Executive Summary

Wind Vision:

A New Era for Wind Power in the United States

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Message from the Director

The wind industry can be characterized by the substantial growth of domestic manufacturing and the level of wind deployment seen in recent years. Wind power systems are now seen as a viable and competitive source of electricity across the nation. Wind power's emerging role is an important option in a portfolio of new energy solutions for future generations. More than 4.5% of our nation's electricity came from wind power in 2013, placing the industry at a crossroads between the opportunities of higher energy penetration and the challenges of increased competition, policy uncertainty, access to transmission and lower energy demand.

The primary goal of the *Wind Vision* was to gain insights, after analyzing and quantifying a future scenario for wind energy, that consider our domestic manufacturing capacity, current and projected cost trends, sensitivities to future demand and fuel prices, and transmission needs. The *Wind Vision* was accomplished by bringing together leaders in energy in an effort to pool their insights, build upon their advancements, and learn from their accomplishments to project a credible future supported by the economic and societal benefits of wind energy.

In writing the *Wind Vision*, we recognize that the Energy Department is not the sole agent to drive a new future for the industry, but the federal Wind Program can provide focus and direction by leading efforts to accelerate the development of next-generation wind power technologies and assisting in solving key market challenges.

I would like to express my deepest sense of gratitude to the hundreds of individuals across our agency, industry, academia, and our national labs for their support, feedback and strategic interest in a renewed vision for wind energy. Their level of involvement signals a bright future for the wind industry.

The stakes for the nation are high. I am confident that, with sustained leadership in innovation, U.S. wind power will continue to make a significant contribution to the ever-evolving energy landscape. The *Wind Vision* is intended to assist in prioritizing the decisions needed to increase the economic competitiveness of the U.S. wind industry throughout the 21st century.

José

José Zayas
Director, Wind and Water Power Technologies Office
U.S. Department of Energy
March 12, 2015

Acronyms

AC	alternating current
AEO	*Annual Energy Outlook*
AP2 (formerly APEEP)	Air Pollution Emission Experiments and Policy
AWEA	American Wind Energy Association
AWC	Atlantic Wind Connection
AWST	AWS Truepower
AWWI	American Wind Wildlife Institute
BA(s)	balancing area(s)
BAU	Business as Usual or Business-as-Usual
BLM	Bureau of Land Management
BMP(s)	best management practice(s)
BOEM	Bureau of Ocean Energy Management
BPT	benefit per ton
Btu	British thermal unit
CAPEX	capital expenditures
CBO	Congressional Budget Office
CCS	carbon capture and sequestration (or storage)
CF	capacity factor
CO_2	carbon dioxide
CREZ	Competitive Renewable Energy Zone

CRS	Congressional Research Service
CSAPR	Cross-State Air Pollution Rule
CSP	concentrating solar power
DC	direct current
DMME	Department of Minerals, Mines, and Energy (Virginia)
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
DWEA	Distributed Wind Energy Association
EIA	U.S. Energy Information Administration
EIPC	Eastern Interconnection Planning Collaborative
ELI	Environmental Law Institute
EPA	U.S. Environmental Protection Agency
ERCOT	Electric Reliability Council of Texas
ESA	Endangered Species Act
FAA	Federal Aviation Administration
FAU	Florida Atlantic University
FCR	fixed charge rate
FERC	Federal Energy Regulatory Commission
ft	feet
FTE	full-time equivalent (jobs)

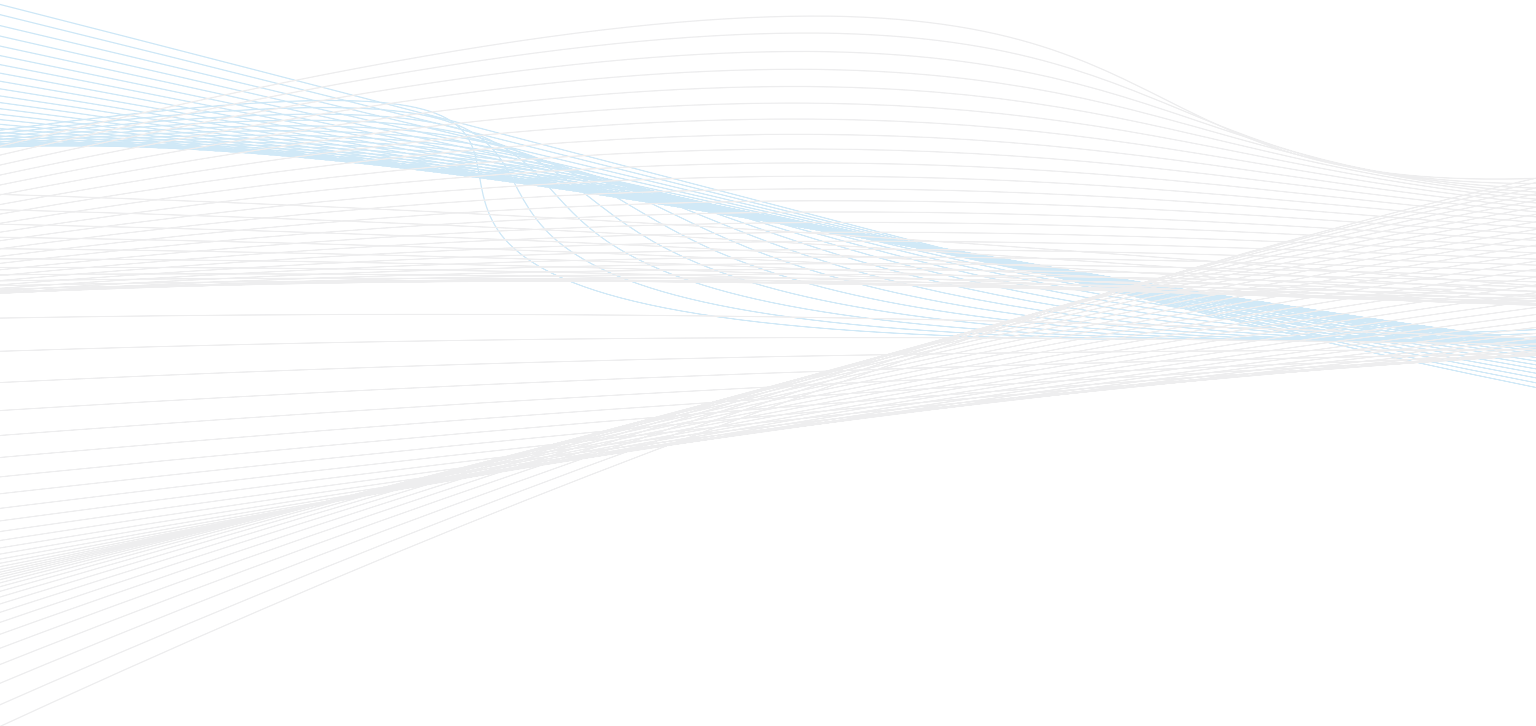
GAO	U.S. Government Accountability Office
GCC	grid connection cost
GCF	gross capacity factor
GHG	greenhouse gas
GW	gigawatt(s)
GWEC	Global Wind Energy Council
HCl	hydrogen chloride
HCP	Habitat Conservation Plan
HUC	Hydraulic Unit Code
HVDC	high-voltage direct-current
HVAC	high-voltage alternating current
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IGCC	integrated gasification combined cycle
I-O	input-output
IP	Interim Policy
ISO	independent system operator
ITC	investment tax credit
IVGTF	Integration of Variable Generation Task Force (of NERC)
IWG	Interagency Working Group (on Social Cost of Carbon)

JEDI	Jobs and Economic Development Impacts (model)
K	kindergarten
kg	kilogram(s)
km	kilometer(s)
kV	kilovolt(s)
kW	kilowatt(s)
kWh	kilowatt-hour(s)
lb	pound(s)
LBNL	Lawrence Berkeley National Laboratory
LCA	life-cycle assessment
LCOE	levelized cost of electricity
LWST	Low wind speed technology
MassCEC	Massachusetts Clean Energy Center
Metocean	meteorological and oceanographic
m	meter(s)
m/s	meters per second
MACRS	modified accelerated cost recovery system
MATS	Mercury and Air Toxics Standards
MBTA	Migratory Bird Treaty Act
MMBtu	million British thermal unit
MISO	Midcontinent Independent System Operator

MW	megawatt(s)
MWh	megawatt-hour
NEPA	National Environmental Policy Act
NERC	North American Electric Reliability Corporation
NGCC	natural gas–combined cycle
NGCCS	natural gas with carbon capture and storage
NGCT	natural gas-fired combustion turbine
NGO(s)	non-governmental organization(s)
NOAA	National Oceanic and Atmospheric Administration
NO_X	nitrogen oxides
NRC	National Research Council
NREL	National Renewable Energy Laboratory
NWTC	National Wind Technology Center
O&M	operations and maintenance
OCC	overnight capital cost
OCS	outer continental shelf
OEM	original equipment manufacturer
OPEX	operating expenses (or expenditures)
ORNL	Oak Ridge National Laboratory
OSW	offshore wind
PM	particulate matter (PM_{10} and $PM_{2.5}$)

PPA	power purchase agreement
PTC	production tax credit
PV	photovoltaic
R&D	research and development
REC(s)	renewable energy credit(s)
ReEDS	Regional Energy Deployment System (model)
RIA	Regulatory Impact Analysis
RPM	revolutions per minute
RPS	renewable portfolio standard
RTO(s)	regional transmission organization(s)
SAIC	Science Applications International Corporation
SCC	social cost of carbon
SO_2	sulfur dioxide
SolarDS	Solar Deployment System (model)
STEM	science, technology, engineering, and math
SWiFT	Scaled Wind Farm Technology
t	metric tonne
TES	thermal energy storage
TRG(s)	techno-resource group(s)
TSS	Traffic Separation Schemes
TWh	terawatt-hour(s); trillion kWh

UK	United Kingdom
UNEP	United Nations Environment Program
U.S.C.	United States Code
USCG	U.S. Coast Guard
USFWS	U.S. Fish and Wildlife Service
UVIG	Utility Variable-Generation Integration Group
WAC	watts alternating current
WDC	watts direct current
WACC	weighted average cost of capital
WEA	wind energy area (offshore)
WinDS	Wind Deployment System (now ReEDS)
WV	*Wind Vision*
WWPTO	Wind and Water Power Technologies Office (DOE)



Executive Summary: Overview

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

1. Documentation of the current state of wind power in the United States and identification of key technological accomplishments and societal benefits 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 conclusions of this collaborative effort, summarized below, demonstrate the important role that wind power has in the U.S. power sector and highlight its potential to continue to provide clean, reliable and affordable electricity to consumers for decades to come. The *Wind Vision* study does not evaluate nor recommend policy actions, but analyzes feasibility, costs, and benefits of increased wind power deployment to inform policy decisions at the federal, state, tribal, and local levels.

A High U.S. Wind Penetration Future is Achievable, Affordable and Beneficial

Wind power is one of the fastest-growing sources of new electricity capacity and the largest source of new renewable power generation added in the United States since 2000. Changes in wind power market dynamics, costs, technology, and deployment since the 2008 DOE report, *20% Wind Energy by 2030,* are documented through analysis of recent history, current status (as of 2013), and projected trends. The analysis of wind installation and operational experience as of 2013 concludes that:

- Wind deployment, including associated manufacturing and installation activities, has demonstrated the ability to scale to satisfy rapid build demands, including the deployment levels of the *Wind Vision Study Scenario* described below;
- 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.

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.

The *Wind Vision* report deepens the understanding of U.S. wind power's potential contributions to clean, reliable electricity generation and related economic and other societal benefits. Results are provided from analyses of U.S. greenhouse gas (GHG) and pollution reductions, electricity price impacts, job and manufacturing trends, and water and land use impacts—for the years 2020, 2030, and 2050. A high U.S. wind penetration is achievable but will require actions as identified in the *Wind Vision* Roadmap.

Study Summary

The *Wind Vision* report 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 *Wind Vision* report updates and expands upon the DOE's 2008 report, *20% Wind Energy by 2030,* through analysis of scenarios of wind power supplying 10% of national end-use electricity demand by 2020, 20% by 2030, and 35% by 2050. This *Study Scenario* provides a framework for conducting detailed quantitative impact analyses. The *Wind Vision* analysis concludes that it is both viable and economically compelling to deploy U.S. wind power generation in a portfolio of domestic, low-carbon, low-pollutant power generation solutions at the *Study Scenario* levels. Realizing these levels of deployment, however, would depend upon both immediate and long-term actions—principally identifying continued wind cost reductions, adding needed transmission capacity, and supporting and enhancing siting and permitting activities—to complement any federal, state, tribal, and local policies that may be enacted. Described in the *Wind Vision* Roadmap, these actions focus on specific key challenges and stakeholder actions that should be considered.

Analysis Overview

The *Wind Vision* analysis models three core scenarios in order to better understand the sensitivities in deployment to various external drivers and, subsequently, to understand the likely economic and environmental effects of those drivers on the scenarios; a *Baseline Scenario*, with U.S. wind capacity held constant at 2013 levels of 61 gigawatts (GW); a *Business-as-Usual Scenario* (*BAU*), and a *Study Scenario*. The *BAU Scenario* is used to evaluate the industry's domestic economic competitiveness today and into the future based on central expectations of future fossil fuel and renewable costs, energy demand, scheduled existing fleet retirements, and federal and state policies enacted as of January 1, 2014.

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. The *Study Scenario* is a plausible outcome, representing what could come about through a variety of pathways, including aggressive wind cost reductions, high fossil fuel costs, federal or state policy support, high demand growth, or different combinations of these factors. The resulting *Study Scenario*—10% by 2020, 20% by 2030, and 35% by 2050 wind energy as a share of national end-use electricity demand—is compared against the *Baseline Scenario* to estimate costs, benefits, and other impacts associated with potential future wind deployment.

National average wind costs are rapidly approaching cost competitive levels, but, without incentives, these costs are higher than the national average for natural gas and coal costs as of 2013. With continued cost reductions, the *Wind Vision* analysis envisions new wind power generation costs to be below national average costs for both new and existing fossil plants within the next decade.

The *Wind Vision* study concludes that with continued investments in technology innovation, coupled with a transmission system that can provide access to high resource sites and facilitate grid integration reliably and cost-effectively, the *Study Scenario* is an ambitious yet viable deployment scenario. Further, the analysis concluded that the U.S. wind supply chain has capacity to support *Study Scenario* wind deployment levels, with cumulative installations of 113 GW of generating capacity by 2020, 224 GW by 2030, and 404 GW by 2050, building from 61 GW installed as of the end of 2013.

