Highlights

Wind Vision:
A New Era for Wind Power in the United States

U.S. DEPARTMENT OF ENERGY

Wind Vision: A New Era for Wind Power in the United States

Wind Vision Objectives

The U.S. Department of Energy's (DOE's) Wind and Water Power Technologies Office has conducted a comprehensive analysis to evaluate future pathways for the wind industry. Through a broad-based collaborative effort, the *Wind Vision* analysis includes four principal objectives:

1. Documentation of the current state of wind power in the United States and identification of key technological and societal accomplishments over the decade leading up to 2014;
2. Exploration of the potential pathways for wind power to contribute to the future electricity needs of the nation, including objectives such as reduced carbon emissions, improved air quality, and reduced water use;
3. Quantification of costs, benefits, and other impacts associated with continued deployment and growth of U.S. wind power; and
4. Identification of actions and future achievements that could support continued growth in the use and application of wind-generated electricity.

The *Wind Vision* analysis results from a collaboration of the DOE with over 250 experts from industry, electric power system operators, environmental stewardship organizations, state and federal governmental agencies, research institutions and laboratories, and siting and permitting stakeholder groups. The conclusions of this effort, summarized below, demonstrate the role that wind power has in the U.S. power sector today and highlights its potential to continue to provide clean, reliable, and affordable electricity to consumers for decades to come. The *Wind Vision* report does not evaluate nor recommend policy actions, but analyzes feasibility, costs, and benefits of increased wind power deployment to inform generally, as well as to provide insights for policy decisions at the federal, state, tribal, and local levels.

Deployment of wind technology for U.S. electricity generation provides a domestic, sustainable, and essentially zero-carbon, zero-pollution, and zero-water use U.S. electricity resource.

Wind Power Today

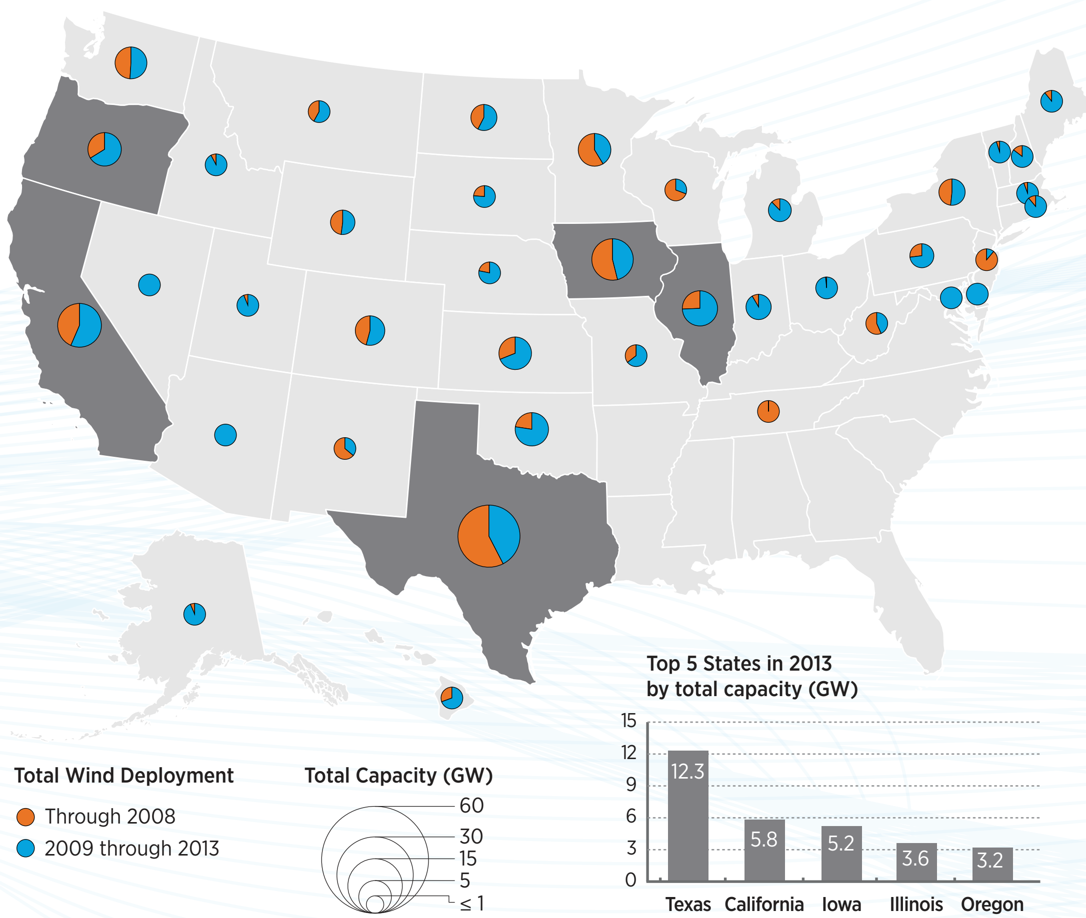
Wind power has become a mainstream power source in the U.S. electricity portfolio, supplying 4.5% of the nation's electricity demand in 2013. With more than 61 gigawatts (GW) installed across 39 states at the end of 2013, utility-scale wind power is a cost-effective source of low-emissions power generation throughout much of the nation. From 2008 to 2013, wind power installations expanded in geographic deployment and cumulative capacity (Figure 1), with corresponding growth in the domestic supply chain. Wind power costs have declined by more than one-third since 2008, and the U.S. manufacturing base has expanded to support annual deployment level growth—from 2 GW/year in 2006, to 8 GW/year in 2008, to peak installations of 13 GW/year in 2012. In the United States, new investments in wind plants averaged $13 billion/year from 2008 through 2013. Global investment in wind power grew from $14 billion in 2004 to $80 billion in 2013, a compound annual growth rate of 21%.

