S. DOE
D. DeWayne Howell,
Peak Composites
John Hryn, Argonne Nat'l Lab
Steve Huddle,
University of Colorado-Denver
Michael Hudon, Intertek
Dave Hurst, NextEnergy
Murat Inolpolat, UMass Lowell
Anant Jain, Intertek
Kerop Janoyan,
Clarkson University
Jennifer Jenkins, DWEA
Tony Jimenez, NREL
Richard Johnson,
Rockwind Partners
Mark Jones, EWT
Jason Jonkman, NREL
Corey Juhl, Juhl Energy
Stephen Kalland, NC Clean
Energy Technology Center
Gary Kanaby, formerly with
Wetzel Engineering
Haran Karmaker,
TECO-Westinghouse
Padma Kasthurirangan,
Niagara Wind and Solar, Inc.
Joshua Kaufman, Pika Energy
Lawrence Kelley, Intertek
Roland Kibler, NextEnergy
Kerry Kisslinger, ES Wind Power
Keith Klontz,
Advanced MotorTech
Swad Komanduri, NextEnergy
Michael Kostrzewa, CSU
Ken Kotalik,
Primus Wind Power
Doug Krause,
Rute Foundations
Brian Kuhn,
Aeronautica Windpower, LLC
Valeria La Saponara, UC Davis
David Laino,
Endurance Wind Power
Greg Lane,
Low Volume Lean Center
Ken Lee, Wetzel Engineering
Johan de Leeuw,
Wind Energy Solutions
Richard Legault,
Eocycle Technologies
Patrick Lemieux, Cal Poly
Greg Lepetsos, AnemErgonics
Tom Lettieri, NIST
Rick Lewandowski, CECET
Barbara Linke, UC Davis
Kenneth Loh, UC Davis

Dave Loomis,
Illinois State University, Center
for Renewable Energy
Blaine Loos,
James Madison University
Jonathan Lynch, Northern Power
Ted Lynch, SMI
Shannon Mahar, Duke Energy
Pier Marzocca,
Clarkson University / RMIT
Mark Mayhew, NYSERDA
John McCoury, Xzeres Wind
Dan McGuire, American Corn
Growers Foundation
Chris McKay, Northern Power
Stephen Meier,
Orchid International
Paul Migliore, AnemErgonics
Jonathan Miles,
James Madison University
Jeff Minnema,
Jeff Minnema Consulting
David Minster, SNL
Keith Monson, formerly with
Dakota Turbines
Todd Monson, SNL
Scott Morton,
University of WY-Retired
Peter Mostow, Wilson Sonsini
Goodrich & Rosati
Greg Mowry,
University of St. Thomas
Eduard Muljadi, NREL
John Muth, PowerAmerica
Manufacturing Innovation
Institute
Brian Naughton, SNL
Matt Newberry, NV Energy
RenewableGenerations
Charles Newcomb,
Endurance Wind Power
Christopher Niezrecki,
UMass Lowell
Stephen Nolet, TPI Composites
Tim Olsen,
Advanced Energy Systems
Lucille Olszewski,
Ensemble Wind
Amanda Ormond,
Four Corners Regional
Resource Center
Alice Orrell, PNNL
Remy Pangle,
James Madison University
Joshua Paquette, SNL
Kim Pearse, GBA
Architects+Engineers
Brett Pingree,
Endurance Wind Power

Ben Polito, Pika Energy
Ken Portolese,
Primus Wind Power
Nathan Post, NREL
Robert Preus, NREL
Wei Qiao,
University of Nebraska-Lincoln
Liyan Qu,
University of Nebraska-Lincoln
Robert Quarterman,
Midnite Solar
Patrick Quinlan,
Black Island Wind Turbines
Dan Radomski, NextEnergy
Heather Rhoads-Weaver,
eFormative Options LLC
Tara Rice, Rural Council
Randy Richmond,
RightHand Engineering
Britton Rife,
eFormative Options LLC
Mark Roest, SeaWave Battery
Chris Rose, REAP
Cliff Ryden,
Blue Pacific Energy, LLC
Mick Sagrillo,
Sagrillo Light & Power
Kurt Sahl, eFormative Options
Dennis Scanlin,
Appalachian State University
Dana Scholbrock, NREL
Kevin Schulte, Sustainable
Energy Developments
Adam Schultz,
University of California-Davis
Jacob Segil,
University of Colorado Boulder
Sevdalin Semov, WPS
Nihar Shah, United Wind
Larry Sherwood, Small Wind
Certification Council
David Simkins,
Renewable NRG
Jim Sims, Molycorp, Inc.
Scott Sklar,
The Stella Group, LTD
Weselley Slaymaker,
WES Engineering
Brian Smith, NREL
Eric Smith,
Keystone Tower Systems
Cris Somerville,
Dakota Wind Turbines
Joseph Spossey, Intertek
Nick Stahl, Northern Power
Ken Starcher,
West Texas A&M
Bill Stein,