Results: Overall Positive Benefit to the Nation

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

- An approximately 1% increase in electricity costs through 2030, shifting to long-term cost savings of 2% by 2050. This results in cumulative system cost savings of $149 billion by 2050.
- Cumulative benefits of $400 billion (net present value 2013-2050) 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 through 2050 for avoided emissions of fine particulate matter (PM), nitrogen oxides (NO_X), and sulfur dioxides (SO_2). Monetized criteria air pollutant benefits exceed the associated costs of the *Study Scenario*

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*Quantitative results presented in this Overview are based on the *Central Study Scenario*, defined on Page xxviii. Modeling analysis is based on current (as of 2013) and projected trend data to inform inputs, assumptions, and other constraints. Financial results are reported in 2013$ except where otherwise noted.

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 through 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 870 miles per year, 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 contiguous U.S. land area in 2050.

The *Study Scenario* also identifies certain other impacts, such as those to wildlife and local communities. It does not, however, monetize these impacts, which are highly dependent on specific locational factors.

Roadmap for Key Stakeholder Actions

The *Wind Vision* analysis concludes that, while the *Study Scenario* is technically viable and economically attractive over the long run, a number of stakeholder actions should be considered to achieve the associated wind deployment levels. Improving wind's competitive position in the market can help the nation maintain its existing wind manufacturing infrastructure and the wide range of public benefits detailed in the *Wind Vision*, including reducing carbon emissions. The *Wind Vision report* outlines a roadmap for moving forward and identifies the following key activities, developed collaboratively with industry and stakeholders:

- Reducing wind power costs;
- Expanding the developable areas for wind power; and
- Deploying wind in ways that increase economic value for the nation, including support for U.S. jobs and U.S. manufacturing.

Wind cost reductions do not depend on disruptive technological breakthroughs, but do rely on continued cost improvements, including rotor scale-up; taller towers to access higher wind speeds; overall plant efficiency improvements achieved through advanced controls; improved plant designs enabled by deepened understanding of atmospheric physics; installation of both intra-region and inter-region transmission capacity to high quality wind resource locations; and collaboration and co-existence strategies for local communities and wildlife that support the timely and cost-effective installation of wind power plants.

Risk of Inaction

Wind's growth over the decade leading to 2014 has been driven largely by wind technology cost reductions and federal and state policy support. Without actions to support wind's competitive position in the market going forward, the nation risks losing its existing wind manufacturing infrastructure and much of the public benefit illustrated by the *Wind Vision* analysis.

Conclusions

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 towards a low-carbon U.S. 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.

The *Study Scenario* results in cumulative savings, benefits, and an array of additional impacts by 2050.

System Costs[a]	Benefits[b,c]		
$	GHG	Air Pollution	H_2O
$149 billion (3%) lower cumulative electric sector expenditures	14% reduction in cumulative GHG emissions (12.3 gigatonnes CO_2-equivalents), saving $400 billion in avoided global damages	$108 billion savings in avoided mortality, morbidity, and economic damages from cumulative reductions in emissions of SO_2, NO_X, and PM 21,700 premature deaths from air pollution avoided	23% less water consumption and 15% less water withdrawals for the electric power sector

Additional Impacts

Energy Diversity	Jobs	Local Revenues	Land Use	Public Acceptance and Wildlife
Increased wind power adds fuel diversity, making the overall electric sector 20% less sensitive to changes in fossil fuel costs. The predictable, long-term costs of wind power create downward price pressure on fossil fuels that can cumulatively save consumers $280 billion from lower natural gas prices outside the electric sector.	Approximately 600,000 wind-related gross jobs spread across the nation.	$1 billion in annual land lease payments $440 million annual lease payments for offshore wind plants More than $3 billion in annual property tax payments	Less than 1.5% (106,000 km²) of contiguous U.S. land area occupied by wind power plants Less than 0.04% (3,300 km²) of contiguous U.S. land area impacted by turbine pads, roads, and other associated infrastructure	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

Note: Cumulative costs and benefits are reported on a Net Present Value basis for the period of 2013 through 2050 and reflect the difference in impacts between the *Central Study Scenario* and the *Baseline Scenario*. Results reported here reflect central estimates within a range; see Chapter 3 for additional detail. Financial results are reported in 2013$ except where otherwise noted.

a. Electric sector expenditures include capital, fuel, and operations and maintenance for transmission and generation of all technologies modeled, but excludes consideration of estimated benefits (e.g., GHG emissions).

b. Morbidity is the incidence of disease or rate of sickness in a population.

c. Water consumption refers to water that is used and not returned to the source. Water withdrawals are eventually returned to the water source.

Executive Summary: Key Chapter Findings

ES.1 Introduction

Wind power is one of the fastest-growing sources of new electricity supply and the largest source of new renewable power generation added in the United States since 2000. Wind power generation in the United States has tripled, increasing from 1.5% of annual electricity end-use demand in 2008 to 4.5% through 2013. As of 2013, there were more than 61 gigawatts (GW) of wind generating capacity installed, and electric system operators and utilities throughout the country routinely consider wind power as part of a diverse electricity generation portfolio. Interest in wind power is stimulated by its abundant resource potential (more than 10 times current electricity demand); competitive, long-term stable pricing; economic development potential; and environmental attributes, including its ability to support reduced carbon emissions, improved air quality, and reduced water use.

At the same time, low natural gas prices, low wholesale electricity prices, and reduced demand for electricity since 2008 are impacting investments for all new electric generation. Annual U.S. wind capacity additions have varied dramatically as a function of these factors as well as trends in wind power costs and policy.

In this context, DOE initiated the *Wind Vision* analysis. Led by the Wind and Water Power Technologies Office in DOE's Office of Energy Efficiency and Renewable Energy, the collaboration that resulted in the *Wind Vision* represents more than 250 energy experts with an array of specialties and includes grid operators, the wind industry, science-based organizations, academia, governmental agencies, and environmental stewardship organizations. The *Wind Vision* serves as an update and significant expansion of an earlier DOE report, *20% Wind Energy by 2030.*[1]

At its core, the *Wind Vision* is intended to inform a broad set of stakeholders—including the industry, policymakers, and the public—on the implications of continued U.S. wind deployment. The analysis conducted does not result in a prediction or forecast of the future, but instead assesses the incremental costs associated with the deployment of wind power as a major part of the nation's energy future, and compares these costs to the value of the resulting benefits. One of the greatest challenges for the 21st century will be bringing affordable, secure, clean energy to the world. This report considers the contribution of U.S. wind power in resolving that challenge.

ES.1.1 Project Perspective and Approach

In 2008, DOE evaluated the technical feasibility of a scenario in which 20% of the nation's annual electricity consumption was served by wind power in 2030. The resulting report, *20% Wind Energy by 2030,* concluded that the U.S. power system could support a 20% wind penetration scenario with an increase in electric sector expenditures of 2% over the time frame of the study (2008–2030), relative to a future with no new wind. The report also identified key activities to be addressed, including expanding transmission infrastructure, reducing the cost of wind power, integrating wind reliably into the bulk power system, and addressing potential concerns related to siting and permitting of wind plants. Since the release of *20% Wind Energy by 2030,* wind power's installed capacity has increased by a factor of three. As of 2013, annual installations have surpassed the initial levels envisioned in the 20% scenario and progress has been made across the challenges that were identified. The *Wind Vision* documents the industry's progress since the 2008 report, leveraging the past to inform future opportunities.

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[1] *20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply.* U.S. Department of Energy. Washington, DC: DOE, 2008. Accessed Feb. 4, 2015: *http://energy.gov/eere/wind/20-wind-energy-2030-increasing-wind-energys-contribution-us-electricity-supply*.

Analytical Framework of the *Wind Vision*

Wind Vision Study Scenario	The *Wind Vision Study Scenario,* or *Study Scenario*, applies a trajectory 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 prescribe 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: Percentages characterize wind's contribution to the electric sector as a share of end-use electricity demand (net wind generation divided by consumer electricity demand).

The *Wind Vision* analysis also seeks to provide better understanding of the future potential of wind power and quantify the costs and benefits of continued investment in wind power. The analysis, modeling inputs, and conclusions presented are based on the best available information from the fields of science, technology, economics, finance, and engineering, and include the historical experience gained from industry growth and maturation in the decade leading up to 2014.

Finally, the *Wind Vision* is action-oriented. It examines the continued development and use of wind power in the United States. The *Wind Vision* roadmap identifies key challenges and the means by which they might be resolved. Priorities aim at positioning wind power to support the continued transformation of the nation's electric power sector.

Although policy is a key variable that is expected to impact the future of wind power in the United States, no policy recommendations are included in the *Wind Vision.* Such recommendations are outside the scope of the current effort. Nonetheless, the *Wind Vision,* and in particular the assessment of costs and benefits, is intended to facilitate informed discussions among diverse stakeholder groups regarding the future of wind power within the electric power sector of the United States. Points of emphasis in the *Wind Vision* analysis are divided into three discrete time-scales: near-term (2020), mid-term (2030), and long-term (2050).

The primary analysis of the *Wind Vision* centers on a future scenario in which wind energy serves 10% of the nation's end-use demand by 2020, 20% by 2030, and 35% by 2050. This scenario, called the *Wind Vision Study Scenario,* was identified as an ambitious but credible scenario after conducting a series of exploratory scenario modeling runs under *Business-as-Usual* conditions. In order to quantify the costs, benefits, and other impacts of future wind deployment, the outcomes of the *Study Scenario* are compared against those of a reference *Baseline Scenario* that fixes installed wind capacity at year-end 2013 levels of 61 GW. The *Baseline Scenario* and *Study Scenario* are not goals or future projections of wind power. Rather they comprise an analytical framework that supports detailed analysis of potential costs, benefits, and other impacts associated with future wind deployment. These three scenarios—*Study Scenario, Baseline Scenario, and Business-as-Usual Scenario*—are summarized above and constitute the primary analytical framework of the *Wind Vision.*

The *Wind Vision* analysis conducts an assessment of future wind power growth projections using a "Business-as-Usual" framework and sensitivities on key variables such as wind power costs, fossil fuel prices, and electricity demand to understand the opportunities for wind (presented in Chapter 1 of the *Wind Vision* report). This evaluation assists in identifying a credible scenario for further analysis of costs and benefits and in highlighting specific future actions that could support continued wind growth, including continued cost reductions.

ES.1.2 Understanding the Future Potential for Wind Power

In order to structure a model to consider the future potential for wind power, the *Wind Vision* starts with *Business-as-Usual,* or *BAU*, conditions. Analysis was performed using the National Renewable Energy Laboratory's Regional Energy Deployment System[2] (ReEDS) capacity expansion model and other supporting models and analyses. The ReEDS model relies on system-wide least-cost optimization to estimate the type and location of fossil, nuclear, renewable, and storage resource development; the transmission infrastructure expansion requirements of those installations; and the generator dispatch and fuel needed

Table ES.1-1. Modeling Inputs and Assumptions in *Business-as-Usual Scenario* Modeling[3,4,5]

Modeling Variables	*Business-as-Usual (BAU) Scenario*	Sensitivity Variables
Electricity demand	AEO 2014 Reference Case (annual electric demand growth rate 0.7%)	1: AEO 2014 High Economic Growth Case (annual electric demand growth rate 1.5%) 2: AEO 2014 Low Economic Growth Case (annual electric demand growth rate 0.5%)
Fossil fuel prices	AEO 2014 Reference Case	1: Low Oil and Gas Resource and High Coal Cost cases (AEO 2014) 2: High Oil and Gas Resource and Low Coal Cost cases (AEO 2014)
Fossil technology and nuclear power costs	AEO 2014 Reference Case	None
Wind power costs	Median 2013 costs, with cost reductions in future years derived from literature review	1: Low costs: median 2013 costs and maximum annual cost reductions reported in literature 2: High costs: constant wind costs from 2014–2050
Other renewable power costs	Literature-based central 2013 estimate and future cost characterization	None
Policy	Policies as current and legislated on January 1, 2014	None
Transmission expansion	Pre-2020 expansion limited to planned lines; post-2020, economic expansion, based on transmission line costs from Eastern Interconnection Planning Collaborative	None

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[2] The Regional Energy Deployment System (ReEDS) is a long-term capacity-expansion model for the deployment of electric power generation technologies and transmission infrastructure throughout the contiguous United States. ReEDS is designed to analyze critical issues in the electric sector, especially with respect to potential energy policies, such as clean energy and renewable energy standards or carbon restrictions. See *http://www.nrel.gov/analysis/reeds/* for more information.

[3] *Annual Energy Outlook 2014.* DOE/EIA-0383(2014). Washington, DC: U.S. Department of Energy, Energy Information Administration, 2014. Accessed Dec. 14, 2014: *http://www.eia.gov/forecasts/aeo/*.

[4] *Phase 2 Report: DOE Draft—Parts 2–7, Interregional Transmission Development and Analysis for Three Stakeholder Selected Scenarios.* Work performed by Eastern Interconnect Planning Collaboration under contract DE-OE0000343. Washington, DC: U.S. Department of Energy, December 2012. Accessed Feb. 4, 2015: *http://www.eipconline.com/Phase_II_Documents.html*.

[5] *Electric Power Monthly.* U.S. Department of Energy, Energy Information Administration, 2014. Accessed Dec. 14, 2014: *www.eia.gov/electricity/monthly/*.

to satisfy regional demand requirements and maintain grid system adequacy. The model also considers technology, resource, and policy constraints.

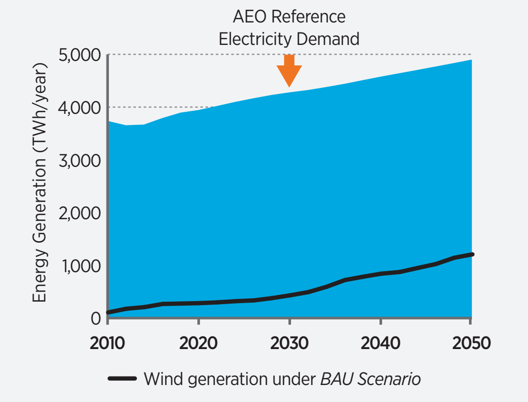
***BAU* conditions assume a future scenario under enacted federal and state policies as of January 1, 2014. Modeling inputs were extracted from the published literature as well as the DOE Energy Information Administration's Annual Energy Outlook (AEO) 2014.** Literature sources were used to develop future projections of renewable power cost and performance. The AEO was the source for fossil and nuclear technology cost and performance projections, as well as the source for fuel prices and electricity load growth projections. The sources of modeling inputs are summarized in Table ES.1-1.