Wind deployment delivers public health and environmental benefits today, including reduced greenhouse gas (GHG) emissions, reduced air pollutants, and reduced water consumption and withdrawals. The power sector is the largest contributor to GHG emissions and a major source of criteria air pollutants such as sulfur dioxide (SO_2) and nitrogen oxides (NO_X). Wind power is already reducing these emissions from the electric power sector (Figure 2).

Analysis of wind installation and operational experience as of 2013 concludes that:

- The U.S. wind industry, including associated manufacturing and installation activities, has demonstrated the ability to scale to satisfy rapid build demands;
- Wind generation variability has a minimal and manageable impact on grid reliability and related costs; and
- Environmental and competing use challenges for local communities, including land use, wildlife concerns, and radar interference issues, can be effectively managed with appropriate planning, technology, and communication among stakeholders.

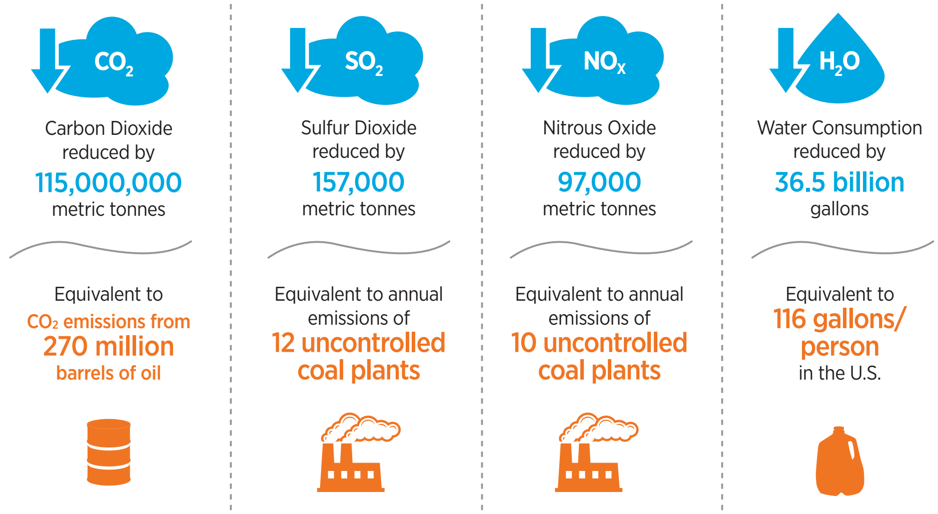
In 2013, cumulative utility-scale wind deployment reached 61 GW across 39 states.



Note: Distributed wind projects with less than 1 MW have been installed in all 50 states.

Figure 1. Utility-scale wind deployment through 2013

Wind generation in 2013 provided a range of environmental benefits.



Note: Emissions and water savings calculated using the EPA's Avoided Emissions and Generation Tool (AVERT). 'Uncontrolled coal plants' are those with no emissions control technology.

Figure 2. Estimated emissions and water savings resulting from wind generation in 2013

The *Wind Vision Study Scenario*

The *Wind Vision* analysis updates and expands upon the DOE's 2008 report, *20% Wind Energy by 2030*,[1] through analysis of a *Study Scenario* of wind power supplying 10% of national end-use electricity demand by 2020, 20% by 2030, and 35% by 2050 (Figure 3). This *Study Scenario* provides a framework for conducting detailed quantitative impact analyses. The *Study Scenario* starts with current manufacturing capacity (estimated at 8-10 GW of nacelle assembly and other large turbine components within the U.S. today) and applies central projections for variables such as wind power costs, fossil fuel costs, and energy demand in order to arrive at a credible projected pathway that would maintain the existing industry, for purposes of calculating potential social and economic benefits.

