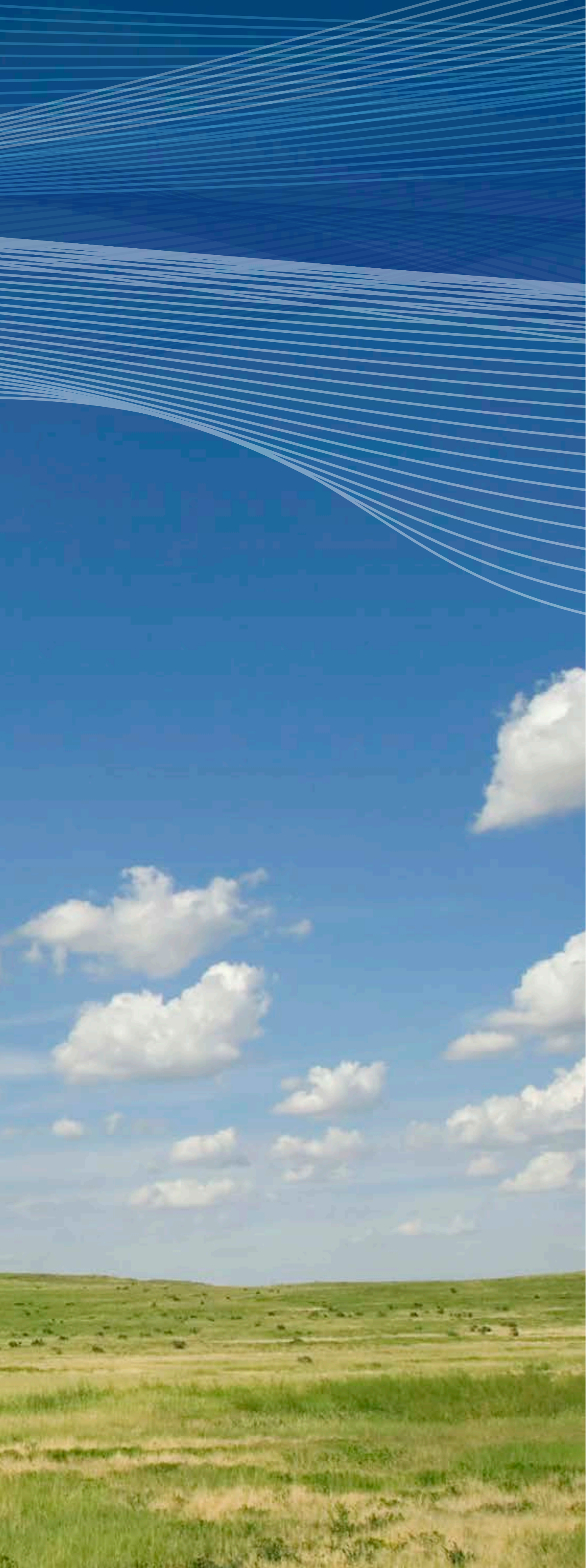
Chapter 1

Wind Vision:

A New Era for Wind Power in the United States

U.S. DEPARTMENT OF ENERGY



1 Introduction to the *Wind Vision*

Summary

The *Wind Vision* consists of four components:

1. **Documentation of the current state of wind power in the United States and identification of key accomplishments and trends over the decade leading up to 2014 (Chapter 2);**
2. **Exploration of the potential 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 (Chapter 3);**
3. **Quantification of costs, benefits, and other impacts associated with continued deployment and growth of U.S. wind power (Chapter 3); and**
4. **Identification of actions and future achievements that could support continued growth in the use and application of wind-generated electricity (Chapter 4).**

The *Wind Vision* and its associated analysis represent a technical update and expansion of a U.S. Department of Energy (DOE) report published in 2008, *20% Wind Energy by 2030—Increasing Wind Energy's Contribution to U.S. Electricity Supply*[1] (hereafter referred to as *20% Wind Energy by 2030*). Major changes have occurred in the electric power sector since the 2000s, when *20% Wind Energy by 2030* was published. In particular, there have been substantial reductions in existing and projected fuel costs for natural gas-fired electric generation, as well as significant reductions in the cost of energy from wind power and other renewable power technologies. Given these changes, DOE's Wind and Water Power Technologies Office initiated the *Wind Vision* study in 2013, soliciting wide-ranging participation from relevant stakeholder groups including the wind business, technology, and research communities; the electric power sector; environmental and energy-related non-governmental organizations; regulatory bodies; and government representatives at the federal and state levels.

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. This modeling used *Business-as-Usual* conditions (federal and state policy conditions that were current on January 1, 2014, and market data from the Energy Information Administration's Annual Energy Outlook 2014) while varying inputs such as fossil fuel costs and wind costs.

This analysis demonstrated a broad array of potential futures for U.S. wind power, including outcomes comparable to the *Study Scenario* under conditions favorable for wind deployment. The credibility of the *Study Scenario* trajectory was further validated after considering current U.S. manufacturing capacity and industry investments, and reviewing broader literature analyses of future scenarios with high levels of renewable electricity.

In order to quantify 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 gigawatts (GW). The *Baseline Scenario* and the *Study Scenario* are not goals or future projections for 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 below and constitute the primary analytical framework of the *Wind Vision.*

Analytical Framework of the *Wind Vision*

Wind Vision Study Scenario	The *Wind Vision Study Scenario,* or *Study Scenario*, applies a 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).

1.0 *Wind Vision*—Historical Context

Wind has been used as a source of power for millennia; historical records show that wind has been harnessed to power sailing vessels since before 3,000 B.C. Experimentation with electricity generation from wind first emerged in the late 19th century, but it was not until the 1970s that wind power began to gain visibility as a potential source of commercial power generation. In the United States, commercial power production from wind first occurred in California in the 1980s. More widespread adoption of commercial wind power generation started in the late 1990s, when declining costs, state and federal policy provisions, and a period of volatility in natural gas fuel prices launched the modern era of U.S. wind power. Electric system operators and utilities now routinely consider wind power as part of a diverse generation portfolio [2, 3, 4, 5].