***BAU* conditions indicate that growth in wind generation and capacity will be limited through 2030 (Figure ES.1-1), with more robust growth occurring between 2030 and 2050.** Wind generation is projected to settle at about 7% of total electricity demand in 2016 after projects currently under construction (and qualifying for the federal production tax credit) are placed into service. *BAU* modeling projects minimal further growth to 10% by 2030. For the period 2015–2030, average annual new capacity additions are estimated at 3 GW/year, substantially below recent (as of 2013) capacity additions. Negative impacts to the wind industry manufacturing sector and employment would be expected under *BAU.* After 2030, however, wind becomes more competitive as a result of continued cost improvements, projected increases in fossil fuel prices, and increased demand for new power generation. As a share of total U.S. electricity demand, wind power reaches 25% in 2050 under the *BAU Scenario,* with average annual new capacity additions from 2031 to 2050 corresponding generally to historical levels of capacity additions between 2009 and 2013.

Analysis results are informed by an array of sensitivities with market conditions that are unfavorable to wind. These conditions were developed to understand wind growth assuming no further cost reductions, AEO 2014 low coal and natural gas prices, and AEO 2014 low electricity demand growth. An array of factors could shift growth in wind capacity and generation even later in the study period (e.g., after 2040), such as continued low fossil fuel prices and no further reductions in wind power costs.

Other factors and market conditions, however, such as low wind power costs, high fossil fuel prices, or high electricity demand can accelerate future wind growth and drive wind penetration (as a share of total U.S. electricity demand) (Figure ES.1-2). In combination, low wind power costs and high fossil fuel prices support wind generation levels approaching 10% by 2020, 25% by 2030, and 40% by 2050.

Under *BAU Scenario* conditions, wind stagnates and annual installations fall to levels 50% or more below the latest five-year average.



Historical and Average New Wind Capacity Additions Under *BAU Scenario*

Period	GW/year	% End-Use Electricity Demand
2009–2013 (actual)	7	4.5%
2014–2020	4	7%
2021–2030	3	10%
2031–2050	8	25%

Note: The *BAU Scenario* assumes AEO Reference Case fuel costs, AEO Reference Case electricity demand, median values for renewable energy costs derived from literature, and policy as current and legislated on January 1, 2014. Percentage of end-use electricity demand data are contributions as of the end of the indicated period (e.g., 2009–2013).

Figure ES.1-1. Wind generation and average new capacity additions under *BAU*

The *Study Scenario* falls within the range of economic sensitivities on the *BAU Scenario.*

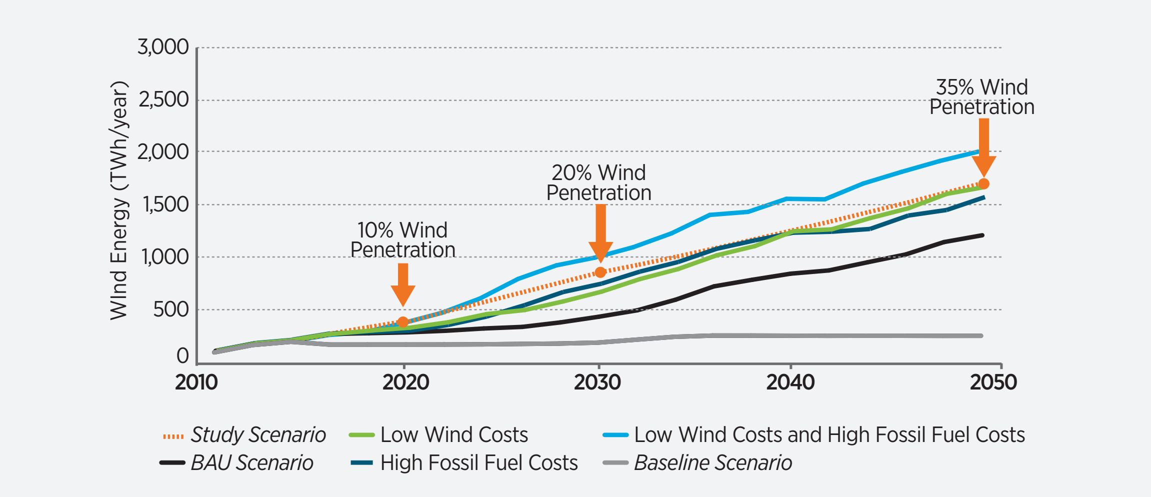


Figure ES.1-2. *Wind Vision Study Scenario* relative to *BAU* and sensitivities[6]

Analysis results are informed by an array of sensitivities with conditions that are favorable to wind. These conditions were developed to understand wind growth assuming aggressive wind cost reductions, AEO 2014 high coal and natural gas prices, and AEO 2014 high demand growth (Figure ES.1-2). When imposed independently, changes in these variables support levels of new wind capacity additions that are comparable to recent historical levels (e.g., 7 GW/year from 2009 to 2013) in the near-term (2020) and in excess of historical levels from 2030 to 2050. In combination, these variables can support levels of new wind growth on the order of 10–15 GW/year throughout the period of analysis.

At the core of the *Wind Vision* analysis is an assessment of costs, benefits, and other impacts from continued wind deployment. Evaluation of costs and benefits requires the development of a future scenario, identified as the *Wind Vision Study Scenario* (or *Study Scenario*), and a reference case, identified as the *Baseline Scenario.* The *Study Scenario* is grounded in the range of credible scenarios examined in the *BAU* and related sensitivity analyses, with specific bounds based on aggressive wind power cost reduction, high fossil fuel prices, or a combination of both. This approach illuminates key opportunities and challenges associated with continued wind power growth, and compares them against an array of environmental and other benefits associated with the scenarios.

ES.1.3 Defining a Credible Scenario to Calculate Costs, Benefits, and Other Impacts

Drawing from the analysis described in Section ES.1.2, the *Wind Vision Study Scenario* was identified as a credible scenario that extends current wind deployment trends, leverages the existing domestic wind industry manufacturing base, and complements the broader literature. In the near-term (2020), the wind deployment in the *Study Scenario* is consistent with the growth found with aggressive wind cost reductions and relatively high fossil fuel prices. It also extends recent (as of 2013) deployment trends and maintains the existing domestic manufacturing base. In the mid-term (2030), the *Study Scenario* falls between modeled wind generation under aggressive cost reductions or aggressive cost

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[6] See Analytical Framework of the *Wind Vision* at the beginning of the Executive Summary for a brief description of the *Wind Vision Study* scenarios analyzed.

Table ES.1-2. Wind Penetration (% share of end-use demand) in *BAU Scenario, BAU Sensitivities,* and the *Study Scenario*[7]

Year	*BAU Scenario*	*BAU* Sensitivities			*Study Scenario*
		High Fossil Fuel Costs	Low Wind Costs	High Fossil Fuel Costs and Low Wind Costs	
2013 (actual)	4.5%	4.5%	4.5%	4.5%	**4.5%**
2020	7%	7%	8%	10%	**10%**
2030	10%	17%	16%	24%	**20%**
2050	25%	32%	34%	41%	**35%**

Note: Percentages characterize wind's contribution to the electric sector as a share of end-use electricity demand (net wind generation divided by consumer electricity demand).

reductions coupled to high fossil fuel prices, while continuing to build from the existing manufacturing base and maintaining consistency with the 2008 study. In the long-term (2050), the *Study Scenario* is grounded by modeled results under low wind costs—i.e., land-based wind levelized cost of electricity (LCOE) reduction of 24% by 2020, 33% by 2030, and 37% by 2050; and offshore wind LCOE reduction of 22% by 2020, 43% by 2030, 51% by 2050 (Figure ES.1-2 and Table ES.1-2.).

The *Study Scenario* is represented by wind power penetration levels, as a share of total U.S. electricity demand, of 10% by 2020, 20% by 2030, and 35% by 2050. Sensitivity analyses within the *Study Scenario,* maintaining the same wind penetration levels, are used to assess the robustness of key results and highlight the impacts of varying wind power costs and fossil fuel prices. In the *Wind Vision,* many of the results emphasize outcomes across the full range of sensitivities; however, the Executive Summary primarily presents impacts for a single *Central* case. The *Central* case, or *Central Study Scenario,* applies common inputs with the *BAU Scenario* for technology cost and performance, fuel pricing, and policy treatment, but is distinguished from that scenario by its reliance on the prescribed *Study Scenario* trajectory (10% wind penetration by 2020, 20% by 2030, and 35% by 2050).

***The Study Scenario* trajectory falls within the range of credible future scenarios, identified in *BAU* and the sensitivity analyses described earlier and illustrated in Figure ES.1-2**. The *Study Scenario* seeks to understand the implications of maintaining consistency with U.S. wind installation trends and performance as well as domestic manufacturing, and leverages up-to-date insights into grid integration management and transmission capacity. Distributed wind applications[8] are not explicitly represented but are considered as part of the broader land-based capacity associated with the *Study Scenario.*

Although U.S. wind generation as of 2013 was entirely land-based, the *Wind Vision* analysis recognizes that offshore wind reached 6.5 GW globally in 2013 and an array of offshore projects in the United States are advancing through the development process. The *Study Scenario* includes explicit allocations for land-based and offshore wind (Figure ES.1-3). Near-term (through 2020) offshore contributions are estimated based on projects in advanced stages of development in the United States and on global

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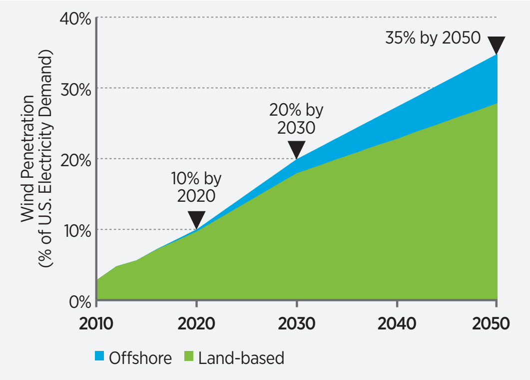
[7] See Analytical Framework of the *Wind Vision* at the beginning of the Executive Summary for a brief description of the *Wind Vision Study* scenarios analyzed.

[8] Distributed wind applications refer to wind power plants or turbines that are connected either physically or virtually on the customer side of the meter.

The *Study Scenario* consists of 10% wind generation by 2020, 20% by 2030, and 35% by 2050 compared against the *Baseline Scenario*.



Cumulative Wind Capacity (GW)		2013	2020	2030	2050
Baseline Scenario	Land-based	61			
Central Study Scenario	Land-based	61	110	202	318
	Offshore	0	3	22	86
	Total	**61**	**113**	**224**	**404**

Note: Wind capacities reported here are modeled outcomes based on the *Study Scenario* percentage wind trajectory. Results assume central technology performance characteristics. Better wind plant performance would result in fewer megawatts required to achieve the specified wind percentage, while lower plant performance would require more megawatts.

Figure ES.1-3. The *Wind Vision Study Scenario* and *Baseline Scenario*

offshore wind technology innovation projections identified in the literature. Longer-term (post-2020) contributions are based on literature projections for global growth and assume continued U.S. growth in offshore, whereby offshore wind provides 2% of U.S. electricity demand in 2030 and 7% in 2050.

Impacts from the *Study Scenario* are compared to a *Baseline Scenario* in which wind capacity is fixed at 2013 levels. The key design feature that distinguishes these scenarios is the level of wind deployment (i.e., 2013 capacity levels in the *Baseline Scenario* and respective wind capacity in the *Study Scenario* that corresponds to the trajectory of 10% wind penetration by 2020, 20% by 2030, and 35% by 2050). Resulting differences in outcomes based on this design feature (e.g., transmission expansion, electricity prices, fossil generation) are evaluated and attributed specifically to wind power deployment. Comparison with the *Baseline Scenario* enables an estimation of the incremental impact of all future (post-2013) wind deployment, including the economic and social benefits of wind.

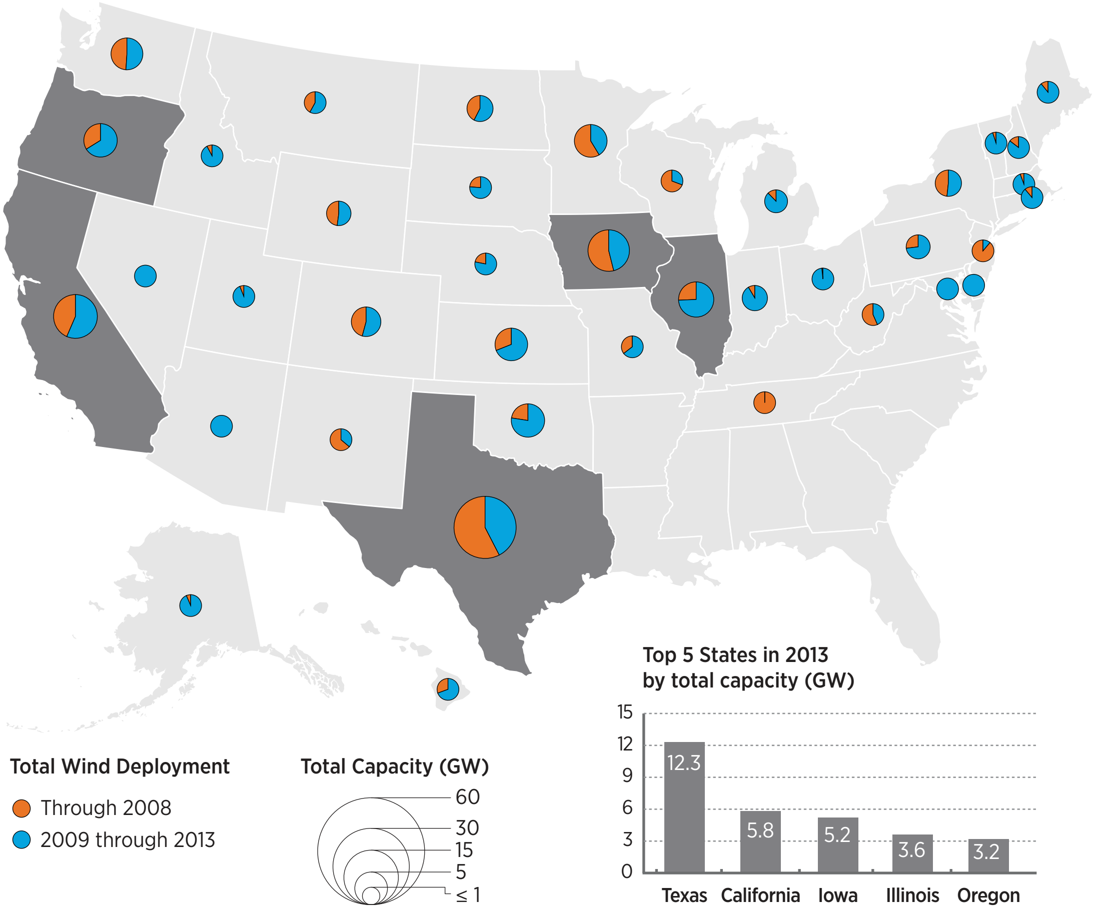
ES.2 State of the Wind Industry: Recent Progress, Status and Emerging Trends

Wind power is becoming a mainstream power source in the U.S. electricity portfolio, supplying 4.5% of the nation's electricity demand in 2013. Since the 2008 publication of the DOE report, *20% Wind Energy by 2030,* the industry has scaled its domestic manufacturing capacity and has driven down wind power costs by more than one-third. A review of these industry developments is summarized in Chapter 2, and these insights were used to inform the modeling inputs and assumptions of the *Study Scenario.*

With more than 61 GW installed across 39 states at the end of 2013, utility-scale wind power is a cost-effective source of low-emissions power generation in those regions where substantial wind potential exists. From 2008 to 2013, wind power installations expanded in geographic deployment and cumulative capacity (Figure ES.2-1), with corresponding growth in the domestic supply chain. Arizona, Delaware, Maryland and Nevada each added their first utility-scale wind projects between 2008 and 2013.