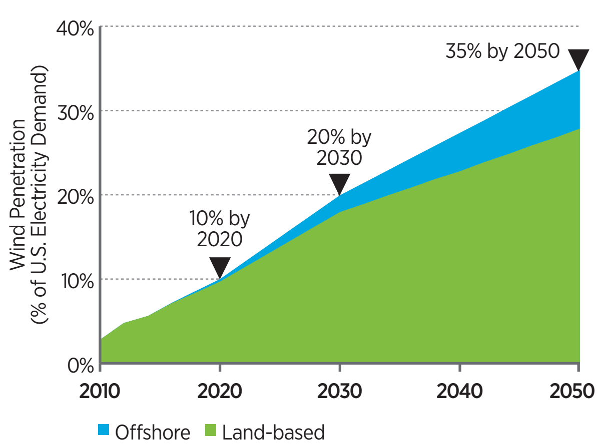


Figure 3. The *Wind Vision Study Scenario*, with contributions from land-based and offshore technology

The *Wind Vision* additionally modeled *Baseline* and *Business-as-Usual (BAU) Scenarios*. All scenario modeling efforts relied on current and projected data from the Energy Information Administration's *Annual Energy Outlook 2014*[2] and the broader literature. The *Baseline Scenario* kept wind deployment fixed at year-end 2013 levels of 61 GW. It was used as the study's analytical reference case to support comparisons of costs, benefits, and other impacts. *BAU* conditions represented a future scenario with federal and state policies as enacted as of January 1, 2014. This analytical framework for the *Wind Vision* study is summarized in Table 1.

[1] *http://energy.gov/eere/wind/20-wind-energy-2030-increasing-wind-energys-contribution-us-electricity-supply*

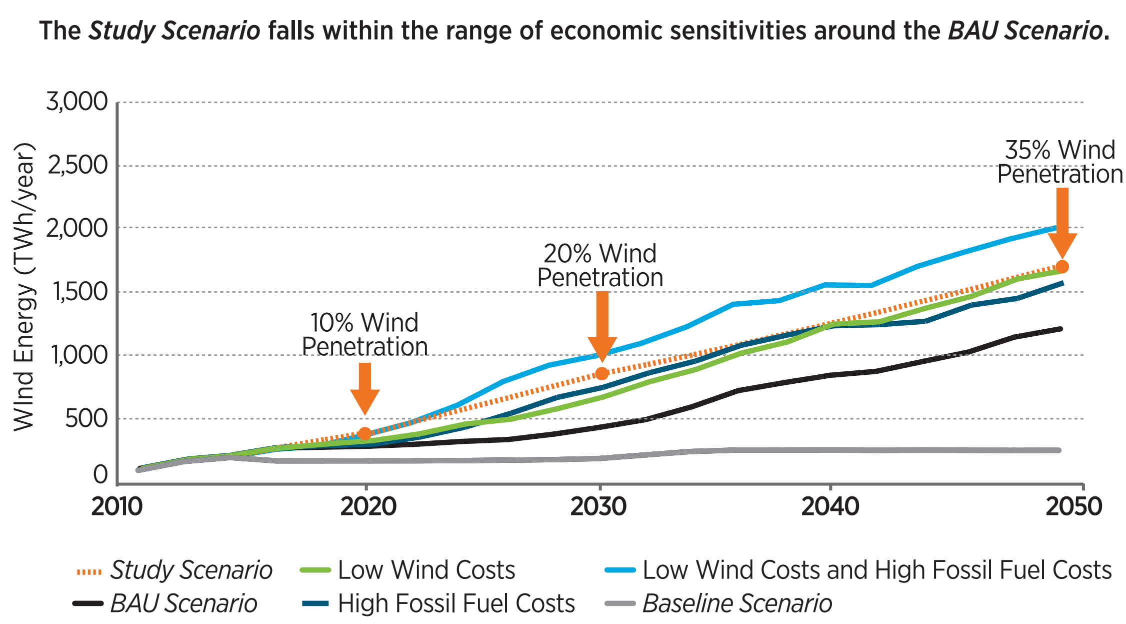
[2] *http://www.eia.gov/forecasts/aeo/*

A large set of sensitivity analyses of *BAU* conditions were performed to understand the impacts of projected energy demand, fossil fuel costs, and wind power costs on future wind deployment levels. Under central *BAU* conditions, historical wind deployment levels (8 GW/yr) are at risk until 2030. Sensitivities modeled, such as low wind power costs and/or high fossil fuel costs, however, can accelerate deployment growth and result in outcomes on the order of 10% wind by 2020, 20% wind by 2030, and 35% wind by 2050 (Figure 4). These *BAU* sensitivity analyses substantiated the *Wind Vision Study Scenario* as a viable scenario.

Table 2 captures the feasibility and economics of the *Study Scenario*.