As of 2013, wind power was one of the fastest-growing sources of new electricity supply. U.S. electricity demand served by wind energy had tripled, increasing from 1.5% of total end-use demand in 2008 to 4.5% in 2013 [6]. From 2008 to 2013, wind power constituted nearly 33% of all U.S. electric capacity additions and, from 2000 to 2013, installed capacity increased at a rate of nearly 30% per year [7]. As of year-end 2013, the United States wind power fleet stood at 61 GW of operating capacity [8]. The U.S. was also the top country globally for wind power generation in 2013, in terms of total wind power electricity generated [9], and ranked second globally for total wind capacity installed [7].

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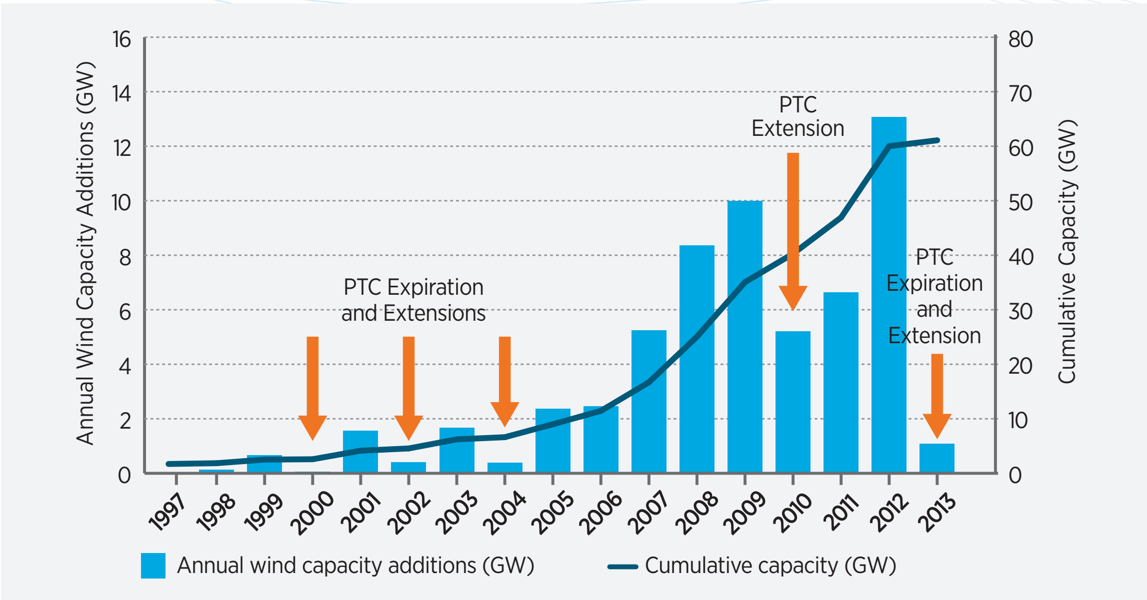
Despite growth of wind power in the United States, wind remains a relatively new contributor to the nation's power portfolio and has an uncertain future. Low natural gas prices and reduced demand for electricity have lowered wholesale power prices since 2008, making it more difficult for sources such as wind to compete in wholesale markets under 2013 market pricing mechanisms. Limited growth in electricity demand since 2008 has reduced investment in new electric generation of all types, including wind power.



Note: As of January 1, 2014 the PTC expired again and lapsed for a period of nearly 12 months. In December 2014 the PTC was extended again, although only through year-end 2014.

Figure 1–1. Historical wind deployment variability and the PTC

Uncertainty about federal support for wind power is also hampering investment [10, 11, 12]. The impact of this policy uncertainty was demonstrated in 2013, as 1.1 GW of new capacity was brought online in that year [8] without federal policy support, as compared to 13.1 GW in 2012 [7] with federal policy support. Figure 1-1 illustrates the boom-bust cycle created by expirations and late extensions or renewals of the federal production tax credit (PTC). As a result of these trends and conditions, independent projections suggest that annual wind capacity additions could fall to levels that are 50% below the 2009–2013 five-year average and 75% below the peak installation year of 2012 in the latter half of the 2010–2020 decade [13, 14, 15, 16].[1]

Projected reductions in demand for wind power could have varied consequences. Of particular significance is the potential loss of domestic wind manufacturing capacity and, in turn, U.S. wind industry jobs. Reduced near-term wind industry investment could also affect the feasibility and costs of achieving reductions in power sector emissions (i.e., carbon dioxide, sulfur dioxide, and nitrous oxide).

In this context, DOE initiated the *Wind Vision*. Led by the Wind and Water Power Technologies Office within DOE's Office of Energy Efficiency and Renewable Energy, the *Wind Vision* represents a collaboration of more than 250 energy experts with an array of specialties. This includes the wind industry, grid operators, science-based organizations, academia, government agencies, and environmental stewardship organizations.

The *Wind Vision* consists of four components:

1. Documentation of the current state of wind power in the United States and identification of key accomplishments and trends over the decade leading up to 2014 (Chapter 2);
2. Exploration of the potential 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 (Chapter 3);
3. Quantification of costs, benefits, and other impacts associated with continued deployment and growth of U.S. wind power (Chapter 3); and
4. Identification of actions and future achievements that could support continued growth in the use and application of wind-generated electricity (Chapter 4).

The findings detailed here and in subsequent chapters of the *Wind Vision* report explore each of these facets with the intention of informing policy makers, the public, and others on the impacts and potential of wind power for the United States.

Analysis, modeling inputs, and conclusions were generated by DOE with support from the national laboratories and are based on the best available information from the fields of science, technology, economics, finance, and engineering, as well as

Text Box 1-1.