Wind power costs have declined by more than one-third since 2008 and the U.S. manufacturing base

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 ES.2-1. Utility-scale wind deployment through 2013

In several aspects, the wind industry has made progress since 2008 exceeding expectations from the DOE Report, *20% Wind Energy by 2030.*

	2008 Actuals	2013 Model Results Detailed in the 2008 Report, *20% Wind Energy by 2030*	2013 Actuals
Cumulative Installed Wind Capacity (GW)	25	48	61
States with Utility-Scale Wind Deployment	29	35	39
Costs (2013\$/MWh)[a]	71	66	45

a. Estimated average levelized cost of electricity in good to excellent wind resource sites (typically those with average wind speeds of 7.5 m/s or higher at hub height) and excluding the federal production tax credit

Figure ES.2-2. Wind power progress since the 2008 DOE Report, *20% Wind Energy by 2030*

has expanded to support annual deployment levels growth—from 2 GW/year in 2006, to 8 GW/year in 2008, to peak installations of 13 GW/year in 2012. While the *20% Wind Scenario* from the 2008 report was not a projection for the future, the growth of wind power since 2008 exceeded the assumptions made in that report. Figure ES.2-2 lists a comparison of historical data from 2008, the 2013 outcomes in the 2008 *20% Wind Scenario,* and actual 2013 wind power statistics. The noted updates in wind power costs and supply chain capacity were used to inform the feasibility of the *Study Scenario.*

ES.2.1 Wind Power Markets and Economics

In the United States, new investments in wind plants averaged \$13 billion/year between 2008 and 2013.[9] Global investment in wind power grew from \$14 billion in 2004 to \$80 billion in 2013, a compound annual growth rate of 21%. Although impacted by policy uncertainty and associated variability in demand, domestically manufactured content for large turbine components has increased. Domestic nacelle assembly capacity, for example, is estimated at 10 GW/year.

The combined import share of wind equipment tracked by trade codes (i.e., blades, towers, generators, gearboxes, and complete nacelles), as a fraction of total equipment-related turbine costs, declined from approximately 80% in 2006–2007 to 30% in 2012–2013. Though not all equipment is tracked, domestic content for some large, key components, such as blades and towers, ranged between 50% and 80% in 2012. Domestic content for nacelle components was significantly lower. The share of wind turbine project costs (including non-turbine equipment project costs that were sourced domestically) was approximately 60% in 2012. In 2013, the wind supply chain included more than 560 facilities across 43 states. Given the transport and logistics challenges of moving large wind turbine components over long distances, continued U.S. manufacturing and supply chain vitality is expected to be at least partially coupled to future levels of domestic demand for wind equipment. Recent fluctuations in demand and market uncertainty have forced some manufacturing facilities to furlough employees and others to cease operations altogether.

The LCOE from wind in good to excellent resource sites declined by more than one-third from 2008 to 2013, falling from \$71/megawatt-hour (MWh) to

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[9] Unless otherwise specified, all financial results reported are in 2013\$.

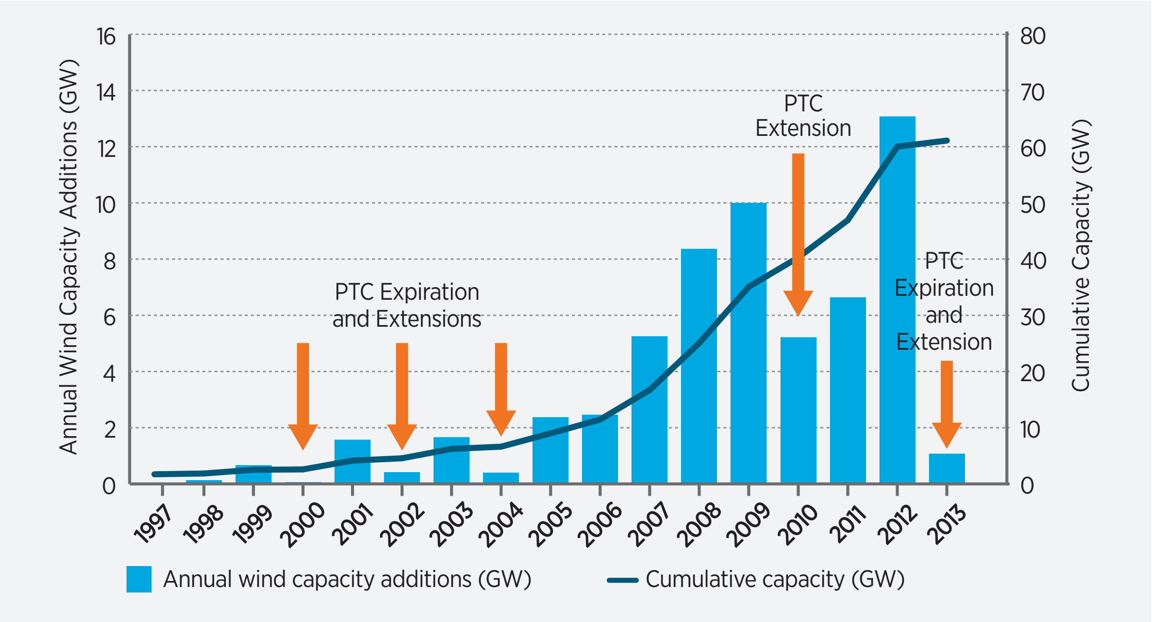
$45/MWh (Figure ES.2-2). In some markets with excellent wind resource and transmission availability, wind power sales prices are competitive with fossil generation, but significant variations are seen in the LCOE of individual wind projects. The LCOE for wind is influenced by the quality of the wind resource and access to transmission, as well as by capital and balance of system costs, plant performance and productivity, operations and maintenance (O&M) costs, and financing costs. Incentives and policies also have significant effects on power purchase agreement prices. In some regions of the country, especially those with state tax incentives, wind power prices are competitive with wholesale power prices and other new sources of generation.

Low natural gas market prices and their subsequent impacts on wholesale electricity prices, along with overall low energy growth since 2008 and a lack of long-term federal policy stability, have influenced recent levels of wind power deployment. Natural gas generation comprised 30% of end-use electricity demand in 2013, compared with 24% in 2008 and a peak of 33% in 2012. Low natural gas prices exerted downward pressure on wholesale power prices in recent years preceding 2013. Over the same period of time, electricity demand has remained relatively constant as a result of the combination of the economic recession and recovery, and improved energy efficiency. Despite these trends, robust wind deployment in the United States since 2008 has been driven by substantial advancements in wind technology and cost reductions, coupled with continued state and federal policy support. At the same time, prior expirations of federal incentives have created a boom-bust cycle for wind power (Figure ES.2-3). Because of electricity market conditions and the latest expiration of the federal production tax credit (PTC), this robust growth is not projected to continue.

ES.2.2 National Social and Economic Impacts of Wind

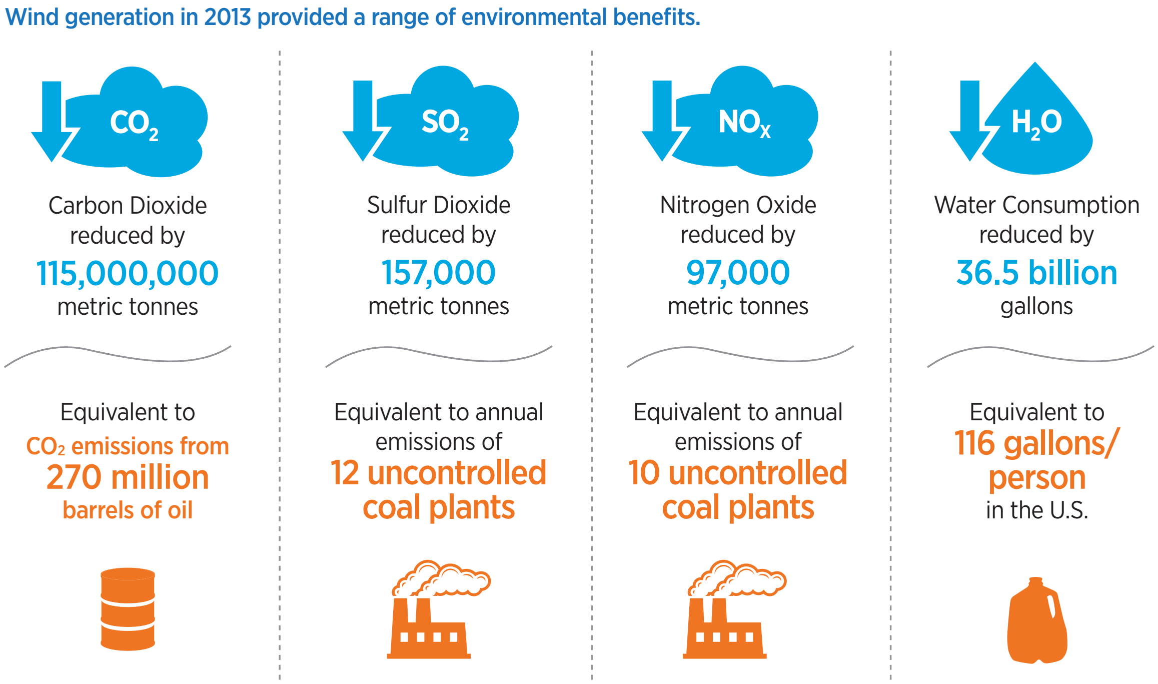
Local economic impacts of wind power are derived from temporary and permanent employment in construction, engineering, transportation, manufacturing, and operations; local economic activity resulting from wind construction; and increased revenues from land lease payments and tax revenue. A study of economic development impacts for wind power installations between 2000 and 2008 found

Policy uncertainty has resulted in fluctuations in historical wind deployment.



On January 1, 2014, the PTC expired again and lapsed for more than 11 months. In early December 2014, the PTC was extended again, but was valid only through year-end 2014.

Figure ES.2-3. Historical wind deployment variability and the PTC



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 ES.2-4. Estimated emissions and water savings resulting from wind generation in 2013[10]

that total county personal income was 0.2% higher and employment 0.4% higher in counties with installed wind power, relative to those without wind power installations. Another study on four rural counties in west Texas found cumulative economic activity resulting from wind investments in local communities to be nearly $520,000 (2011$) per MW of installed capacity over the 20-year lifetime of the wind plant. In 2013, an estimated total of more than 50,000 onsite and supply chain jobs were supported nationally by wind investments**.**

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 nitrous oxides (NO_X). Wind power is already reducing these emissions from the power sector (Figure ES.2-4). Future wind deployment levels will affect the magnitude of these benefits.

ES.2.3 Wind Technology, Manufacturing, and Logistics

Continued advancements and scale-up of turbine technology have helped reduce wind power costs and enable broader geographic deployment of wind power. Significant effort has been applied to improve performance and reliability of individual wind turbines. These improvements have included design of longer blades and taller towers (Figure ES.2-5), developments in innovative drive train designs, and increased use of improved controls and sensors that collectively capture energy from the wind more cost effectively. Wind technology improvements have made lower wind speed sites more economically viable, even in regions previously thought to have little or no wind potential. In 2013, wind project development was underway in nearly every U.S. state and the focus of innovation was shifting from individual turbine performance to overall plant performance characteristics, which will continue to drive down wind electricity generation costs.

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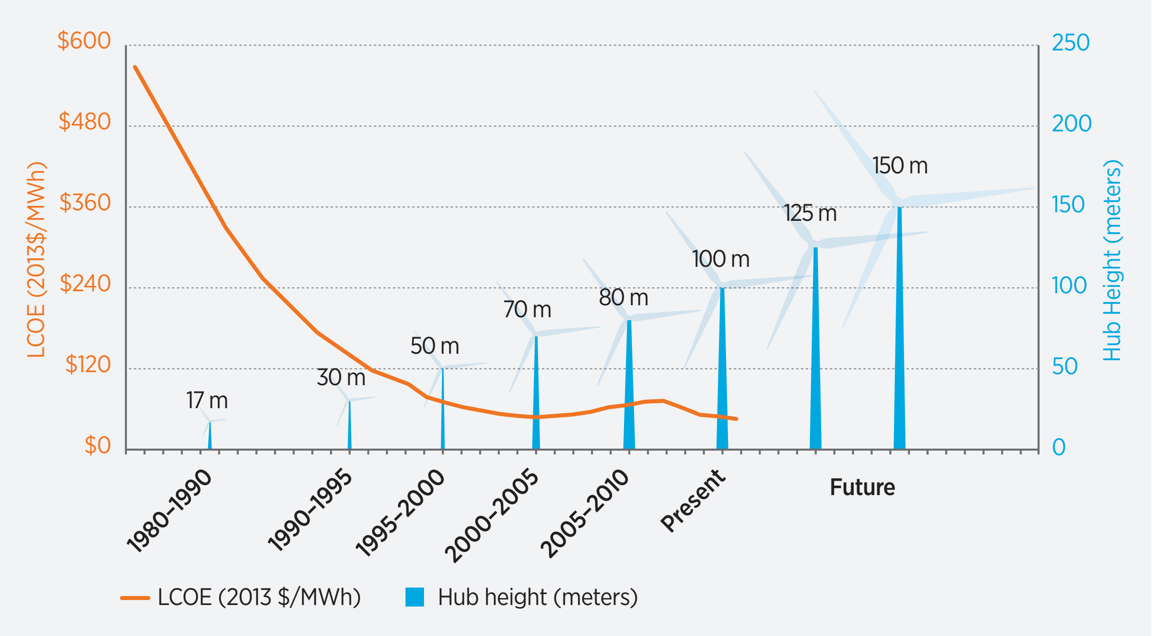
[10] The Clean Air Benefits of Wind Energy. Washington, DC: American Wind Energy Association. Accessed February 3, 2015: *http://www.awea.org/Advocacy/Content.aspx?ItemNumber=5552.*

Scale-up of wind technology has supported cost reductions.