Table 1. Analytical Framework of the *Wind Vision*

Analytical Framework of the *Wind Vision*	
Wind Vision Study Scenario	The *Wind Vision Study Scenario,* or *Study Scenario*, applies a scenario of 10% of the nation's end-use demand served by wind by 2020, 20% by 2030, and 35% by 2050. It is the primary analysis scenario for which costs, benefits, and other impacts are assessed. The *Study Scenario* comprises a range of cases spanning plausible variations from central values of wind power and fossil fuel costs. The specific *Study Scenario* case based on those central values is called the *Central Study Scenario*.
Baseline Scenario	The *Baseline Scenario* applies a constraint of no additional wind capacity after 2013 (wind capacity fixed at 61 GW through 2050). It is the primary reference case to support comparisons of costs, benefits, and other impacts against the *Study Scenario*.
Business-as-Usual Scenario	The *Business-as-Usual (BAU) Scenario* does not predetermine a wind future trajectory, but instead models wind deployment under policy conditions current on January 1, 2014. The *BAU Scenario* uses demand and cost inputs from the Energy Information Administration's *Annual Energy Outlook 2014*.



Note: Under *BAU* conditions, wind deployment is stagnant until 2030. Conditions of low wind power costs and/or high fossil fuel costs, however, can accelerate deployment growth and result in outcomes on the order of 10% wind by 2020, 20% wind by 2030, and 35% wind by 2050. Low wind power costs start at median 2013 costs and then decline 24% by 2020, 33% by 2030, and 37% by 2050. High fuel costs use the Low Oil and Gas Resource and High Coal Cost Case from Annual Energy Outlook, 2014.

Figure 4. *BAU* conditions and sensitivities using high fossil fuel costs and low wind power costs

Table 2. Requirements and Feasibility Assessment of the *Study Scenario*

Framework of the *Study Scenario*[3]

	10% Wind by 2020	20% Wind by 2030	35% Wind by 2050
Installed Capacity (GW)	110 (Land) 3 (Offshore) 113 (Total)	202 (Land) 22 (Offshore) 224 (Total)	318 (Land) 86 (Offshore) 404 (Total)

Viability of the *Study Scenario*

Wind Resources	The nation has abundant wind resources on land and offshore. Current estimates indicate that the gross resource potential is more than 10 times our current electric sector capacity. The *Study Scenario* would utilize less than 5% of the country's technical wind resource potential.
Land Area	Most of the land used for a wind plant can continue to support activities such as farming, ranching, and forestry. Total land area occupied by wind plants in the *Study Scenario* equates to about 106,000 km^2, which is less than 1.5% of the total land area of the contiguous United States. The actual land area within wind plants that is occupied by wind turbines, roads, and other project infrastructure is approximately 3,200 km^2 in 2050. This comprises less than 0.05% of total contiguous U.S. area and is equivalent to less than one-third of total land area occupied by U.S. golf courses today.
Geographic Diversity	Utility-scale wind power was deployed in 39 states as of the end of 2013. Continued expansion in the *Study Scenario* occurs as offshore turbines are deployed in coastal states and advancements in land-based turbine technology emerge to support lower-wind speed areas such as the Southeastern United States. By 2050, wind power is anticipated to be deployed in all 50 states.
Transmission Expansion	Transmission additions in the *Study Scenario* are estimated at approximately 900 circuit miles/year in the 2020s and approximately 1,100 circuit miles/year from 2031 to 2050 (assuming a generic 900 MW transmission line capacity equivalent to a single circuit 345 kV line). This is comparable to the average 900 circuit miles/year built since the early 1990s.
Grid Integration	At the nationwide penetration levels of the *Study Scenario*, technological and institutional solutions would be needed to increase system flexibility. However, many states in the country already operate with large amounts of wind. Nine states operated with more than 12% wind generation levels and two of these states operated with more than 25% wind generation levels in 2013.
Manufacturing and Supply Chain	The industry deployed 13 GW in 2012 and can support *Study Scenario* annual wind deployment levels that average roughly 8 GW/year through 2020, 12 GW/year from 2021-2030, and 18 GW/year from 2031 through 2050. For the period of 2031-2050 repowering of the existing fleet constitutes a substantial share of annual wind deployments.
Wind Power Demand	In the *Study Scenario*, average new capacity additions remain below their 2012 peak (13 GW) through 2030. While these levels of production are feasible, demand will hinge on various factors. In the near-term, wind power demand is projected to fall due to unstable federal policy, reduced overall electricity demand, and low natural gas prices.
Wind Power Costs	A sensitivity analysis of *BAU* conditions that uses low wind costs (24% reduction in LCOE by 2020, 33% by 2030, and 37% by 2050) largely delivers the *Study Scenario* wind penetration levels (Figure 3). Wind LCOE has fallen by more than one-third from 2008 to 2013, but continued reductions will depend on an array of variables including future market conditions and continued R&D.