Snapshot of the Wind Business in 2013

- Total wind capacity nationwide was 61 GW [6].
- Wind provided 4.5% of U.S. electricity end-use demand [6].
- 39 states had utility-scale wind projects; all 50 states had distributed wind projects [8].
- 17 states generated wind electricity in excess of 5% of their in-state generation; of these, 9 states exceed 12%, and Iowa and South Dakota both produced more than 25% of their in-state generation from wind [6].
- Several major electric utility system operators received nearly 10% or more of their electricity from wind power [3, 4].
- The wind business directly supported more than 50,500 jobs, with some 17,400 jobs in manufacturing spread over 43 states [8].
- The domestically-manufactured content of wind equipment installed in the United States increased over the previous decade, and was higher for large components such as blades, towers, and turbine assembly [7].

1. Wind deployments are expected to be consistent in 2015 with historical levels due to a provision in the latest federal tax credit extension that allows for projects under construction by year-end 2013 to qualify for the production tax credit, which formally expired on December 31, 2013. Accordingly, the full impact of the recent federal tax credit expiration is not anticipated in the market until 2016. The five-year average annual installation rate (from 2009–2013) is approximately 7.3 GW per year, while peak annual installed capacity exceeded 13 GW in 2012.

historical experience gained from a decade of industry growth and maturation. The *Wind Vision* report, particularly its assessment of costs and benefits, is intended to facilitate informed discussions among various stakeholder groups including energy sector decision makers; the wind power business, technology, and research communities; the electric power sector; and the general public about the future of wind power.

The *Wind Vision* and its associated analysis represent a technical update and expansion of a DOE report published in 2008, *20% Wind Energy by 2030—Increasing Wind Energy's Contribution to U.S. Electricity Supply* [1] (hereafter referred to as *20% Wind Energy by 2030*). The 2008 report was motivated by key issues at that time, including the technical feasibility of a scenario in which 20% of the nation's electricity demand is served by wind energy and the general magnitude of impacts associated with large-scale wind deployment. To address these complex questions, DOE—together with the domestic wind industry and representative organizations from the electric power, academia, and environmental sectors—conducted a thorough feasibility assessment from 2006 to 2008, resulting in the *20% Wind Energy by 2030* report.

The *Wind Vision* and its associated analysis represent a technical update and expansion of a DOE report published in 2008, *20% Wind Energy by 2030—Increasing Wind Energy's Contribution to U.S. Electricity Supply*

Since publication, results and conclusions of the 2008 study have been a valuable resource for wind development. The major points of *20% Wind Energy by 2030* are summarized in Appendix B. Of particular significance is that, as of year-end 2013, many of the 2008 report's modeled outcomes for 2013 have been surpassed, including those around wind power deployment rates and costs (Figure 1-2; see also Appendix B). The Text Box 1-1 provides a snapshot of the wind industry as of 2013.

	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)[1]	71	66	45

1. 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 1–2. Wind power progress since the 2008 DOE report, *20% Wind Energy by 2030*

1.1 Key Trends Motivating the *Wind Vision*

Major changes have occurred in the electric power sector since the early 2000s. In particular, there have been substantial reductions in the current and projected fuel costs for natural gas-fired electric generation, as well as significant reductions in the cost of energy from wind power and other renewable power technologies. These and other trends (documented in Chapter 2) affect the relative economic and environmental position of wind power in the portfolio of available generation options. In this context, an updated evaluation of the long-term potential for wind power and a new assessment of the possible contributions and impacts of future wind deployment are needed to inform planning and decision making.

1.1.1 Wind Business Evolution

Global investment in renewable power and fuels has increased five-fold since the early 2000s [17]. Public and private investment in wind has facilitated technology advancements that support record low costs and opened previously marginal resource areas to commercial wind power development. In particular, increases in wind turbine sizes and heights have contributed to improvements in energy production per unit of capacity. Since 2009, wind technology gains have been coupled with falling equipment prices, providing the conditions for an overall reduction in contracted prices for wind power of more than 50% [7].

Wind power resources at the national, regional, and local levels are better understood than in the past, and experience with siting and permitting of new land-based wind plants has grown since the mid-2000s. Enhanced wind resource characterization is enabling more informed investments into areas most likely to support viable wind power projects. Experience gained in permitting has facilitated more informed decision making by developers, local communities, and regulators, although it has also illuminated persistent challenges. Improved clarity in regulatory requirements and the application of lessons learned have created new opportunities for deployment of wind technology on land and in regions suited for offshore development.

These trends toward improved technology, better understanding of the resource and siting issues, and falling equipment costs, suggest opportunities for continued reductions in the cost of electricity from wind. By year-end 2013, 39 states had utility-scale wind projects and all 50 states had distributed wind projects [8].[2] With growth in offshore wind in Europe and several offshore projects in advanced stages in the United States, the emergence of a U.S. offshore wind sector is also increasingly viable.

1.1.2 Electric Sector Evolution

Recent advancements in horizontal drilling and hydraulic fracturing have increased supplies of natural gas and reduced both natural gas and wholesale electricity prices. A sluggish economy from 2008 to 2013 and increased energy efficiency measures have further slowed the growth of electricity demand and reduced the need for new generation of all types. This combination of relatively inexpensive fuel and decreased need for new electric generation has reduced the demand for new wind plants.[3] Under 2013 policy conditions, these forces may cause the U.S. market for wind equipment to fall below levels that support a vibrant industry and a robust domestic wind manufacturing sector [10].

In 2013, wind generation in Iowa and South Dakota exceeded 25% of the electricity generation in those states, and seven other states procured more than 12% of their annual in-state electricity supply from wind power.