Note: LCOE is estimated in good to excellent wind resource sites (typically those with average wind speeds of 7.5 m/s or higher), excluding the federal production tax credit. Hub heights reflect typical turbine model size for the time period.

Figure ES.2-5. Wind technology scale-up trends and the levelized cost of electricity

Technology advancements now center on complementing larger wind turbines with enhanced siting strategies and advanced control systems for arrays of wind turbines. A better understanding of wind resources and continued technology developments are leading trends in improved performance, increased reliability, and reduced cost of wind electricity. As turbine technology advances and components like blades and towers increase in size, transportation costs could increase and manufacturing may become more complex. The industry is working to balance costs and benefits, with innovative transport solutions across the supply chain. Continued innovation in turbine design, manufacturing, transportation, and construction can allow industry to address logistical barriers for the next generation of larger wind turbines.

Domestic manufacturing could continue to expand, provided domestic demand remains stable. Domestic wind components and skilled labor requirements will continue to be dependent on near-term domestic demand. Lack of stable domestic demand for wind power could reverse the trend of higher domestic content in wind turbine manufacturing.

ES.2.4 Wind Integration and Delivery

Large amounts of wind power are reliably and effectively integrated into the electric power system. Wind power contributed 4.5% of U.S. electricity demand and 3.2% of global electricity demand through 2013; two states, Iowa and South Dakota, exceeded 25% of in-state generation from wind in 2013; and seven other states operated with greater than 12% of their annual electricity generation from wind (Colorado, Idaho, Kansas, Minnesota, North Dakota, Oklahoma, and Oregon). Power system operators who have experience with wind now view its use routinely as a dependable component in the portfolio of generating options. Wind power has been successfully integrated into the power system and can contribute to grid management services in flexible power systems. Improved wind forecasting, wind plant controls, and expanding the geographical area for reserve sharing and demand response have all contributed to increased power system flexibility.

Many potential sites with high quality wind energy resources have minimal or no access to electrical transmission facilities. This creates a bottleneck to cost-effective wind deployment. Various efforts have yielded progress nationally on overcoming transmission barriers. For example, the Competitive Renewable Energy Zones Plan in Texas enabled transmission expansion to connect wind-rich resources in the Texas Panhandle to population centers in the central and eastern regions of the state. Prior to the Competitive Renewable Energy Zones Plan, 7 GW of wind power were operating within Texas. By early 2014, interconnection agreements had been signed for proposed projects totaling an additional 7 GW, and applications had been submitted for 24 GW of wind power. Dedicated efforts like those In Texas could be a model for transmission expansion in other regions of the country.

ES.2.5 Wind Deployment: Siting, Regulation, and Collaboration

Extensive experience and focused research have shown that adverse impacts to wildlife and local communities resulting from wind deployment need to be managed through careful siting, thoughtful public engagement, and mitigation strategies. Emphasis is now on optimizing co-existence, addressing community and regulatory concerns in the development process, and using mutually agreed-upon strategies to reduce or eliminate potential negative impacts, all while supporting responsible wind power deployment. Siting concerns are being addressed by on-going research. One example of this work is a 2014 DOE study produced by Lawrence Berkeley National Laboratory. Findings from this study indicate no statistical impact on home property values near wind facilities. Another example is a recent American Wind Wildlife Institute study that provides the most recent assessment of the avian mortality impact of wind plants. Open collaboration with a community and its leaders provides increased public involvement and understanding of best practices for both land-based and offshore wind deployment.

A number of government agencies, industry organizations, researchers, academics, non-government organizations, and collaborative groups are working to address wind-related issues, from permitting and environmental oversight to manufacturing and workforce training. Work by collaborative groups has shifted from the basic sharing of information and best practices to active engagement aimed at solving specific problems at the local, regional, and national levels. Example collaborative bodies in this effort include the American Wind Wildlife Institute, the Bats and Wind Energy Cooperative, the National Wind Coordinating Collaborative, and the Utility Variable-Generation Integration Group. These parties have enhanced education to help stakeholders understand the role and impact of wind on the energy market, communities, and the environment.

The wind power community has addressed substantive siting and regulatory issues, and continues to work closely with regulatory organizations to streamline regulatory processes. Requirements can vary widely by state, locality, site ownership and oversight, project size, grid interconnection, and other project attributes. As a result, wind power projects across the country must adhere to different and changing regulatory standards, leaving uncertainties in development timelines and increasing risks to successful project development.

ES.3 Costs, Benefits, and Other Impacts of the *Study Scenario*

The *Wind Vision* analysis considered an array of impacts for the *Study Scenario* (10% wind penetration by 2020, 20% by 2030, and 35% by 2050) relative to the *Baseline Scenario*. Modeling inputs for these scenarios are consistent with those applied in the prior *BAU Scenario* and sensitivities (see Table ES.1-1) except wind power deployment is fixed at *Study Scenario* levels. Under *BAU* conditions, wind power deployment occurs if and where wind power is economically competitive. In the *Study Scenario,* wind deployment begins in 2013 at 61 GW and then is added in future years to reach levels of 10% wind penetration by 2020, 20% by 2030, and 35% by 2050. In the *Baseline Scenario,* wind power deployment begins in 2013 at 61 GW and then remains fixed at 61 GW for all future years. Although the *Study Scenario* does not precisely replicate the prior *BAU* or related sensitivity outcomes, aggressive wind cost reductions (land-based wind LCOE reduction of 24% by 2020, 33% by 2030, and 37% by 2050 and offshore wind LCOE reduction of 22% by 2020, 43% by 2030, 51% by 2050), high fossil fuel prices (e.g., \$3/MMBtu coal price and \$7/MMBtu electric sector natural gas price), or various combinations of the two could support the level of wind penetration achieved in the *Study Scenario.*

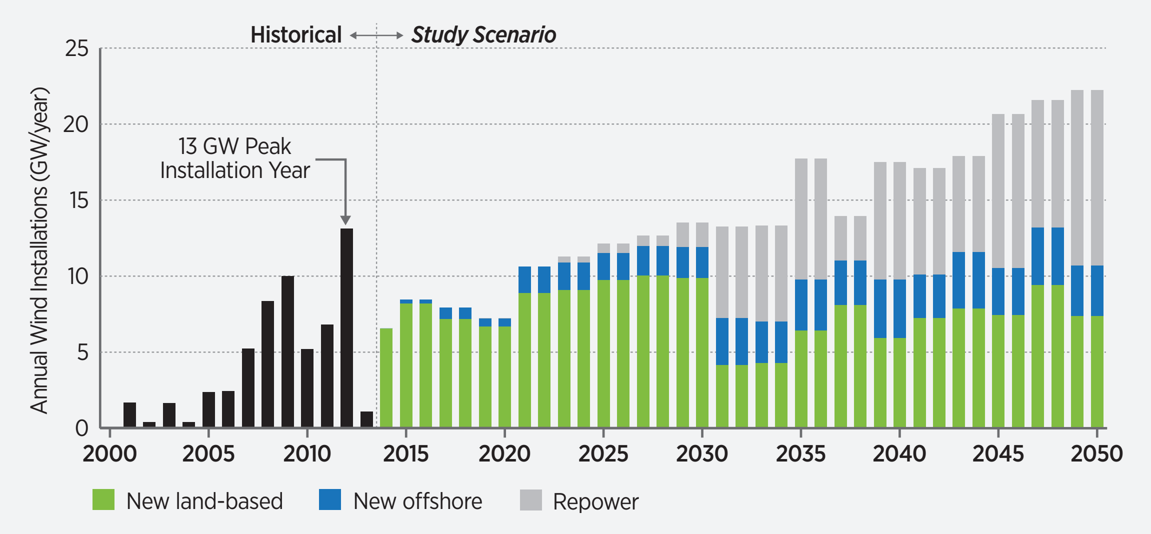
ES.3.1 Wind Industry and Electric Sector Impacts

In the *Central Study Scenario*, total installed wind capacity increases from the 61 GW installed at year-end 2013 to approximately 113 GW by 2020, 224 GW by 2030, and 404 GW by 2050. This growth represents nearly three doublings of installed capacity and includes all wind market segments: land-based, distributed, and offshore wind. Of these installed capacity amounts, offshore wind comprises 3 GW, 22 GW, and 86 GW for 2020, 2030, and 2050, respectively. The amount of installed capacity needed to meet the deployment levels considered in the *Study Scenario* will depend on future wind technologies. For example, with improvements in wind technology yielding higher capacity factors, only 382 GW of wind capacity is needed to reach the 35% penetration level in 2050. Conversely, 459 GW would be required using today's technologies without further advancements. Growth in the *Study Scenario* utilizes approximately 5% of the available land-based wind resource (after exclusions for environmentally sensitive or other protected areas) and 5.5% of the available offshore wind resource of the nation.

The *Study Scenario* supports new capacity additions at levels comparable to the recent (as of 2013) past, but drives increased demand for new wind turbine equipment as a function of repowering needs. Demand for wind turbines averages approximately 8 GW/year from 2014 to 2020 and 12 GW/year from 2021 to 2030, and increases to 18 GW/year from 2031 to 2050. While aggregate demand trends upward (Figure ES.3-1), it is primarily concentrated in the new land-based segment in the near-term. Deployment of offshore plants and repowering (the replacement of turbine equipment at the end of its useful life with new state-of-the-art turbine equipment) become more significant segments of the industry in the 2031–2050 timeframe.

Although electricity rates increase by 1% between 2020 and 2030, the *Central Study Scenario* results in a net savings of \$149 billion relative to the *Baseline Scenario* for the period of 2013–2050. Savings are incurred from 2031 to 2050 as fossil fuel prices trend upward and aging power infrastructure requires replacement. Increasing wind generation to the levels of the *Study Scenario* simultaneously reduces carbon dioxide (CO_2) emissions, improves air quality resulting in lower levels of illness and premature loss of life, and reduces demand on water resources, among other impacts.

The *Study Scenario* results in relatively constant new capacity additions but also supports increased demand for turbines due to repowering.



Note: New capacity installations include capacity added at a new location to increase the total cumulative installed capacity or to replace retiring capacity elsewhere. Repowered capacity reflects turbine replacements occurring after plants reach their useful lifetime. Wind installations shown here are based on model outcomes for the *Central Study Scenario* and do not represent projected demand for wind capacity.

Figure ES.3-1. Historical and forward-looking wind power capacity in the *Central Study Scenario*

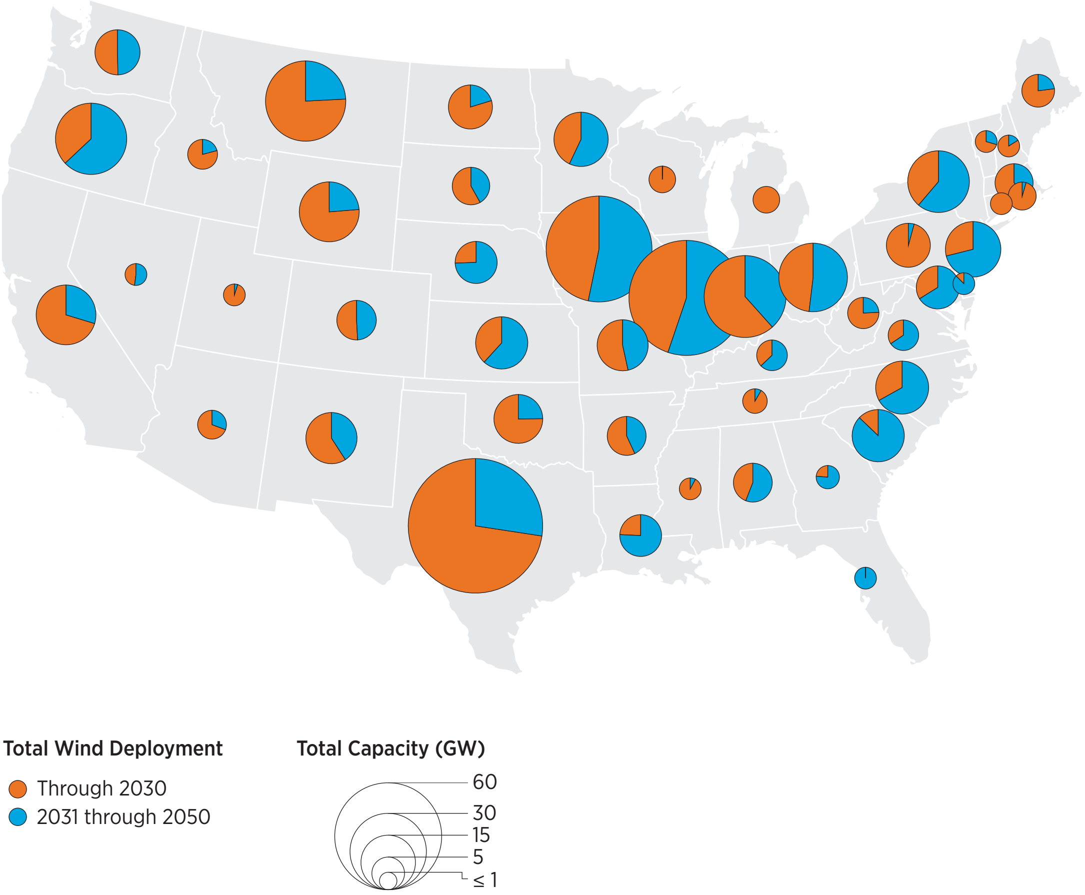
In the *Study Scenario,* wind industry expenditures (new capital and development expenditures, annual operating expenditures, and repowered capital expenditures) grow to more than $30 billion/year from 2020 to 2030, and are estimated at approximately $70 billion/year by 2050. By 2050, annual expenditures exceed $20 billion/year for operations, $25 billion/year for repowering, and $25 billion/year for new greenfield development.