[3] The results presented in this table represent the outcomes of the *Central Study Scenario*. Multiple sensitivities of the *Study Scenario* are presented in the full report. The quantities reported compare the *Central Study Scenario* against the *Baseline Scenario*.

High Wind Penetration is Achievable, Affordable, and Beneficial

The *Wind Vision* analysis concludes that U.S. wind deployment at the *Study Scenario* levels would have an overall positive economic benefit for the nation (Figure 5). Numerous economic outcomes and societal benefits for the *Study Scenario* were quantified (Table 3), including:

- An approximately 1% increase in electricity cost through 2030, shifting to long-term cost savings of 2% by 2050.
- Cumulative benefits of $400 billion in avoided global damage from GHGs with 12.3 gigatonnes of avoided GHG emissions through 2050. Monetized GHG benefits exceed the associated costs of the *Study Scenario* in 2020, 2030, and 2050, and on a cumulative basis are equivalent to a levelized global benefit from wind energy of 3.2¢/kWh of wind.
- Cumulative benefits of $108 billion for avoided emissions of fine particulate matter (PM), nitrogen oxides (NO_X), and sulfur dioxides (SO_2) through 2050. Monetized criteria air pollutant benefits exceed the associated costs of the *Study Scenario* in 2020, 2030, and 2050, and on a cumulative basis are equivalent to a levelized public health benefit from wind energy of 0.9¢/kWh of wind.
- Quantified consumer cost savings of $280 billion (by 2050) from reduced natural gas prices outside of the electricity sector, in response to reduced demand for natural gas and its price elasticity. This is equivalent to a levelized consumer benefit from wind energy of 2.3¢/kWh of wind.
- A 23% reduction in water consumed by the electric sector (in 2050), with significant value in locations with constrained water availability.
- Transmission capacity expansion similar to recent national transmission installation levels of 890 miles per year (through 2030), assuming equivalent single-circuit 345-kilovolt lines with a 900-MW carrying capacity.
- Land use requirements for turbines, roads, and other wind plant infrastructure of 0.04% of U.S. land area in 2050.

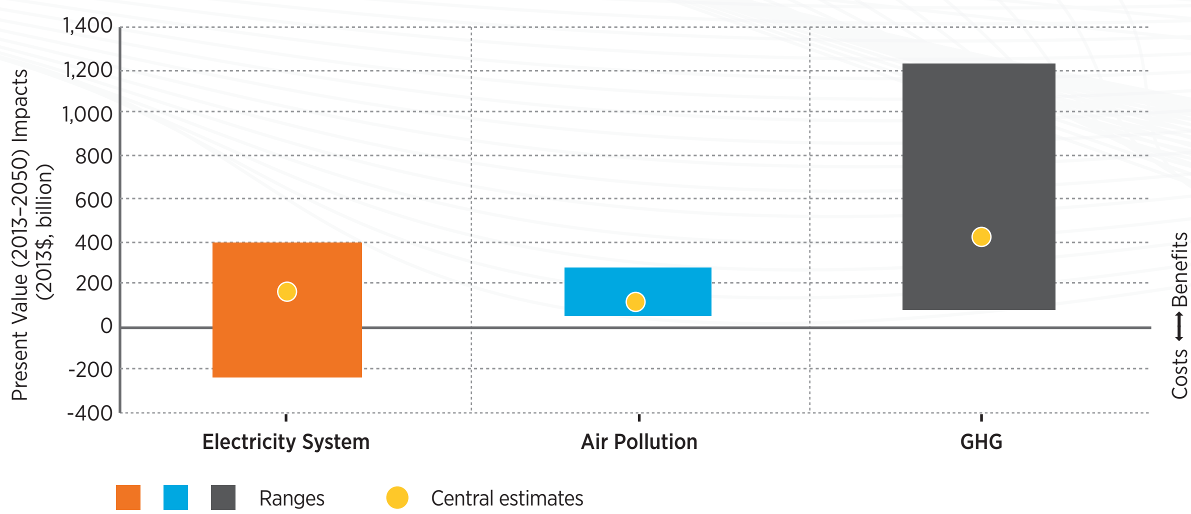


Figure 5. Cumulative (2013-2050) present value of monetized impacts of the *Study Scenario* relative to the *Baseline Scenario*

Table 3. Value and Benefits of the *Study Scenario*

Impacts of the *Study Scenario* by 2050: Costs, Benefits and Value Delivered[4]