At the same time, experience with wind power in the electric sector has been rapidly evolving. In 2013, wind generation in Iowa and South Dakota exceeded 25% of the electricity generation in those states, and seven

2. Distributed wind is the use of wind turbines at homes, farms and ranches, businesses, public and industrial facilities, off-grid, and other sites connected either physically or virtually on the customer side of the meter. These turbines are used to offset all or a portion of local energy consumption at or near those locations, or are connected directly to the local grid to support grid operations. Distributed wind systems can range in size from a 1-kilowatt or smaller off-grid wind turbine at a remote cabin to a 10-kilowatt turbine at a home or agricultural load to several multi-megawatt wind turbines at a university campus, manufacturing facility, or any large energy user.

3. The increased use of flexible natural gas-fired generation, however, has helped support wind integration. For additional detail, see Chapter 2.

Table 1–1. Trends in Global Wind Capacity Additions

Year	World Annual Installations (GW)	U.S. Annual Installations (GW)	Europe Annual Installations (GW)	China Annual Installations (GW)	World Total Wind Capacity (GW)
2011	39.0	6.8	9.6	17.6	238.0
2012	45.1	13.1	12.7	13.0	283.0
2013	35.5	1.1	12.0	16.1	318.1

Sources: Global Wind Energy Council 2014 [20], International Energy Agency, IEA Wind 2013 [21]

other states procured more than 12% of their annual in-state electricity supply from wind power. Wind accounted for 4.5% of U.S. electricity end-use demand in 2013 [6], while hydropower, the most prominent renewable power source by percentage, accounted for 7.2% of the nation's electricity end-use demand [18].

As of 2013, many electric utility and power system organizations had experience operating their systems with variable wind power. Power system operators with wind supplying approximately 10% or more of their power generation through 2013 include XcelEnergy and the Electric Reliability Council of Texas [3, 4]. These and other system operators have successfully developed strategies (e.g., use of wind forecasting, broad balancing areas) to better accommodate wind's variable output characteristics [2, 3, 4, 5] and treat wind as an established part of the generating fleet (see also Chapter 2). This compares with the early 2000s, when concerns existed about potential operating costs and reliability impacts associated with the introduction of wind power into the electric system.

1.1.3 Wind Manufacturing Sector Impacts

The domestically manufactured content of wind equipment installed in the United States increased in the decade leading up to 2013, especially for large components such as blades, towers, and turbine assembly [7]. Domestic demand has been identified as a key driver of wind power manufacturing investment [19]. If local markets for new installations deteriorate, manufacturing could move from the United States to other active regions of the world, including Asia and Europe (Table 1-1).

The domestically manufactured content of wind equipment installed in the United States increased in the decade leading up to 2013, especially for large components such as blades, towers, and turbine assembly.

Growth in new manufacturing facilities, which require significant capital, is limited by policy uncertainty but remains critical to continued innovation and future cost reductions. Projected reductions in demand for new wind power installations put U.S. wind manufacturing investment in more than 560 nationwide facilities at risk. Table 1-1 compares recent U.S. installation trends with outcomes in regions with more stable policy conditions, including Europe and China.

1.1.4 Economic and Environmental Impacts

Slow economic growth in the United States and worldwide has increased policy focus on economic development. Wind projects and manufacturing bring wind-related jobs, increased tax revenues, and capital investment to local economies [22, 23, 24], as well as an array of other economic and environmental impacts as highlighted in Text Box 1-2.[4] At the same time, wind investment displaces investment in other electric generation technologies.

Public awareness has expanded to focus not only on economic conditions, but also on climate change and other environmental concerns related to electricity generation. As a result, the relative impacts on the environment from clean energy sources such as wind power are beginning to figure more prominently into decisions affecting future capacity additions.

4. Unless otherwise specified, all financial results reported in this chapter are in 2013$.

Text Box 1-2.

Economic and Environmental Benefits of U.S. Wind Power through 2013

Affordable Energy: Power Purchase Agreements for land-based wind energy negotiated from 2011–2013 averaged about $30–$40/megawatt-hour (MWh), with regional variation from about $20 to $80/MWh [7] (2013$). These costs included policy support such as the PTC.

Employment and Local Economic Benefits: By the end of 2013, approximately 50,500 individuals were employed directly in the wind equipment supply, construction, and operation sectors, with 17,400 of these in the manufacturing sector [8]. In the 39 states with utility-scale wind deployment, wind plants create permanent jobs for site operations and provide local tax and lease payments.

Domestic Manufacturing: A growing portion of the equipment used in U.S. wind power projects since 2008 has been sourced domestically [7]. According to the American Wind Energy Association, there were 560 domestic wind-related manufacturing facilities at the end of 2013 [8].

Greenhouse Gas Reductions and Fossil Fuel Displacement: Estimates indicate wind power displaced 115 million metric tonnes of carbon dioxide nationally in 2013. Major utility companies have reported fleet-wide greenhouse gas reductions and have attributed these reductions in part to existing wind capacity [25].

Reduced Water Consumption: During the Texas drought of 2011, some fossil and nuclear power plants could not be operated because of shortages of cooling water. While this was occurring, the wind plants in Texas operated reliably and helped to maintain dependable electric service for customers of the Electric Reliability Council of Texas [26, 27]. National estimates indicate wind saved 36.5 billion gallons of water use within the electric power sector in 2013 [28].

1.2 Understanding the Future Potential for Wind Power

For the *Wind Vision*, economics-based electric sector modeling is used to establish a credible scenario from which costs and benefits could be calculated (Chapter 3).

This initial analysis includes a *BAU Scenario* and a series of sensitivities focused on wind costs, fossil fuel costs, and electricity demand. Analysis of wind deployment in these scenarios is conducted using the National Renewable Energy Laboratory's Regional Energy Deployment System (ReEDS) capacity expansion model, and is designed to inform the project team of the economic potential for wind based on changes in fundamental electric sector variables and assuming policy as of January 1, 2014.[5]

The National Renewable Energy Laboratory's ReEDS model is an electric sector capacity expansion model that calculates the competing costs of differing energy supply options and selects the most cost-effective solution. Model results are based on total system costs, including transmission, system planning, and operational requirements. ReEDS uses detailed spatial data to enable comparative electricity sector cost evaluation based on local costs and regional pricing. The model optimizes the construction and operation of electric sector assets to satisfy regional demand requirements while maintaining grid system adequacy. ReEDS uses its high spatial resolution and statistical treatment of variable wind

5. The federal production tax credit remains expired, state renewable portfolio standards policies are as written as of January 1, 2014, and the U.S. Environmental Protection Agency's Clean Power Plan is not modeled. Pending regulatory policies, including the Cross State Air Pollution Rule, Mercury Air Toxics Standard, and others, are captured only implicitly through announced coal plant retirements.

