U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Wind Vision Detailed Roadmap Actions

2017 Update

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Wind Vision Detailed Roadmap Actions

2017 Update

In March 2015, the U.S. Department of Energy (DOE) released *Wind Vision: A New Era for Wind Power in the United States*, which explores and quantifies the economic and environmental costs and benefits of a scenario in which wind provides 10% of U.S. electrical demand in 2020, 20% in 2030, and 35% in 2050. The *Wind Vision* report also includes a Roadmap that describes actions stakeholders can pursue to achieve the vision and its underlying wind deployment scenario. The *Wind Vision* and its Roadmap were compiled by representatives from DOE and its national laboratories in consultation with the wind industry, trade associations, academia, environmental organizations, and other stakeholders. When the *Wind Vision* was released in 2015, DOE announced its intention to engage the wind community from time to time to track progress and update the Roadmap periodically.

This report expands on the top-tier actions outlined in the 2015 *Wind Vision* Roadmap, and updates the findings based on comments from nearly 100 stakeholders during a series of topical meetings that took place throughout 2016–2017. Seven working sessions were held to assess the Roadmap's status and needs across the topical areas identified in the Roadmap: Wind power resources and site characterization; Wind plant technology advancement; Supply chain, manufacturing, and logistics; Wind power performance, reliability, and safety; Wind electricity delivery and integration; Wind siting and permitting (with a separate session on wildlife issues); Collaboration, education, and outreach; Workforce development; and Policy analysis. This process is described in more detail in the *2016–2017 Status Assessment and Update on the Wind Vision Roadmap: Findings from Topical Working Sessions report*.

The *Wind Vision* Roadmap and this update effort describe the actions that would be needed to achieve and reduce the cost of the *Wind Vision*. The update reflects feedback from stakeholders and does not commit the U.S. Department of Energy to performing specific actions. Achieving the *Wind Vision Study Scenario* would require efforts from a diverse set of stakeholders, including a number of actions that would be led by industry.

Most of the top-tier roadmap actions include additional, detailed subactions.[1] The relevant top-tier actions are listed here, followed by the related detailed actions. For additional context on the original planned actions, see the *Wind Vision* Roadmap (*Chapter 4 of the 2015 Wind Vision report*) and *Appendix M of the 2015 Wind Vision,* which listed detailed roadmap actions prior to the 2016–2017 update effort.

Document highlight key

Black: No change from the 2015 *Wind Vision*

Red: Increased priority

Green: Reduced priority

Yellow: New action (not included in 2015 *Wind Vision*)

Blue: Significant text revision, or important new insight from the status and update effort

1 There are no detailed subactions for roadmap Action 9.1: Refine and Apply Energy Technology Cost and Benefit Evaluation Methods; Action 9.2: Refine and Apply Analysis Methods; and Action 9.3: Maintain the Roadmap as a Vibrant, Active Process for Achieving the *Wind Vision Study Scenario*.

1 Wind Power Resources and Site Characterization

Action 1.1: Improve Wind Resource Characterization for Both Land-Based and Offshore Applications	
Collect data and develop models to improve wind forecasting at multiple temporal scales (e.g., minutes, hours, days, months, and years).	
DELIVERABLE	**IMPACT**
Data, validated models, and measurement techniques that improve the ability to predict wind plant power output over several spatial and temporal scales.	Improved siting and increased wind plant performance resulting in increased revenue, improved reliability, and decreased operating costs. Reduced project financing costs and power system operating costs.
Key Themes: Reduce Wind Costs; Expand Developable Areas **Markets Addressed:** Land, Offshore	

ACTION	DELIVERABLE	IMPACT	BEGIN	END
Action 1.1.1: Improve wind forecasting in minutes, hours, and days time frames. Develop, validate, and apply models and measurement techniques that accurately characterize and forecast the wind in various time frames (e.g., hours, days, months).	Estimates of regional wind energy content and timing over generating-unit commitment and dispatch time intervals.	Reduced project financing costs, reduced power system operating costs, improved project siting, and a sound basis for advanced turbine and wind plant design.	2014	2030
Action 1.1.2: Improve seasonal forecasting for wind. Develop credible forecasts of seasonal wind patterns to enable improved decisions on nonwind power plant operations and maintenance, and on electricity market participation.	Estimates of seasonal wind energy content versus time and location.	Better informed decisions on overall operation of the electric power system.	2017	2030
Action 1.1.3: Understand interannual variations, such as those forced by nonlinearities in the weather system, or by ENSO or similar phenomena, to reduce uncertainties in long-term energy production and financing risks.	Estimates of wind energy production over periods of several years.	Better informed decisions on wind power plant financing.	2017	2030
Action 1.1.4: Develop models that predict the effect of changing weather patterns on wind resources; couple this with assembly of comprehensive data sets needed for design and validation of the models. Develop credible forecasts of the impact of the changing weather patterns and the interannual variability of weather patterns on regional wind resources.	Estimates of regional wind energy content versus time and location over periods of several decades.	Better informed decisions on investments in wind power plant and transmission equipment.	2014	2030

Red: Increased priority
Green: Reduced priority
Yellow: New action (not included in 2015 *Wind Vision*)
Blue: Significant text revision, or important new insight from the status and update effort

ACTION	DELIVERABLE	IMPACT	BEGIN	END
Action 1.1.5 Accelerate development and acceptance of innovative remote measurement systems (e.g., lidar). Develop high-spatial-resolution sensing technology and techniques for use in high-fidelity experiments and siting wind power plants. Examples include buoy-based profiling lidars and fixed scanning lidars.	"Bankable" remote-sensing technologies for wind power plant siting and scientific research. Bankability based on validation studies and peer-reviewed articles.	Reduction in cost and deployment time for site-specific resource characterization; acceptance of next-generation measurement practices; alternatives to fixed-bottom tall towers. Improved efficiency and performance of wind power systems.	2014	2030
Action 1.1.6: Establish monitoring systems and conduct long-term collection of wind-characteristics data. Improve understanding of wind resource characteristics that affect loads on wind turbine components.	Long-term (multiyear) data sets of wind characteristics; including temporal variations of wind speed, direction, and energy, as well as turbulence intensity and ramping behavior.	Improved capability for wind power plant siting and long-term energy prediction; increased plant life; reduced development risks; and reduced levelized cost of energy (LCOE) through reduced financing costs.	2017	2030
Action 1.1.7: Improve data sets for extreme events; include loading on turbine components. Develop improved data sets for land-based and "extreme" event meteorological ocean (metocean) statistics, including joint probabilities (e.g., wind and wave).	Maps, statistics, and classifications of extreme events, values, and return periods for wind, waves, and other metocean phenomena.	Reduced uncertainty in power plant design; reduced financing and insurance costs.	2014	2030
Action 1.1.8: Create archives and collaborative frameworks for data related to wind resources and their impacts. Develop workable frameworks for collaborative private–public data sharing and research.	Archiving for both land-based and offshore data, implemented according to contemporary standards; case studies and sample legal agreements for sharing data collected by the private sector.	Expanded access to land-based and metocean data to address scientific barriers and advance knowledge.	2014	2030
Action 1.1.9: Enhance resource maps and related models. Develop improved models for resource characterization and forecasting.	Improved model physics; models validated in land-based and offshore environments for a full range of atmospheric and oceanographic conditions; reports and journal articles.	Higher confidence and accuracy from validated resource maps; improved inflow characterization for turbines and wind power plant design; improved forecasting for wind power plant operations.	2014	2030

Note: In the 2015 *Wind Vision* Roadmap, subactions for Wind Resource Characterization were defined in more detail for offshore applications than for land-based applications. One finding of the *2016–2017 Status Assessment and Update* effort is that many of those subactions apply equally to both land-based and offshore situations. Action 1.1 has been augmented accordingly, and now includes a number of additional subactions. Much of the related text was actually included in the 2015 *Wind Vision* Roadmap under Action 1.3.

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Action 1.1.1: Improve wind characteristics forecasting in minutes, hours, and days time frames.

Reducing the error and uncertainty of wind resource forecasts and wind power generation facilitates the integration of wind into the electric grid. Stakeholder action is needed to develop, validate, and apply models and measurement techniques that accurately characterize and forecast the wind in various time frames (e.g., minutes, hours, days, months, and years). Forecasts on the hourly scale support dispatch decisions; multihour forecasts warn of ramp events (rapid changes in power output); and day-ahead forecasts inform unit-commitment decisions.

It is important that these forecasts address major wind characteristics beyond just wind speed, such as turbulence and stability. Two main aspects of numerical weather prediction models are the data assimilation scheme and the model physics, both of which can be improved through stakeholder action to support wind integration.

Action 1.1.2: Improve seasonal forecasting for wind.

Although short-term (hours to days) wind forecasting has improved substantially over the past decade, forecasting on a seasonal basis is at a much earlier stage. Improved seasonal forecasting would allow electric power system operators to schedule maintenance for both wind power plants and nonwind generators optimally. Planned maintenance of wind plants could be scheduled for periods when low winds are expected, and maintenance for other plants could be planned for periods of high wind production. This would also reduce the incidence of unplanned outages, which can be costly because they often occur during periods of high electricity demand and require emergency repairs on short notice.

Action 1.1.3: Understand interannual variations, such as those forced by nonlinearities in the weather system, or by ENSO or similar phenomena.

Wind power plant energy production can vary substantially from year to year. These year-to-year variations are not well understood, and are influenced by large-scale natural drivers of major weather patterns such as the El Nino Southern Oscillation (ENSO). Improved understanding of these variations, the factors that drive them, and their frequency and magnitude would improve long-term energy predictions from wind power plants. In turn, this would reduce development risks, financing costs, and the delivered cost of wind electricity.

Action 1.1.4: Develop models that predict the effect of changing weather patterns on wind resources; couple this with assembly of comprehensive data sets needed for design and validation of the models.

Wind power plants have economic lifetimes that can range from 20 to 30 years. Over this period, changes in weather patterns can affect the wind resource characteristics at a wind plant, with consequent changes in the plant's power production. It is important but challenging to reliably quantify these effects. A long-term measurement campaign is needed to develop and validate results of models that can align changes in global-scale atmospheric forcing to the detailed flow through a wind plant.

Action 1.1.5: Accelerate development and acceptance of innovative remote measurement systems (e.g., lidar).

Remote-sensing techniques are needed to collect the detailed intraplant data required to fully characterize wind power plant flows, and to support resource assessment efforts. As turbine hub heights continue to grow and as development expands offshore, conventional meteorological towers become costly and impractical. Additional research is required to transition remote-sensing measurements from the realm of scientific inquiry to "bankable" data with sufficient reliability to support large investment decisions. The performance of these systems must be completely characterized in a wide variety of terrain and weather conditions so their performance is fully understood. A key activity for this task is the development of internationally accepted standards for these new measurement technologies.

One of the largest barriers to offshore resource characterization is the high cost of tall meteorological masts needed to characterize wind conditions; the land-based norm is not readily transferable to water environments. At an offshore site, the cost of free-standing, offshore meteorological masts can be roughly two times their land-based counterparts in shallow water. These masts may not be feasible in deeper waters where floating wind turbines might be deployed. Permitting requirements for fixed meteorological towers are demanding and can take 1 to 2 years to satisfy.

Technological alternatives are needed to overcome these hurdles. Surface-based remote-sensing technologies, including profiling, scanning, and floating versions of lidar systems are essential for viable and bankable alternatives to mast-based measurement programs for offshore wind. Accelerated development and validation of new technologies like lidar will enable the collection of reliable offshore wind data for offshore research and commercial projects.

Action 1.1.6: Establish monitoring systems and conduct long-term collection of wind-characteristics data.

These long-term data sets, including information on wind speeds, energy content, turbulence, and other features, will improve wind power plant siting decisions and provide more accurate long-term energy prediction. Another need is to better understand the linkages between wind characteristics and loads on wind turbine components. Insights gained will increase the life of wind power plants and turbine components, reduce development risks, and thereby reduce the levelized cost of energy (LCOE) through lower financing costs.

Action 1.1.7: Improve data sets for extreme events; include loading on turbine components.

Design criteria for offshore structures as established by the International Electrotechnical Commission, American Petroleum Institute, and other organizations include 50-, 100-, and possibly 500-year return periods for extreme wind and wave events. Because of the lack of long-term measurements in U.S. waters, existing probability statistics for extreme conditions contain a high degree of uncertainty. As evidenced by severe weather events in recent years, climatological statistics for extreme event probabilities derived solely from historical records may need to be revised. More reliable statistics for extreme event probabilities, derived from a combination of new observations and modeling approaches, are required to reduce the need for large uncertainty margins in system design, which will lead to lower investment risk and costs. This need is greatest for offshore wind, because the domestic offshore development experience base is minimal. However, once developed, an improved understanding of extreme events and their impacts will also provide substantial benefits for land-based wind.

Action 1.1.8: Create archives and collaborative frameworks for data related to wind resources and their impacts.

Although the experience base for land-based wind is extensive, most of the detailed wind resource data are privately held and are not generally available to the wind community. On the offshore front, each offshore project will likely require a minimum of 1 year's worth of on-site metocean monitoring as part of the design and energy assessment process. Most offshore project development is expected to be financed by the private sector, which implies that the metocean data collection will be privately held as well. Given the critical importance of observational data to advance the greater industry's understanding of the wind resource environment both offshore and on land, there would be substantial value in finding ways for privately held data to be shared, either partially or in full, with the research community and other stakeholders. Mechanisms for data sharing should be designed, while respecting the competitive interests of developers.

Action 1.1.9: Enhance resource maps and related models.

In addition to more observational data, there is a need for improved modeling capabilities to accurately interpolate and extrapolate information from a limited number of stations to broader areas while representing important dynamic processes. These processes are particularly important for offshore wind, and include complex land-sea-air interactions that play a vital role in sea breeze circulations, low-level jets, thermal profiles and stability, and other marine boundary-layer phenomena. Given the evolution of increasingly taller hub heights and larger rotor diameters, wind turbines are becoming more exposed to potentially significant flow discontinuities across their swept areas. Models will play an important role in both resource characterization and operational forecasting.

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Action 1.2: Understand Intraplant Flows	
Collect data and improve models to understand intraplant flow, including turbine-to-turbine interactions, micro-siting, and array effects.	
DELIVERABLE	**IMPACT**
Data, validated models, and measurement techniques to minimize turbulence induced by adjacent turbines through optimized siting.	Increased wind plant energy production and reduced turbine maintenance requirements.
Key Themes: Reduce Wind Costs **Markets Addressed:** Land, Offshore	

ACTION	DELIVERABLE	IMPACT	BEGIN	END
Action 1.2.1: Improve multiscale complex flow models; include wake modeling and intra-array effects. Conduct a measurement campaign; improve understanding of complex terrain; develop integrated models linking large-scale climatology, meso-scale meteorological processes, microscale terrain, and wind power plant array effects.	Experimental data and computational models that define the effects of turbine wakes, complex terrain, and complex meteorological phenomena on wind power plant flows.	Foundational understanding of complex flows in wind power plants, which enables improved power plant design and energy production forecasting.	2014	2030
Action 1.2.2: Optimize the siting of turbines in a wind power plant. Develop tools based on state-of-the-art models and standardized micro-siting methods; refine and set standards for modeling techniques for wind resource and micro-siting.	Computational tools with the capability to efficiently optimize turbine siting within a wind plant.	Increased energy capture and reduced fatigue loads.	2014	2030

Action 1.2.1: Improve multiscale complex flow models; include wake modeling and intra-array effects.

Generating wind power is basically a combination of large-scale weather processes and the detailed aerodynamic flow of wind through a turbine rotor. This process is not well-understood. A combined experimental and theoretical investigation is required to provide insight into the fundamental physical processes, and to develop numerical simulation tools that can successfully model this complex system. This model is the foundation for many of the other actions in this roadmap. Therefore, development of this model should be initiated immediately. A substantial effort is also required to validate the results of the model for a wide range of wind power plant configurations and atmospheric characteristics.

Action 1.2.2: Optimize the siting of turbines in a wind power plant.

The aerodynamic interactions between wind turbines in a large-scale wind plant can reduce the power output of the plant by 10%–15%. Additionally, the effects of any complex terrain features present at the site can further reduce the plant's power production. Improved numerical simulation tools are needed to accurately calculate these effects, enabling wind plant design to mitigate these adverse effects and produce maximum power in a wide variety of atmospheric conditions. A data-gathering campaign is required to develop and validate the accuracy of the numerical simulation tools.

Action 1.3: Characterize Offshore-Specific Wind Resources	
Collect and analyze data to characterize offshore wind resources and external design conditions for all coastal regions of the United States, and to validate forecasting and design tools and models at heights at which offshore turbines operate.	
DELIVERABLE	**IMPACT**
Resource maps, forecasting tools, weather models, measurement stations, and technical reports documenting physical design basis.	Improved offshore research and development (R&D) strategy and accelerated offshore wind deployment.
Key Themes: Reduce Wind Costs; Expand Developable Areas **Markets Addressed:** Offshore	

ACTION	DELIVERABLE	IMPACT	BEGIN	END
Action 1.3.1: Characterize offshore wind resource and external design conditions, including turbine loads from wind, water, ice, and their interactions. Validate at heights in which offshore turbines operate. Establish reference facilities to provide high-quality scientific observations and measurements.	Resource maps, forecasting tools, weather models, measurement stations, and technical reports documenting the physical design basis.	Accelerated adoption of offshore technology due to lower project risk and uncertainty.	2014	2030
Action 1.3.2: Create offshore monitoring for metocean data collection. Establish high-intensity, benchmark metocean measurement and research facilities in strategic offshore locations.	An offshore monitoring network and multiyear validated data sets, accessible to multiple stakeholders.	Improved understanding of physical metocean conditions at higher spatial resolution; advanced modeling capabilities for dynamic processes and land-sea-air interactions; reduced uncertainty in wind plant design and performance.	2014	2030
Action 1.3.3: Improve wake modeling. Evaluate plant wakes and impacts on adjacent wind turbines and wind plants; advance wake and energy prediction models.	Quantitative studies and technical papers.	Improved turbine and plant layouts for optimum energy production; improved energy forecasting; improved turbine reliability; reduced wake-induced loads.	2014	2030

Action 1.3.1: Characterize offshore wind resource and external design conditions, including turbine loads from wind, water, ice, and their interactions.

Resource characterization initiatives are required to gather the scientific data needed to develop and validate detailed models of offshore wind characteristics. Knowledge of wind characteristics is required to effectively design offshore wind plants and accurately predict their power production. The resource characterization initiatives will be required at all offshore wind areas of the United States, including the Gulf of Mexico, Atlantic, Great Lakes, and Pacific. Reference facilities must be established to provide the necessary high-quality scientific data. These high-quality field measurements can be used to validate the numerical simulations that provide the needed spatial and temporal resolution.

Action 1.3.2: Create offshore monitoring for metocean data collection.

Data needs and modeling efforts require detailed knowledge of the marine atmospheric boundary layer, the air-sea interface, and the subsurface ocean/lake water profile. Regional initiatives in strategically sited metocean measurement and research facilities are the most cost-effective approach to addressing several knowledge gaps

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in a concentrated fashion. Regional data sets available to the public are desirable in areas where offshore wind turbines might be deployed. The measurement environment should span the full water and atmospheric column, more than 150 meters above the surface. The deployed systems should complement and validate low-intensity, low-cost, standardized metocean monitoring systems (buoys) in intervening areas.

Action 1.3.3: Improve wake modeling.

The understanding of wake impacts on turbine fatigue loads and energy production is more challenging for offshore projects because they are generally larger in scale than their land-based counterparts. Also, surface roughness and atmospheric stability regimes are significantly different. Due to their relative simplicity, current commercial wake modeling tools cannot accurately simulate wake development, propagation, and dissipation behavior for large arrays. This results in undesirably high levels of prediction uncertainty. Improved wake modeling is needed to better optimize turbine layouts and mitigate wake-induced impacts and uncertainties on project performance and reliability. Wake modeling advancement will enable projects yielding higher energy production and lower operation and maintenance (O&M) costs.