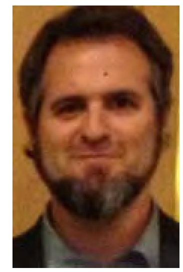
Black Island Turbines
Kim Stelson,
University of Minnesota
Susan Stewart,
Penn State University
Kean Stimm, Kean Wind
Christian Storbeck, UL
Val Stori,
Clean Energy States Alliance
Ryan Storke, CEC Energy
Rich Stromberg, formerly with
Alaska Energy Authority
Charles Sullivan, Dartmouth
Brent Summerville,
Summerville Wind & Sun
Diego Tebaldi, Northern Power
Suzanne Tegen, NREL
Russell Tencer, United Wind
Lise Trudeau,
MN Department of Commerce
Steve Turek,
Wind Turbine Industries Corp.
Daniel Valyou,
Clarkson University
Case van Dam, UC Davis
Ben Vickery, NIST
Kelly Visconti, U.S. DOE
Arturo Villegas,
XPEED Turbine Technology
Karin Wadsack,
Northern AZ University
Qi Wang, NREL
William Werner, BLM
Kyle Wetzel, Wetzel Engineering
Thomas Williams, Ventera Wind
Paul Williamson,
formerly of Maine Ocean & Wind
Industry Initiative
Jolene Willis,
Illinois Institute for Rural Affairs
at Western IL University
Robert Wills,
forENGics & Intergrid
David Willy,
Northern AZ University
Thomas Wind,
Wind Utility Consulting
David Winkelman,
Small Wind Turbines
David Wokosin,
Northwestern University
David Wooley,
Keyes, Fox & Wiedman
Jay Yeager, Xzeres Wind Corp
Wenbin Yu, Purdue University
Chris Zhao, Enwind
Bob Zider, Vermont
Manufacturing Extension Center

Appendix C-6. SMART Wind Consortium Core Team

Jennifer Jenkins – Executive Director, DWEA, has more than 10 years of experience in the wind industry, including her tenure at Southwest Windpower's Government Affairs department. In this role, she helped secure passage of the federal 30% tax credit for small wind systems. In her current role as Executive Director of DWEA, she works with members, stakeholders, and policy makers to find opportunities to grow the distributed wind market. She earned her B.S. in Environmental Science with an emphasis on policy and public administration from Northern Arizona University and is the 2012 recipient of the Women of Wind Energy's Rising Star award.

Heather Rhoads-Weaver – Founder and Principal Consultant, eFormative Options LLC, specializes in policy and market analysis, funding development, and stakeholder communications. She managed the launch of the SMART Wind Roadmap and the DOE/PNNL-funded Distributed Wind Policy Comparison Tool (www.windpolicytool.org). Recent clients have included the Clean Energy States Alliance and the Small Wind Certification Council. She received Windustry's 2013 Distinguished Service in Community Wind Award and was named DWEA's 2014 Person of the Year, Women of Wind Energy's 2012 Mentor of the Year, and U.S. DOE/NREL's 2006 Small Wind Advocate of the Year. Ms. Rhoads-Weaver has served as Secretary for DWEA's Board of Directors and co-chair of DWEA's State Policy Committee. She also served as AWEA's first Small Wind Advocate, was founder of NW Sustainable Energy for Economic Development, and worked for Global Energy Concepts, the National Wind Coordinating Committee, and Iowa Citizen's Action Network. She holds an M.S. from the University of Northern Iowa and a B.A. from Wesleyan University.

Trudy Forsyth – Managing Director, Wind Advisors Team, has more than 20 years of experience in wind technology. She led the DOE/NREL small and distributed wind program for 18 years where she helped design new U.S. small wind turbines, test prototypes and commercial turbines to standards, develop international and national standards, and develop distributed wind marketing and education materials. Ms. Forsyth worked closely with DOE program managers to develop multi-year strategies and implement program objectives. She is currently the president of the SWCC Board, past president for Women of Wind Energy, and a DWEA board member. She holds a BS and MS in mechanical engineering.



Brent Summerville, PE – President, Summerville Wind & Sun, is a licensed professional engineer in North Carolina with a BS in Mechanical Engineering from North Carolina State University and a Masters in Appropriate Technology from Appalachian State University (ASU). He began his career in renewable energy at ASU by designing, installing, troubleshooting, and providing training on solar water, PV, micro-hydro, and distributed wind energy projects. He gained extensive experience testing small wind turbines while serving as manager of ASU's Small Beech Mountain Wind Research & Demonstration Site.

Ruth Baranowski – Communications Consultant, Wind Advisors Team, provides communications support for the SMART Wind Consortium, documenting meeting discussions and outcomes and editing materials. Her 13 years of experience in the wind industry include serving as the communications coordinator for DOE's Wind Powering America initiative, based at NREL. She holds a B.A. in mass communications from Colorado State University and an M.S. in technical communications from the University of Colorado Denver.

Britton Rife – Policy and Communications Consultant, eFormative Options, conducts distributed energy policy and market analysis. She has worked as a lobbyist to support strengthening and extending the Washington State Renewable Energy Cost Recovery Program and has provided communications and stakeholder engagement support for the SMART Wind Consortium project. She is passionate about environmental sustainability and holds a B.A. in Environmental Studies from the University of Oklahoma.

Appendix D. References and Resources

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Sustainable Manufacturing, Advanced Research & Technology Wind Roadmap

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

Photo sources: Bergey Windpower, Windsine, Niagara Wind & Solar, Endurance Wind Power, Primus Wind Power, M.A. Mortenson

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