Table 1–2. Modeling Inputs and Assumptions in *Business-as-Usual Scenario* Modeling

Modeling Variables	*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

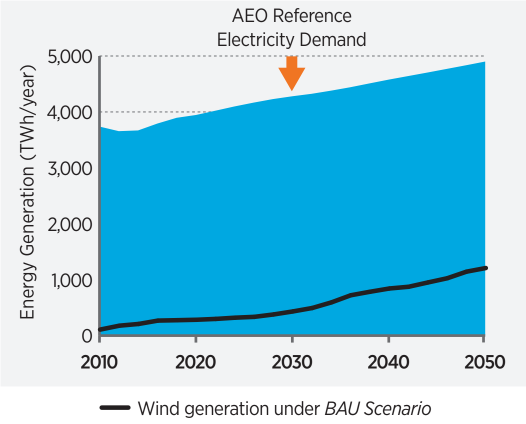
Sources: Energy Information Administration, 2014 [6], Annual Energy Outlook EIA 2014 [29], Eastern Interconnection Planning Collaborative [30].

(and solar) to represent the relative value of geographically and temporally constrained renewable power sources (see Chapter 3 and Appendices G and H for further detail).[6]

The project initially explores wind deployment under the *BAU Scenario*, which is summarized in Table 1-2 (see Chapter 3 and Appendices G and H for more detail).

The results of the *BAU Scenario* analysis suggest that wind generation would serve approximately 7% of total electricity demand once projects under construction at the end of 2013 (and qualified for the now-expired PTC) are placed into service. Minimal additional growth, up to 8% of total electricity demand, is observed by the mid-2020s. From 2015 to 2030, new wind capacity additions average 3 GW/year, less than 50% of the five-year average of approximately 7.3 GW/

6. ReEDS analysis scenarios represent economically optimal futures as determined by the ReEDs decision framework. Although these scenarios are not intended to be market projections or predictions of future wind deployment, they do provide insight into the potential for wind as a function of current power sector conditions and expectations for changes in key model variables with time (e.g., fuel and technology costs). The ReEDS model originated as the Wind Deployment System, or WinDS model, which was used in the *20% Wind Energy by 2030* report. Alaska and Hawaii are excluded from the modeling analysis in this study, as ReEDS is limited to modeling the 48 contiguous states.



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 currently enacted on January 1, 2014 (i.e., no wind PTC or ITC and no assumed changes in state level RPS policies). Percentage of end-use electricity demand data are contributions as of the end of the indicated period (e.g., 2009-2013).

Figure 1-3. Wind generation and average new capacity additions under *BAU*

year achieved from 2009 to 2013. Wind installations increase again in the late 2020s and return to levels more consistent with those prior to 2013 by the mid-2030s. Wind generation in the *BAU Scenario* is estimated at just over 1,200 terawatt-hours, or about 25% of total electricity demand in 2050 (Figure 1-3).

Starting from this initial *BAU Scenario,* a series of sensitivities is explored, evaluating changes in wind costs as well as changes in fossil fuel costs and demand.

High and low wind costs are bounded by the range of projected costs drawn from the literature (see Chapter 3 and Appendix H). High and low fossil fuel costs are based on the range of projected costs in the Energy Information Administration's *Annual Energy Outlook (AEO) 2014* [29] (see Chapter 3 and Appendix G). The sensitivities consider changes in single variables relative to the *BAU Scenario,* such as wind costs, as well as changes in multiple variables, such as low wind costs and high fossil fuel costs.

Table 1-3. Wind Penetration (% Share of End-Use Demand) in the *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%**

ReEDS analysis scenarios represent economically optimal futures as determined by the ReEDs decision framework. Although these scenarios are not intended to be market projections or predictions of future wind deployment, they do provide insight into the potential for wind as a function of current power sector conditions and expectations for changes in key model variables with time (e.g., fuel and technology costs). The ReEDS model originated as the Wind Deployment System, or WinDS model, which was used in the *20% Wind Energy by 2030* report. Alaska and Hawaii are excluded from the modeling analysis in this study, as ReEDS is limited to modeling the 48 contiguous states.

7. See Analytical Framework of the *Wind Vision* at the beginning of this chapter for a description of the scenarios analyzed.

Sensitivities with high wind costs, low fossil fuel costs, or low demand growth are observed to delay the onset of wind generation and capacity growth in the late 2020s under *BAU*, extending into the late 2030s or even the 2040s. Sensitivities that combine these variables (e.g., high wind power costs and low fossil fuel costs) result in levels of wind generation in 2050 slightly below 2013 levels, as minimal new capacity is added over the period of analysis and some existing wind capacity is retired at the end of its useful life.

Sensitivities with low wind costs, high fossil fuel costs, or high demand accelerate wind growth and drive results in wind penetration (as a share of end-use demand) to approximately 8% in 2020, 16% in 2030, and 33% in 2050. Sensitivities combining these variables (e.g., low wind costs and high fossil fuel costs) are found to support wind generation levels of 10% by 2020, 24% by 2030, and 41% by 2050 (Table 1-3).