2 Wind Plant Technology Advancement

Action 2.1: Develop Next-Generation Wind Plant Technology	
Develop next-generation wind plant technology for rotors, controls, drivetrains, towers, and offshore foundations for continued improvements in wind plant performance and scale-up of turbine technology.	
DELIVERABLE	**IMPACT**
Wind power systems with a lower cost of energy.	Reduced energy costs for U.S. industry and consumers. Increased wind deployment nationwide.
Key Themes: Reduce Wind Costs; Expand Developable Areas **Markets Addressed:** Land, Offshore	

ACTION	DELIVERABLE	IMPACT	BEGIN	END
Action 2.1.1: Develop cost-effective turbine technology for very low wind speeds. High-capacity-factor wind turbines with tall towers and large blades are a critical part of this initiative.	Cost-effective wind energy in low-wind-speed sites.	Greater geographic diversity of wind energy supply, minimizing the need for new transmission lines.	2014	2030
Action 2.1.2: Develop larger wind turbines. Develop technology for a new generation of much larger turbines that overcome cost and logistics barriers. A focus for this effort should be the design and manufacture of very large blades and towers, while overcoming logistical challenges such as transportation and installation.	Large, affordable turbines.	Significant reduction in siting and permitting challenges; lower bill of materials, balance of system, and O&M costs; significant reduction in the number of turbines needed to meet deployment goals.	2014	2040
Action 2.1.3: Develop advanced rotors. Use stronger, lighter materials to enable larger rotors; improve aerodynamic designs, novel rotor architectures, active blade elements, aeroelastic tailoring, sweep, noise reduction devices, active aerodynamic controls, and downwind, lower solidity rotors.	Rotors with increased energy capture, lighter weight, and lower noise.	Lower cost of energy, reduced deployment barriers.	2014	2040
Action 2.1.4: Improve drivetrain and power electronics. Create advanced generator designs; use alternative materials for rare-earth magnets and power electronics; improve grid support through power electronics; improve reliability of gearboxes.	Increased power conversion system efficiency and reliability; reduced cost.	Increased overall wind plant efficiency; improved grid stability	2014	2030
Action 2.1.5: Develop advanced control systems. Develop advanced control systems that reduce structural loads on turbines, increase energy capture, and operate the wind plant in an integrated manner to increase efficiency and support grid stability.	Next-generation control systems that increase power production and improve grid stability.	Lower cost of energy, improved grid stability.	2014	2035
Action 2.1.6: Develop tall towers. Develop taller towers that reach higher wind speeds aloft and enable larger rotors, but are not constrained by logistics.	Much taller towers that can be efficiently transported to wind plants.	Increased energy capture for a given land area, allowing development of lower wind speed sites.	2014	2030

ACTION	DELIVERABLE	IMPACT	BEGIN	END
Action 2.1.7: Develop next-generation foundations and installation systems. New foundation designs that will efficiently support the taller towers described in Action 2.1.6 are needed for both land-based and offshore turbines. New installation systems must be developed to mitigate the limitations of conventional crane technologies.	Cost-effective foundation and turbine installations.	Lower cost of energy, increased developable area.	2014	2030
Action 2.1.8: Deploy demonstration projects. Support and deploy full-scale demonstration projects for key advanced offshore technologies in various geographic regions.	Full-scale turbine technology in demonstration projects that showcase offshore wind technology.	Reduced investor and public perception of risks; initiation of infrastructure development.	2014	2020
Action 2.1.9: Develop advanced support structures. Innovate to produce offshore support structures that avoid high construction costs and enable mass production.	Low-cost piles, jackets, foundations, and installation methods.	Efficient mass production and deployment methods; reduced project costs and vessel bottlenecks.	2014	2030
Action 2.1.10: Develop new turbine technology systems. Research and develop cost-effective technology for floating wind turbines.	Cost-effective wind turbine technology that can be deployed in water depths up to 700 meters.	Increased siting options and lower LCOE.	2014	2050
Action 2.1.11: Evaluate solutions to ice loading. Develop technology to mitigate ice loading for freshwater ice floes.	Cost-effective wind turbines (fixed and floating) designed to withstand extreme ice loading in cold regions of the United States.	Increased siting options and lower LCOE.	2014	2030
Action 2.1.12: Devise strategies to bolster offshore systems against hurricanes. Develop wind turbine systems and design strategies to address offshore wind deployment in hurricane-prone areas.	Cost-effective wind turbine systems designed and certified to withstand extreme tropical cyclone events.	Increased siting options and lower LCOE.	2014	2025
Action 2.1.13: Improve distributed wind technology. Optimize technology design for low to moderate wind resources, where distributed wind applications are typically located.	Lower-cost distributed wind turbines for low wind speed locations.	Much lower LCOE at moderate wind speed sites.	2014	2020

Action 2.1.1: Develop cost-effective turbine technology for very low wind speeds.

One of the most important new technologies for wind power is the development of much larger rotors for a given power-rating turbine. This permits increased energy capture and capacity factors, lowering the cost of energy. These larger rotors, and corresponding taller towers, permit the cost-effective development of sites with lower average wind speeds than was previously economical. This technology trend should be continued, allowing wind power to be economically competitive across the United States.

Action 2.1.2: Develop larger wind turbines.

The total number of wind turbines required for the *Wind Vision Study Scenario* can be significantly reduced by continuing the development of much larger machines, both in terms of electrical capacity and physical size. Key technologies for turbine growth are segmented rotor blades that can be easily transported to the wind plant and then assembled on site, and a similar technology being developed for on-site assembly of larger-diameter towers.

Since the modern wind power industry began in the early 1980s, the average capacity of wind turbines has increased almost 50 times. This growth in turbine size is indicative of the tremendous cost savings that have been realized by the industry since it began, largely due to fewer turbines generating the same plant output. The benefits of larger turbines are inherent in both land-based and offshore wind plants, but the challenges for land-based wind are different and land-based wind turbine growth has not kept pace with offshore. Transport of very large components by truck or rail is limited by physical constraints such as highway overpass heights and rail or road turning radii. These constraints do not apply to offshore wind.

Today, the average offshore wind turbine being deployed has grown to nearly 4 megawatts (MW), and this growth is expected to continue. As evidence, almost every turbine manufacturer in the offshore wind market is developing a 5-MW to 8-MW wind turbine, and the industry forecasts the development of 10-MW wind turbines in the near future. These new machines are specifically designed to operate offshore. They also embody a unique set of offshore technology challenges that the industry is working to overcome. These technologies include rotor designs that implement advanced blade composite materials, assembly techniques, inspection, advanced blade testing, downwind rotor operation, and a new vein of advanced control methods and mechanisms. Drivetrains are becoming more reliant on direct-drive and medium-speed generators with permanent magnets and advanced power electronics that can operate at very low speeds and overcome the reliability concerns of conventional gear-driven systems.

Action 2.1.3: Develop advanced rotors.

Many opportunities exist for continued improvements in rotor technology. Lower noise airfoil and rotor designs can be developed to increase the developable land area in the United States. Advanced materials can be used to reduce weight and structural loads, and enable larger rotor diameters. Active aerodynamic controls on the blades can be used to reduce operational fatigue loads on the entire turbine system, and sophisticated aeroelastic tailoring can be used to passively reduce the structural loads on the entire wind turbine structure.

Action 2.1.4: Improve drivetrain and power electronics.

Continued development is needed to reduce costs and improve the reliability and efficiency of the drivetrains and power conversion systems that turn the rotor's rotational power into electrical power. Technological development of conventional multistage geared approaches, medium-speed systems, and direct-drive architectures—each of which has advantages—should be continued. High-flux permanent magnets can improve the efficiency of all three configurations. Efforts to develop alternatives to the existing rare-earth technologies should be pursued. New materials for power conversion electronics, such as silicon carbide, can increase efficiency and eliminate the need for complex liquid-cooling systems.

Action 2.1.5: Develop advanced control systems.

Advanced control systems that minimize turbine structural loads have been key contributors to the development of today's generation of much larger rotors. The continued development of these control systems in the future will likely take advantage of additional sensors, such as the forward-looking lidar system that comprehensively senses the wind characteristics upstream of the rotor. An additional opportunity is the development of integrated wind plant control systems that operate all of the wind turbines in a synergistic manner to increase power production and reduce fatigue loads. These wind plant controls can also actively control the power output characteristics of the plant to promote grid stability.

Action 2.1.6: Develop tall towers.

Taller towers are the necessary complement to larger rotors. Taller towers also provide access to the stronger winds that exist at higher elevations above the ground. They are key to the cost-effective development of lower-wind-speed sites. Logistic constraints limit the maximum diameter of tower sections that can be transported over land, however, causing the cost of tall towers to increase disproportionately. For these reasons, innovations that permit increased on-site assembly of towers are needed.

Action 2.1.7: Develop next-generation foundations and installation systems.

The fabrication and installation costs of offshore foundations and support structures have led to higher costs for offshore wind technology. Offshore costs can be lowered considerably by reducing construction time and dependency on high-priced, heavy-lift vessels, as well as through technology innovations, mass production, and standardization of the support structure. This opportunity will guide the development of advanced offshore foundations and substructures. For land-based turbines, new foundation designs are needed to efficiently support the taller towers to be developed per Action 2.1.6.

Action 2.1.8: Deploy demonstration projects.

As of 2016, the industry has deployed one commercial offshore wind farm in the United States. This limited experience causes a perception that such installations are high-risk. A key need is to deploy and successfully demonstrate state-of-the-art offshore wind technology to determine the extent to which today's technology is reliable and can withstand environmental conditions in the United States. The U.S. Department of Energy initiated an Offshore Wind Advanced Technology Demonstration Program,[2] which is scheduled to deploy two independent pilot offshore wind projects using full-scale commercial turbines. Developers will receive assistance to offset the initial risk of being first-of-a-kind. In exchange, the public will receive a first-hand account of actual offshore wind turbine performance.

Action 2.1.9: Develop advanced support structures.

Offshore foundations and support structures have followed a conservative path, leveraging the experience of the oil and gas industry. As of 2016, there were nearly 13 gigawatts of offshore wind deployed worldwide. The support structure and cost of offshore construction, however, have contributed much of the higher cost of offshore wind technology, where 70% of the capital expenditures are nonturbine costs. Industry projections indicate that offshore costs can be lowered considerably by reducing construction time at sea and dependency on high-priced, heavy-lift vessels, and by mass producing and standardizing the support structure.

Action 2.1.10: Develop new turbine technology systems.

Nearly 60% of the net technical resource potential for offshore wind is in water deeper than 60 meters [1]. Deep water is also further from shore, where environmental, competing-use, and viewshed impacts are lower and wind resources are more abundant. Costs have been shown to increase with depth for fixed-bottom systems, so foundation costs for these systems are expected to be higher as depths increase beyond 60 meters. Floating offshore wind system costs, however, may not increase as rapidly with water depth.

New technologies that can operate at greater depths are emerging, leveraging oil and gas experience. They have the potential to match the costs of existing fixed-bottom systems and, with innovations in moorings and manufacturing, they are expected to achieve lower costs. New floating technology standards and certification procedures need to be created and adopted to provide guidance to technology and offshore wind system developers.

Action 2.1.11: Evaluate solutions for ice loading.

More than 135 gigawatts of net technical U.S. resource potential can be found in the Great Lakes, where winter ice sheets introduce another engineering challenge for offshore wind turbines [1]. Ice floes and consolidated ice can introduce high-dynamic loading on the tower and support structure, which must be anticipated and taken into consideration during the design. Designs to resist ice loading from various sources are needed to allow wind turbines in the Great Lakes. These designs could deploy systems on individual towers to break up or deflect ice. Standards and certification procedures to evaluate long-term ice load cases need to be drafted, validated, and adopted to provide guidance to technology and offshore wind system developers.

2 See *http://energy.gov/eere/wind/offshore-wind-advanced-technology-demonstration-projects* for more information.

Water depths more than 60 meters are assumed to require floating platform technology. As of 2017, there are no examples of floating systems that could be installed permanently in the Great Lakes and be able to withstand the consolidated ice loading on the mooring system. New technology could be developed to overcome this barrier to access more of the resource potential in the Great Lakes.

Action 2.1.12: Devise strategies to bolster offshore systems against hurricanes.

Hurricanes frequently affect the U.S. coastline, particularly from Cape Cod, Massachusetts, to Galveston, Texas, as well as in Hawaii. Extreme hurricane conditions can exceed the limits of an offshore wind turbine designed using current wind turbine standards and practices. New design approaches and operating strategies need to be created to guard offshore wind turbines against these extreme events and, in turn, lower the risk for offshore deployment in hurricane-prone regions. Hurricane resiliency may lead to hurricane-class turbines under international standards, and further adoption of proven codes used by the oil and gas industries.

Action 2.1.13: Improve distributed wind technology.

By optimizing design tools and next-generation wind technology for distributed wind resources, several cost factors of distributed wind could be addressed. Advanced technology represents a significant opportunity to increase energy capture and reduce installed system and maintenance costs, especially technology that addresses low to moderate wind resources typical in distributed wind locations. For example, most medium-sized turbines used in distributed wind applications are based on 20-year-old designs and are slated for high wind resource, low-turbulence environments. Developing new designs for distributed wind turbines would lower several costs, including the levelized cost of electricity.

Red: Increased priority | Green: Reduced priority | Yellow: New action (not included in 2015 *Wind Vision*) | Blue: Significant text revision, or important new insight from the status and update effort

Action 2.2: Improve Standards and Certification Processes	
Update design standards and certification processes using validated simulation tools to enable more flexibility in application and reduce overall costs.	
DELIVERABLE	**IMPACT**
Certification processes that provide the required level of reliability while remaining flexible and inexpensive.	Lower overall costs, increased reliability, and reduced barriers to deployment.
Key Themes: Reduce Wind Costs **Markets Addressed:** Land, Offshore, Distributed	

ACTION	DELIVERABLE	IMPACT	BEGIN	END
Action 2.2.1: Create flexible certification processes. Eliminate needless conservatism. Enable efficient, custom design and certification process. Validate standards using modern turbines and test data. Establish a reliability basis for standards.	Lower cost and more flexible certification processes.	Custom wind turbine designs that can be efficiently brought to market, lowering the cost of energy.	2014	2040
Action 2.2.2: Define actual operating conditions. Develop a thorough understanding of actual operating conditions within a wind plant to enable turbine and component designs suitable for these conditions.	An accurate design basis for the development and certification of advanced technology.	Reduction in cost; increased reliability.	2014	2030
Action 2.2.3: Foster international collaboration and consistency. Enhance international collaboration in R&D and standardization, make standards internationally consistent, conduct large-scale testing, and improve wind integration. Exchange best practices. Sustain efforts to validate standards using open data. Formalize a gap-discovery and tracking processes for standards. Enable risk-based standards, design and certification.	Uniform certification processes worldwide.	Lower cost and reduced time to develop and certify new technologies; more markets for U.S.-based companies.	2014	2050

Action 2.2.1: Create flexible certification processes.

The standards for wind power systems should be revisited and updated. The foundation for the next generation of standards should be based on systematic reliability, while simultaneously providing designers and manufacturers the flexibility to optimize the systems for specific sites without excessive recertification costs or delays. The next generation of certification standards can be developed following a comprehensive campaign to measure structural loads and validate the accuracy of the industry's simulation tools for the full range of operational conditions experienced over the lifecycle of the system.

Action 2.2.2: Define actual operating conditions.

The standards currently in use were developed with a focus on the operational conditions for a single turbine. This occurred well before the modern U.S. trend of installing large arrays of turbines in a single wind power plant. The current standards address the altered operational environment in the interior of a wind power plant in a superficial manner. They do not rigorously address the details of this interior environment. A field measurement campaign is needed to inform the next generation of standards with respect to the actual operational conditions in the interior of a large array of wind turbines.

Action 2.2.3: Foster international collaboration and consistency.

Developing and approving revised international standards for the certification of wind power systems takes many years. A sustained focus will be needed to achieve the goals of greater flexibility and lower costs while increasing reliability. The development of the next generation of standards will require collaboration among the wind industry, research laboratories, and national authorities around the globe. Coordination of national, state, and local permitting processes is required to make the new standards consistent among the many authorities with jurisdiction over the permitting process.

Action 2.3: Improve and Validate Advanced Simulation and System Design Tools	
Develop and validate a comprehensive suite of engineering, simulation, and physics-based tools that enable the design, analysis, and certification of advanced wind plants. Improve simulation tool accuracy, flexibility, and ability to handle innovative new concepts.	
DELIVERABLE	**IMPACT**
Reliably accurate predictions of all characteristics of existing and novel wind turbine and wind plant configurations.	Improved technical and economic performance, increased reliability, and reduced product development cycle time.
Key Themes: Reduce Wind Costs **Markets Addressed:** Land, Offshore, Distributed	

ACTION	DELIVERABLE	IMPACT	BEGIN	END
Action 2.3.1: Create a load validation campaign. Measure structural loads; validate simulation tools; develop technologies to reduce operational and nonoperational loads. Address all normal and fault conditions required for certification and prediction of life and reliability.	A complete assessment of the accuracy of structural load predictions for all conditions.	Increased confidence in predicted structural loads; reduced need for costly excess structural margins.	2014	2030
Action 2.3.2: Develop a wind plant systems engineering design tool. Develop robust wind plant design tools that enable adaptation of wind power plant design to specific local conditions (e.g., cold climates and low-wind sites), grid connection costs, local atmospheric conditions, and complex terrain.	Integrated design capability for an entire wind plant.	Reduction in cost, increased reliability, increased areas for deployment of customized wind plant designs.	2014	2025
Action 2.3.3: Develop aeroelastic analysis for wind plants. Develop integrated simulation of aerodynamics and structural dynamics of all turbines in a large-scale wind plant. This requires high-performance computing capability with physics-based simulation that computes energy capture and structural dynamics of an entire wind plant.	Computational capability for aerodynamics and structural dynamics of an entire wind plant.	Increased energy capture and increased reliability.	2014	2025

Action 2.3.1: Create a load validation campaign.

A comprehensive validation campaign is needed to define the accuracy, strengths, and weaknesses of today's simulation tools for a wide range of modern wind energy systems. This effort will directly support development of the next generation of certification standards described in Action 2.2. It will also support the identification of key opportunities and needs for improvements in the suite of simulation tools. A broad collaborative effort by academia, research laboratories, and the wind industry can then develop the specific improvements identified in the validation campaign.

Action 2.3.2: Develop a wind plant systems engineering design tool.

The focus of simulation tool development is shifting away from exclusive attention on the wind turbine and toward a comprehensive modeling capability for an entire wind plant. A systems engineering tool needs to be developed to provide a physics-based, comprehensive techno-economic model for the wind plant system. The tool must properly account for the physical interactions between the many components of that system. This capability can then be used to further optimize wind power plants for improved economic performance.

Action 2.3.3: Develop aeroelastic analysis for wind plants.

Simulation tools that can calculate the detailed aerodynamic and structural dynamic behavior of wind turbines have been evolving for decades. These tools provide a strong capability for the analysis of individual wind turbines. Consistent with the trend of considering the entire power plant as a system, these aeroelastic simulation tools need to be extended to accurately compute the detailed aerodynamic and structural dynamic behavior of all the turbines in a wind power plant, including aerodynamic, control system, and electrical system interactions among the individual machines. These simulation tools also need to have the flexibility to address novel configurations. This is a significant computational challenge requiring high-performance computing resources for a complete solution.

