



U.S. Department of Energy

Energy Efficiency and Renewable Energy

Bringing you a prosperous future where energy
is clean, abundant, reliable, and affordable



20% Wind Energy by 2030

Increasing Wind Energy's Contribution to
U.S. Electricity Supply

Prepublication Version

May 2008

GRATEFUL APPRECIATION TO PARTNERS

The U.S. Department of Energy would like to acknowledge the in-depth analysis and extensive research conducted by the National Renewable Energy Laboratory and the major contributions and manuscript reviews by the American Wind Energy Association and many wind industry organizations that contributed to the production of this report. The costs curves for energy supply options and the WinDS modeling assumptions were developed in cooperation with Black & Veatch. The preparation of this technical report was coordinated by Energetics Incorporated of Washington, DC and Renewable Energy Consulting Services, Inc. of Palo Alto, CA. All authors and reviewers who contributed to the preparation of the report are listed in Appendix D.

NOTICE

This report is being disseminated by the Department of Energy. As such, the document was prepared in compliance with Section 515 of the Treasury and General Government Appropriations Act for Fiscal Year 2001 (Public Law 106-554) and information quality guidelines issued by the Department of Energy. Further, this report could be "influential scientific information" as that term is defined in the Office of Management and Budget's Information Quality Bulletin for Peer Review (Bulletin). This report has been peer reviewed pursuant to section II.2 of the Bulletin.

Neither the United States government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof.

Available electronically at <http://www.osti.gov/bridge>

Available for a processing fee to U.S. Department of Energy and its contractors, in paper, from:

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: <mailto:reports@adonis.osti.gov>

Available for sale to the public, in paper, from:

U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: <http://www.ntis.gov/ordering.htm>



20% Wind Energy by 2030

Increasing Wind Energy's Contribution to U.S. Electricity Supply

DOE/GO-102008-2567 • May 2008

More information is available on the web at:

www.eere.energy.gov/windandhydro

<http://www.nrel.gov/docs/fy08osti/41869.pdf>

Prepublication Version
May 2008

Chapter 1. Executive Summary & Overview

1.1 INTRODUCTION AND COLLABORATIVE APPROACH

Energy prices, supply uncertainties, and environmental concerns are driving the United States to rethink its energy mix and develop diverse sources of clean, renewable energy. The nation is working toward generating more energy from domestic resources—energy that can be cost-effective, and replaced or “renewed” without contributing to climate change or major adverse environmental impacts.

In 2006, President Bush emphasized the nation’s need for greater energy efficiency and a more diversified energy portfolio. This led to a collaborative effort to explore a modeled energy scenario in which wind provides 20% of U.S. electricity by 2030. Members of this 20% wind collaborative (see 20% Wind Scenario sidebar) produced this report to start the discussion about issues, costs, and potential outcomes associated with the 20% Wind Scenario. A 20% Wind Scenario in 2030, while ambitious could be feasible if the significant challenges identified in this report are overcome.

This report was prepared by DOE in a joint effort with industry, government, and the Nation’s national laboratories (primarily the National Renewable Energy Laboratory and Lawrence Berkeley National Laboratory). The report considers some associated challenges, estimates the impacts and considers specific needs and outcomes in the areas of technology, manufacturing and employment, transmission and grid integration, markets, siting strategies, and potential environmental effects associated with a 20% Wind Scenario.

20% Wind Scenario: Wind Energy Provides 20% of U.S. Electricity Needs by 2030

Key Issues to Examine:

- Does the nation have sufficient wind energy resources?
- What are the wind technology requirements?
- Does sufficient manufacturing capability exist?
- What are some of the key impacts?
- Can the electric network accommodate 20% wind?
- What are the environmental impacts and benefits?
- Is the scenario feasible?

Assessment Participants:

- U.S. Department of Energy (DOE)
 - Office of Energy Efficiency and Renewable Energy (EERE), Office of Electricity Delivery and Energy Reliability (OE), and Power Marketing Administrations (PMAs)
 - National Renewable Energy Laboratory (NREL)
 - Lawrence Berkeley National Laboratory (Berkeley Lab)
 - Sandia National Laboratories (SNL)
- Black & Veatch engineering and consulting firm
- American Wind Energy Association (AWEA)
 - Leading wind manufacturers and suppliers
 - Developers and electric utilities
 - Others in the wind industry

In its Annual Energy Outlook 2007, the U.S. Energy Information Agency estimates that U.S. electricity demand will grow by 39% from 2005 to 2030, reaching 5.8 billion megawatt-hours (MWh) by 2030. To meet 20% of that demand, U.S. wind power capacity would have to reach more than 300 gigawatts (GW) or more than 300,000 megawatts (MW). This growth represents an increase of more than 290 GW within 23 years.¹

The data analysis and model runs for this report were concluded in mid-2007. All data and information in the report are based wind data available through the end of 2006. At the time this report was written (2007), the U.S. wind power fleet numbered 11.6 GW and spanned 34 states.² American wind farms are expected to generate an estimated 48 billion kilowatt-hours of wind energy in 2008, more than 1% of U.S. electricity supply. This capacity addition of 5,244 MW in 2007 exceeds the more conservative growth trajectory developed for the 20% Wind Scenario of about 4,000 MW/year in 2007 and 2008. The wind industry is on track to grow to a size capable of installing 16,000 MW/year, consistent with the latter years in the 20% Wind Scenario, more quickly than the trajectory used for this analysis.