Viewed as a whole, this analysis demonstrates that there is a broad array of potential futures for U.S. wind power. Even with a focus exclusively on wind costs and fossil fuel costs, under *BAU* conditions, wind could supply levels of generation that are essentially unchanged on the low end and in excess of 40% of total electricity demand by 2050 on the high end. Across many of the cases, wind becomes increasingly competitive with time. This occurs as wind costs continue to decline, electricity demand increases, fuel costs trend upwards, and existing power generation plants reach retirement age. These results, along with the potential for electric sector developments that are excluded from the sensitivities, indicate wind power could supply a substantial portion of future U.S. electricity needs.

1.3 Defining a Scenario for Calculating Costs, Benefits, and Other Impacts

Based on the modeling work described in this chapter, a scenario for calculating costs and benefits was selected and is referred to as the *Study Scenario.* This specific scenario is represented by a trajectory for wind generation that results in 10% of the nation's end-use demand being served by wind in 2020, 20% by 2030 and 35% by 2050.

Sensitivity analyses within the *Study Scenario* (detailed in Chapter 3) are used to assess the robustness of key results and highlight the impacts

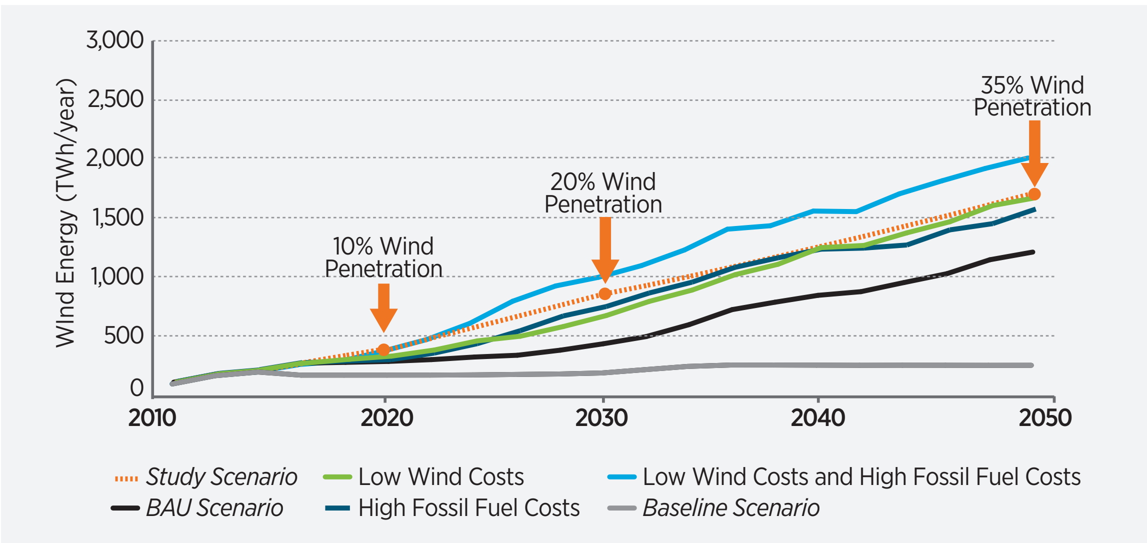
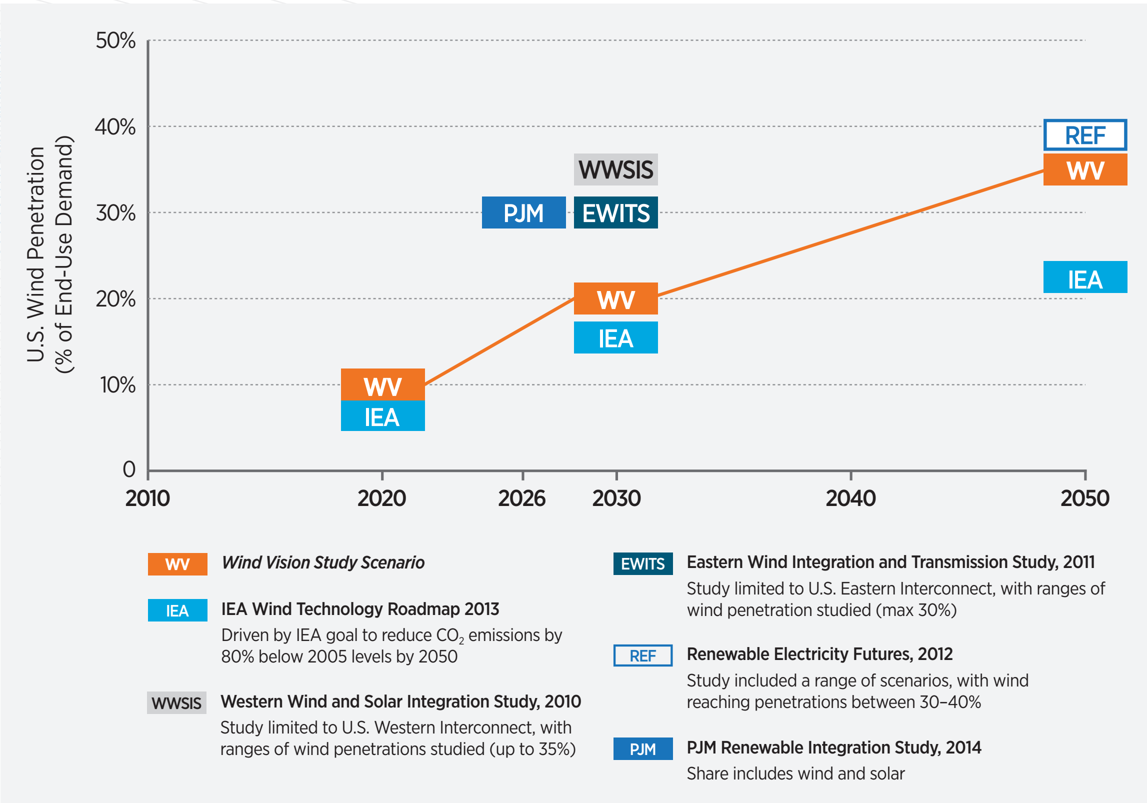


Figure 1-4. *Wind Vision Study Scenario* relative to *BAU Scenario* and Sensitivities

of varying wind costs and fossil fuel costs. The *Central Study Scenario,* which is the primary case discussed here and in the Executive Summary, applies *BAU* costs and performance, fuel costs, and policy treatment, but is distinguished from *BAU* modeling by its reliance on the *Study Scenario* wind power trajectory (10% by 2020, 20% by 2030, 35% by 2050).