Action 2.4: Establish Test Facilities	
Develop and sustain world-class testing facilities to support industry needs and continued innovation.	
DELIVERABLE	**IMPACT**
Cost-effective, publicly available test facilities for all critical wind plant subsystems.	Lower cost of energy from increased reliability, reduced product development time, and support of innovative technology development.
Key Themes: Reduce Wind Costs **Markets Addressed:** Land, Offshore	

ACTION	DELIVERABLE	IMPACT	BEGIN	END
Action 2.4.1: Expand field test facilities. Increase the electrical capacity and available land area of field testing facilities at the National Renewable Energy Laboratory and Texas Tech University to support the development of the next generation of much larger wind turbines.	Field test facilities that support future needs for scientific research and innovative product development and certification.	Improved quality of scientific research and shortened product development timelines.	2014	2025
Action 2.4.2: Establish component and subsystem testing laboratories. Develop laboratory facilities that can test the full range of wind plant subsystems in realistic environmental conditions. Testing the interactions between subsystems is a critical capability.	Laboratory facilities that support the development of innovative subsystems and U.S. manufacturing competitiveness, and permit systematic testing to meet reliability objectives.	Reduction of costs, increased reliability, increased U.S. manufacturing competitiveness.	2014	2025

Action 2.4.1: Expand field test facilities.

Field test facilities are essential for scientific research, the development of innovative new turbines, and the certification of market-ready systems. The existing field testing facilities in the United States are not adequate for the coming generation of much larger turbines. The field test facility at the National Wind Technology Center, with its harsh flow and controllable grid interface, could be increased in both electrical capacity and in land area to support the growing need. The electrical capacity could also be increased at the complementary Scaled Wind Farm Technology, or SWiFT, field test facility at Texas Tech University, and the site's capabilities could be expanded to support wind plant aerodynamics and control research.[3]

Action 2.4.2: Establish component and subsystem testing laboratories.

No publicly available facilities exist in the United States to support testing of the many subsystems in a wind turbine and wind plant. Such a facility is needed to support reliability improvements in these subsystems, and to permit a robust laboratory testing program for the development of subsystem innovations. The complex interactions between subsystems are frequently the root cause of reliability issues. This facility could provide the capabilities needed to examine these interactions in a realistic and controlled environment.

Action 2.5: Develop Revolutionary Wind Power Systems	
Invest R&D into high-risk, potentially high-reward technology innovations.	
DELIVERABLE	**IMPACT**
A portfolio of alternative wind power systems with the potential for revolutionary advances.	Lower cost of energy, mitigation of deployment barriers.
Key Themes: Reduce Wind Costs **Markets Addressed:** Land, Offshore	

ACTION	DELIVERABLE	IMPACT	BEGIN	END
Action 2.5.1: Develop innovative designs. Encourage and enable the emergence of new, innovative designs in the wind industry and the wind research community through public/private partnerships. Demonstrate promising technologies in laboratory and field tests. Support should transition from public to private sources as commercial prospects grow.	A portfolio of revolutionary wind power systems that explore new technological pathways.	Alternative approaches to wind power generation that provide access to challenging sites.	2014	2050

Action 2.5.1: Develop innovative designs.

The conventional wind turbine configuration—a three-bladed, horizontal-axis rotor operating upwind of a tubular tower, with variable-pitch and variable-speed—has proven to be a robust and cost-effective arrangement. Alternative configurations need to be rigorously assessed, however, to ensure that their potential advantages and disadvantages are completely understood. Examples of alternative configurations include downwind rotor, floating vertical-axis wind turbines, and airborne wind power systems. Public support is needed for the early stage investigations of these concepts, as the new technologies are too immature to receive the sustained support needed for a complete investigation. As the technologies mature and clear advantages over existing configurations are confirmed, further development will naturally transition to private sources.

3 The National Wind Technology Center and the Scaled Wind Farm Technology site are both U.S. Department of Energy facilities.

3 Supply Chain, Manufacturing, and Logistics

Action 3.1: Increase Domestic Manufacturing Competitiveness	
Increase domestic manufacturing competitiveness with investments in advanced manufacturing and research into innovative materials.	
DELIVERABLE	**IMPACT**
New information, analysis tools, and technology to develop a cost-competitive, sustainable, domestic wind power supply chain.	Reduced capital cost components, increased domestic manufacturing jobs and capacity, increased domestic technological innovation, and economic value capture.
Key Themes: Reduce Wind Costs; Increase Economic Value for the Nation **Markets Addressed:** Land, Offshore, Distributed	

ACTION	DELIVERABLE	IMPACT	BEGIN	END
Action 3.1.1: Conduct competitiveness assessments. Conduct comprehensive global manufacturing competitiveness assessments to inform future investments and manufacturing technology development. Update and expand the 2014 DOE Competitiveness Analysis.	Reports and tools to assess the competitiveness of U.S. manufacturers in a global context, including analysis of the cost-benefit of various manufacturing and trade policies.	Information and tools to guide investment and inform policy leading to improved domestic wind manufacturing competitiveness.	2014	2020
Action 3.1.2: Develop innovative manufacturing technology. Develop and deploy new manufacturing technology to increase domestic innovation and productivity. Include on-site manufacturing for very large components.	Manufacturing technology innovation and commercialization through individual organizations and Industry-led consortia.	Increased domestic manufacturing competitiveness, capacity, and structure to innovate and commercialize next-generation technologies in the United States.	2014	2050
Action 3.1.3: Scale manufacturing capacity. Enable domestic manufacturers to scale up in component size and production volume to competitively produce next-generation wind technology.	Access to capital and information to allow domestic manufacturers to upgrade equipment and facilities, and commercialize new manufacturing technologies capable of producing wind turbine components of sufficient size and quantity.	Reduced component cost; improved throughput and capacity.	2014	2025
Action 3.1.4: Improve supply chain efficiency through cross-industry synergies. Identify cost reduction opportunities along the supply chain from raw materials through fabrication.	Information exchange of the common needs of wind and complementary industries for raw materials, material forms, and fabrication capabilities, which would reduce input costs up the supply chain.	Diversified, sustainable, and more cost-competitive supply chains, especially in steel, cast iron, composite materials, and intermediate forms.	2014	2025
Action 3.1.5: Document public-domain, industry-specific manufacturing knowledge. Include manufacturing "know-how," and design codes and standards. Identify manufacturing knowledge gaps.	Information on manufacturing technologies and techniques in publicly available documents.	Faster and more widespread application of existing and emerging manufacturing technologies.	2017	2030

Red: Increased priority — Green: Reduced priority — Yellow: New action (not included in 2015 *Wind Vision*) — Blue: Significant text revision, or important new insight from the status and update effort

Action 3.1.1: Conduct competitiveness assessments.

Thorough surveys and analyses are needed to understand the competitive cost structure of U.S. and foreign suppliers, as is an assessment of the trade and manufacturing policies that are in place globally and driving competitive differences. This information will serve as a baseline to expand U.S. wind supply-chain value capture and domestic competitiveness. The data and tools developed can be used to inform new policies that support U.S. manufacturers and help industry prioritize key investments in manufacturing R&D and the use of capital, which will improve domestic manufacturing competitiveness.

In 2014, DOE published a competitiveness analysis assessing the situation through the end of 2012 [2]. That analysis needs to be updated and expanded.

Action 3.1.2: Develop innovative manufacturing technology.

Competitiveness assessments can guide and prioritize specific manufacturing technology that can be developed and deployed to improve the cost structure of U.S. manufacturers. Some technology development could be conducted by individual manufacturers through a combination of internal, government, and other funding sources to produce a competitive advantage through proprietary processes and technologies. Other more fundamental technology development could be conducted more collaboratively by industry-led consortia to address common manufacturing needs, much like the organization SEMATECH (from Semiconductor Manufacturing Technology) does for the semiconductor industry. The various Institutes for Manufacturing Innovation established through the White House's National Network for Manufacturing Innovation initiative could also serve as valuable forums to exchange knowledge, facilitate innovation, and develop technologies across industries and institutions that don't otherwise collaborate. Wind industry participation in these institutes, such as the Clean Energy Manufacturing Innovation Institute for Composite Materials and Structures, and the Next Generation Power Electronics National Manufacturing Innovation Institute, will allow industry to benefit from these resources.

Regardless of the research and development model, the importance of a competitive, domestic manufacturing industry to support long-term innovation cannot be overlooked [3, 4]. The close interaction between manufacturing and R&D staff is a primary catalyst for inventing, developing, and commercializing new technologies domestically. A report from the President's Council of Advisors on Science and Technology notes that, "Manufacturing has driven knowledge production and innovation in the United States by supporting two-thirds of private sector R&D and by employing scientists, engineers, and technicians to invent and produce new products [5]." It will be crucial to have a competitive domestic manufacturing industry to help develop and commercialize the many technologies that will be needed for ongoing pursuit of the *Wind Vision Study Scenario*.

One key path for advancement of wind technology focuses on increases in both turbine size and tower height, leading to a need for larger turbine components. These larger components present challenges in both manufacturing and transport. Hence, innovations in on-site manufacturing for such components need to be actively pursued and compared with options for transporting these components (see Action 3.2.2).

Action 3.1.3: Scale manufacturing capacity.

Innovation alone cannot increase domestic competitiveness; these new technologies will have to be commercialized in the nation's factories. Deploying new manufacturing technologies or even current state-of-the-art equipment in new or retooled facilities requires access to capital, which can be a significant barrier to U.S. manufacturers. This is especially true in the small- and medium-sized businesses that make up a significant portion of the domestic supply chain. Sufficient capital from public and private sources is critical to enabling domestic manufacturers to match and exceed the capabilities and capacity of foreign competition and manufacture the quantity, quality, and physical scale of next-generation wind plant technology [3]. Analysis tools are needed to support the development of effective financial policies that can ensure domestic manufacturers can scale up in both production volume and component size to meet the objectives of the *Wind Vision Study Scenario*.

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Action 3.1.4: Improve supply chain efficiency through cross-industry synergies.

Even with highly productive, advanced manufacturing facilities, much of the cost of manufacturing is embedded in the raw materials and subassemblies that serve as inputs to the top-tier manufacturers. Opportunities exist in steel mills, foundries, and fiber composite suppliers to produce new standardized material forms that can reduce costly, labor-intensive processes like welding or composite layup and infusion that put domestic manufacturers at an inherent disadvantage due to the higher cost of labor in the United States. If done in coordination with synergistic industries like aerospace, automotive, and offshore oil and gas, this new production would incent material suppliers with a diverse and sufficient market to retool or expand capacity.

Action 3.1.5: Document public-domain, industry-specific manufacturing knowledge.

Substantial manufacturing knowledge for wind turbine equipment has been developed but has not been formally documented. Although some of this knowledge is proprietary, much of it could be shared in the public domain. A critical segment of the knowledge is "know-how;" (i.e., knowledge and experience that is understood by skilled laborers and passed on by word of mouth, but which is not well-documented). Much of this knowledge would still be transferred through person-to-person interactions, but the learning process would be aided by documentation.

Action 3.2: Develop Transportation, Construction, and Installation Solutions	
Develop transportation, construction, and installation solutions for deployment of next-generation, larger wind turbines.	
DELIVERABLE	**IMPACT**
Transportation, construction, and installation technology and methods capable of deploying next-generation, land-based and offshore wind.	Reduced installed turbine capital costs and deployment of cost-effective wind technology in more regions of the country.
Key Themes: Reduce Wind Costs; Expand Developable Areas **Markets Addressed:** Land, Offshore	

ACTION	DELIVERABLE	IMPACT	BEGIN	END
Action 3.2.1: Develop transportation best practices. Develop best practices to enable the safe, reliable, and cost-effective transportation of wind components over land.	Guidelines developed through the coordination of industry, state, and local officials to identify and develop best practices for transportation of current and future wind components.	Clarity on transportation constraints across states to guide improved logistics planning and design of new components for transportability.	2014	2020
Action 3.2.2: Develop innovative transportation, construction, and installation technologies. Develop innovative transportation, construction, and installation technologies to meet the needs created by next-generation wind turbine technology. Include innovative approaches for transport of very large components as an alternative to on-site manufacturing.	Analysis of primary infrastructure and logistics challenges of larger wind turbines. Technology development and demonstration to validate potential solutions. Analysis of trade-offs between on-site manufacturing and transport for very large components.	Validated innovative construction, assembly, and transportation techniques to reduce cost and enable deployment of next-generation wind technology to access new resources on land and offshore.	2014	2025

Action 3.2.1: Develop transportation best practices.

As components increase in size and weight, the limitations of ground transport from factory to installation site become more pressing, especially for land-based systems [6]. Issues include safety, maintaining the integrity of the public infrastructure, and increased cost of components designed according to transportation constraints rather than optimized for performance. Industry and state and local government agencies need to assess the key issues and develop best practices to support improved logistics planning and clarify transportation constraints. This will enable original equipment manufacturers (OEMs) and transportation and logistics companies to develop new component designs and logistics solutions to ensure larger turbines can be deployed cost-effectively.

Action 3.2.2: Develop innovative transportation, construction, and installation technologies.

New construction and installation techniques, materials, and equipment will be needed to install next-generation wind plant technologies. Concepts that could address some of the challenges presented by larger, heavier components, such as on-site manufacturing and assembly of towers or other components, will need to be demonstrated before being widely deployed. Dedicated technology demonstration sites, independent of commercial projects, could provide a venue to test new construction and installation technologies without incurring added risk to commercial projects. Proving out a new construction material or installation method can reduce risk and provide confidence to ensure new ideas can be deployed and financed.

Options for transport of very large components also need to be assessed and, where feasible, developed. The relative merits and challenges of these options need to be compared with those of on-site manufacturing options to enable selection of the most cost-effective approaches.

Action 3.3: Develop Offshore Wind Manufacturing and Supply Chain	
Establish domestic offshore manufacturing and supply chain, and port infrastructure.	
DELIVERABLE	**IMPACT**
Increased domestic supply of offshore wind components and labor.	Increased economic growth in major offshore ports and regional manufacturing centers.
Key Themes: Increase Economic Value for the Nation **Markets Addressed:** Offshore	

ACTION	DELIVERABLE	IMPACT	BEGIN	END
Action 3.3.1: Establish offshore wind deployment levels sufficient to sustain the supply chain. Commit to offshore wind deployment levels that can support and sustain the supply chain needed to reduce cost and, in turn, drive additional deployment.	Strong domestic supply of offshore wind components and labor to support a sustainable U.S. wind manufacturing construction and service industry.	Increased economic growth in major offshore ports and regional manufacturing centers, and lower cost through supply chain industrialization. Achievement of this Roadmap Action will facilitate the success of other offshore-related Actions.	2014	2030
Action 3.3.2: Support offshore manufacturing supply chain development and use. Conduct regional supply chain asset mapping based on likely build-out of Wind Energy Areas. Create an online directory. Pursue potential synergies with the offshore oil and gas industry.	Comprehensive database of component manufacturing capabilities, locations, and gaps.	Understanding of gaps and ability to inform existing suppliers of offshore wind market opportunities; ability to inform developers and investors of the full range of available supply chain options.	2014	2030
Action 3.3.3: Create a network of U.S. port facilities. Develop, upgrade, and maintain a network of U.S. port facilities to support offshore wind manufacturing deployment and service. Pursue repurposing of underused existing port assets.	New manufacturing facilities developed in close proximity to ports and quayside (i.e., ship loading and unloading platforms) service operations.	Reduced capital costs for new offshore wind facilities and increased regional job growth.	2020	2030

Red: Increased priority | Green: Reduced priority | Yellow: New action (not included in 2015 *Wind Vision*) | Blue: Significant text revision, or important new insight from the status and update effort

Action 3.3.1: Establish offshore wind deployment levels sufficient to sustain the supply chain.

As the U.S. offshore sector approaches more widespread deployment, issues of manufacturing capacity, skilled workforce, and maritime infrastructure requirements are coming into sharper focus. Studies commissioned by the U.S. Department of Energy in 2013–2014 provide an excellent knowledge base for considering strategic approaches to planning, promoting, and investing in necessary industrial-scale assets in a cost-effective, efficient manner. Specifically, this work addresses port readiness [7]; manufacturing, supply chain, and workforce [8]; and vessel needs [9] under a variety of deployment assumptions through 2030.

There is a wide range of economic development and job creation opportunities associated with offshore wind development. The United States has significant existing assets, which are currently used by other industries or underutilized, that can be deployed in support of offshore wind development. Development of the necessary manufacturing base, workforce, and maritime infrastructure to support a viable offshore wind industry will require integrated public and private sector vision, commitment, and investment.

European experience illustrates the significant impact that supply chain gaps and vessel shortages can have on project cost and risk management [10]. It also shows the dangers of losing economic development advantage in the competitive, global offshore wind market through lack of strategic investment and planning [11]. Supply chain efficiencies have been targeted in the United Kingdom as a key opportunity for lowering the cost of offshore wind power [9]. Roadmap actions 3.3.2 and 3.3.3 are aimed at using lessons from the European Union to position the United States to realize offshore wind power's full economic development potential.

Commitment to significant, achievable offshore wind deployment levels is a necessary precursor to investment in new manufacturing facilities, workforce development, and port infrastructure to support the offshore wind industry. Because the majority of offshore wind development will occur in areas managed by the U.S. Department of the Interior through the Bureau of Ocean Energy Management, and the offtake markets are managed by state governments, the key participants to initiate this action are public sector agencies, in consultation with relevant stakeholders. Achievement of this Roadmap Action will facilitate the success of other offshore-related Actions.

Action 3.3.2: Support offshore manufacturing supply chain development and use.

The offshore sector will use some aspects of the existing land-based wind supply chain. However, larger components intended specifically for offshore use, including foundation technologies, will likely require facilities located near ports. An estimated regional market of 300 megawatts per year will be necessary to support a turbine manufacturer [8].

Industrial infrastructure is primarily a function of market demand. The project-by-project approach of supply chain mobilization that is necessary for the first offshore wind projects will not be an effective or efficient process in planning for industry-scale deployment. The United States needs to develop offshore wind manufacturing infrastructure capabilities at key offshore wind port facilities to enable cost efficiency and maximize economic development benefits. The scale of deployment needed to support significant private sector investment in new manufacturing facilities, port improvement, and purpose-built vessel construction is likely to occur regionally rather than state by state.

A comprehensive database of the capabilities of component manufacturers available in each of five offshore wind development regions is needed to help communicate needs and opportunities.[4]

Action 3.3.3: Create a network of U.S. port facilities.

Significant port infrastructure is in place throughout the potential offshore wind development regions. Most ports currently meet the standards necessary to support O&M; however, staging ports will generally require investment to increase load-bearing capacity to accommodate nacelles and foundations. The state governments of Massachusetts, New Jersey, and North Carolina are investing in port infrastructure to accommodate anticipated first-stage projects. The most expensive improvement is typically quayside soil-bearing to support jack-up barges. Ports will be strategic

4 This activity has already been conducted in several states.

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hubs in the offshore wind construction process; all manufacturing and transport logistics will transit through them. The ability for offshore staging ports to engage multiple industries will be beneficial, especially as the industry ramps up through initial projects that may have gaps in construction activity [10].

It is estimated that a given port can support the activities associated with approximately 500 megawatts of capacity during the installation phase. When regional construction projections are mapped out over time, the results suggest that a minimum of one to four staging ports will be required per region. A minimum of approximately four O&M ports will be needed; however, the actual number of O&M ports required will depend on the specific project locations

4 Wind Power Performance, Reliability, and Safety

Action 4.1: Improve Reliability and Increase Service Life	
Increase reliability by reducing unplanned maintenance through better design and testing of components, and through broader adoption of condition monitoring systems and maintenance.	
DELIVERABLE	**IMPACT**
Reduced uncertainty in component reliability, and increased economic and service lifetimes.	Lower operational costs and financing rates. Increased energy capture and investment return.
Key Themes: Reduce Wind Costs **Markets Addressed:** Land, Offshore	

ACTION	DELIVERABLE	IMPACT	BEGIN	END
Action 4.1.1: Enhance maintenance-based remaining-useful-life (RUL) predictions. Transition from service-life to condition-based component maintenance and replacement.	Condition-based monitoring technology and intelligence built into future turbine models.	Reduced component failures through remote detection, which enables proactive decision-making by operators.	2014	2025
Action 4.1.2: Optimize decision-making for maintenance. Develop maintenance-decision strategies based on evolving understanding of RUL.	Procedures for determining timing for component repair and replacement based on RUL predictions.	Reduced turbine downtime and maintenance costs, enabling increased energy generation and reduced energy costs.	2017	2030
Action 4.1.3: Conduct design research and accelerated life testing. Improve design standards and accelerated life testing of componentry to simulate operating environments.	Testing centers and published research that improve the accuracy of component and turbine reliability testing and certifications.	Better understanding of long-term O&M costs and potential replacement and remanufacturing expenses that may be incurred in out-years of equipment lifetimes.	2014	2030
Action 4.1.4: Design offshore turbines and turbine systems for reliability. Develop high-reliability turbine systems that reduce offshore service requirements.	Turbines and turbine subsystems designed and tested for higher reliability using proven methods.	Offshore O&M plant costs reduced to land-based levels on a per-megawatt basis.	2014	2050

Action 4.1.1: Enhance maintenance-based remaining-useful-life predictions.