The *Study Scenario* suggests continued geographical diversity in wind power deployment. Figure ES.3-2 illustrates the state-level distribution of utility-scale wind capacity (land-based and offshore) in 2030 and 2050 under the *Central Study Scenario*. By 2030, installed wind capacity exists in all but one state, with 37 states having more than 1 GW of capacity. By 2050, wind capacity exists in all 50 states, with 40 states having more than 1 GW of installed wind capacity. As of 2013, wind installations of 62 MW and 206 MW exist in Alaska and Hawaii respectively. While future wind deployment in these states is expected and could potentially grow beyond 1 GW, these states are not counted among the states with more than 1 GW in 2030 or 2050 because the modeling analysis was restricted to the 48 contiguous states.

Variations in wind resource quality, relative distances to load centers, and existing infrastructure drive regional differences in modeled wind penetration levels. Based on model outcomes from the *Study Scenario,* most of the western and central parts of the United States have penetration levels that exceed the 10% nationwide level by 2020, with some regions approaching or exceeding 30% penetration. By 2050, wind penetration levels exceed 40% across much of the West and upper Midwest, with less substantial—but still sizeable—levels in other parts of the country. In the Southeast, wind penetration levels are lower than in other regions, but are significantly higher than levels found in that region in 2013, particularly for coastal areas.

The levels of wind penetration examined in the *Study Scenario* increase variability and uncertainty in electric power system planning and operations (Figure ES.3-3). From the perspective of planning reserves, wind power's aggregated capacity value in the *Study Scenario* was about 10–15% in 2050 (with lower marginal capacity value), thereby reducing the ability of wind compared to other generators to contribute to increases in peak planning reserve requirements. In addition, the uncertainty introduced by wind in the *Study Scenario* increased the level of operating reserves that must be maintained by the system. Transmission constraints result in average curtailment of 2–3% of wind generation, modestly increasing the threshold for economic wind deployment. These costs are embedded in the system costs and retail rate impacts noted below. Such challenges can be mitigated by various means including increased system flexibility, greater electric system coordination, faster dispatch schedules, improved forecasting, demand response, greater power plant cycling, and—in some cases—storage options. Specific circumstances dictate the optimal solution. Continued research is expected to provide more specific and localized assessments of impacts.

The *Study Scenario* results in broad-based geographic distribution of wind capacity.



Note: Results presented are for the *Central Study Scenario*. Across *Study Scenario* sensitivites, deployment by state may vary depending on changes in wind technology, regional fossil fuel prices, and other factors. ReEDS model decision-making reflects a national optimization perspective. Actual distribution of wind capacity will be affected by local, regional, and other factors not fully represented here. Alaska and Hawaii cannot be currently modeled in ReEDS but will contribute to overall wind deployment.

Figure ES.3-2. *Study Scenario* distribution of wind capacity by state in 2030 and 2050

The *Study Scenario* includes impacts that will require investments by the wind industry and the electric sector at large.

Industry Investment	Deployment	Integration[b]	Transmission[c]	Offshore Wind
• 8–11 GW/year average net capacity additions throughout the 2013–2050 period • 18 GW/year annual turbine demand as more wind plants are repowered from 2031 to 2050 • $70 billion/year[a] by 2050 annual wind industry investment from new capacity additions, repowered capacity, and operations and maintenance	• 404 GW of cumulative capacity by 2050 for 35% wind energy • All 50 states with wind deployment by 2050 • 37 states by 2030 and 40 by 2050 with more than 1 GW of wind power (within the contiguous United States)	• Increased system flexibility is required, but can be acquired from many sources • 2–3% average curtailment of annual wind generation; estimated wind capacity value of 10–15% by 2050 • Integration solutions required, but will vary by region	• 2.7x incremental transmission needs by 2030; 4.2x by 2050 • 10 million MW-miles incremental transmission capacity required by 2030 Cumulatively 29 million incremental MW-miles required by 2050 • Through 2020: incremental 350 circuit miles/year needed 2021–2030: incremental 890 circuit miles/year, and 2031–2050: incremental 1,050 circuit miles/year	• Established U.S. offshore wind market and supply chain by 2020 • 22 GW installed by 2030 and 86 GW installed by 2050 • By 2050, offshore wind in multiple regions, including the East Coast, West Coast, Great Lakes, and Gulf of Mexico

a. Expenditures in 2013$

b. Increased costs associated with greater demand for system flexibility and wind curtailments are embedded in the system costs and retail rate impacts reported in Chapter 3.

c. All transmission estimates reported are the incremental difference between the *Study Scenario* and *Baseline Scenario*. Estimated circuit miles assume a single circuit 345 kV transmission line with a nominal carrying capacity of 900 MW. ReEDS transmission capacity additions exclude those added for reliability purposes only and conductor replacement on existing infrastructure. Estimates shown here represent point to point transfers, for which explicit corridors have not been identified.

Figure ES.3-3. Summary of wind industry and other electric sector impacts in the *Central Study Scenario*

Table ES.3-1. Transmission Impacts in the *Central Study Scenario*

	Historical Average	2014–2020	2021–2030	2031–2050	Cumulative 2014–2050
Study Scenario MW-miles (change from *Baseline Scenario*)		311,000/year	801,000/year	949,000/year	29,000,000
Study Scenario circuit miles (change from *Baseline Scenario*)[a]	870/year	350/year	890/year	1,050/year	33,000
		By 2020	**By 2030**	**By 2050**	
Ratio of *Study Scenario* to *Baseline Scenario*		1.5x	2.7x	4.2x	

Note: ReEDS transmission capacity additions exclude those added for reliability purposes only and conductor replacement on existing infrastructure. Estimates shown here represent point to point transfers, for which explicit corridors have not been identified.

a. Assuming a representative transmission line with a carrying capacity of 900 MW, typical for single-circuit 345 kV lines

Required new transmission capacity for the *Central Study Scenario* is 2.7 times greater in 2030 than for the respective *Baseline Scenario,* and about 4.2 times greater in 2050. Transmission expenditures are less than 2% of total electric sector costs in the *Central Study Scenario* (Table ES.3-1). Incremental cumulative (2013 and on) transmission needs of the *Central Study Scenario* relative to the *Baseline Scenario* amount to 10 million MW-miles by 2030 and 29 million MW-miles by 2050. Assuming only single-circuit 345-kilovolt lines (with a 900-MW carrying capacity) are used to accomplish this increase, an average of 890 circuit miles/year of new transmission lines would be needed between 2021 and 2030, and 1,050 miles/year between 2031 and 2050. This is comparable with the average of 870 circuit miles added each year since 1991 (as of 2013).[11] New transmission capacity in the *Study Scenario* is primarily concentrated in the Midwest and southern Central regions of the United States.

In the *Study Scenario*, wind primarily displaces fossil fuel-fired generation, especially natural gas, with the amount of displaced gas growing over time. In the long-term (after 2030), wind in the *Study Scenario* also affects the growth of other renewable generation and, potentially, future growth of nuclear generation. The avoided generation mix will ultimately depend on uncertain future market conditions, including fossil fuel prices and technology costs. Displaced fossil fuel consumption leads to avoided emissions and other social impacts. With wind penetration increasing to the levels envisioned under the *Study Scenario,* the fossil fleet's role to provide energy declines while its role to provide reserves increases.

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[11] Transmission estimates for the *Study Scenario* exclude maintenance for the existing grid, reliability-driven transmission, and other factors that would be similar between the *Baseline Scenario* and the *Study Scenario*.

ES.3.2 Costs of the *Wind Vision Study Scenario*

National average retail electricity prices for both the *Baseline Scenario* and the *Study Scenario* are estimated to grow (in real terms) between 2013 and 2050. Through 2030, retail electricity prices of the *Central Study Scenario*, relative to the *Baseline Scenario*, are less than 1% higher. In the long-term (2050), retail electricity prices are expected to be lower by 2%. A wider range of future costs and savings are possible as estimated by the sensitivity scenarios (Table ES.3-2). In 2020, retail electricity rates range from nearly zero cost difference up to a 1% cost increase when comparing the *Study Scenario* to the *Baseline Scenario.* In 2030, incremental costs are estimated to be as high as a 3% cost under the most unfavorable conditions for wind (low fossil fuel prices combined with high wind power costs). Under the most favorable conditions in 2030, the *Study Scenario* results in a 2% reduction in retail electricity prices relative to the *Baseline Scenario.* By 2050, incremental electricity prices of all sensitivities of the *Study Scenario* are estimated to range from a 5% increase to a 5% savings in electricity prices over all cases for the corresponding *Baseline Scenario.*

Relative to the *Baseline Scenario,* the *Central Study Scenario* results in an approximately 1% increase in retail electricity rates in the near-term (2020) to mid-term (2030), but cost savings by 2050. On a cumulative net present value basis, the long-term system cost reductions outweigh near- and mid-term cost increases across most conditions analyzed.

On an annual basis, the impacts on electricity consumers in the *Central Study Scenario* are estimated to include costs of $2.3 billion (0.06¢/kilowatt-hour [kWh]) compared to the *Baseline Scenario* in 2020, costs of $1.5 billion (0.03¢/kWh) in 2030, and savings of $13.7 billion (0.28¢/kWh) in 2050 (Table ES.3-2). Across the range of sensitivities, annual consumer impacts range from cost increases of $0.8 billion to $3.6 billion in 2020, savings of $12.3 billion to costs of $14.6 billion in 2030, and savings of $31.5 billion to costs of $26.9 billion in 2050. Electricity costs and savings driven by future wind deployment will depend strongly on future technology and fuel price conditions.

Table ES.3-2. Change in Electricity Prices for the *Study Scenario* Relative to the *Baseline Scenario*

	2020	2030	2050
Central Study Scenario electricity price (change from *Baseline Scenario*)	0.06¢/kWh cost (+0.6%)	0.03¢/kWh cost (+0.3%)	0.28¢/kWh savings (-2.2%)
Central Study Scenario annual electricity consumer costs (change from *Baseline Scenario*)	$2.3 billion costs	$1.5 billion costs	$13.7 billion savings
Study Scenario sensitivity range (% change from *Baseline Scenario*)	+0.2% to + 0.9%	-2.4% to +3.2%	-5.1% to +4.8%
Study Scenario annual electricity consumer costs range (change from *Baseline Scenario*)	$0.8 to $3.6 billion costs	$12.3 billion savings to $14.6 billion costs	$31.5 billion savings to $26.9 billion costs

Note: Expenditures in 2013$

In present value terms, cumulative electric sector expenditures (fuel, capital, operating, and transmission) are lower for the *Study Scenario* than for the *Baseline Scenario* under Central conditions and many sensitivities. From 2013 to 2050, the *Central Study Scenario* results in cumulative present value (3% real discount rate) savings of approximately $149 billion (-3%). Potential electricity sector expenditures range from savings of $388 billion (-7%) to a cost increase of $254 billion (+6%), depending on future wind power cost trends and fossil fuel prices.

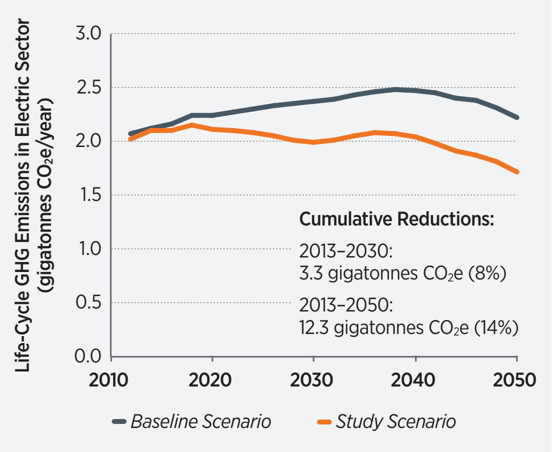
The *Central Study Scenario* results in a 16% reduction in carbon dioxide (CO_2) emissions by 2030 and 23% by 2050 from the electricity sector, relative to the *Baseline Scenario.* Other air pollutants affecting public health also decrease and water savings accrue in many regions of the country, including arid water-stressed regions in the Southwest. The estimated value of CO_2 reductions ranges from $85–$1,230 billion, while reductions in other air pollutants are valued at $52–$272 billion.

ES.3.3 Benefits of the *Study Scenario*

The *Central Study Scenario* reduces electric sector life-cycle GHG emissions by 6% in 2020 (0.13 gigatonnes CO_2-equivalents), 16% in 2030 (0.38 gigatonnes CO_2-equivalents), and 23% in 2050 (0.51 gigatonnes CO_2-equivalents), compared to the *Baseline Scenario*. Cumulative GHG emissions are reduced by 12.3 gigatonnes CO_2-equivalents from 2013 to 2050 (14%) (Figure ES.3-4). Based on the U.S. Interagency Working Group's Social Cost of Carbon estimates, these reductions yield global avoided climate change damages estimated at $85–$1,230 billion, with a central estimate of $400 billion (2013–2050 discounted present value). This is equivalent to a benefit of wind energy that ranges from 0.7¢–10¢/kWh of wind, with a central benefit estimate of 3.2¢/kWh of wind.

The *Central Study Scenario* results in reductions in other air pollutants (e.g., PM, SO_2, and NO_x), yielding societal health and environmental benefits that range from $52–$272 billion (2013–2050, discounted present values) depending on the methods of quantification. The majority of the benefits come from reduced premature mortality due to reductions in SO_2 emissions in the eastern United States. In total, the health and environmental benefits are equivalent to a benefit of wind energy that ranges from 0.4¢/kWh of wind to 2.2¢/kWh of wind. Table ES.3-3 highlights some of the air pollution benefits.

Life-cycle GHG emissions are lower in the *Central Study Scenario* than in the *Baseline Scenario*.



Note: Life-cycle GHG emissions consider upstream emissions (e.g., manufacturing and raw materials), ongoing combustion and non-combustion emissions, and downstream emissions (e.g., decommissioning).