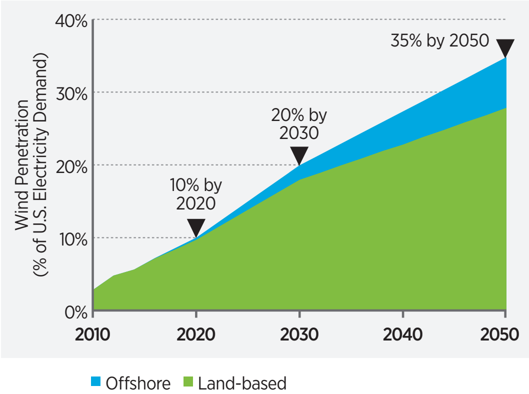
The positioning of the *Study Scenario* relative to the *BAU* results and a sub-sample of the sensitivities that entail aggressive wind cost reductions, high fossil fuel costs, or a combination of these two variables is shown in Figure 1-4. These data demonstrate that the *Study Scenario* falls within the range of outcomes indicated by economic modeling. The *Study Scenario* trajectory leverages and maintains the existing domestic industry's supply chain and manufacturing workforce, and maintains consistency with recent (i.e., 2010–2013) annual historical installations of new wind capacity.

The *Study Scenario* and the assessment of its impacts described in Chapter 3 build upon the *20% Wind Energy by 2030* report and other literature, as summarized in Figure 1-5. *Renewable Electricity Futures* [31] found wind penetration levels of 30–40% (of total end-use electricity demand) by 2050 across a series of scenarios that explored an 80% by 2050 renewable power future. A recent assessment of the literature conducted by the Intergovernmental Panel on Climate Change found median global wind penetration across carbon mitigation scenarios to be at levels of 13–14% by 2050, with a large number of scenarios (75th percentile) achieving levels of 21–25% by 2050 [32]. The International Energy Agency has estimated wind



Sources: International Energy Agency 2013 [33]; GE Energy 2010 [34]; Lew et al. 2013 [35]; EnerNex 2011 [36]; National Renewable Energy Laboratory 2012 [31]; Mai et al. 2014 [38]; GE Energy Consulting 2014 [39]

Figure 1–5. Wind penetration levels studied in recent literature



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 1–6. The *Wind Vision Study Scenario* and *Baseline Scenario*

penetration levels by 2050 that limit global mean temperature increases to 2°C at 15–18% globally and 20–25% for the United States [33]. In addition, an array of power system studies has examined comparable levels of wind penetration, illustrated in Figure 1-5.[8]

U.S. wind generation is based entirely on land-based technology as of 2014. The DOE recognizes, however, that offshore wind has become prominent in Europe—6.5 GW through year-end 2013 [40]—and could emerge in the United States in the near future. While the economics for offshore wind are unfavorable as of 2014, the *Study Scenario* includes an explicit allocation for offshore wind. Near-term (through 2020) offshore contributions are estimated based on projects in advanced stages of development in the United States and on global 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 (Figure 1-6). Due to quantitative modeling limitations, distributed wind applications are captured only at a qualitative level in the *Study Scenario*.

All subsequent analysis within the *Wind Vision* study is based on the *Study Scenario* trajectory and an associated scenario that provides the point of reference to calculate costs, benefits, and other impacts. This reference scenario is called the *Baseline Scenario;* it fixes installed wind capacity at year-end 2013 levels of 61 GW (Figure 1-6). Although the *Baseline Scenario* maintains wind capacity at this constant level, existing wind capacity is repowered in future years once the existing assets reach the end of their useful lives.

The *Baseline Scenario* construct allows estimates for system costs, rate impacts, land-use requirements, and transmission and integration impacts to be calculated for all future wind deployment. The benefits and impacts of large-scale wind deployment on greenhouse gas and air pollution emissions reductions, wind-supported domestic jobs, water use and withdrawal savings, air pollution impacts, and lease and property tax payments are estimated for all future wind additions. This approach highlights the degree of change within the electric power sector resulting from wind deployment specifically (e.g., new transmission needs resulting from wind deployment),

8. Such studies include the *Western Wind and Solar Integration Study* [33, 34], the Eastern Wind Integration and Transmission Study [36], and an array of regional and transmission operator studies evaluating future renewable power scenarios summarized and reported by [37]. Although there is substantial diversity covered by the literature in this space (i.e., some studies examine the build-out of the power system, while others focus on operational characteristics given high penetration wind), analysis examining timeframes beyond 2030 often considers wind penetration levels on the order of 20% and above. The *Western Wind and Solar Integration Study* explores scenarios in which wind and solar supply up to 35% penetration by 2030 within the U.S. Western Interconnect. The *Eastern Wind Integration and Transmission Study* considers a future for the Eastern Interconnect in which wind reaches up to 30% penetration by 2030. Specific power system studies summarized by [37] focus on capacity, but also demonstrate that high penetration wind (e.g., 10–50% on a capacity basis) can be managed at costs up to $5–10/MWh.

as well as the incremental impact of all future wind deployment, for the purposes of understanding the economic value of wind.

While the *Study Scenario* and *Baseline Scenario* provide the wind penetration growth trajectory, a series of sensitivities on the two scenarios highlight the changes in the resulting system costs and other relevant metrics associated with changes in wind costs and fossil fuel costs. For each variable, three sets of inputs are defined: low, central, and high. Within the sensitivity analysis, variables are altered independently (e.g., changing only the wind costs) and in combination (e.g., changing both wind costs and fossil fuel costs).