Running components until they fail can result in costly downtime, replacements, and repairs. Condition-based monitoring technology provides operators with intelligence and advance warning of component wear and tear, which can allow operators to make proactive decisions on maintenance and replacements. With such data, operators can plan and schedule repairs to coincide with weather or production windows to reduce costs and turbine downtime. Condition-based monitoring technology can also save technician time by reducing the frequency of technician turbine inspections and troubleshooting. Although condition-based monitoring sensors are becoming inexpensive, much work remains to develop predictive analysis methodologies that convert the raw sensor data into actionable maintenance alerts.

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Action 4.1.2: Optimize decision-making for maintenance.

As predictions of remaining useful life (RUL) become more accurate, they can be incorporated into strategies for component maintenance and replacement decisions. This approach can reduce unplanned outages, minimize downtime, and allow repairs to be scheduled for periods of low energy production—all of which will increase annual wind energy generation and reduce wind energy costs.

Action 4.1.3: Conduct design research and accelerated life testing.

Most existing certification standards lack a specific reliability basis. Developing a reliability component to certification standards could drive significant changes to product development. Another knowledge gap is an understanding of actual operating conditions, particularly in the interior of a wind plant. Collecting more field data and developing better algorithms that simulate such conditions could contribute to improved reliability designs in future turbines.

Action 4.1.4: Design offshore turbines and turbine systems for reliability.

Offshore wind turbines currently use many techniques for O&M and service that were developed for land-based systems. Offshore wind turbines are more difficult and costly to repair than their land-based counterparts, however, so the value proposition for more sophisticated repair and failure prevention strategies is much greater. Reliability and service strategies need to be integrated into turbine designs. Condition-based monitoring systems need to become more intelligent to provide accurate remote diagnostics.

Red: Increased priority

Green: Reduced priority

Yellow: New action (not included in 2015 *Wind Vision*)

Blue: Significant text revision, or important new insight from the status and update effort

ACTION 4.2: Develop a World-Class Database on Wind Plant Operation under Normal Operating Conditions	
Collect wind turbine performance and reliability data from wind plants to improve energy production and reliability under normal operating conditions.	
DELIVERABLE	**IMPACT**
Database of wind turbine performance and reliability data representing the U.S. fleet.	Lower unplanned maintenance costs, lower financing and insurance rates, and increased energy production.
Key Themes: Reduce Wind Costs **Markets Addressed:** Land, Offshore, Distributed	

ACTION	DELIVERABLE	IMPACT	BEGIN	END
Action 4.2.1: Collect and analyze field data to understand the specific mechanisms that cause early failure and what those failures cost.	Broad, national data sets that collate component failure information across OEMs and operators (e.g., the Blade Reliability Collaborative, Gearbox Reliability Collaborative, and the Continuous Reliability Enhancement for Wind Database and Analysis Program).	Higher component, turbine, and plant reliability through improved OEM designs that help owners/operators anticipate and avoid failure modes and conditions.	2014	2030
Action 4.2.2: Create and maintain national data sets on performance.	An online, publicly available database of turbine and wind power plant performance.	Database against which owners, operators, and OEMs can benchmark their equipment and operating practices.	2017	2050
Action 4.2.3: Create and maintain national data sets on reliability with periodic releases of updated statistics.	An online, publicly available database of turbine and wind power plant availability and repairs.	Database against which owners, operators, and OEMs can benchmark their equipment and operating practices.	2014	2050

Action 4.2.1: Collect and analyze field data to understand the specific mechanisms that cause early failure and what those failures cost.

Operators and OEMs collect vast amounts of data on the performance of existing wind turbines in the field through real-time monitoring and analysis. This information is generally held privately, making it difficult for smaller industry players and outsiders in the financial community and public sector to have accurate insights into the performance and reliability of turbine equipment. Creating and maintaining national data sets, such as the Gearbox Reliability Collaborative, Blade Reliability Collaborative, and the Continuous Reliability Enhancement for Wind (known as CREW), can assist in providing the public and others outside the industry with factual, transparent information on turbine performance and reliability. Such groups can support coordination and sharing of best practices among industry players.

Action 4.2.2: Create and maintain national data sets on performance.

Although wind power has become established as a viable electricity-generating technology, its level of maturity is determined going forward by the performance of wind turbines and wind power plants in providing affordable, predictable, and reliable electrical energy and essential reliability services. Continued expansion of the acceptance of wind energy within the electric sector requires an ongoing track record of reliable performance compiled and disseminated by trusted sources. Quantitative findings, modeling, and statistical analyses can be incorporated into published benchmark data reports that are designed to increase confidence in wind technology, particularly for those who do not have access to privately held data.

Red: Increased priority | Green: Reduced priority | Yellow: New action (not included in 2015 *Wind Vision*) | Blue: Significant text revision, or important new insight from the status and update effort

Action 4.2.3: Create and maintain national data sets on reliability with periodic releases of updated statistics.

Reliability analyses that attempt to improve the understanding of the existing situation must establish a baseline performance, identify performance drivers, and determine root causes. A national reliability benchmark remains highly desirable for the wind industry, to assist with its objectives of maximizing power performance yield; decreasing financial risk and uncertainty; and understanding reliability trends across turbine models, turbine components, geographical locations, and age. Quantitative findings, modeling, and statistical analyses can be incorporated into published benchmark data reports that are designed to increase industry confidence, particularly for those who do not have access to privately held data.

Red: Increased priority | Green: Reduced priority | Yellow: New action (not included in 2015 *Wind Vision*) | Blue: Significant text revision, or important new insight from the status and update effort

ACTION 4.3: Ensure Reliable Operation in Severe Operating Environments	
Collect data, develop testing methods, and improve standards to ensure reliability under severe operating conditions including cold weather climates and areas prone to high force winds.	
DELIVERABLE	**IMPACT**
High availability and low component failure rates in all operating environments.	Lower unplanned maintenance costs, lower financing and insurance rates, and increased energy production.
Key Themes: Reduce Wind Costs **Markets Addressed:** Land, Offshore, Distributed	

ACTION	DELIVERABLE	IMPACT	BEGIN	END
Action 4.3.1: Address, understand, and resolve issues related to high turbulence, lightning, and icing. Collect and analyze field data from wind plants in severe operating environments to understand the conditions under which each component operates and the specific mechanisms that cause early failure.	Broad, national data sets that collate component failure information across OEMs and operators (e.g., the Blade Reliability Collaborative and Gearbox Reliability Collaborative).	Higher component, turbine and plant reliability through improved OEM designs that help owner/operators anticipate and avoid failure modes and conditions.	2014	2030
Action 4.3.2: Create a Distributed Wind Reliability Database. Create and maintain a performance/reliability database for distributed wind projects.	An online, publicly available database of turbine performance, availability, and repairs.	Accurate tracking and reporting of distributed wind system performance, reliability, and safety issues; record of progress with wind technology and applications, as well as early indication of specific issues.	2014	2050

Action 4.3.1: Address, understand, and resolve issues related to high turbulence, lightning, and icing.

Operators and OEMs collect vast amounts of data on the performance of existing wind turbines in the field through real-time monitoring and analysis. This information is generally held privately, making it difficult for smaller industry players and outsiders in the financial community and public sector to have accurate insights into the performance and reliability of turbine equipment. Creating and maintaining national data sets, such as those identified in Action 4.2.1, can provide valuable information on performance and reliability. Action 4.3.1 provides a specific focus on reliability data under severe operating conditions.

Action 4.3.2: Create a distributed wind reliability database.

While much research and data collection focus on project O&M costs and events for wind plants, parsing out O&M costs for distributed wind projects is challenging, and no industry-standard reporting method currently exists. Lack of information about performance and availability of technology is one of the main roadblocks to wider deployment of distributed wind. A comprehensive database consisting of information on the performance and reliability of nationwide distributed wind projects would provide a valuable record of progress with wind technology and applications, as well as early indications of specific issues, while reducing uncertainty about distributed wind. The database would be publicly available and accessible online. It would include turbine performance, availability, and repairs, as well as accurate tracking and reporting of system performance, reliability, and safety issues.

ACTION 4.4: Develop and Document Best Practices in Wind O&M	
Develop and promote best practices in O&M strategies and procedures for safe, optimized operations at wind plants.	
DELIVERABLE	**IMPACT**
Regular updates to the American Wind Energy Association O&M Recommended Practices document and other industry-wide documents.	Consistency and improvement of O&M practices and transferability of worker skills.
Key Themes: Reduce Wind Costs **Markets Addressed:** Land, Offshore	

ACTION	DELIVERABLE	IMPACT	BEGIN	END
Action 4.4.1: Collaborate with trade organizations and other agencies to improve workplace safety and practices. Coordinate with agencies that can help ensure worker safety practices are disseminated and adopted across the industry.	Maintained and sustained collaboration with the Occupational Safety and Health Administration to expand safety awareness and training for wind technicians, and to educate Occupational Safety and Health Administration employees on wind industry safety practices and standards.	Continuous improvement in workplace safety performance and the safety reputation of the industry.	2014	2030
Action 4.4.2: Identify and adopt O&M practices that reduce disruption to wind plant neighboring communities and wildlife. Conduct related research on wind plant interactions with the local environment and communities.	Research on operational practices that minimize disruption to wildlife, neighboring communities, and other local concerns.	Wind power in operation as a good neighbor in local communities.	2014	2030

Action 4.4.1: Collaborate with trade organizations and other agencies to improve workplace safety and practices.

Wind plants are interesting workplace environments that pose an array of unique conditions for workers, including high voltage work, extreme weather conditions, and working at heights. Given these conditions, adherence to best practices in worker safety is of paramount importance. Continued collaboration with agencies, such as the Occupational Safety and Health Administration and coordination administered by trade organizations like the American Wind Energy Association, can ensure that worker safety practices are disseminated and adopted across the industry, which helps protect the safety of the workforce and the reputation of the industry overall.

Action 4.4.2: Identify and adopt O&M practices that reduce disruption to wind plant neighboring communities and wildlife.

After siting and permitting approvals are complete, it is the owner/operator who interacts with the neighboring community for the next 20-plus years of plant operation. Research on wind plant interaction with wildlife, and impact on public health and local communities should continue. The findings of this research must be continually considered for incorporation into existing O&M practices. Adopting such practices can improve local acceptance of wind power plants and reduce negative impact on wildlife and neighboring areas.

ACTION 4.5: Develop Aftermarket Technology Upgrades and Best Practices for Repowering and Decommissioning	
Develop aftermarket upgrades to existing wind plants and establish a body of knowledge and research on best practices for wind plant repowering and decommissioning.	
DELIVERABLE	**IMPACT**
Aftermarket hardware and software upgrades to improve operational reliability and energy capture, along with reports and analyses on wind repowering and decommissioning.	Increased energy production and improved decision-making for aging wind plant assets, including repowering, to avoid greenfield development costs.
Key Themes: Reduce Wind Costs **Markets Addressed:** Land	

ACTION	DELIVERABLE	IMPACT	BEGIN	END
Action 4.5.1: Create component retrofits and upgrades that enable improved performance and/or reliability. Conduct third-party research to validate for improved performance and reliability.	Third-party research and publications analyzing performance and cost-effectiveness of component upgrades.	Increased energy production and reliability through improved componentry.	2014	2030
Action 4.5.2: Create a body of knowledge on wind plant repowering and decommissioning practices. Research and publish information on repowering, decommissioning, and service life extension.	Analytical tools that support comparing the costs and benefits of repowering, retiring, or continuing to operate a wind plant.	Optimized production of current and future wind plants.	2014	2030

Action 4.5.1: Create component retrofits and upgrades that enable improved performance and/or reliability.

An array of aftermarket upgrades is available for wind plant owners and operators today. Options range from software control updates to lidar-based devices that collect more advanced wind speed measurement and directional data. These upgrades all have the potential to increase the energy production of existing wind plant assets and improve reliability. There is insufficient information, however, to validate the performance and value provided by many of these aftermarket upgrades. Research should be conducted by neutral third parties to provide trusted information on the performance and cost-effectiveness of various aftermarket upgrades. This information can then be used to validate whether retrofits and upgrades will improve performance and reliability.

Action 4.5.2: Create a body of knowledge on wind plant repowering and decommissioning practices.

The majority of the U.S. fleet of wind turbines was installed after 2005, with a few exceptions of older turbines from the 1980s in California and Hawaii. As these turbines approach the end of their useful life (generally around 20 years), owners and operators will face the decision of whether to retire the equipment, repower the site with new turbines, or extend the operating life of the existing turbines. There is currently limited cost–benefit analysis for these investment decisions or best practices in plant repowering and decommissioning in general. Research and publications on the costs and techniques used for plant decommissioning, plant repowering, and turbine service life extension will be important to establish a body of knowledge on the subject that supports cost-effective, environmentally sensitive decisions for wind plant owners and operators.

5 Wind Electricity Delivery and Integration

ACTION 5.1: Encourage Sufficient Transmission	
Collaborate with the electric power sector to encourage sufficient transmission to deliver potentially remote generation to electricity consumers and provide for economically efficient operation of the bulk power system over broad geographic and electrical regions.	
DELIVERABLE	**IMPACT**
Studies, methodologies, and validated tools that inform cost-effective, reliable electricity delivery from wind power and all other generation types.	Increased transmission, reduced electricity costs, and increased wind generation with less curtailment.
Key Themes: Reduce Wind Costs; Expand Developable Areas **Markets Addressed:** Land, Offshore	

ACTION	DELIVERABLE	IMPACT	BEGIN	END
Action 5.1.1: Optimize use of existing transmission and distribution (T&D) system and modernize it with the best available technology. Secure additional electricity transport capability by ensuring optimal use of existing T&D infrastructure.	Analyses of underutilized T&D assets, including estimates of additional available capacity; outreach to relevant decision-makers aimed at use of the additional capacity identified.	Increased electricity transport capability without the need for new T&D lines, resulting in increased ability to integrate renewable generation.	2017	2030
Action 5.1.2: Conduct cost-benefit analysis. Perform cost and benefit analysis of new transmission designs to determine whether a given design is promising, and whether alternating-current-only or alternating current/direct current hybrid options make sense.	Cost-benefit analyses of candidate transmission additions with appropriate recommendations on subsequent action.	Increased development of cost-effective transmission, resulting in increased ability to integrate renewable generation.	2014	2030
Action 5.1.3: Analyze system dynamics. Develop methods to analyze system dynamics, including voltage and frequency performance, synthetic inertia and system stability, and determine the technical and economic basis for utilization of advanced wind power control schemes.	A full range of analytic models, market structure options, and best practices showing how the characteristics and capabilities of advanced solid-state-coupled renewable resources interact with conventional generators and automatic generation control, and how the new control capabilities of the renewable resources can best be used.	Integration of high penetrations of renewable generation at minimal cost, while maintaining power system reliability.	2015	2040
Action 5.1.4: Reduce jurisdictional barriers. Develop an institutional framework to reduce barriers to transmission across multiple jurisdictions when there is a net benefit to society.	An institutional framework allowing for effective multistate transmission development that benefits society.	Relief of bottlenecks in developing the transmission needed for reliable power system operation and for integrating large amounts of wind power.	2015	2025

Red: Increased priority
Green: Reduced priority
Yellow: New action (not included in 2015 *Wind Vision*)
Blue: Significant text revision, or important new insight from the status and update effort

Action 5.1.1: Optimize use of existing transmission and distribution (T&D) system and modernize it with the best available technology.

There is broad agreement that the existing T&D system can provide more capacity and deliverability of energy through such measures as improved modeling, state estimation, visibility (including strategically placed telemetry and phasor measurement units), faster coordination of reserves and reliability services, and improvements at the seams for imports and exports. Analyses are needed to identify and quantify opportunities to: (a) reduce energy flow bottlenecks and constraints—both technical and institutional, (b) upgrade capacity on existing transmission corridors, (c) modernize rating calculations under the full range of operating conditions, (d) capitalize on changes in power flows as older power plants retire and new resources come on line, and (e) benefit from distribution-system upgrades underway to accommodate the expansion of distributed generation.

Action 5.1.2: Conduct cost-benefit analysis.

Analysis is needed to determine whether new transmission technologies and network designs will increase reliability, allow more wind generation to be delivered to load, and be cost-effective. Cost-benefit analysis of new transmission designs is needed to determine whether a given design is promising, and whether alternating-current-only or alternating current/direct current hybrid options make sense. Studies to develop alternative transmission network designs that balance a range of technical, economic, and regulatory issues will promote the economic development of wind generation. Study results will inform stakeholders about alternative transmission network designs and provide the foundation for building new transmission.

Action 5.1.3: Analyze system dynamics.

New analytical methods are required to accurately represent the characteristics and capabilities of advanced solid-state-coupled wind, solar, and storage devices. These methods will provide the ability to properly analyze the power system to ensure reliability, while minimizing costs and fully exploiting control capabilities of advanced devices. Once models are available for relevant devices and components, it will be possible to develop methodologies and best practices to use the advanced control capabilities offered by solid-state-coupled wind, solar, and storage devices to enhance power system reliability and mitigate any identified adverse conditions. This will both increase power system reliability and enable the economic integration of larger amounts of wind generation. Areas of particular interest include system dynamics, synthetic inertia, and system stability.

Action 5.1.4: Reduce jurisdictional barriers.

Long transmission lines that cross multiple-state jurisdictional boundaries can be particularly difficult to site. A framework that identifies and quantifies benefits for all participants can help facilitate acceptance. Developing an institutional framework that allows for the development of economically justified multistate transmission will help relieve bottlenecks and reliably integrate larger amounts of wind generation.

ACTION 5.2: Increase Flexible Resource Supply

Collaborate with the electric power sector to promote increased flexibility from all resources including conventional generation, demand response, wind and solar generation, and storage.

DELIVERABLE	IMPACT
Analysis of flexibility requirements and capabilities of various resources. Frequent assessments of supply curve for flexibility. Implementation of cost-effective rules and technologies.	Reduced wind integration costs, reduced wind curtailment, improved power system efficiency and reliability.