Electricity Rates for Consumers	*Study Scenario* electricity rates are expected to be under 0.1 cents/kWh [less than 1%] higher in 2030, but then decline by 2050, relative to the *Baseline Scenario*. Across all years and an array of sensitivities, the rate differences between the *Study Scenario* and *Baseline Scenario* range ±0.6 cents/kWh [5%].	By 2050: 0.3 cents/kWh [2%] savings
Power System Costs[5]	In the *Study Scenario*, savings from reduced fossil fuel purchases among other sources help drive long-term savings. Power system costs include capital, operations and maintenance (O&M), and fuel costs for all generation, storage, and transmission modeled in the power sector.	Cumulative 2013-2050: $149 billion [3%] savings
Greenhouse Gas (GHG)[6]	The electricity sector is the largest source for GHG emissions nationally. By 2050, cumulatively the *Study Scenario* reduces GHG emissions by 12.3 gigatonnes CO_2-equivalents, compared with the *Baseline Scenario*. These reduced emissions help avoid costs incurred from climate change damages.	Cumulative 2013-2050: $400 billion in avoided global climate change damages
Public Health and Air Quality[7]	Traditional fossil fuel power plants emit pollutants such as particulate matter (PM), nitrous oxides (NO_X), and sulfur dioxide (SO_2) that can result in mortality, morbidity, and economic damages due to reduced air quality. The *Study Scenario* reduces these pollutants, avoiding 21,700 premature deaths and reducing overall economic damages from air pollution.	Cumulative 2013-2050: $108 billion in avoided health and economic damages from air pollution
Water	Water consumption refers to water that is used and not returned to its source. Water scarce regions like the Southwestern U.S. can benefit from reduced water consumption by the power sector. In the *Study Scenario*, water consumption is reduced 4% in 2020 and 11% in 2030.	In 2050: 260 billion gallons [23%] saved
Jobs[8]	Gross job estimates include direct, indirect, and induced jobs. There were 50,000 direct and indirect wind jobs in 2013. By 2030, gross jobs reach approximately 230,000.	By 2050: approximately 600,000 gross jobs supported by wind investments
Natural Gas	Higher levels of wind deployment place downward price pressure on natural gas. For consumers of natural gas outside the electricity sector, the *Study Scenario* delivers savings through lower bills. Higher levels of wind deployment also reduce long-term natural gas price risk to the overall electricity portfolio.	Cumulative 2013-2050: $280 billion saved for consumers By 2050: Total electric system costs are 20% less sensitive to natural gas price fluctuations

Local Impacts

Local Revenues	Land owners receive lease payments when wind plants are located on or near their property. These payments grow from $350 million in 2020 to $650 million in 2030.	By 2050: $1.0 billion annually
	Local communities collect taxes from wind plants. In 2020, these tax payments total $900 million and by 2030 reach $1.7 billion.	By 2050: $3.2 billion annually
Public Acceptance and Wildlife	Careful siting, continued research, thoughtful public engagement, and an emphasis on optimizing coexistence can support continued responsible deployment that minimizes or eliminates negative impacts to wildlife and local communities.	

[4] The results presented in this table represent the outcomes of the *Central Study Scenario*. Multiple sensitivities of the *Study Scenario* are presented in the full report. The quantities reported compare the *Central Study Scenario* against the *Baseline Scenario*.

[5] Present value of total electric system expenditures between 2013 and 2050 using a 3% discount rate.

[6] Greenhouse gas estimates are based on a life-cycle assessment. Monetized value estimated using the Interagency Working Group's Social Cost of CO_2 methodology, using the 3% discount rate.

[7] Air pollution benefits were calculated using several methodologies in the full report. The Environmental Protection Agency's (EPA) "low" estimate is presented here as the central case.

[8] Direct jobs include manufacturing, installation, construction, and operations and maintenance jobs. Indirect jobs include roles such as attorneys, educators, and analysts in the wind industry. Induced jobs refer to jobs at restaurants, gas stations, and other local businesses that receive additional revenues from the economic activity of a wind plant. The estimates are dependent on the levels of domestic content in the wind turbine equipment.

Roadmap for Action

The *Wind Vision* analysis concludes that the *Study Scenario* is technically feasible, generates long-term savings, and brings substantial environmental and local community benefits. A balanced set of key actions is required, to achieve the wind deployment levels of the *Study Scenario*. Optimizing wind contributions requires coordination among multiple parties who can implement a set of complementary approaches. The *Wind Vision* Roadmap organizes efforts into three key themes—reducing wind costs, expanding developable areas, and increasing economic value for the nation. The strategic approach is summarized in Table 4.

Actions highlighted in the *Wind Vision* Roadmap inform ongoing DOE technology research and development initiatives. By increasing energy production per dollar invested, among other goals, such initiatives are intended to support broad-based cost reductions as well as the expansion of wind development potential in areas where limited potential was thought to exist.