Figure ES.3-4. Lifecycle GHG emissions in the *Central Study Scenario* and *Baseline Scenario*

Table ES.3-3. Health Benefits in 2050 of Reduced Air Pollution in the *Central Study Scenario*

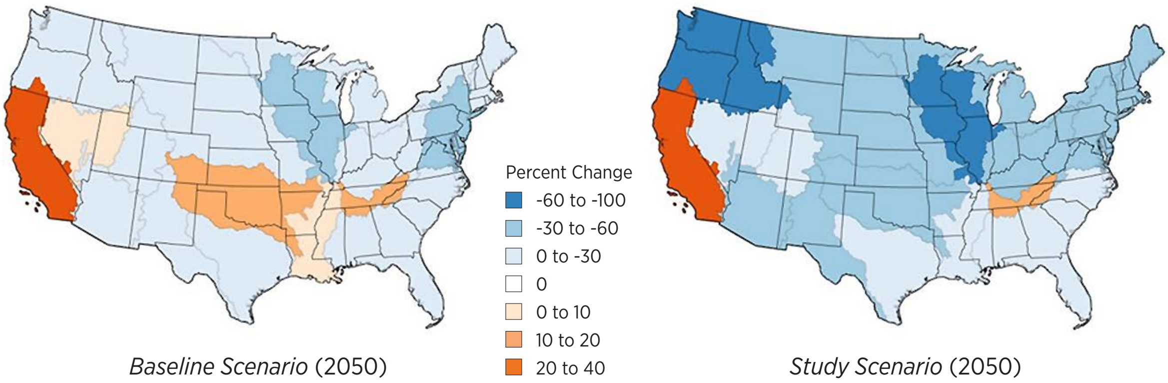
Type of Benefit	Amounts
Cumulative monetized benefits (2013$)	$108 billion
Avoided premature deaths	21,700
Avoided emergency room visits for asthma due to $PM_{2.5}$ effects	10,100
Avoided school loss days due to ozone effects	2,459,600

Note: Central estimate results are presented, which follow the 'EPA Low' methodology for calculating benefits, further detailed in Chapter 3. Monetized benefits are discounted at 3%, but mortality and morbidity values are simply accumulated over the 2013–2050 time period. Health impacts presented here are a subset of those analyzed. $PM_{2.5}$ is particulate matter of diameter 2.5 microns or less. The full set of results is presented in detail in Chapter 3.

The *Central Study Scenario* results in reduced national electric-sector water withdrawals (1% in 2020, 4% in 2030, and 15% in 2050) and water consumption (4% in 2020, 11% in 2030, and 23% in 2050) compared to the *Baseline Scenario*. Anticipated reductions, relative to the *Baseline Scenario,* exist in many parts of the United States, including the water-stressed arid states in the Southwest (Figure ES.3-5). Reductions in water use driven by the *Study Scenario* would have environmental and economic benefits, and would help reduce competition for scarce water resources.

The value of reduced GHG and air pollution emissions in the *Central Study Scenario* relative to the *Baseline Scenario* exceeds the under 1% cost increase in electricity rates in 2020 and 2030. By 2050, the *Central Study Scenario* results in savings across all three categories—electricity rates, GHG emissions, and air pollution emissions (Figure ES.3-6). Savings are also incurred on a cumulative basis across all three metrics (Figure ES.3-7). The range of GHG benefits was estimated following the Interagency Working Group's Social Cost of Carbon methodology and varying discount rates. The range of air pollution benefits was calculated following methodologies of the U.S. Environmental Protection Agency (EPA) and the Air Pollution Emission Experiments and Policy model, known as AP2. Several other categories of impacts such as water use are analyzed but not monetized, due to a lack of established peer-reviewed, national-scale methodologies.

Electric sector water consumption is 23% lower in the *Central Study Scenario* relative to the *Baseline Scenario* by 2050.

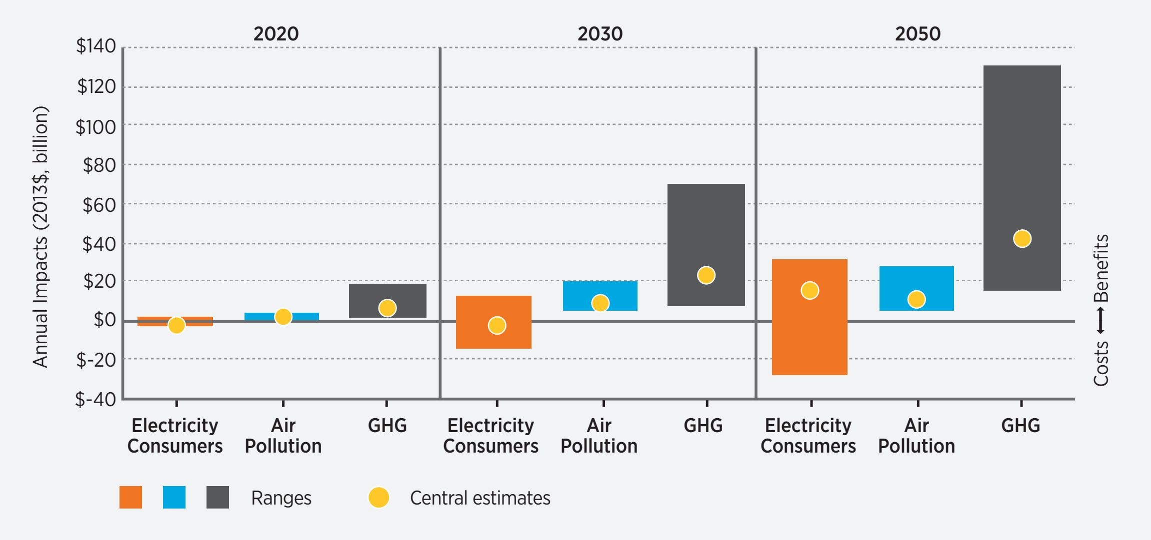


Baseline Scenario (2050)

Study Scenario (2050)

Figure ES.3-5. Change in water consumption used in electricity generation from 2013 to 2050 for the *Baseline Scenario* and *Central Study Scenario*

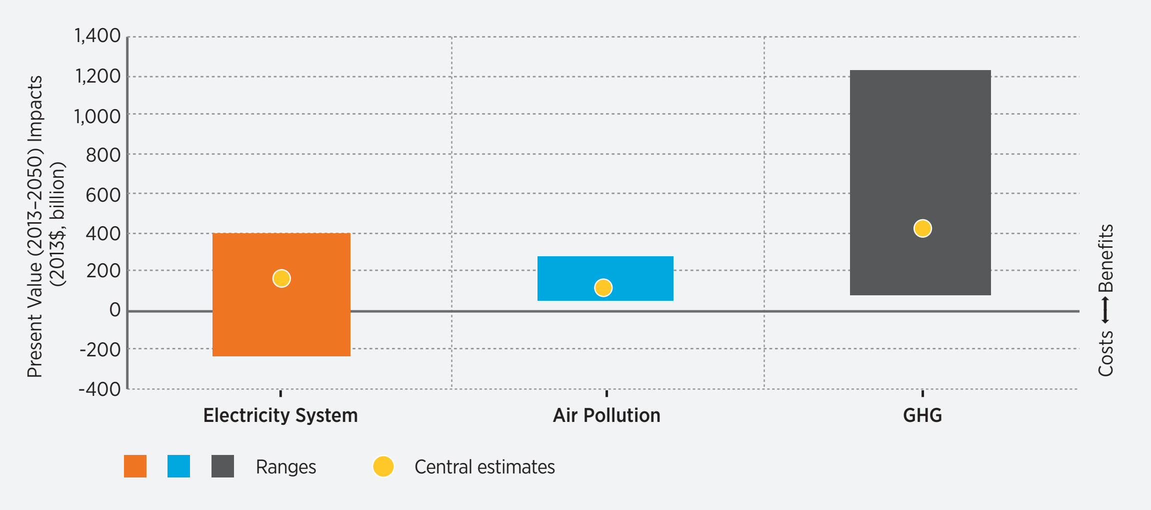
Reduced GHG, SO_2, NO_X, and fine particulate matter emissions provide benefits in 2020, 2030, and 2050 in addition to the savings in electricity rates achieved in the *Central Study Scenario* by 2050.



Note: Results represent the annual incremental costs or benefits (impacts) of the *Study Scenario* relative to the *Baseline Scenario.* Central estimates are based on *Central Study Scenario* modeling assumptions. The electricity consumers costs range reflects incremental expenditures (including capital, fuel, and operations and maintenance for transmission and generation of all technologies modeled) across a series of sensitivity scenarios. Air pollution and GHG estimates are based on the *Central Study Scenario* only, with ranges derived from the methods applied and detailed in the full report.

Figure ES.3-6. Monetized impacts of the *Study Scenario* relative to the *Baseline Scenario* in 2020, 2030, and 2050

On a present value (2013–2050) basis, the *Central Study Scenario* results in electricity system cost savings relative to the *Baseline Scenario,* in addition to the benefits of reduced air pollution and GHG emissions.



Note: Results represent the present value of incremental costs or benefits (impacts) of the *Study Scenario* relative to the *Baseline Scenario.* Central estimates are based on *Central Study Scenario* modeling assumptions. The electricity system cost range reflects incremental expenditures (including capital, fuel, and operations and maintenance for transmission and generation of all technologies modeled) across a series of sensitivity scenarios. Air pollution and GHG estimates are based on the *Central Study Scenario* only, with ranges derived from the methods applied and detailed in the full report.

Figure ES.3-7. Cumulative (2013-2050) present value of monetized impacts of the *Study Scenario* relative to the *Baseline Scenario*

ES.3.4 Additional Impacts Associated with the *Study Scenario*

Other impacts from the *Study Scenario* include reduced sensitivity (20% less) to future fossil fuel price volatility, support for a vibrant wind industry supply chain (526,000–670,000 jobs by 2050), and increased tax revenue and lease payments to local communities. In addition, the *Study Scenario* results in manageable but non-trivial impacts to land use, local wildlife populations, and host communities.

The *Study Scenario* contributes to a reduction in both long-term natural gas price risk and natural gas prices, compared to the *Baseline Scenario*. The *Central Study Scenario* results in total electric system costs that are 20% less sensitive to long-term fluctuations in coal and natural gas prices (Figure ES.3-8). Additionally, the *Central Study Scenario* leads to a potential $280 billion in consumer savings due to reduced natural gas prices outside the electric sector, equivalent to a levelized consumer benefit from wind energy of 2.3¢/kWh of wind.

The *Study Scenario* supports a robust domestic wind industry, with wind-related gross jobs from investments in new and operating wind plants ranging from 201,000–265,000 in 2030 and increasing to 526,000–670,000 in 2050 (Figure ES.3-8). Actual future wind-related jobs (on-site, supply chain, and induced) will depend on the future strength of the domestic supply chain and additional training and educational programs as necessary.

Wind project development examined in the *Wind Vision* affects local communities through land lease payments and local property taxes. Under the *Central Study Scenario,* wind power capacity additions lead to land-based lease payments that increase from $350 million in 2020 to $650 million in 2030, to $1,020 million in 2050. Offshore wind lease payments increase from $15 million in 2020 to $110 million in 2030, to $440 million in 2050. Property tax payments associated with wind projects are estimated to be $900 million in 2020; $1,770 million in 2030; and $3,200 million in 2050.

Under the *Central Study Scenario,* the land area occupied by turbines, roads, and other infrastructure equates to 0.03% of total land area in the contiguous United States in 2030 and 0.04% in 2050. This land area equates to less than one-third of total land area occupied by U.S. golf courses in 2013. Total land area occupied by wind plants in 2050 (accounting for requisite turbine spacing and typical densities) equates to less than 1.5% of the total land area in the contiguous United States.

Continued wind deployment will need to account for the potential impacts on avian, bat, and other wildlife populations; the local environment; the landscape; and communities and individuals living in proximity to wind projects. Continued research, technological solutions (e.g., strategic operational strategies and wildlife deterrents), and experience are anticipated to make siting and mitigation more effective and efficient.

The *Study Scenario* results in cumulative savings, benefits, and an array of additional impacts by 2050.

System Costs[a]	Benefits[b,c]		
$	GHG	Air Pollution	H_2O
$149 billion (3%) lower cumulative electric sector expenditures	14% reduction in cumulative GHG emissions (12.3 gigatonnes CO_2-equivalents), saving $400 billion in avoided global damages	$108 billion savings in avoided mortality, morbidity, and economic damages from cumulative reductions in emissions of SO_2, NO_X, and PM 21,700 premature deaths from air pollution avoided	23% less water consumption and 15% less water withdrawals for the electric power sector

Additional Impacts

Energy Diversity	Jobs	Local Revenues	Land Use	Public Acceptance and Wildlife
Increased wind power adds fuel diversity, making the overall electric sector 20% less sensitive to changes in fossil fuel costs. The predictable, long-term costs of wind power create downward price pressure on fossil fuels that can cumulatively save consumers $280 billion from lower natural gas prices outside the electric sector.	Approximately 600,000 wind-related gross jobs spread across the nation.	$1 billion in annual land lease payments $440 million annual lease payments for offshore wind plants More than $3 billion in annual property tax payments	Less than 1.5% (106,000 km²) of contiguous U.S. land area occupied by wind power plants Less than 0.04% (3,300 km²) of contiguous U.S. land area impacted by turbine pads, roads, and other associated infrastructure	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

Note: Cumulative costs and benefits are reported on a Net Present Value basis for the period of 2013 through 2050 and reflect the difference in impacts between the *Central Study Scenario* and the *Baseline Scenario*. Results reported here reflect central estimates within a range; see Chapter 3 for additional detail. Financial results are reported in 2013$ except where otherwise noted.

a. Electric sector expenditures include capital, fuel, and operations and maintenance for transmission and generation of all technologies modeled, but excludes consideration of estimated benefits (e.g., GHG emissions).

b. Morbidity is the incidence of disease or rate of sickness in a population.

c. Water consumption refers to water that is used and not returned to the source. Water withdrawals are eventually returned to the water source.

Figure ES.3-8. Summary of costs, benefits, and other outcomes associated with the *Study Scenario* relative to the *Baseline Scenario* by 2050

ES.3.5 Impacts Specific to Offshore and Distributed Wind

The *Study Scenario* contributions from offshore wind are characterized by an industrial base that evolves from its nascent state in 2013 to one that can supply more than 80 GW of offshore capacity by 2050. This deployment represents just 5.5% of the resource potential for offshore areas adjacent to the 28 coastal and Great Lakes states. Under this scenario, the offshore wind industry would complement and bolster a strong land-based industry through the use of common supply chain components and the development of workforce synergies.

The cost of offshore wind needs to be aggressively reduced. Through innovation and increasing scale, however, this market segment could bring notable potential benefits. In particular, offshore wind offers the ability to reduce wholesale market power clearing prices and consumer costs in transmission-congested coastal areas, supports local jobs and port development opportunities, and offers geographic proximity to densely populated coastal regions with limited renewable power alternatives.

Distributed wind applications, including customer-sited wind and wind turbines embedded in distribution networks, offer a number of unique and relevant attributes. On-site distributed wind turbines allow farmers, schools, and other energy users to benefit from reduced utility bills, predictable costs, and a hedge against the possibility of rising retail electricity rates. At the same time, decentralized generation such as distributed wind can benefit the electrical grid. Distributed wind also supports a domestic market; U.S. suppliers dominate the domestic small wind turbine market with 93% of 2013 sales on a unit basis and 88% on a capacity basis. These suppliers also maintain domestic content levels of 80–95% for turbine and tower hardware and are well positioned to capitalize on export opportunities, including the growing demand for decentralized electricity around the globe.