Key Themes: Reduce Wind Costs, Expand Developable Areas
Markets Addressed: Land, Offshore, Distributed

ACTION	DELIVERABLE	IMPACT	BEGIN	END
Action 5.2.1: Increase industry understanding of flexibility needs and capabilities, and expand use of these capabilities throughout the electric power sector. Improve understanding of flexibility's role in aiding wind power integration.	Government and industry involvement in workshops and related activities to deliver the results of analysis and modeling.	Understanding among the power system industry of wind integration impacts and means to address challenges. Understanding among regulators of integration impacts, challenges and mitigation measures.	2014	2025
Action 5.2.2: Develop flexibility methods and models. Develop methods, models, metrics, and targets for assessing flexibility needs.	Methods, models, metrics, and targets that can be used to assess the need for, and supply of, flexibility.	Availability of tools and approaches to quantify flexibility needs to help accommodate high levels of wind generation on the bulk power system.	2015	2025
Action 5.2.3: Develop flexibility supply curves. Develop and update flexibility supply curve data so that cost-effective solutions can be identified.	Periodic and regular assessments of the current suite of technologies that can provide flexibility to the power system, including the associated costs. Regular assessment, e.g., every 2–3 years, will ensure that new technologies and costs are included in the analysis.	Relevant information provided to the power system industry and regulators regarding the potential sources and costs of flexibility—both in generation and demand response; identification and adoption of cost-effective flexibility solutions in the bulk power system.	2015	2050
Action 5.2.4: Increase demand response. Develop inventory of potential demand response resources organized by equipment type, aggregate resource size, resource capability, and location.	Increased use of demand response as a flexible resource to help maintain system balance.	Additional source of flexibility that can help cost-effectively maintain system balance with high levels of wind energy.	2015	2050
Action 5.2.5: Analyze new market designs and encourage implementation of features that efficiently balance resource adequacy, reliability revenue requirements, and market considerations. Analyze the effect of new, innovative market designs, such as performance-based rates for frequency regulation.	Operating and market rules that do not hinder access to the existing physical flexibility. (Without this, physical flexibility can be stranded and unavailable to the power system operator.)	Increased effectiveness of physical resources to provide needed flexibility.	2015	2050

Red: Increased priority
Green: Reduced priority
Yellow: New action (not included in 2015 *Wind Vision*)
Blue: Significant text revision, or important new insight from the status and update effort

ACTION	DELIVERABLE	IMPACT	BEGIN	END
Action 5.2.6: Conduct comprehensive renewable energy integration study, including all energy technologies, for all of North America. Examine all of North America with a total system view of all sources of energy and reliability services.	A thorough analysis of the opportunities, challenges, benefits, costs, and other impacts associated with the integration of large shares of renewable energy sources into the North American power system.	Comprehensive understanding of renewable energy opportunities and challenges under a wide range of operating, interconnection, and future expansion scenarios for the entire North American power system.	2017	2020

Action 5.2.1: Increase industry understanding of flexibility needs and capabilities, and expand use of these capabilities throughout the electric power sector.

Power system engineers evaluate reliability requirements based on the capabilities and limitations of conventional generators. Assistance is required to understand that the increased flexibility offered by both existing and advanced technologies can be utilized to increase reliability, decrease costs, and facilitate greater wind generation penetration. Advanced generation provides increased flexibility, faster and more accurate ramping, lower minimum loads, and increased cycling capability. Demand response and storage can provide a response that is faster than the conventional generation governor response. Industry understanding of new capabilities is required before these resources will gain acceptance. Activities such as DOE and industry workshops are useful for delivering the results of analysis and modeling.

Action 5.2.2: Develop flexibility methods and models.

Technology-neutral metrics are required to quantify specific reliability requirements so that new technologies can be utilized in place of and alongside conventional technologies. Modeling and simulation are required to determine the needed metrics. Developing industry-accepted tools will facilitate power system planners and operators in accommodating high levels of wind generation on the bulk power system through greater deployment of advanced, flexible resources.

Action 5.2.3: Develop flexibility supply curves.

The full suite of flexible resources cannot be utilized unless system operators are aware of the available resource pool and its capabilities to provide each type of reliability response. Flexibility supply curves should initially be developed by researchers and then transferred to utilities. Regular updates will enable the identification and implementation of cost-effective solutions.

Action 5.2.4: Increase demand response.

Demand response is increasingly shown to be capable of providing the full range of reliability response from cycles to hours. Advantages of this approach for wind generation include reducing the need for conventional generation, generation minimum loads, and wind curtailment, all while enabling greater wind penetration, maintaining reliability, and lowering power system costs. Developing an inventory of potential demand response resources (industrial, commercial, and residential) organized by equipment type, aggregate resource size, resource capability, and location will help speed full utilization. Improved communications, monitoring, and control can reduce the cost of demand response implementation. Greater understanding of demand response capabilities will expand the range of demand response services that power system operators actively access.

Action 5.2.5: Analyze new market designs and encourage implementation of features that efficiently balance resource adequacy, reliability revenue requirements, and market considerations.

Operating and market rules need to be examined and perhaps revised so that they do not inadvertently hinder access to the physical flexibility that is potentially available from demand response and other flexibility resources. Appropriate market incentives can motivate demand response while reducing power system and wind integration costs. Specific examples include performance-based rates for frequency regulation per Federal Energy Regulatory Commission Orders 755 and 784, the role of scarcity pricing, and the intersections with capacity markets. Revenue adequacy for conventional generation should also be addressed.

Action 5.2.6: Conduct comprehensive renewable energy integration study, including all energy technologies, for all of North America.

Many renewable energy integration studies have been conducted during the past 10–15 years, covering geographic areas ranging from individual utility service territories to large regions of the United States. However, none have considered the entire nation or the nation along with Canada and Mexico. Opportunities exist for sharing renewable as well as conventional generation resources across national boundaries. Furthermore, studies to date have shown that cooperative operation of power systems over larger and larger areas facilitates the integration of substantial amounts of renewable power generation and provides electric service reliability benefits. It is a natural extension to ask if expanded power sector cooperation among all three nations of North America would provide additional integration and reliability benefits.

In the past, integration studies have also provided substantial educational benefits to the participants through improved understanding of the capabilities, limitations, characteristics, and technological status of the various renewable energy options, as well as the overall system benefits of increased operating flexibility and expanded connectivity. A comprehensive study for North America is likely to expand these educational benefits.

This study could also lead to future work that incorporates the energy integration perspectives associated with expanded electrification of the transportation and industrial sectors.

Red: Increased priority
Green: Reduced priority
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Blue: Significant text revision, or important new insight from the status and update effort

ACTION 5.3: Encourage Cost-Effective Power System Operation with High Wind Penetration	
Collaborate with the electric power sector to encourage operating practices and market structures that increase cost-effectiveness of power system operation with high levels of wind power.	
DELIVERABLE	**IMPACT**
Coordination of wind integration studies at the state and federal levels and promulgation of practical findings, especially to entities with less wind integration experience.	Increased wind integration levels, appropriate amounts of operating reserves, reduced curtailment, and lower integration costs.
Key Themes: Reduce Wind Costs; Expand Developable Areas **Markets Addressed:** Land, Offshore	

ACTION	DELIVERABLE	IMPACT	BEGIN	END
Action 5.3.1: Improve market and reliability rules. Identify and eliminate excessive limitations on flexibility embedded in current market and reliability rules.	Alternative standards and rules to mitigate inappropriate limitations on wind generators and advanced technologies providing reliability services.	Reduced barriers for new technologies to supply energy and ancillary services; elimination of inappropriate limitations on new technology market entry.	2015	2030
Action 5.3.2: Improve understanding of wind integration issues. Increase industry understanding of wind power system integration and develop appropriate operating practices and market rules.	Enhanced understanding of how to economically maintain power system reliability while accommodating increasing amounts of wind generation.	Scientific background necessary to help promulgate operating practices like subhourly energy scheduling and balancing over larger areas; potential to dramatically reduce wind integration costs.	2015	2025

Action 5.3.1: Improve market and reliability rules.

Market and reliability rules, including North American Electric Reliability Corporation standards, were developed based on the characteristics and limitations of conventional generators. The capabilities and limitations of technologies such as wind, solar, demand response, and storage were not considered because these technologies were not significant participants when the rules were developed. Identifying and mitigating limitations on flexibility embedded in current market and reliability rules may facilitate increased penetration of wind power while increasing power system reliability. Costs could also be reduced as the full capabilities of new technologies are exploited.

Action 5.3.2: Improve understanding of wind integration issues.

Power system planners and operators require assistance in understanding the impact increased wind generation will have on their systems. Some systems have little or no wind capacity, and therefore offer little or no experience about operating a power system with wind generation. Systems with significant amounts of wind do offer experience, but cannot offer certainty about higher penetrations. Assistance is required to help power system planners and operators convert research results concerning higher penetrations of wind generation into best operating practices. Topics of interest include subhourly energy scheduling and balancing, larger balancing areas, and utilizing the response and control capabilities offered by solid-state-coupled devices like advanced wind turbines, solar PV, storage, and advanced demand response.

ACTION 5.4: Provide Advanced Controls for Grid Integration	
Optimize wind power plant equipment and control strategies to facilitate integration into the electric power system, and provide balancing services such as regulation and voltage control.	
DELIVERABLE	**IMPACT**
Advanced wind turbine and wind plant controls that can be used to provide voltage support, regulation, synthetic inertial response, and frequency regulation by wind plants. Bulk power market designs and/or tariffs are necessary to pay for these services.	Allows power system operator access to additional flexibility from wind plants, when it is economical or necessary for reliability. This will reduce cost and increase reliability.
Key Themes: Reduce Wind Costs; Expand Developable Areas **Markets Addressed:** Land, Offshore	

ACTION	DELIVERABLE	IMPACT	BEGIN	END
Action 5.4.1: Develop advanced active power controls. Encourage incentives for use of advanced turbine and plant control technologies and strategies.	Optimized wind turbine and plant control strategies to facilitate reliable, coordinated bulk power system operations and planning. Action 5.3.1 is a companion action because it provides market signals for the services needed for reliability and economic operation.	Increased wind generation through less curtailment, increased power system reliability, and lower operating costs.	2014	2030

Action 5.4.1: Develop advanced active power controls.

The latest generation of wind turbines has increasingly adopted advanced controls that allow the wind turbine to respond to control signals. Wind turbines can often respond to automatic generation control, frequency response via appropriate droop settings, system disturbances using synthetic inertial response, and even economic dispatch signals. These abilities are not routinely provided because of the lack of market signals, which means there is no incentive to provide these services. In addition, these controls will evolve from turbine-level to wind-plant-level, allowing for more economic and reliable operation. The evolution of these controls must be matched by the evolution of bulk system market design.

ACTION 5.5: Develop Optimized Offshore Wind Grid Architecture and Integration Strategies	
Develop optimized subsea grid delivery systems and evaluate the integration of offshore wind under multiple arrangements to increase utility confidence in offshore wind.	
DELIVERABLE	**IMPACT**
Modeling tools and design information for utilities to evaluate infrastructure needs for offshore power delivery into land-based grid.	Increased utility confidence in offshore wind and reduced cost of offshore wind due to aggregation of power, lower environmental footprint, reduced transmission congestion, and possible higher capacity value.
Key Themes: Reduce Wind Costs; Expand Developable Areas **Markets Addressed:** Offshore	

ACTION	DELIVERABLE	IMPACT	BEGIN	END
Action 5.5.1: Develop and build systems to aggregate power from multiple offshore projects. Propose strategies to aggregate multiple projects onto common interconnects.	Efficient methods for delivering power from large-scale offshore wind plants to coastal grid interconnects.	Reduced capital requirements and environmental impacts; more orderly delivery of power to coastal grids, resulting in reduced offshore wind costs.	2018	2040
Action 5.5.2: Evaluate direct and indirect economic benefits of offshore wind. Evaluate all direct and indirect economic benefits of offshore wind, including savings to ratepayers from peak-coincident, price-suppression impacts.	Studies of the direct and indirect economic benefits of offshore wind, including savings to ratepayers from peak-coincident, price-suppression impacts in various coastal transmission systems.	Educated public and decision-makers, including appellate courts, with regard to the economic value of offshore wind; facilitated approval of power purchase contracts.	2014	2040

Note: In the 2015 *Wind Vision* Roadmap, Actions 5.5.1 and 5.5.2 were included under Actions 5.1 and 5.2, respectively. In this 2017 Update, they have been placed under Action 5.5.

Action 5.5.1: Develop and build systems to aggregate power from multiple offshore projects.

Under the *Wind Vision Study Scenario*, several gigawatts of offshore wind projects will be deployed by 2050. If each project is required to provide a radial transmission line and separate interconnect, competing use conflicts may arise, likely resulting in higher costs for offshore wind. Proposed strategies to aggregate multiple projects onto common interconnects would result in lower costs and a more orderly delivery of power to coastal communities. Regulators and utilities can work with offshore wind developers to seek the most efficient and reliable solutions.

Action 5.5.2: Evaluate direct and indirect economic benefits of offshore wind.

The current levelized cost of offshore wind does not reflect all direct and indirect economic factors that may impact the cost to ratepayers. Methods of land-based grid integration and forecasting need to be extended to offshore grid systems and include unique attributes of offshore wind, such as locational-marginal-price benefits, capacity value (in general and during peak demand), grid congestion, and the aggregation of multiple wind power facilities into common shore-based interconnects.

Research indicates that offshore wind tends to be more consistent during periods of peak summer electricity demand along the East Coast [12]. Power from offshore turbines with low fuel cost would be dispatched first, offsetting the cost of more expensive peak generators. One study estimated that the savings to New England ratepayers over the proposed 25 years of operation of the Cape Wind project off Cape Cod, Massachusetts, could total more than $7 billion [13, 14]. This analysis was acknowledged in approvals of the Cape Wind power purchase contract by the Massachusetts Public Utility Commission and the state Supreme Court [14].

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ACTION 5.6: Improve Distributed Wind Grid Integration	
Improve grid integration of and increase utility confidence in distributed wind systems.	
DELIVERABLE	**IMPACT**
Modeling tools and information that utilities can use to evaluate integration of distributed wind into distribution systems.	Improved distributed wind power integration and delivery into distribution systems and increased utility confidence in this integration.
Key Themes: Reduce Wind Costs; Expand Developable Areas **Markets Addressed:** Distributed	

ACTION	DELIVERABLE	IMPACT	BEGIN	END
Action 5.6.1: Develop distributed system modeling tools. Collaborate with the Utility Variable-Generation Integration Group and similar organizations, such as those supporting smart grid initiatives, to update distributed system modeling tools.	New modeling tools that include all types of distributed generation and advanced grid support capabilities.	Improved wind power integration and delivery in distribution systems.	2014	2020
Action 5.6.2: Improve communication and control capabilities. Increase grid support capability (low-voltage ride-through and line-fault ride-through functions), including communications and control.	A new edition of Institute of Electrical and Electronics Engineers (IEEE) 1547. Updated distribution system modeling tools.	Improved wind power integration and delivery into distribution systems.	2014	2020
Action 5.6.3: Provide technical information to utilities about integration challenges and possibilities. Educate utilities on the technical characteristics, limitations, and benefits of integrating increased levels of variable generation from distributed wind systems.	Factual, technical data provided to electrical utilities on characteristics, limitations and benefits of distributed wind systems.	Improved collaboration and engagement.	2014	2020

Action 5.6.1: Develop distributed system modeling tools.

Increased collaboration by the distributed wind community with industry stakeholder groups, such as the Utility Variable-Generation Integration Group, smart grid organizations, and those supporting smart grid initiatives, will increase the exchange of ideas on advanced distributed system modeling. Working with these organizations, as well as supporting research on distributed system modeling and analysis, could allow the distributed wind community to facilitate lower cost, streamlined distributed generation models leading to optimized planning. Reducing costs and increasing confidence in distributed wind integration through better distribution system modeling tools, informed utilities, and standards development will improve distributed wind deployment.

Action 5.6.2: Improve communication and control capabilities.

As distributed energy's share in the nation's generation mix increases, the need for improved communication and control capabilities becomes more evident. Specific standards covering grid support capability, including low-voltage or low-frequency ride-through functions, as well as communications and control for interconnecting distributed resources with electric power systems [16], would support a wider application of wind power. Developing a new revision of IEEE 1547 is important for establishing a framework for distributed generation that supports the grid and allows improved wind power integration and delivery into distribution systems.

Red: Increased priority | Green: Reduced priority | Yellow: New action (not included in 2015 *Wind Vision*) | Blue: Significant text revision, or important new insight from the status and update effort

Action 5.6.3: Inform utilities of integration possibilities.

Utilities are a key partner for wider use of wind power in the United States. Utilities, however, are often unaware of the latest technologies supporting the integration of distributed wind. A dedicated effort to inform utilities of the integration challenges and possibilities and provide factual, technical data on the technical characteristics, limitations, and benefits of increased levels of variable generation from distributed wind systems will allow them to make more educated decisions about strategies and business plans for renewable energy.

6 Wind Siting and Permitting

ACTION 6.1: Develop Mitigation Options for Competing Human Use Concerns	
Develop impact reduction and mitigation options for competing human use concerns, such as radar, aviation, and maritime shipping and navigation.	
DELIVERABLE	**IMPACT**
A better understanding of the impacts of wind development and appropriate mitigation options leading to streamlined site assessment and trusted hardware and software technology solutions that address the most pressing competing use conflicts.	Decreased impact of all wind technologies allowing project developers to site wind projects while limiting competing public use impacts.
Key Themes: Reduce Wind Costs; Expand Developable Areas **Markets Addressed:** Land, Offshore, Distributed	

ACTION	DELIVERABLE	IMPACT	BEGIN	END
Action 6.1.1: Develop better understanding of wind turbine and radar interactions. Conduct research to understand and mitigate wind turbine impact on existing radar systems.	A strong understanding of the impact of wind turbines on existing radar systems and communally accepted mitigation strategies for these limitations.	Consensus understanding of radar/wind turbine interactions and a known course of action to address the problems associated with them.	2014	2020
Action 6.1.2: Reduce potential wind turbine and radar interaction. Implement approved minimization and mitigation strategies for radar systems with high impact on current or expected wind development.	To the extent possible, replacement of all outdated radar systems that are having the highest impact on current and potential near-term wind development.	Minimization of wind-radar impacts; continued wind development with minimal radar performance impacts.	2015	2025
Action 6.1.3: Address issues of aircraft safety and public perception. Test and demonstrate improved lighting and aircraft avoidance systems to ensure safe compliance with the Federal Aviation Administration 500-foot height requirement.	Technology, regulation, and systems that address wind turbine height concerns over most of the nation.	Confidence for developers and manufacturers to install the most cost-effective technology available without fear of uncertain regulatory processes.	2014	2020
Action 6.1.4: Alter existing or design new shipping routes. Develop transportation and shipping routes consistent with offshore wind power to optimize the safe coexistence of offshore wind and maritime commerce; address in the context of integrated ocean-use planning.	A study that recommends appropriate adjustments to existing shipping lanes or new routes to minimize interference with proposed Wind Energy Areas.	Increased number of viable sites for offshore wind development.	2014	2050

Action 6.1.1: Develop better understanding of wind turbine and radar interactions.

Wind turbine interactions with aircraft and weather radar systems have been a safety and security concern for several years and have been a driving concern for developers of new wind facilities in the United States and abroad. Progress has been made to develop and streamline a process to determine if a proposed wind project is likely to impact existing radar systems. Accommodating future wind power growth in the United States, however, will require an expanded understanding of radar/wind turbine interaction. This understanding will lead to new technologies to minimize and mitigate interference impacts. Although studies are underway and software tools are being developed to mitigate current concerns, more information is needed on the exact nature of the impact of different wind technologies, radar systems, and operational conditions.

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Green: Reduced priority
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An example of recent progress is the work of the third Interagency Field Test and Evaluation of Wind Turbine-Radar conducted by the Federal Aviation Administration, DOE, the U.S. Department of Defense, and other U.S. government agencies. This study completed operational field tests to better understand the physical and electromagnetic interference between radar systems and wind plants. Data from these tests will be used to help assess near-term mitigation options and develop long-term mitigation techniques. If deployment levels approach those outlined in the *Wind Vision Study Scenario*, additional expanded work to understand longer-term wind turbine and radar impacts will be needed.

Action 6.1.2: Reduce potential wind turbine and radar interaction.

A number of approaches are being considered to mitigate the impact of wind plants on radar. The first is careful upfront planning and siting of wind plants so that little or no interference is caused to nearby radars. This approach is being used by regulating authorities working with wind plant developers. This technique takes time because it often requires lengthy and iterative applications for study, which focus results on a simple pass/fail analysis. Another approach is to upgrade the affected radars or introduce new filtering and advanced processing tools to sort wind turbine clutter from actual aircraft. These radar upgrades, however, are still unable to completely resolve the interference issues, partly because of the complexity of the interaction.

Another approach is to reduce the scattering from the turbine. This can be done by applying radar cross-section minimization techniques, such as shaping, and radar-absorbing materials to the wind turbine. Yet, another promising approach is to deploy specialized, high-resolution Doppler "fill in" radars that just cover the wind plant in question. These are being developed with the intention of differentiating aircraft or other targets from the wind plant itself. Other techniques, including multistatic radar, have also been suggested.

Action 6.1.3: Address issues of aircraft safety and public perception.