The *Wind Vision Study Scenario* is not designed to achieve any specific clean energy or carbon reduction goals. Nevertheless, the contributions of wind power in the *Study Scenario* support clean energy and carbon reduction goals. This scenario also entails a future for wind power that is consistent with broader national energy goals of grid resiliency, affordable electricity, and reduced environmental impacts including lower power sector carbon emissions.

It is possible that new disruptive concepts for converting wind power into electricity could emerge in the analysis period through 2050. Since it is difficult to predict such an occurrence, the *Wind Vision* and its *Study Scenario* do not explicitly include disruptive possibilities. The focus instead is on steady incremental optimization and continued advancement of concepts currently in use or under development. Should any major new concept emerge with potential for application at large scale, the content and results of this assessment would need to be reexamined.

1.4 Project Implementation

The *20% Wind Energy by 2030*, the *Wind Vision* study was conducted with wide-ranging participation from relevant stakeholder groups including the wind business, technology, and research communities; the electric power sector; environmental and energy-related non-governmental organizations; regulatory bodies; and government representatives at the federal and state levels. A complete listing of project participants and their contributions is in Appendix N.

DOE's Wind and Water Power Technologies Office managed the *Wind Vision* in collaboration with the American Wind Energy Association and the Wind Energy Foundation. These three organizations solicited the participation of the wind industry as well as broader stakeholders, including multiple organizations and industry sectors that view wind from a neutral perspective (including Independent System Operators, environmental stewardship organizations that evaluate wind's impacts on wildlife and the environment, other governmental organizations not related to renewable energy, and academia). Individual expert input for the project was provided by a Senior Peer Review Group comprising senior executives who represent wind, electric power, non-governmental organizations, academia, and government organizations, and who are intimately aware of wind power deployment and market issues. Overall project coordination was carried out by DOE.[9]

Eleven task forces covering the topic areas listed below conducted analyses and prepared sections of this report.

- Market Data and Analysis
- Scenario Modeling
- Wind Plant Technology
- Operations and Maintenance, Performance, and Reliability
- Manufacturing and Logistics
- Project Development and Siting
- Transmission and Integration
- Offshore Wind
- Distributed Wind
- Roadmap Development
- Communications and Outreach

Task forces each included 10–40 members, several of whom assumed primary responsibility for preparing key sections of this report. Representatives from four national laboratories—the National Renewable

9. The Office of Management and Budget's "Final Information Quality Bulletin" provides guidelines for properly managing peer review at federal agencies in compliance with section 515(a) of the Information Quality Act (Pub. L. No. 106-554). The *Wind Vision* assessment has followed these guidelines.

Energy Laboratory, Sandia National Laboratories, Lawrence Berkeley National Laboratory, and Pacific Northwest National Laboratory—provided leadership and technical expertise for each of the task forces. Other task force members included representatives from the wind industry (domestic and international), academia, the electric power sector, and non-governmental organizations. In addition to the task forces, 18 peer reviewers who were not involved in the writing or analysis reviewed the report content for accuracy and objectivity.

Various offices within DOE and other federal agencies also provided counsel and review throughout the effort. DOE's Office of Energy Efficiency and Renewable Energy was a principal internal adviser. DOE's Office of Energy Policy and Systems Analysis also provided guidance. Consultations were conducted with other DOE energy programs, including solar, geothermal, and water (hydro-electric), to obtain the best available information on characteristics for those technologies. Coordination was also established with other federal agencies, such as the U.S. Department of the Interior's Bureau of Ocean Energy Management, U.S. Environmental Protection Agency, Federal Energy Regulatory Commission, and the National Oceanic and Atmospheric Administration.

1.5 Report Organization

The *Wind Vision* examines the prospective contributions, impacts, and value offered by wind power as part of a diverse future low carbon electricity portfolio, and presents an updated scenario for wind expansion in 2020, 2030, and 2050. This introductory chapter is followed by three additional chapters and a series of appendices. Chapter 2 discusses the status of the wind industry, describing historic progress, relevant conditions as of 2013, and emerging trends. Chapter 3 describes the *Wind Vision* analysis and modeling results and provides a detailed discussion of the impacts associated with the *Study Scenario,* including expected costs and benefits. Chapter 4 identifies technical, economic, and institutional actions that could support achievement of the *Study Scenario*.

The appendices provide additional background and detail developed by the expert task forces:

- **Appendix A** is a glossary that contains definitions of frequently used terms in the report.
- **Appendix B** is a summary of the prior DOE report *20% Wind Energy by 2030.*
- **Appendix C** is a discussion of regulatory agencies and permitting processes affecting U.S. wind projects.
- **Appendix D** contains information on the costs and timeline for project permitting in 2014, providing further detail to topics discussed in Chapter 2.
- **Appendix E** contains information on the domestic supply chain capacity, providing further detail to topics discussed in Chapter 2.
- **Appendix F** contains information on testing facilities, providing further detail to topics discussed in Chapter 2.
- **Appendix G** contains additional, non-wind inputs and assumptions used for the ReEDS scenario modeling.
- **Appendix H** details the wind cost inputs and assumptions used for the ReEDS scenario modeling.
- **Appendix I** is a more detailed review of the Jobs and Economic Development Impacts Model (known as JEDI) used to quantify job impacts of the *Study Scenario*.
- **Appendix J** provides further details on the methods used to estimate greenhouse gas reductions of the *Study Scenario.*
- **Appendix K** provides further results from the analysis of the water impacts of the *Study Scenario.*
- **Appendix L** provides further details regarding the methods used to quantify the air pollution impacts of the *Study Scenario*.
- **Appendix M** provides detailed *Wind Vision* roadmap actions for relevant sectors, expanding upon material presented in Chapter 4.
- **Appendix N** lists the individuals who contributed to this project.
- **Appendix O** describes the impacts of higher turbine heights on the regional deployment of wind—including technology, marketing and permitting challenges.

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Chapter 1

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

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