ES.4 The Wind Vision Roadmap: A Pathway Forward

The roadmap was developed through a collaborative effort led by DOE, with contributions and rigorous peer review from industry, the electric power sector, environmental stewardship organizations, academia, national labs, and participants at various levels of government. It defines specific top-level activities for all major stakeholder sectors, including the wind industry, the wind research community, and others. Though the roadmap includes actions intended to inform analysis of various policy options, it is beyond the scope and purview of the *Wind Vision* to suggest policy preferences or recommendations, and no attempt is made to do so.

The objective of the *Wind Vision* roadmap is to identify the challenges and actions necessary to increase the opportunities for U.S. wind deployment. This portfolio of actions (Chapter 4 and Appendix M) builds upon the successes of wind power to date and addresses remaining gaps. The actions cover the major domestic wind applications on land (including distributed applications) and offshore. Additionally, the roadmap provides a framework from which others can define specific activities at greater levels of detail.

> The *Wind Vision* includes a detailed roadmap of technical and institutional actions necessary to overcome the challenges to wind power making a significant contribution to a cleaner, low-carbon, domestic energy economy.

The *Wind Vision Study Scenario* was created for the purpose of examining costs and benefits. Although it represents a potential future for wind growth, it is unlikely to be realized without continued technology and systems improvements. In aggregate, the roadmap actions are a series of steps that can be expected to increase the likelihood of achieving wind power growth at the levels considered in the *Study Scenario.*

ES.4.1 Core Roadmap Actions

Optimizing wind contributions requires coordination among multiple parties who can implement a set of complementary approaches around three agreed-upon themes (Table ES.4-1):

1. **Reduce Wind Costs:** Chapter 3 of the *Wind Vision* report indicates that the costs associated with the *Study Scenario* can be reduced across the range of sensitivities with wind cost reductions. Accordingly, reductions in LCOE are a priority focus. This theme includes actions to reduce capital costs; reduce annual operating expenses; optimize annual energy production and reduce curtailment and system losses; reduce financing expenses; reduce grid integration and operating expenses; and reduce market barrier costs, including regulatory and permitting, environmental, and radar mitigation costs.
2. **Expand Developable Areas:** Expansion of wind power into high-quality resource areas is also important for realizing the *Study Scenario* at cost levels described in Chapter 3 of the *Wind Vision* report. Key actions within this theme include actions to expand transmission; responsibly expand developable geographic regions and sites; improve the potential of low-wind-speed locales; improve the potential of ocean and Great Lakes offshore regions; improve the potential in areas requiring careful consideration of wildlife, aviation, telecommunication, or other environmental issues; and improve the potential of high wind resource locations that have poor access to electricity transmission infrastructure. National parks, densely populated locations, and sensitive areas such as federally designated critical habitat are generally excluded from the roadmap actions, since they are likely not to be developed as wind sites.
3. **Increase Economic Value for the Nation:** The *Study Scenario* projects substantial benefits for the nation, but additional steps are needed to ensure these benefits are realized and maximized. This theme includes actions to provide detailed and accurate data on costs and benefits for decision makers; grow and maintain U.S. manufacturing throughout the supply chain; train and hire a U.S. workforce; provide diversity in the electricity generating portfolio; and provide a hedge against fossil fuel price increases. The overall aim is to ensure that wind power continues to provide enduring value for the nation.

High-level roadmap actions are summarized in Text Box ES.4-1 and explained in detail in the *Wind Vision* report (Chapter 4 and Appendix M). These core roadmap actions fall into nine 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; and policy analysis.

The roadmap is the beginning of an evolving, collaborative, and necessarily dynamic process. The *Wind Vision* roadmap is not prescriptive. It does not detail how suggested actions are to be accomplished; it is left to the responsible organizations to determine the optimum timing and sequences of specific activities. It suggests an approach of continual updates to assess impacts and redirect activities as necessary and appropriate through 2050. These updates, which are intended to be conducted at least every two years, would be informed by analysis and would ensure that the roadmap adapts to changing technology, market, and political factors.

The *Wind Vision* depicts a future in which wind power has the potential to be a significant 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 stakeholders, such as state and federal agencies and government, utility companies, equipment research and development organizations, manufacturers, national laboratories, and academic institutions. Bringing these participants together on a regular basis to revisit this roadmap and update priorities will be essential to maintaining and sustaining focus on wind power's long-term future for the nation.

Table ES.4-1. 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[a]	• 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

a. Several action areas address more than one key theme.

Text Box ES-1.

High-Level Wind Vision Roadmap Actions

1 Wind Power Resources and Site Characterization

Action 1.1 – Improve Wind Resource Characterization. Collect data and develop models to improve wind forecasting at multiple temporal scales—e.g., minutes, hours, days, months, years.

Action 1.2 – Understand Intra-Plant Flows. Collect data and improve models to understand intra-plant flow, including turbine-to-turbine interactions, micro-siting, and array effects.

Action 1.3 – Characterize Offshore 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.

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.

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.

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.

Action 2.4 – Establish Test Facilities. Develop and sustain world-class testing facilities to support industry needs and continued innovation.

Action 2.5 – Develop Revolutionary Wind Power Systems. Invest research and development (R&D) into high-risk, potentially high-reward technology innovations.

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.

Action 3.2 – Develop Transportation, Construction, and Installation Solutions. Develop transportation, construction and installation solutions for deployment of next-generation, larger wind turbines.

Action 3.3 – Develop Offshore Wind Manufacturing and Supply Chain. Establish domestic offshore manufacturing, supply chain, and port infrastructure.

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.

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.

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.

Action 4.4 – Develop and Document Best Practices in Wind O&M. Develop and promote best practices in operations and maintenance (O&M) strategies and procedures for safe, optimized operations at wind plants.

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.

Continues next page

Text Box ES-1. *(Continued)*

High-Level Wind Vision Roadmap Actions

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.

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.

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.

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.

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.

Action 5.6 – Improve Distributed Wind Grid Integration. Improve grid integration of and increase utility confidence in distributed wind systems.

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, maritime shipping, and navigation.

Action 6.2 – Develop Strategies to Minimize and Mitigate Siting and Environmental Impacts. Develop and disseminate relevant information as well as minimization and mitigation strategies to reduce the environmental impacts of wind power plants, including impacts on wildlife.

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.

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.

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.

7 Collaboration, Education, and Outreach

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.

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.

8 Workforce Development

Action 8.1 – Develop Comprehensive Training, Workforce, and Educational Programs. Develop comprehensive training, workforce, and education programs, with engagement from primary schools through university degree programs, to encourage and anticipate the technical and advanced-degree workforce needed by the industry.

9 Policy 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.

Action 9.2 – Refine and Apply Policy Analysis Methods. Refine and apply policy analysis methodologies to understand federal and state policy decisions affecting the electric sector portfolio.

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.

ES.4.2 Risk of Inaction

Without actions to improve wind's competitive position in the market, such as those described in the roadmap and summarized in Text Box ES.4-1, the nation risks losing its existing wind manufacturing infrastructure and a range of public benefits as illustrated in the *Wind Vision*. The analytical results in Chapter 3 of the *Wind Vision* report reveal significant cumulative 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.

Although it is outside the scope of this report, one of the core challenges of the *Study Scenario* is that current policies and market economics at the end of 2013 lack mechanisms to recognize the full value of low-carbon generation. The actions in the roadmap can help reduce the costs of low-carbon electricity generation from wind, ultimately lowering the cost of curbing future emissions and complementing any low-carbon policies enacted.

ES.5 Conclusions

One of the greatest challenges for the 21st century is producing and making available clean, affordable, and secure energy for the United States. Wind power can be a substantial part of addressing that challenge. The *Wind Vision* demonstrates that wind can be deployed at high penetrations with economics that are compelling. Although the wind industry has adopted improved technology and exhibited growth in the years leading up to 2013, the path that allowed the industry to serve 4.5% of current U.S. end-use electricity demand is different from the path needed to achieve 10% by 2020, 20% by 2030, and 35% by 2050. A new strategy and updated priorities are needed to provide positive outcomes for future generations.

The *Wind Vision* report highlights the national opportunity to capture domestic energy as well as environmental and economic benefits with accelerated and responsible deployment of advanced wind power technologies across all U.S. market sectors and regions. It quantifies the associated costs and benefits of this deployment and provides a roadmap for the collaboration needed for successful implementation. Carrying out the *Wind Vision* roadmap actions will also provide cost reductions in the implementation of any future policy measures.

ES.5.1 The Opportunity

The *Wind Vision* analysis modeled a future *Study Scenario* (with various sensitivities) in which 10% of the nation's electricity demand is met by wind power in 2020, 20% by 2030, and 35% by 2050. The near-term (2020) and mid-term (2030) incremental costs associated with large-scale deployment of wind are less than 1% with most scenarios. Over the long term (through 2050), the *Study Scenario* offers net savings to the electric power sector and electricity consumers.

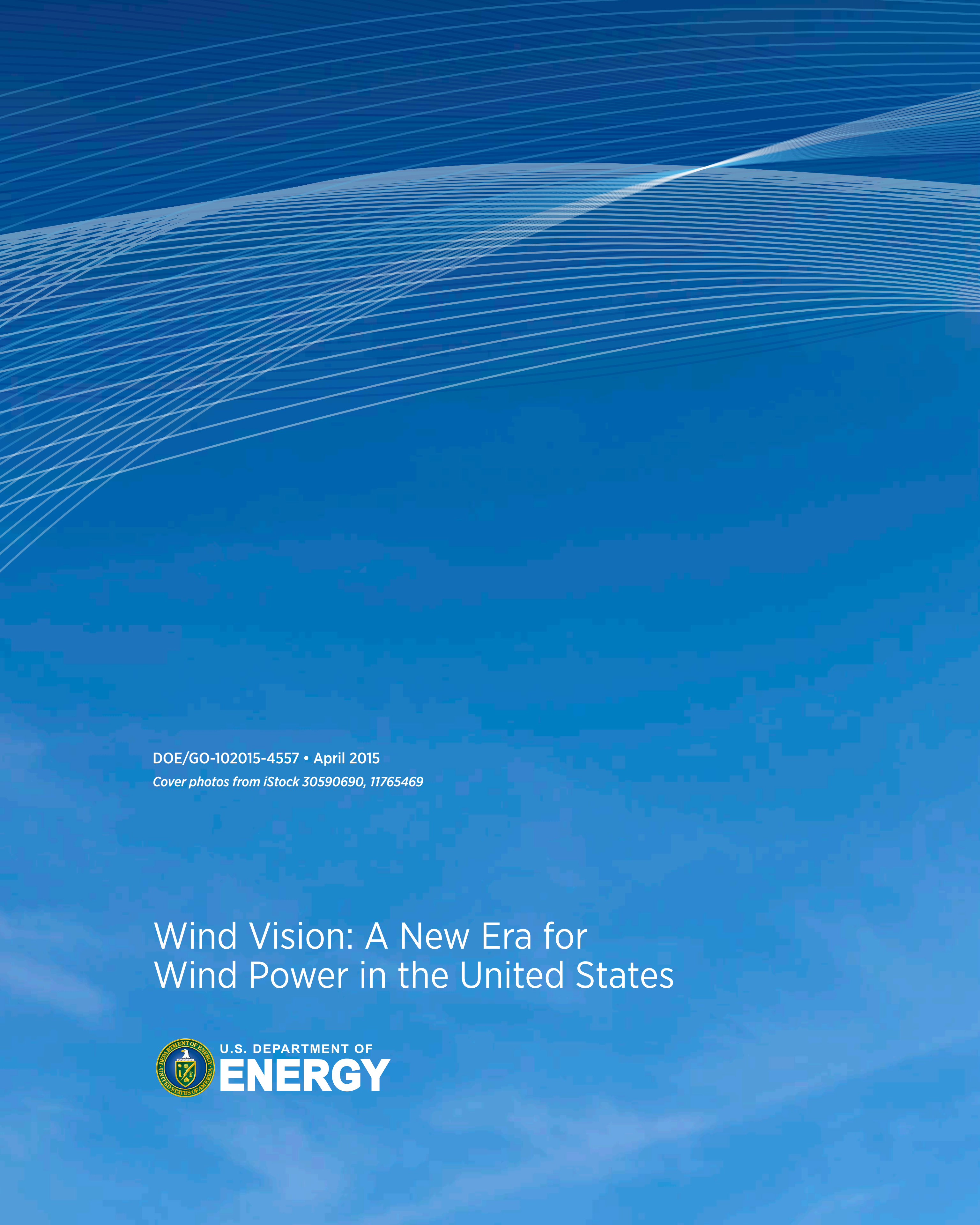
Increasing wind power can simultaneously deliver an array of benefits to the nation that address issues of national concern, including climate change, air quality, public health, economic development, energy diversity, and water security. For example, the 12.3 gigatonnes of CO$_2$-equivalents avoided over the period 2013–2050 in the *Central Study Scenario* delivers $400 billion in savings for avoided global damages. This is equivalent to a benefit of 3.2¢/kWh of U.S. wind energy produced. The value of long-term social benefits such as these can be provided by wind energy and far exceeds the initial investment required.

ES.5.2 The Challenge

While the wind industry is maturing, many future actions and efforts remain critical to further advancement of domestic wind energy. Continued technology development is essential to minimizing costs in the near term and maximizing savings in the long term. Shifts in bulk power market and institutional practices could ease delivery and integration of even higher penetrations of wind power. Engagement with the public, regulators, and local communities can enable wind energy deployment to proceed with minimal negative impacts and applicable benefits to host communities and local wildlife. Continued research and analysis on energy policy as well as wind costs, benefits, and impacts is important to provide accurate information to policymakers and the public discourse. Finally, a commitment to regularly revisit the *Wind Vision* roadmap and update priorities across stakeholder groups and disciplines is essential to ensuring a robust wind future.

ES.5.3 Moving Forward

The *Wind Vision* roadmap identifies a high-level portfolio of new and continued actions and collaborations across many fronts to help the United States realize significant long-term benefits and protect the nation's energy, environmental, and economic interests. Near-term and mid-term investments, such as those experienced in the years leading up to 2013, are needed. These investments are more than offset by long-term savings and social benefits. Stakeholders and other interested parties needs to take the next steps in refining, expanding, operationalizing, and implementing the high-level roadmap actions. These steps could be developed in formal working groups or informal collaborations and will be critical in overcoming the challenges, capitalizing on the opportunities, and realizing the national benefits detailed within the *Wind Vision*.



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