The expanded wind deployment examined in the *Wind Vision Study Scenario* must take into account the safety of commercial and recreational aviation. Excessive aircraft safety requirements on wind, however, will either eliminate locations that could support wind development or add to the overall cost of power produced by wind plants.

Support for expanded wind development will require a combination of technology approaches, permitting support, the development of tools and systems to ensure there is no adverse impact, and education for people and organizations in both the wind and aviation industries. Addressing aviation safety and public perception, along with wind and radar system interference issues (Actions 6.1.1 and 6.1.2), will provide improved wind turbine siting information and avoidance technology. The goals are to ensure and improve aircraft safety. It is essential that the wind and aviation industries take a collaborative, proactive and consultative approach to addressing ongoing and newly identified issues.

Action 6.1.4: Alter existing or design new shipping routes.

Shipping lanes exist along the entire length of the U.S. seacoast, affecting all potential Wind Energy Areas in the Atlantic, Pacific, Great Lakes, and Gulf of Mexico. For example, competition with existing shipping lanes reduced the initial Maryland Wind Call Area from a potential of 30 lease blocks to nine lease blocks because there was no clear process for assessing impacts of wind development. The U.S. Coast Guard oversees a study of all shipping lanes, known as the Atlantic Coast Port Access Route Study,[5] to evaluate current and future shipping needs. Maritime commerce and safety are national priorities.

Strategies to accommodate shipping needs and wind power in the context of integrated ocean-use planning will contribute to expanded offshore wind development. Consistency in guidance from jurisdictional agencies should be pursued.

5 *https://www.regulations.gov/document?D=USCG-2011-0351-0144*

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ACTION 6.2: Develop Strategies to Mitigate Siting and Environmental Impacts

Develop and disseminate relevant information as well as mitigation strategies to reduce the environmental impacts of wind plants, including impacts on wildlife. Mitigation covers the full range of avoidance, minimization, and compensatory mitigation. Whenever possible, avoidance is preferred.

DELIVERABLE	IMPACT
Accurate information and peer-reviewed studies on actual environmental impacts of wind power deployment, including on wildlife and wildlife habitat.	Decreased environmental impact by all wind technologies, improved understanding of the relative impact of wind development, defined methodologies to assess potential impacts and risks, and shorter and less expensive project deployment timelines.

Key Themes: Reduce Wind Costs, Expand Developable Areas
Markets Addressed: Land, Offshore, Distributed

ACTION	DELIVERABLE	IMPACT	BEGIN	END
Action 6.2.1: Improve understanding of interactions among wind energy, wildlife, and their habitats—including the relative risks of these interactions. Develop and disseminate relevant information on wildlife and habitat impacts, including cumulative impacts in relation to other activities within the ecosystem.	Information and peer-reviewed studies on the actual wildlife and habitat impacts of wind power deployment in relation to other energy production, which can be used and shared through a variety of platforms.	Improved understanding of the relative impact of wind development; shorter and less expensive project deployment timelines.	2014	2050
Action 6.2.2: Develop strategies to reduce wildlife impacts, including avoidance, minimization, and compensatory mitigation. Develop, test, and conduct research on strategies to avoid, minimize, or compensate for impacts to wildlife.	Proven technologies and strategies that will reduce wind power impacts on wildlife.	Decreased wildlife impact by all wind technologies; shorter and less expensive project deployment timelines.	2014	2050
Action 6.2.3: Develop a funding pool for wildlife research. Implement a shared funding pool from industry, government, and other interested parties to fund wildlife research administered by an independent third party with appropriate oversight.	Fact-based research, mitigation practices, and independent analysis on key wildlife impacts.	Expansion of industry- and government-based research that is credible and independent of undue influence from interested parties.	2014	2050
Action 6.2.4: Perform strategic assessment of offshore wind. Conduct strategic environmental assessments to inform siting and add to the knowledge base for future permitting of offshore wind projects.	Assessments that provide baseline environmental data for offshore wind needed by federal and state governments to inform siting, permitting, and marine spatial planning efforts.	Increased knowledge of which marine resources may be at risk in certain locations; reduced permitting timelines and risk for projects.	2014	2030
Action 6.2.5: Continue monitoring environmental impacts, including ongoing assessment of opportunities and risks. Continual monitoring of environmental and wildlife impacts to assess changes and their potential impacts.	Periodic updates of known environmental impacts, targeting market and impact assessments.	Improved understanding of known impacts, as well as their evolution over time due to changes in technology, markets and affected species.	2014	2050
Action 6.2.6: Expand development of wildlife-deterrent technologies. Build on related efforts already underway in both the private and public sectors.	Technology that deters wildlife from wind turbines or enables operational strategies that minimize harmful impacts.	Reduced harmful impacts on wildlife, reduced wind equipment curtailment, and increased operating revenues.	2017	2030

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Action 6.2.1: Improve understanding of interactions among wind energy, wildlife, and their habitats—including the relative risks of these interactions.

As wind development has expanded, more information is available on the environmental impacts of wind deployment. Significant gaps exist, however, in the industry's understanding of potential impacts. Regulators and local decision-makers often cite a lack of scientifically credible information as an issue. The cumulative impacts of wind development on particular species need to be understood and made available. In some cases, this information is available but not easily accessible; in other cases, a great deal of data may have been collected for a specific wind facility but is not publicly available. Where information about impacts exists, it will take effort to convert that information into a form identified stakeholders can use. It will also require effort to ensure that data can be used more broadly to conduct regional- or national-scale impact assessments. Engagement at multiple levels will be needed to respond to the expanding wind industry and changes in potentially impacted species.

As these interactions are identified and studied, their risk levels relative to each other should be estimated. Attention should then be paid to those interactions that present the highest risks to wildlife and their habitats.

Some potential environmental impacts of wind development have been studied, but either the results are not publicly documented or they are site-specific. As discussed in Chapter 2 of the *Wind Vision,* broad wildlife and habitat impacts have been identified, but only limited public, peer-reviewed documentation of the actual impacts is available. Understanding the potential impact of wind deployment will reduce development risk for land-based wind, and for offshore and distributed wind. Such impact assessments are most effective when provided by a trusted, third-party source. Without active industry engagement on this topic, public and regulatory pressures will likely increase as deployment moves toward new areas or areas with known environmental issues.

Action 6.2.2: Develop strategies to reduce wildlife impacts, including avoidance, minimization, and compensatory mitigation.

Even appropriately sited wind development can have negative impacts on local wildlife, primarily avian and bat species. Although significant work has been done to develop avoidance, minimization and mitigation strategies for certain wildlife impacts, continued and expanded efforts are needed to allow substantial expansion of wind deployment. Most efforts have aimed at avoiding potential impacts on a site-specific basis. The industry is also funding tools that could be applied either at a specific wind project or at other locations. With programs such as lead shot abatement or electrical pole retrofits, potential impacts can be offset. Each minimization and mitigation option must undergo rigorous long-term assessment, testing, and validation before it can be considered acceptable by regulatory organizations—a time-intensive and costly process.

As technology and the status of species change and deployment expands into new areas with different environmental sensitivities, additional strategies will need to be developed, tested, and implemented.

Action 6.2.3: Develop a funding pool for wildlife research.

Wind industry research on the environmental impacts of development focuses on specific areas or species and may not be widely coordinated with other research activities or openly accessible to potential stakeholders. An expanded degree of credibility and broader access to data resources could be provided by organizations independent of direct influence by any specific sector of the industry (i.e., turbine manufacturers, development companies, federal agencies, and state agencies). Such organizations could gather existing research, and identify and address potential wildlife and habitat impacts. These organizations could create impartial organizational structures, set up and implement credible independent screening and peer-review processes, address issues that may be difficult for specific industry sectors, and further expand the credibility of results. The organizations would require a long-term funding base that would cover organizational costs and support a robust research agenda. Such a research agenda would likely be carried out by a small internal staff and trusted external contractors. The implementation of this concept as a public and private partnership would strengthen the credibility of any results and provide a process for expanded collaboration on domestic public impact research.

Action 6.2.4: Perform strategic assessment of offshore wind.

The permitting and leasing processes for offshore wind are tied to understanding the potential environmental impact, primarily through National Environmental Policy Act (NEPA) compliance and assessment of environmental effects of installations. On the Outer Continental Shelf, the Bureau of Ocean Energy Management—in consultation with resource agencies—determines the level of NEPA documentation needed in accordance with the current state of knowledge and thresholds of proposed impacts and benefits.

NEPA requires an "appropriate" level of environmental review for various activities. The Bureau of Ocean Energy Management has interpreted this to mean an Environmental Impact Statement or an Environmental Assessment for Site Assessment Plans or Construction and Operation Plans (30 CFR 585.14[c], 585.613[b], 585.628[b]). The Bureau of Ocean Energy Management explained "appropriate" NEPA review when issuing its Final Rule: "ensure that environmental analysis for [Outer Continental Shelf] renewable energy proposals is proportional to the scope and scale of each proposal, is effectively tiered to programmatic NEPA documents, and efficiently incorporates other publicly available information by reference … ensure that mitigation and monitoring information informs future decision-making processes."[6]

The lack of information about specific issues related to the marine environment and coastal communities has slowed the NEPA process. As new environmental studies and environmental assessments are completed, the results could be incorporated in future NEPA reviews. For example, the Bureau of Ocean Energy Management Environmental Assessment and Finding of, "No Significant Impacts for Site Assessment Activities in the Mid-Atlantic Wind Energy Areas" concluded that any future site assessment activities consistent with those studied in this environmental assessment would not require future NEPA reviews before implementation. As more NEPA reviews are conducted and experience is gained with new offshore technologies, it will become appropriate to execute less comprehensive NEPA reviews under the NEPA statute. This will expedite the permitting process.

So far, much of the cost for filling gaps in knowledge has been borne by offshore wind project developers, which has slowed offshore wind development. Peer-reviewed, publicly available environmental studies are needed to assist in building the knowledge base and closing information gaps.

Action 6.2.5: Continue monitoring environmental impacts, including ongoing assessment of opportunities and risks.

The national wind market has changed rapidly in the early 2000s, from both technology and deployment standpoints. Continued evolution is likely if the deployment levels of the *Wind Vision Study Scenario* are implemented. Changes in understanding or regulation of the impacts of the U.S. energy system on all wildlife species will also affect perception of any potential impact, changing whether mitigation measures are more or less necessary. As part of this ongoing development, understood impacts will change and new impacts will be identified. Ongoing assessments of existing and potentially new environmental impacts will need to be implemented to ensure that information dissemination and research activities target concerns identified by key deployment stakeholders.

Action 6.2.6: Expand development of wildlife-deterrent technologies.

Technological solutions could be instrumental in reducing wind turbine impacts on wildlife, either by helping wildlife avoid wind turbine equipment or by modifying wind power plant operating strategies when wildlife are present or approaching. Prospective technologies include acoustic or visual deterrents to help eagles and other raptors and bats avoid turbines; tailored curtailment strategies for bats, eagles, and other raptors through use of radar or other sensors; development of a bat-friendly turbine; and development of bird-friendly glass (for compensatory mitigation). Remote-sensing equipment would also be useful in facilitating wildlife studies. Promising projects pursuing solutions such as these are underway in both the private and public sectors and should be encouraged and expanded.

6 Bureau of Ocean Energy Management Final Rule, 74 Federal Register 19643, April 29, 2009.

Red: Increased priority | Green: Reduced priority | Yellow: New action (not included in 2015 *Wind Vision*) | Blue: Significant text revision, or important new insight from the status and update effort

ACTION 6.3: Develop Information and Strategies to Mitigate the Local Impact of Wind Deployment and Operation	
Continue to develop and disseminate accurate information to the public on local impacts of wind power deployment and operations. Mitigation includes avoidance, minimization, and compensatory mitigation.	
DELIVERABLE	**IMPACT**
Accurate information and peer-reviewed studies on the impacts of wind power deployment that can be used and shared through a variety of platforms.	Decreased impact by all wind technologies, defined methodologies to assess potential impact, and shorter and less expensive project deployment timelines.
Key Themes: Expand Developable Areas **Markets Addressed:** Land, Offshore, Distributed	

ACTION	DELIVERABLE	IMPACT	BEGIN	END
Action 6.3.1: Document and disseminate public information on public impact. Develop and disseminate relevant information to the public on impacts, including economic impacts, and the social and economic value of power system externalities.	Information and peer-reviewed studies on the actual impacts of wind power deployment, along with activities for dissemination of this information through a variety of platforms to inform the public and siting officials.	Improved understanding of the relative impact of wind development; shorter and less expensive project deployment timelines.	2014	2025
Action 6.3.2: Develop mitigation strategies. Devise, test, and research strategies to mitigate (avoid, minimize, or compensate for) public impact.	Proven technologies and strategies that will reduce the impact of wind power on local populations.	Decreased impact by all wind technologies.	2014	2025
Action 6.3.3: Establish a funding pool for public impact research. Implement a shared funding pool from industry, government, and other interested parties to fund public impact research administered by an independent third party with appropriate oversight.	Fact-based research, mitigation practices, and independent analyses on key public impacts.	Expansion of industry- and government-based research that is credible and independent of influence from interested parties.	2014	2050
Action 6.3.4: Continue monitoring public impact. Execute ongoing monitoring of public impact to assess changes in social understanding and comprehend the potential impacts of that change.	Periodic updates of known public impacts targeting market, public perceptions, and impact assessments.	Improved understanding of known impacts, as well as their evolution over time due to changes in technology, markets, and public perception.	2014	2050

Action 6.3.1: Document and disseminate public information on public impact.

As wind development expands, more information is becoming available on the local community impacts of wind deployment. However, there are gaps in the level of understanding of potential impacts. The general public and local decision-makers often cite a lack of scientifically credible information as an issue. In some cases, this information is available but not readily accessible; in others, the information is not conclusive. Where information does exist, it should be made readily available in a form that is understandable for identified stakeholders. Continued and increased engagement at multiple levels will be needed given the expanding nature of the industry. If wind development becomes commonplace in specific regions, a tipping point may occur and information dissemination efforts may no longer be needed.

Red: Increased priority | Green: Reduced priority | Yellow: New action (not included in 2015 *Wind Vision*) | Blue: Significant text revision, or important new insight from the status and update effort

Industry has identified a host of public impacts from wind power. Some research has been done to understand these impacts, but, in most cases, impacts have not been documented. As discussed in Chapter 2 of the *Wind Vision*, public impacts such as turbine noise, economic development, economic value of power system externalities, and public safety have been identified for specific projects. However, minimal public, peer-reviewed documentation of the actual impacts is available. For example, longitudinal studies of the long-term community impacts of wind development have never been undertaken. Such an assessment would be helpful in understanding the impact of local wind development and useful to communities considering local development.

Full understanding of the potential impact of wind deployment at all levels is needed: land-based, offshore, and distributed. If provided by a trusted third-party source, this understanding will reduce development timelines, costs, and implied development risk. Active industry engagement is necessary to reduce public acceptance pressures, which will likely increase as deployment moves into new areas and closer to higher population areas.

Action 6.3.2: Develop mitigation strategies.

As noted previously, even appropriately sited wind development can have negative impacts from the perspectives of some stakeholders. As wind deployment expands into new areas closer to population centers, there is an increasing likelihood for negative impacts to be highlighted. With that in mind, the wind industry continues to fund tools that help identify potential negative impacts and support development of related minimization or mitigation options. Some of these mitigation strategies are technology-specific, while others could be developed and implemented more broadly. Even with industry efforts underway, a wider engagement is needed to address both current and potential future public impact issues.

Action 6.3.3: Establish a funding pool for public impact research.

The broader wind industry; including turbine manufacturers, development companies, federal agencies, state agencies, and trade associations; conducts research about the public impacts of wind power. Each organization and its research can be viewed differently by potential stakeholders. Although each sector of the wider industry will continue to fund research addressing its specific interests, research independent of direct influence from any sector of the industry would lend an increased degree of credibility to the results. Such research should be conducted by an organization(s) with a mission to identify and address potential negative public impact. This organization or organizations would be able to develop an impartial organizational structure, implement credible independent screening and peer-review processes, and address issues that may be difficult for specific industry sectors. This effort would require a long-term funding base, which would not only cover organizational costs, but also support a robust research agenda that would likely be carried out by a small internal staff and trusted external contractors. This implementation as a public and private partnership would strengthen the credibility of any results and provide a process for expanded collaboration on domestic public impact research.

A substantial body of science-based information on these topics has been developed over the past several years, and additional relevant insights continue to emerge from ongoing studies. Hence, the need for a dedicated funding pool has been reduced. What is required, however, is continued efforts to share this information with the general public, regulators, permitting officials, and other relevant decision-makers.

Action 6.3.4: Continue monitoring public impact.

The national wind market has changed rapidly in the early 2000s, from both technology and deployment standpoints. If the deployment levels discussed in the *Wind Vision Study Scenario* are successfully pursued, the rate of change in both technology and deployment practices will continue to develop and evolve. Changes in social understanding of wind development will also impact perception of any potential impact, changing whether mitigation measures are more or less necessary. As part of this ongoing development, known impacts will change and new impacts will be identified. Ongoing assessments of existing and potentially new public impacts will need to be implemented to ensure that information dissemination and research activities target concerns identified by key deployment stakeholders.

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ACTION 6.4: Develop Clear and Consistent Regulatory Guidelines for Wind Development	
Streamline regulatory guidelines for responsible project development on federal, state, and private lands, as well as in offshore areas.	
DELIVERABLE	**IMPACT**
Defined regulatory guidelines for the deployment of offshore, land-based, and distributed wind turbines, developed in collaboration with the wind industry to provide comprehensible and geographically consistent regulations for the deployment of wind technologies.	Allows developers to clearly understand the processes to deploy wind technologies on federal, state, or private lands, thus reducing costs.
Key Themes: Reduce Wind Costs; Expand Developable Areas **Markets Addressed:** Land, Offshore, Distributed	

ACTION	DELIVERABLE	IMPACT	BEGIN	END
Action 6.4.1: Encourage regulatory process for wind development on federal lands. Encourage federal regulatory consistency for development on federal lands, including a defined pathway for both wind and transmission that is consistent, based on peer-reviewed science, and incorporates an appropriate evaluation of risk.	A clear and well-defined permitting process for development on federal lands.	Reduced investment costs, shorter development times, and consistent development pathways.	2014	2020
Action 6.4.2: Create a model deployment framework. Development of a consensus-based, wind power deployment framework that summarizes best practices, defined studies, and standard development considerations and that can be used as a nonbinding template for future development of offshore, land-based, and distributed wind.	A model development framework for deployment of all wind technologies.	More consistent deployment with wider public acceptance of the process, lower costs, and shorter deployment timelines.	2014	2020
Action 6.4.3: Create a streamlined leasing and permitting process for offshore wind. Decrease the regulatory timeline and complexity for offshore wind, while maintaining a high level of safety for the public and environment, consistent with existing statutes.	A streamlined leasing and permitting process to eliminate redundant pathways. Demonstration of an efficient process through successful project deployments.	A more consistent and efficient regulatory framework; lower costs and shorter deployment timelines.	2014	2020
Action 6.4.4: Increase available sites to accommodate growth of offshore wind. Support the identification of offshore wind power development zones in state and federal waters, allowing timely build-out of offshore wind capacity to meet *Wind Vision Study Scenario* levels.	Additional Atlantic Wind Energy Area designations; use of competitive leasing auctions to open additional sites, including those in deeper water, as well as the Pacific Ocean and Gulf of Mexico.	Increased number of available commercial sites to enable the expansion of offshore wind deployment across the United States.	2018	2030
Action 6.4.5: Implement a consistent, streamlined permitting process for distributed wind. Engage local and state governments in improving the permitting process and enacting certification requirements for distributed wind technologies.	Consistent state and local permitting, including certification requirements, for distributed wind technologies.	Expanded distributed wind deployment through streamlined siting and permitting approval processes; removal of artificial barriers to deployment.	2014	2020

Action 6.4.1: Encourage regulatory process for wind development on federal lands.