Table 4. Roadmap Strategic Approach

Core Challenge	Wind has the potential to be a significant and enduring contributor to a cost-effective, reliable, low carbon, U.S. energy portfolio. Optimizing U.S. wind power's impact and value will require strategic planning and continued contributions across a wide range of participants.		
Key Themes	**Reduce Wind Costs** Collaboration to reduce wind costs through wind technology capital and operating cost reductions, increased energy capture, improved reliability, and development of planning and operating practices for cost-effective wind integration.	**Expand Developable Areas** Collaboration to increase market access to U.S. wind resources through improved power system flexibility and transmission expansion, technology development, streamlined siting and permitting processes, and environmental and competing use research and impact mitigation.	**Increase Economic Value for the Nation** Collaboration to support a strong and self-sustaining domestic wind industry through job growth, improved competitiveness, and articulation of wind's benefits to inform decision making.
Issues Addressed	Continuing declines in wind power costs and improved reliability are needed to improve market competition with other electricity sources.	Continued reduction of deployment barriers as well as enhanced mitigation strategies to responsibly improve market access to remote, low wind speed, offshore, and environmentally sensitive locations.	Capture the enduring value of wind power by analyzing job growth opportunities, evaluating existing and proposed policies, and disseminating credible information.
Wind Vision Study Scenario Linkages	Levelized cost of electricity reduction trajectory of 24% by 2020, 33% by 2030, and 37% by 2050 for land-based wind power technology and 22% by 2020, 43% by 2030, and 51% by 2050 for offshore wind power technology to substantially reduce or eliminate the near- and mid-term incremental costs of the *Study Scenario*.	Wind deployment sufficient to enable national wind electricity generation shares of 10% by 2020, 20% by 2030, and 35% by 2050.	A sustainable and competitive regional and local wind industry supporting substantial domestic employment. Public benefits from reduced emissions and consumer energy cost savings.
Roadmap Action Areas*	• 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 • Collaboration, Education, and Outreach • Workforce Development • Policy Analysis	• Wind Power Resources and Site Characterization • Wind Plant Technology Advancement • Supply Chain, Manufacturing, and Logistics • Wind Electricity Delivery and Integration • Wind Siting and Permitting • Collaboration, Education, and Outreach • Policy Analysis	• Supply Chain, Manufacturing, and Logistics • Collaboration, Education, and Outreach • Workforce Development • Policy Analysis

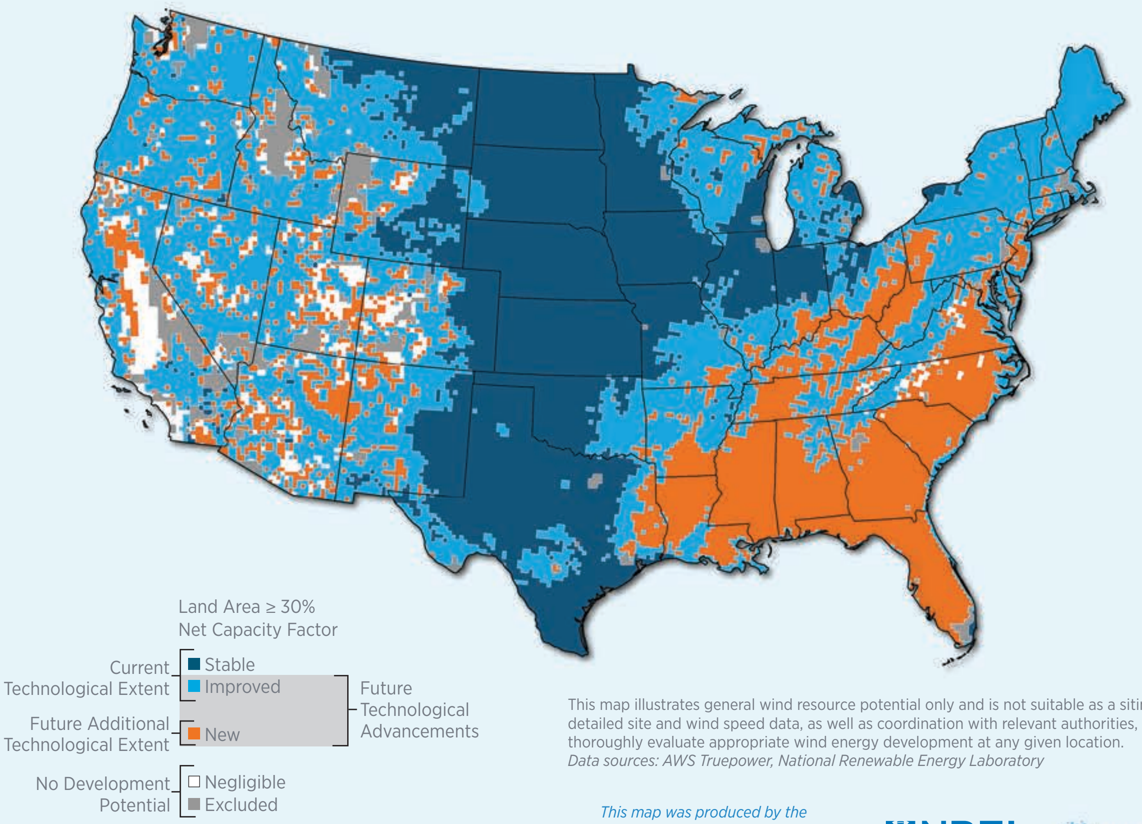
*Several action areas address more than one key theme.