Investors and wind developers deploy capital and resources in areas with more certain returns or lower identified risks. Wind resources span public and private lands, but wind developers have traditionally invested in development on private land, where the regulatory process and cost for permits are understood. The wind industry has faced several challenges on public lands that have discouraged investors. Oil and gas leases have tended to get processed ahead of wind leases, and even permits for single meteorological towers have experienced lengthy processing times. Environmental assessment processes have been lengthy and inconsistently administered among the decentralized federal field offices.

Wind power development on U.S. public lands has significant potential, and policymakers have acknowledged this opportunity by prioritizing the development of renewable energy, including wind, on public trust lands. Development on private lands, however, has greatly outpaced development on public lands. Activities such as streamlining the process for meteorological tower permits and the overall regulatory approach toward wind power development on federal lands would create a more predictable process and open millions of acres of public land (usually in less-populated parts of the country) for wind power development. As with private land, measures such as those outlined in Action 6.2 would be used to minimize and mitigate environmental effects.

Action 6.4.2: Create a model deployment framework.

Conceptually, the process for developing wind projects is fairly well understood, and some elements of the process have been documented in best practice guides and handbooks. Still, the actual process for deploying distributed and land-based projects is not an entirely well-defined process, and the process for offshore wind deployment is even less defined. The lack of defined and consistent development frameworks results in widely different project development processes and different results. For this reason, there is no clear process to define what types of tests or considerations are important for wind deployment, such as noise or flicker analysis, community engagement steps, or guidelines on when to initiate dialog with different development stakeholders. Issues that are driven through defined regulatory processes, such as the assessment of environmental impacts, are typically better understood due to the outside regulatory process. A deployment framework may not be necessary for large development companies working with communities experienced with wind development. If neither party has this experience, however, the lack of a process can result in non-optimal projects. For instance, important items may be dismissed or skipped because of a lack of project knowledge by one or more project participants.

A nonmandatory framework that is widely available and well-documented would provide a basic structure for project development. This framework would provide recommendations on studies that should be undertaken, community engagement steps, and deployment best practices. This framework would also identify potential regulatory overlaps or complications, in hopes of reducing project development timelines. Although there would be no attempt to mandate its use, the development of a defined process could result in reduced development timelines, less contention about what steps should be undertaken, and a lower overall cost for the development process. This action would be completed in conjunction with other recommended actions described in this document, such as Actions 6.4.1 and 6.4.5.

> In 2016 the Bureau of Ocean Energy Management and DOE jointly issued a national strategy for offshore wind development.[7] Some wind deployment stakeholders have suggested that an approach along similar lines could be instrumental in facilitating wind development on federal lands—which has traditionally been difficult, as described in Action 6.4.1. Deployment frameworks for land-based wind, however, are well-developed in the private sector, suggesting that a public-domain model framework is not needed.

Action 6.4.3: Create a streamlined leasing and permitting process for offshore wind.

The regulatory and permitting process for offshore wind power crosses jurisdictional territories for multiple state and federal agencies, as well as local permitting authorities. The process is largely untested given the small number

7 *https://www.energy.gov/eere/wind/downloads/national-offshore-wind-strategy-facilitating-development-offshore-wind-industry*

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of permitted offshore wind projects to date. The offshore environment is also complex, with little known about the potential interactions of habitats and species with the installation and operation of wind turbines. Marine animals and habitats may interact with offshore wind turbines, and offshore turbines may encounter different avian species than those common around land-based wind plants. Regulators are working to integrate and apply existing laws and regulations to offshore wind technology where there is a higher degree of uncertainty. Many key agencies and authorities must now become proficient with this new technology. Applying laws and the need to gain proficiency in the technology are contributing to long offshore permitting timelines, estimated to be from 5 to 7 years. This lengthy process, combined with the uncertainty and risk of getting a permit, drives up offshore wind project costs and prevents installations from moving forward.

Efficient coordination between state and federal agencies is critical for an emerging offshore wind industry to succeed in the United States. The permitting and siting process for offshore projects would benefit from increased engagement among offshore wind developers, regulators, and other stakeholders. For example, military practice areas, shipping lanes, recreational fishing and boating, and commercial fishing can all have a significant impact on offshore wind siting and operations. Much progress has been made to better define and streamline the permitting process, yet redundant and complex permitting pathways and procedures still exist. If these are addressed in a collaborative process including all interested parties, permitting of offshore wind projects will be more efficient.

Action 6.4.4: Increase available sites to accommodate growth of offshore wind.

Available offshore wind sites can be expanded by increasing access to areas currently not being considered for development. Providing access to transmission through proposed private ventures, and creating predictable, straightforward permitting processes, would open significant potential for the U.S. offshore wind market. The waters off the U.S. coasts are busy and contribute to the livelihood of many people. As such, conversations about the use of state and federal waters for offshore wind development are complex and potentially contentious. A highly collaborative approach offers the best opportunity to devise mutually acceptable solutions and increase available sites for offshore wind deployment.

Action 6.4.5: Implement a consistent, streamlined permitting process for distributed wind.

Smaller-scale distributed wind projects have historically been grouped with large-scale, land-based wind projects for various zoning and permitting requirements. Small wind systems are typically considered to be outside of existing zoning, permitting, and electrical interconnection rules, so they require exceptions. Small wind projects also do not have economies of scale or the same level of impact as larger, land-based wind projects, and are often burdened by expensive and time-consuming permitting requirements. Resolving these issues would allow distributed wind to fit more easily into existing permitting, zoning, and electrical interconnection requirements.

Some work could be expanded to support small wind deployment. Work by the National Association of Counties and the Distributed Wind Energy Association was aimed at reducing permitting barriers for distributed wind while protecting resident interests. The resulting report, "County Strategies for Successfully Managing and Promoting Wind Power," was published in 2012 in conjunction with the Distributed Wind Energy Association's Small Wind Model Zoning Ordinance [17, 18, 19]. As part of this report, the National Association of Counties conducted extensive research to learn and share best practices from county governments on regulating wind power systems. The report suggests that counties research wind technologies and adopt a wind power engagement strategy *before* public inquiries to ensure efficient government processes and adherence to planning objectives [19]. Further work could be undertaken to define expanded governance approaches for appropriate deployment of small wind systems, outline special or conditional use requirements, and identify appropriate small wind permitting and zoning requirements, including height, setbacks, lighting, aesthetics, and fees.

ACTION 6.5: Develop Wind Site Pre-Screening Tools	
Develop commonly accepted standard siting and risk assessment tools allowing rapid pre-screening of potential development sites.	
DELIVERABLE	**IMPACT**
A single or series of interlinked siting tools or frameworks that support wind turbine siting.	Decrease permitting time while easing permitting processes, leading to lower project development costs with improved siting and public acceptance.
Key Themes: Reduce Wind Costs **Markets Addressed:** Land, Offshore, Distributed	

ACTION	DELIVERABLE	IMPACT	BEGIN	END
Action 6.5.1: Develop verified tools to support wind turbine siting and assessment. Building from the base of tools that are currently used to support siting decisions, develop additional methods, tools, or validation approaches to support siting decisions.	A set of siting support tools that address key siting issues (such as sound, visual impact, flicker, and economic impacts) that are known to be accurate.	A higher degree of trust in and expanded availability of proven and accurate siting and impact assessment tools; reduced project development timelines and costs.	2014	2020
Action 6.5.2: Investigate challenging siting issues for complex or unique siting locations. Development of tools, methodologies, research, and deployment processes that will support the expanded deployment of wind technologies on isolated grids and under extreme conditions.	Research, tools, applications, and demonstration activities that support the use of wind power in high-value, small market applications.	Expanded deployment of wind in extreme or remote locations.	2014	2020
Action 6.5.3: Develop offshore wind spatial planning tools and methods. Develop methods and tools for spatial planning to meet economic, social, and environmental objectives, all with the objective of ensuring appropriate deployment of offshore wind technologies.	Screening tools to support siting decision processes.	Decreased permitting time and streamlined permitting processes; lower cost project development; improved siting and general public acceptance.	2014	2020
Action 6.5.4: Provide analysis and modeling tools for offshore wind. Develop analysis and modeling tools for determining risk to navigation and the potential impacts of plants on marine radars.	Accurate, validated models that predict navigational impacts of offshore wind turbines on radars.	Reduced navigation risk due to radar interference; facilitation of siting of offshore wind projects; increased marine safety.	2014	2020
Action 6.5.5: Develop distributed wind resource and modeling tools. Accurately characterize distributed wind resources and benchmark current models against desired capabilities.	High-resolution, physics-based models that can characterize distributed wind resources in highly complex, lower elevation environments.	Physics-based simulation of the flow characteristics that enable reliable assessment of turbine performance and reliability.	2014	2020
Action 6.5.6: Reduce the cost of distributed wind assessment tools. Develop lower cost site assessment and analysis tools.	Virtual meteorological tower capability and low-cost remote-sensing validation procedures and equipment. Reliable computer tools linked to existing 30-meter wind maps that are flexible enough to input micro-siting blockages, such as trees and buildings.	Improved understanding of wind resources where turbines are used in distributed applications; reduced uncertainty in distributed wind system performance; reduced time and cost to identify and eliminate poor sites; improved identification of productive locations.	2014	2020

Red: Increased priority
Green: Reduced priority
Yellow: New action (not included in 2015 *Wind Vision*)
Blue: Significant text revision, or important new insight from the status and update effort

Action 6.5.1: Develop verified tools to support wind turbine siting and assessment.

Many tools provide understanding of the viability, impacts, and benefits of wind development. These include visualization tools that offer an accurate depiction of wind facilities and economic assessment tools, allowing a community, state or region to better understand the economic impacts of wind development. Other tools and data sets help developers and regulators screen large areas based on wind resource, land type, and a large number of competing uses or other conditions, including transmission or areas of environmental sensitivity. These tools, however, are not used in a coordinated way, and may not be validated or proven to offer firm results.

The creation of improved or validated siting tools, methods, and approaches could simplify and build confidence in the wind development process by reducing or eliminating some of the associated risks. Since many of the tools currently used across the industry were privately created, this process would require the establishment of a viable validation framework, as well as close partnerships with industry. A set of high-quality but simple, publicly accessible tools could be made available for the most common community concerns, such as visual representation, flicker, economic impact, and noise propagation. With these tools, community members could conduct their own basic assessments of potential wind power impacts and gain improved confidence in the overall development process.

Action 6.5.2: Investigate challenging siting issues for complex or unique locations.

In locations where land access, grid interconnection, and siting conflict issues are minimized, wind project development can proceed using a relatively well-understood process. There are locations in which this development process is not as clear, however, such as sites with isolated grids or microgrids where wind contributions can be unusually high (e.g., islands), or in areas of high potential conflict. In some cases, additional requirements can be met by focusing on existing guidelines. In other cases, more detailed technical research and/or the development of tailored technology will be required to meet specific needs.

Initial investigations into the deployment of wind technologies in isolated grids and complex locations would be the focus in this action. Additional topics could include the installation of wind turbines on capped landfills to support municipal wind development and the development of low-environmental-impact small wind turbines for installations on sensitive lands.

Action 6.5.3: Develop offshore wind spatial planning tools and methods.

The marine spatial planning process is an important element of large-scale, offshore wind development. Consideration of offshore wind in the myriad of competing and complementary ocean uses is complex and still lacks cohesion across U.S. coastal regions. Federal involvement would help link marine spatial planning efforts (at state and federal levels) with candidate sites for offshore wind power. Selecting candidate sites and analyzing potential cumulative effects will involve mapping available wind resources and other attributes for successful offshore wind development. It will also involve scientific assessments of vulnerable marine resources along the U.S. coastline with compatible and conflicting areas of public use. Marine spatial planning efforts could support and inform a coordinated process among existing regulatory authorities with regional priorities and integrated spatial data. Federal involvement, expanded coordination across all levels of government and other affected parties, technical expertise, and financial resources throughout the entire siting and permitting process would help ensure adequate participation by stakeholders and the use of the best science, as well as all known and available best practices.

Action 6.5.4: Provide analysis and modeling tools for offshore wind.

Marine-band radars (S-band and X-band) are non-Doppler radars used for collision avoidance and navigation at sea. Because these bands differ from those used on land, proposed offshore wind projects will utilize different assessment protocols and mitigation approaches for radar interference than those applied to land-based wind plants. Each offshore wind project will present varied conditions, such as ambient marine and weather conditions, typical radars being used, and the specific configuration of the proposed wind array. These elements must be evaluated in order to inform a navigational risk assessment for the particular types of vessels using the waterway. Current modeling tools and analysis methods are insufficient for these unique offshore conditions.

Action 6.5.5: Develop distributed wind resource and modeling tools.

Improving distributed wind resource characterization is a crosscutting opportunity to reduce the levelized cost of electricity; increase stakeholder confidence; reduce customer acquisition costs; and improve grid planning, operation, and power quality. This process requires accurately characterizing distributed wind resources and benchmarking current models against desired capabilities, such as high-resolution, physics-based models that work in highly complex, lower elevation environments. Better resource and modeling enables properly-sited distributed wind turbines and mitigates financial risk.

Action 6.5.6: Reduce the cost of distributed wind assessment tools.

R&D emphasis on characterizing distributed wind resources and developing reduced cost assessment tools will increase the accuracy of performance predictions, in turn ensuring more realistic economics for wind developers and electricity consumers. Reducing the cost of site assessment and analysis tools includes developing virtual assessments of meteorological tower capability and low-cost, remote-sensing validation procedures and equipment. Further advances, especially in the area of reliable computer tools linked to existing 30-meter wind maps, could add flexibility and reduce micro-siting blockages such as trees and buildings. These improved energy resource characterization and assessment tools would support understanding of wind resources where turbines are used in distributed applications, reduce uncertainty in distributed wind system performance, reduce the time and cost to identify and eliminate poor sites, and allow potentially productive areas to be identified.

7 Collaboration, Education, and Information Dissemination

ACTION 7.1: Provide Information on Wind Power Impacts and Benefits	
Increase public understanding of broader societal impacts of wind power, including economic impacts; reduced emissions of carbon dioxide, other greenhouse gases, and chemical and particulate pollutants; less water use; and greater energy diversity.	
DELIVERABLE	**IMPACT**
Information and peer-reviewed studies delivered in a stakeholder-targeted method that provides accurate information on the impacts and benefits of wind power independently and in relation to other energy choices.	Retention or expansion of areas open to wind development; decreased fear and misconceptions about wind power; lower project deployment costs and timelines; all leading to more wind installations, better public relations, and lower costs of power.
Key Themes: Expand Developable Areas; Increase Economic Value for the Nation **Markets Addressed:** Land, Offshore, Distributed	

ACTION	DELIVERABLE	IMPACT	BEGIN	END
Action 7.1.1: Engage with key stakeholders. Involve key stakeholders and proactively provide information on wind impacts and benefits through venues such as publications, electronic and social media, workshops, and other mechanisms.	Science-based, impartial information and peer-reviewed products that are packaged for various national audiences using a range of outreach venues, which can also be repurposed by state or regional organizations.	Increased understanding of the impacts and benefits of wind development; more and lower cost wind installations.	2014	2030
Action 7.1.2: Convene organizations to support engagement on local wind power issues. Institute state or regional efforts to gather, analyze, and distribute information and data regarding the impacts of wind power plants, including environmental, socioeconomic, public acceptance, and radar-related.	Regional- or state-level delivery of informational and educational products, targeted at local stakeholders, addressing local challenges to wind development.	Better and lower-cost decisions about local project development.	2014	2030
Action 7.1.3: Develop consensus-based organizations to support appropriate wind deployment. Implement a national, consensus-based organization(s) to help facilitate discussions on wind-related impacts and provide negotiated paths forward in the implementation of best practices at the regional, state, or federal levels.	An independent organization(s) that will build consensus around appropriate wind deployment methodologies at the regional or state level.	Implementation of consensus-based wind deployment approaches that fairly recognize stakeholder concerns and encourage decisions grounded in science-based information.	2014	2030

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Action 7.1.1: Engage with key stakeholders.

Stakeholders in decisions about all types of wind development need concise and accurate information on the known impacts of wind development. Without unbiased, science-based information, stakeholders are unable to consider potential positive and negative impacts of expanded development that would allow them to make educated decisions about the appropriate deployment of wind technologies. Key stakeholders cover a broad range that includes land owners and county commissioners, state and federal siting regulators, electric sector planners and regulators, and academic and vocational educators. Outreach methods will differ by stakeholder group but could include printed publications, electronic and social media, presentations at topical conferences, webinars, workshops, and direct outreach. Disseminating information through credible, influential groups would also allow the information to reach a broad base of stakeholders, especially given the range of viewpoints represented.

Action 7.1.2: Convene organizations to support information sharing on local wind power issues.

Although considered in a national context throughout this report, the decision to deploy wind technologies is largely a local decision discussed at the county or state level. As with any development, local decisions for wind deployment are driven by local considerations. Outsiders such as wind developers or state regulatory personnel may be treated with some degree of suspicion. The development of local or regional organizations that can address local concerns related to environmental, socioeconomic, public acceptance, aviation, and other impacts of wind power plants will help communities make balanced assessments of the positive and negative impacts. Local and regional entities will also be able to develop locally relevant content, which will have the most impact when addressing local concerns.

Action 7.1.3: Develop consensus-based organizations to support appropriate wind deployment.

As with any new development in the power sector, wind development comes with a host of impacts to the local area and to the wider electrical system. As a result, wind development can include interaction with many stakeholders with sometimes conflicting interests. Consensus-based organizations that can help facilitate discussions on wind-related impacts and address diverging interests early in the process are needed. This will provide negotiated paths forward in the implementation of best practices at the regional, state, and federal level, which is needed to support the deployment levels outlined in the *Wind Vision Study Scenario*. Such efforts should be broad-based and, to the extent possible, inclusive of all entities affected by the expanded deployment of appropriately sited wind development.

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ACTION 7.2: Foster International Exchange and Collaboration	
Foster international exchange and collaboration on technology R&D, standards and certifications, and best practices in siting, operations, repowering, and decommissioning.	
DELIVERABLE	**IMPACT**
Expanded international collaboration including information sharing, joint research, and staff exchanges allowing expanded education about wind power and expert collaboration from across the wind industry.	Expanded understanding of the benefits of wind power across the energy sector; expanded cross-industry collaboration on pressing research topics.
Key Themes: Reduce Wind Costs; Expand Developable Areas **Markets Addressed:** Land, Offshore, Distributed	

ACTION	DELIVERABLE	IMPACT	BEGIN	END
Action 7.2.1: Support wind turbine certification and improve wind turbine standards. Continue support for turbine certification programs and develop specific standards, while making International Electrotechnical Commission and other national standards consistent for all wind turbine technologies.	Continuous updates of all wind turbine standards.	Continuously improved load modeling, reliability, and safety testing for all wind turbine frames; increased number of certified turbines; minimized divergence of national and international standards.	2014	2050
Action 7.2.2: Continue international research collaboration. Expand multinational research through ongoing work with organizations such as the International Energy Agency, bilateral partnerships, and research collaborations.	Collaborative research projects that bring together worldwide technical experts from all sectors to address the most pressing wind-power-related research questions.	Reduced total energy cost from wind technology by addressing the most significant technical, production, and deployment questions faced by the industry.	2014	2030
Action 7.2.3: Continue international collaboration to address wind deployment challenges. Work with and through organizations, such as the International Renewable Energy Agency, bilateral partnerships, development banks, and international donor organizations, to expand multinational technical assistance and information dissemination about appropriate deployment of wind technologies.	Science-based, impartial information and peer-reviewed products packaged for various international audiences using a range of outreach venues, combined with active technical assistance in all areas of wind deployment, from resource assessment through long-term operations.	Expanded international wind market; possible increased demand for U.S. exports; increased rate of technology development; lower costs; greater environmental benefits.	2014	2040

Action 7.2.1: Support wind turbine certification and improve wind turbine standards.