Technology Innovation Drives Geographic Expansion

Technology research and development are key elements of realizing the benefits of the *Study Scenario* with minimal near-term costs and maximum long-term savings. Advanced technology can also open new regions to wind development, subsequently providing more opportunities for the business community, the utility sector, and the public to deploy wind power in locations that are consistent with public and electric sector needs.

Technology advancements since 2008 have increased the total land area that supports a 30% net capacity factor level or greater by nearly 70% with particularly noteworthy impacts in the West, Midwest, Northeast, and Mid-Atlantic. (A 30% net capacity factor or greater is economically competitive at most locations.) Continued innovations in rotor size and hub height could further expand the land area achieving a 30% or greater net capacity factor by an additional 67% with impacts extending well into the Southeast, East, Great Lakes, and Interior West.

Future generation wind turbines with expanded energy capture capabilities and hub heights of up to 140 meters could unlock additional wind power resource potential across nearly 720,000 square miles, nearly tripling the amount of developable land area for wind when compared with 2008 turbine technology. States with significant increases in wind development potential resulting from such technological advancements include



This map illustrates general wind resource potential only and is not suitable as a siting tool. More detailed site and wind speed data, as well as coordination with relevant authorities, are needed to thoroughly evaluate appropriate wind energy development at any given location.
Data sources: AWS Truepower, National Renewable Energy Laboratory

This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy March 2015

Note: Dark blue coloring identifies high-quality wind resource areas that see no change in available land area meeting the 30% minimum net capacity factor threshold with technology advancement because the entire area is capable of achieving this threshold today. Light blue coloring identifies land area that meets the capacity factor threshold today but sees an increase in the proportion of the area able to achieve this threshold as a result of turbine and hub height improvements. Orange coloring identifies new land area able to achieve the minimum 30% net capacity factor level as a result of turbine and hub height improvements.

Figure 6. Land area achieving a minimum 30% net capacity factor based on current (2013) technology, larger rotor designs and a 140-m hub height

Alabama, Florida, Georgia, Kentucky, Louisiana, Minnesota, North Carolina, South Carolina, Tennessee, and Virginia.

These results are illustrated by Figure 6, which indicates the land area with sites that can achieve a 30% net capacity factor based on current (2013) technology, land area with potential today that sees increased potential with technology improvements, and new land areas achieving the 30% minimum net capacity factor as a function of technology advancement.

Technology advancement provides the opportunity for wind power to expand to all U.S. states. Key innovations are needed to improve reliability, lower the cost of energy, and expand the areas where wind can be competitively deployed. Innovations, such as increased rotor diameter, optimization of wind plants, and increases in hub heights, are needed in order to capture better wind resource conditions at greater heights above ground level. As wind power technology continues to grow in scale and becomes increasingly viable around the nation, permitting, siting, and regulatory challenges will also require attention. Engagement with stakeholders at the local, state, and federal levels—including agencies such as the Federal Aviation Administration and Department of Defense—is expected to facilitate the constructive resolution of these challenges, while public and private sector research and development resources are currently working to resolve the remaining technical and cost hurdles needed to bring this future to fruition.

Conclusions

The results of the *Wind Vision* analysis reveal significant health, carbon, environmental, and other social benefits deriving from the penetration levels of the *Wind Vision Study Scenario*.

Reduced economic activity and increased energy efficiency measures have slowed the growth of electricity demand and reduced the need for new generation of any kind. This decreased need for new generation, in combination with decreased natural gas costs and other factors, has reduced demand for new wind plants. Absent actions that address these trends, a loss of domestic manufacturing capacity is expected and the potential benefits associated with the *Study Scenario* may not be realized.

The *Wind Vision* analysis demonstrates the economic value that wind power can bring to the nation, a value exceeding the costs of deployment. Wind's environmental benefits can address key societal challenges such as climate change, air quality and public health, and water scarcity. Wind deployment can provide U.S. jobs, U.S. manufacturing, and lease and tax revenues in local communities to strengthen and support a transition of the nation's electricity sector toward a low-carbon economy.

The path needed to achieve 10% wind by 2020, 20% by 2030, and 35% by 2050 requires new tools, priorities, and emphases beyond those forged by the wind industry in growing to 4.5% of current U.S. electricity demand. Consideration of new strategies and updated priorities as identified in the *Wind Vision* could provide substantial positive outcomes for future generations.

Highlights

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