Although wind technology has reached a relatively high level of technical acceptance, it is not universally accepted. This is especially true for newer technologies, such as lower wind speed components, offshore wind, and distributed wind. Even though standards and certifications for larger land-based wind systems exist, the industry is still immature. With rapid technology advancement, standards are typically in need of constant review to ensure they meet the current industry needs. As U.S. companies continue to look toward export markets to support expanded manufacturing growth, especially in the distributed wind market, there is the need to ensure parity with domestic, international, and other national standards so that U.S. technology can compete globally. It is also important to ensure that international manufacturing does not undercut the U.S. market, especially with inferior products that could, in turn, impair the credibility of wind technology. Continued support for international wind turbine certification and standards development will be required to allow active participation by U.S.-based experts in the private and public sectors for all wind technologies.

Action 7.2.2: Continue international research collaboration.

Although vibrant, the global wind industry remains small when compared to other energy industries. As the market grows, greater collaboration will be needed to address ongoing technical challenges, especially increasingly larger wind components, deployment into less-developed markets such as offshore, and an expanding market for distributed wind technologies. To allow the commercial and industrial sectors to address these challenges, the wind industry will need to go beyond relatively simple information exchange (successfully implemented by the International Energy Agency Wind program) and fully embrace collaborative, international R&D across industry, academia, and research laboratories. Specific activities would include implementation of multifunded, cross-border research projects on topics of common interest; increased use of the limited, existing testing infrastructure; and broader collaboration to support the next generation of larger testing facilities. Expanded researcher and academic exchanges—for example, permanent researcher-in-residence programs at all significant national laboratories worldwide—would allow private and public researchers and educational professionals to share ideas and the results of their most recent research, thus enhancing the diffusion of new ideas and solutions. Expanded international collaboration on the development of wind power research agendas would also be helpful.

Action 7.2.3: Continue international collaboration to address wind deployment challenges.

Expanded knowledge of the applicability of wind technology and how to address the most pressing deployment challenges of integration, public acceptance, environmental impact, radar, and other competing uses are not unique to the United States. Knowledge gained from research in other countries, primarily Europe, Canada, and Australia, has provided valuable insight into the potential impacts of wind development and expands research done in the U.S. market. Beyond activities in the International Energy Agency Wind program portfolio, further bilateral or multilateral research that can bolster U.S. findings or build from impactful research conducted in other countries to enhance understanding of U.S. deployment strategies could support wind power deployment.

Collaboration with organizations such as the International Renewable Energy Agency can bring the experience base from the United States to other developing markets, expanding wind development in general and growing the potential for U.S. export markets. Higher wind deployment will allow for not only increased research and resulting lower costs, but also the opening of additional export markets for U.S. manufacturing. This will help stabilize the U.S. wind industry and allow increased industrywide efficiency improvements.

8 Workforce Development

ACTION 8.1: Develop Comprehensive Training, Workforce, and Educational Programs	
Develop comprehensive training, workforce, and educational programs, with engagement from primary schools through university degree programs, to encourage and anticipate the technical and advanced-degree workforce needed by the industry.	
DELIVERABLE	**IMPACT**
A highly skilled, national workforce guided by specific training standards and defined job credentials to support the growth of the wind industry.	A sustainable workforce to support the domestic and, as appropriate, the expanding international wind industry.
Key Themes: Reduce Wind Costs, Increase Economic Value for the Nation **Markets Addressed:** Land, Offshore, Distributed	

ACTION	DELIVERABLE	IMPACT	BEGIN	END
Action 8.1.1: Develop a foundation for a national wind workforce. Develop the foundational knowledge to address wind-focused training, workforce, and educational infrastructure, ensuring ongoing engagement from primary schools through university degree programs to encourage and anticipate the technical and advanced-degree workforce needed by the wind industry.	Analysis and research products that will help identify improvement opportunities, leading to new, highly skilled wind professionals entering the workforce.	Better understanding of industry workforce needs, training standards, and existing educational programs that will lower costs, increase system reliability, improve worker safety, and reduce the negative impacts of deployment.	2014	2040
Action 8.1.2: Develop robust wind education programs for primary and secondary levels. Develop and implement primary and secondary education programs that not only introduce more people to the impacts and benefits of wind power but also engage students of all types to enter all levels of the wind power workforce.	Engaging, standards-based wind power educational materials, curricula, activities, and teacher training programs that help support a general understanding of wind.	Increased interest in wind power at primary and secondary education levels, leading to expansion of the national wind workforce over time.	2014	2030
Action 8.1.3: Develop technical training programs for wind. Build a robust network of community college, vocational, apprenticeship, and organizational technical centers; develop and implement programs supporting technically minded individuals who are interested in working in the wind industry.	A nationally coordinated and recognized, multilevel educational infrastructure to support the training and continued development of technical workers for the wind industry.	An adequate number of highly skilled and competently trained technical workers to support the long-term growth of the wind industry.	2014	2025
Action 8.1.4: Create a robust higher education infrastructure. Provide a broad range of advanced degreed individuals to support the needs of the wind industry; develop and implement university-level educational programs across the spectrum of wind industry professional needs.	Nationally coordinated and recognized, multilevel educational infrastructure to provide workers with the advanced degrees that the wind industry needs.	Enough highly skilled and competently trained professionals to support the long-term growth of the wind industry.	2014	2030

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ACTION	DELIVERABLE	IMPACT	BEGIN	END
Action 8.1.5: Develop and implement certified training programs and credentials for distributed wind workforce, including site assessors and installers. Train and certify distributed wind assessors; formalize and implement distributed wind installer training.	Certification programs for distributed wind site assessors and distributed wind installers.	Skilled practitioners to support the growth of the industry; reduced sales acquisition costs; improved quality of installations; improved consumer confidence in systems.	2014	2030
Action 8.1.6: Develop and implement offshore wind workforce training programs. Create and continuously update training modules to reflect technology changes, market conditions, and lessons learned.	Offshore workforce training modules and updates; ongoing analyses and assessments of gaps in training programs, facilities, and training requirements.	A workforce with the skills required to expand offshore wind using domestic workers.	2014	2030
Action 8.1.7: Increase diversity in the wind energy workforce. Pursue workforce diversity by exposing wind opportunities more broadly to minorities and across the gender spectrum.	Educational materials focused on wind activities suitable for students and workers at all levels, along with strategies for engaging racial and gender minority sectors.	Improved appreciation of wind energy opportunities within minority sectors; a more diversified wind energy workforce.	2017	2030

Action 8.1.1: Develop a foundation for a national wind workforce.

Efforts are underway to support and expand wind industry workforce development options and better understand the wind industry's workforce development needs. Various industry groups and educational organizations have already implemented workforce development programs. Activities are also supported by DOE's Wind and Water Power Program, the National Renewable Energy Laboratory, the American Wind Energy Association, the U.S. Department of Labor, and the National Science Foundation. Many of these efforts are conducted in an uncoordinated fashion, however, with typically few direct ties to defined levels of expertise. Educational organizations and, in some cases, interested local parties are also implementing activities. One of the first needs is to obtain better understanding and coordination of the defined workforce and educational needs for this sector.

Action 8.1.2: Develop robust wind education programs for primary and secondary levels.

The active engagement of students at the primary and secondary levels not only introduces more people to the impacts and benefits of wind power, but also "primes the pump" of the wind power workforce at all levels. Educational work in the STEM topics—Science, Technology, Engineering, and Math— including energy and wind technologies specifically, should be made available to students at the kindergarten (K)–12 level so that they will have the skills and interest to enter the renewable energy workforce. There is also a need to ensure that more minorities and women of all backgrounds are engaged in science and math education and supported in pursuing careers in technology fields, and this is most likely to be successful if it happens at an early age.

Action 8.1.3: Develop technical training programs for wind.

The development of programs at community colleges, vocational centers, and direct technical centers will support a vast majority of the individuals who will join the wind industry. In many cases, these institutions focus on people with technical skills and professional development, developing or expanding skills needed to work in the land-based, offshore, and distributed wind markets. Expanded needs for worker education and safety become more critical in the technical training fields. This is particularly true given the development of offshore wind plants, which will impose additional training requirements, and the expansion of the distributed wind market, which will mean a need for more site assessors, installers, and maintenance providers. Although the wind industry will continue to play a critical role in worker training programs, expanded collaboration to ensure a universal

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understanding of the required skills and defined achievement levels will improve the quality of the workforce overall and allow expanded worker flexibility and development.

Action 8.1.4: Create a robust higher education infrastructure.

Many of the skills required for the successful long-term development of the wind industry, from engineering to business, call for individuals with advanced degrees [20]. The need to reduce the cost of wind systems, especially in the offshore and remote environment, will require expanded research and deployment innovation. These activities will, for the most part, be driven by individuals with advanced degrees at organizations that can focus on long-term, high-risk innovative strategies; i.e., research universities and laboratories. Given the limited number of university programs that provide graduate degrees in wind-related fields and the extended lead time that it takes to develop high levels of technical proficiency in a specific field, the near-term expansion of university-level programs in the wind sector is of high importance. University programs also need to include some level of direct collaboration or interaction with industry in order to connect students with the most pressing challenges facing the industry, as well as to provide industry with knowledge of cutting-edge academic research.

Action 8.1.5: Develop and implement certified training programs and credentials for distributed wind workforce, including site assessors and installers.

Having a well-trained base of assessors for distributed wind will lead to several immediate and long-term benefits for the deployment of distributed wind. Skilled practitioners, able to effectively use assessment and analysis tools, will, among other things, reduce sales acquisition costs, leading to lower total costs of projects. Additionally, a formalized wind turbine installer program covering the technological and physical attributes, as well as the science, of wind turbines will be beneficial. Certification programs for installers will improve consumer confidence in distributed wind systems and raise the overall quality of installations. In the long run, developing programs for training and certifying distributed wind site assessors and installers will support the growth of the industry.

Action 8.1.6: Develop and implement offshore wind workforce training programs.

Given commonalities in turbine technologies, there are many common training needs for land-based and offshore wind plant workers. There are, however, significant differences in risks, regulatory framework, and inspection and enforcement protocols between land-based and offshore wind. While land-based wind workers might drive to and from a construction site in a pick-up truck, a lengthy ocean transit in specially designed vessels or helicopters is the norm for offshore workers. When the weather prohibits safe transfer and transit, the offshore worker may be required to take shelter in the turbine. The specific risks associated with offshore activities must be mitigated by training specifically designed for offshore construction, operations, and maintenance.

The offshore wind industry can learn many lessons from the offshore operations experience of the oil and gas industry, including the safe transfer of large work crews. The implementation of effective safety and environmental management systems is an important part of these lessons learned.

As the United States approaches construction of its first offshore wind plant, there is a need for well-trained and properly certified offshore workers. Training programs that meet this demand require the creation of a framework for offshore wind O&M technicians. In addition, short-service construction workers and vessel operators must have clear pathways to obtaining training and certification in order to work in the offshore renewable energy industry.

As the offshore wind industry continues to grow, training venues must not only keep pace with demand but also continuously update training modules to reflect advances in technology and lessons learned.

Action 8.1.7: Increase diversity in the wind energy workforce.

Wind energy activity has lower-than-average diversity across the entire spectrum from primary school programs through employment. In the academic arena, projects such as the Collegiate Wind Competition have very little racial, ethnic, or gender diversity. In the employment arena, efforts so far to expose wind industry jobs more broadly to women and minorities have been very limited. A suite of educational materials is needed that introduces opportunities in wind energy to students and workers at various levels. Strategies for exposing these materials and the opportunities they describe to racial and gender minority sectors need to be developed and implemented.

9 Analysis

ACTION 9.1: Refine and Apply Energy Technology Cost and Benefit Evaluation Methods	
Refine and apply methodologies to comprehensively evaluate and compare the costs, benefits, risks, uncertainties, and other impacts of energy technologies.	
DELIVERABLE	**IMPACT**
A set of recognized and approved methodologies to objectively evaluate the costs, benefits, and impacts of energy technologies in concert with regular application of these tools.	Increased decision-maker access to comprehensive, comparative energy information.
Key Themes: Increase Economic Value for the Nation **Markets Addressed:** Land, Offshore, Distributed	

ACTION 9.2: Refine and Apply Analysis Methods	
Refine and apply analysis methodologies to understand federal and state decisions affecting the electric sector portfolio.	
DELIVERABLE	**IMPACT**
A set of recognized and approved methodologies to objectively evaluate the economic, environmental, societal, and wind industry impacts of existing and possible future energy policies, in concert with regular application of these tools.	Increased decision-maker access to comprehensive evaluations of energy options to achieve wind power deployment in fulfillment of national energy, societal, and environmental goals, while minimizing the cost of meeting those goals.
Key Themes: Increase Economic Value for the Nation **Markets Addressed:** Land, Offshore, Distributed	

ACTION 9.3: Maintain the Roadmap as a Vibrant, Active Process for Achieving the *Wind Vision Study Scenario*	
Track wind technology advancement and deployment progress, prioritize R&D activities, and regularly update the wind roadmap.	
DELIVERABLE	**IMPACT**
Periodically produced publicly available reports tracking technology advancement and deployment progress, as well as updated wind roadmaps.	Systematic evaluation of progress towards increased domestic deployment of wind power and identification of any new challenges to be addressed.
Key Themes: Reduce Wind Costs; Expand Developable Areas; Increase Economic Value for the Nation **Markets Addressed:** Land, Offshore, Distributed	

Note: The 2015 *Wind Vision* report did not include detailed subactions for roadmap actions 9.1, 9.2, and 9.3. However, these actions are listed here for completeness, and they were discussed in some of the topical working sessions..

The importance of Action 9.1 was emphasized in several of the topical working sessions during the 2016–2017 effort to update the *Wind Vision* Roadmap actions. This action is viewed as a high priority for the nation and as worthy of substantial attention involving the full spectrum of the energy and environmental stewardship communities.

Additional recommendations arose in two of the topical working sessions. In the Wind Electricity Delivery and Integration session, participants stressed the importance of wind community engagement in the electricity-market design process. Participants suggested that electricity markets should recognize and equitably compensate the full spectrum of energy and reliability services. In the Supply Chain, Manufacturing, and Logistics session, participants stressed the prospective value of national regulations governing the interstate transport of wind power equipment.

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References

[1] Musial, Walt; Heimiller, Donna; Beiter, Philipp; Scott, George; and Draxl, Caroline. *2016 Offshore Wind Energy Resource Assessment for the United States*. NREL/TP-5000-66599. Golden, CO; National Renewable Energy Laboratory, 2016. *https://www.nrel.gov/docs/fy16osti/66599.pdf*

[2] *U.S. Wind Energy Manufacturing and Supply Chain: A Competitiveness Analysis.* DE-EE-0006102. Work performed by Global Wind Network, Cleveland, OH. Washington, DC: U.S. Department of Energy, June 2014. Accessed Oct. 10, 2014: *https://www.energy.gov/eere/downloads/us-wind-energy-manufacturing-supply-chain-competitiveness-analysis*.

[3] Berger, S. *Making in America: From Innovation to Market*. Cambridge, MA: MIT Press, 2013. Accessed Feb. 3, 2015: *http://mitpress.mit.edu/books/making-america*.

[4] Wessner, C.W.; Wolff, A.W., eds. *Rising to the Challenge: U.S. Innovation Policy for the Global Economy*. Washington, DC: National Academies Press, 2012. Accessed Feb. 3, 2015: *www.nap.edu/openbook.php?record_id=13386*.

[5] *Report to the President on Capturing Domestic Competitive Advantage in Advanced Manufacturing*. Report to the President. Washington, DC: President's Council of Advisors on Science and Technology, July 2012; 70 pp. Accessed Feb. 3, 2015: *https://www.manufacturing.gov/sites/default/files/2018-01/pcast_amp_steering_committee_report_final_july_27_2012.pdf*

[6] Cotrell, J.; Stehly, T.; Johnson, J.; Roberts, J.O.; Parker, Z.; Scott, G.; Heimiller, D. *Analysis of Transportation and Logistics Challenges Affecting the Deployment of Larger Wind Turbines*. NREL/TP-5000-61063. Golden, CO: National Renewable Energy Laboratory, 2014. Accessed Dec. 19, 2014: *https://www.nrel.gov/docs/fy14osti/61063.pdf*.

[7] Elkinton, C.; Blatiak, A.; Ameen, H. *Assessment of Ports for Offshore Wind Development in the United States.* Document 700694-USPO-R-03. Work performed by GL Garrad Hassan America, San Diego, CA. Washington, DC: U.S. Department of Energy, March 2014. Accessed Dec. 19, 2014: *https://www.energy.gov/eere/wind/downloads/wind-offshore-port-readiness*.

[8] Hamilton, B.; Battenberg, L.; Bielecki, M.; Bloch, C.; Decker, T.; Frantzis, L.; Karcanias, A.; Madsen, B.; Paidipati, J.; Wickless, A.; Zhao, F. *U.S. Offshore Wind Manufacturing and Supply Chain Development.* DE-EE0005364. Work performed by Navigant Consulting for U.S. Department of Energy Office of Energy Efficiency & Renewable Energy. Burlington, MA: Navigant, Feb. 22, 2013; 191 pp. Accessed Feb. 3, 2015: *https://www.energy.gov/eere/wind/downloads/assessment-vessel-requirements-us-offshore-wind-sector*.

[9] *Assessment of Vessel Requirements for the U.S. Offshore Wind Sector.* Work performed by Douglas-Westwood, Kent, UK, for U.S. Department of Energy (DOE). Washington, DC: U.S. DOE, 2013. Subtopic 5.2 of U.S. Offshore Wind: Removing Market Barriers grant opportunity under Funding Opportunity Announcement 414, 2013. Accessed Dec. 19, 2014: *http://energy.gov/eere/wind/downloads/assessment-vessel-requirements-us-offshore-wind-sector*.

[10] *Offshore Wind Cost Reduction Pathways Study*. London: The Crown Estate, May 2012. Accessed Dec. 19, 2014.

[11] *Offshore Wind Project Timelines 2013*. London: Renewable UK and Crown Estate, 2013. Accessed Dec. 20, 2014.

[12] Bailey, B.; Wilson, W. "The Value Proposition of Load Coincidence and Offshore Wind." *North American Windpower*, January 2014. *https://www.awstruepower.com/knowledge-center/articles/*.

[13] "Analysis of the Impact of Cape Wind on New England Energy Prices." CRA Project No. D15007-00. Work performed for Cape Wind Associates by Charles River Associates. Boston: CRA, 2010; 13 pp. Accessed Feb. 3, 2015: *http://www.crai.com/uploadedFiles/Publications/analysis-of-the-impact-of-cape-wind-on-new-england-energy-prices.pdf?n=944*.

[14] "Update to the Analysis of the Impact of Cape Wind on Lowering New England Energy Prices." CRA Project No. D17583-00. Work performed for Cape Wind Associates by Charles River Associates. Boston: CRA, 2012.

[15] *Alliance to Protect Nantucket Sound, Inc., vs. Department of Public Utilities*. 461 Massachusetts 166, Docket DPU 10-54. National Grid and Cape Wind Association, 2010.

[16] "Standard for Interconnecting Distributed Resources with Electric Power Systems." IEEE 1547 Working Group, 2014. Accessed Dec. 20, 2014: *http://grouper.ieee.org/groups/scc21/1547/1547_index.html*.

[17] "DWEA Model Zoning Ordinance, Final." Flagstaff, AZ: Distributed Wind Energy Association (DWEA), 2012.

[18] "Distributed Wind Model Zoning Ordinance." Flagstaff, AZ: Distributed Wind Energy Association, February 2014.

[19] Lang, J.; Wasser, C.; Jenkins, J.; DiFrancisco, L. *County Strategies for Successfully Managing and Promoting Wind Power: Implementing Wind Ordinances in America's Counties.* Distributed Wind Energy Association Planning and Zoning Committee Issue Brief. Washington, DC: National Association of Counties, 2012. Accessed Feb. 3, 2015.

[20] Leventhal, M.; Tegen, S. *National Skills Assessment of the U.S. Wind Industry in 2012*. NREL/TP-7A30-57512. Golden, CO: National Renewable Energy Laboratory, 2013. Accessed Dec. 19, 2014: *https://www.nrel.gov/docs/fy13osti/57512.pdf*.

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