1.1.1 SCOPE

This report examines some of the costs, challenges, and key impacts of generating 20% of the nation's electricity from wind energy in 2030. Specifically, it investigates requirements and outcomes in the areas of technology, manufacturing, transmission and integration, markets, environment and siting.

The modeling done for this report estimates that wind power installations with capacities of more than 300 gigawatts (GW) would be needed for the 20% wind in 2030 scenario. Increasing U.S. wind power to this level from today's 11.6 GW level would require significant changes in transmission, manufacturing and markets. This report presents an analysis of one specific scenario for reaching the 20% level and contrasts it to a scenario of no wind growth beyond the level in 2006. Major assumptions in the analysis have been highlighted throughout the document and have been summarized in the appendices. These assumptions may be considered optimistic. In this report, no sensitivity analyses have been done to estimate the impact that changes in the assumptions would have on the information presented here. As summarized at the end of this chapter, the analysis provides an overview of some potential impacts of these two scenarios by 2030. This report does not compare the Wind Scenario to other energy portfolio options, nor does it outline an action plan.

To successfully address energy security and environmental issues, the nation needs to pursue a portfolio of energy options. None of these options by itself can fully address these issues; there is no "silver bullet." This technical report examines one potential scenario in which wind power serves as a significant element in the portfolio. However, the 20% Wind Scenario is not a prediction of the future. Instead, it paints a picture of what a particular 20% Wind Scenario could mean for the nation.

¹ AEO data from 2007 were used in this report. AEO released new data in March of 2008, which were not incorporated into this report. While the new EIA data could change specific numbers in the report, it would not change the overall message of the report.

² According to AWEA, the U.S. wind energy industry installed 5,244 MW in 2007, expanding the nation's total wind power generating capacity by 45% in a single calendar year and more than doubling the 2006 installation of 2,454 MW. American Wind Energy Associations 2007 Market Report, January 2008. Government sources for validation of 2007 installed MW were not available at the time this report was written

1.1.2 CONTRIBUTORS

Report contributors include a broad cross section of key stakeholders, including leaders from the nation's utility sector, environmental communities, wildlife advocacy groups, energy industries, the government and policy sectors, investors, and public and private businesses. In all, the report reflects input from more than 50 key energy stakeholder organizations and corporations. Appendix D contains a list of contributors. Research and modeling was conducted by experts within the electric industry, government, and other organizations.

This report is not an authoritative expression of policy perspectives or opinions held by representatives of DOE.

1.1.3 ASSUMPTIONS AND PROCESS

To establish the groundwork for this report, the engineering company Black & Veatch (Overland Park, Kansas) analyzed the market potential for significant wind energy growth, quantified the potential U.S. wind supply, and developed cost supply curves for the wind resource. In consultation with DOE, NREL, AWEA, and wind industry partners, future wind energy cost and performance projections were developed. Similar projections for conventional generation technologies were developed based on Black & Veatch experience with power plant design and construction (Black and Veatch, forthcoming 2008).

To identify a range of challenges, possible solutions, and key impacts of providing 20% of the nation's electricity from wind, the stakeholders in the 20% Wind Scenario effort convened seven expert task forces to examine specific

Wind Energy Deployment System Model Assumptions (See Appendices A and B)

- Assumes that the contributions to U.S. electricity supplies from other renewable sources of energy would remain at 2006 levels in both scenarios.
- Assumes capital costs would be reduced by 10% over the next two decades and capacity factors would be increased by about 15% (corresponding to a 15% increase in annual energy generation by a wind plant)
- Assumes future environmental study and permit requirements are not expected to add significant costs to wind technology.
- The assumptions used for the WinDS model were obtained from a number of sources, including technical experts (see Appendix D), the WinDS base case (Denholm and Short 2006), AEO 2007 (EIA 2007), and a study performed by Black & Veatch (2007). These assumptions include projections of future costs and performance for all generation technologies, transmission system expansion costs, wind resources as a function of geographic location within the continental United States, and projected growth rates for wind generation.
- Assumes cost of new transmission is generally split between the originating project, be it wind or conventional generation, and the ratepayers within the region.
- Assumes that 10% of existing grid capacity is available for wind energy.
- Current long-term power purchase agreements are not implemented in WinDS. The model assumes that local load is met by the generation technologies in a given region.
- Wind energy generation prescribed annually at national level to reach 20% wind energy by 2030
 - A stable policy environment that supports accelerated wind deployment
 - Balance of generation economically optimized with no policy changes from those in place today (e.g., no production tax credit [PTC] beyond 12/31/08)
 - Technology cost and performance assumptions as well as electric grid expansion and operation assumptions that affect the direct electric system cost.
- Land-based and offshore wind energy technology cost reductions and performance improvements expected by 2030 (see tables A-1, B-10, and B-11)
- Fossil fuel technology costs and performance generally flat between 2005 and 2030 (see tables A-1 and B-13)
- Nuclear technology cost reductions expected by 2030 (see tables A-1 and B-13)
- Reserve and capacity margins calculated at the North American Electric Reliability Corporation (NERC) region level, and new transmission capacity added as needed (see sections A.2.2 and B.3)
- Wind resource as a function of geographic location from various sources (see Table B-8)
- Projected electricity demand, financing assumptions, and fuel prices based on *Annual Energy Outlook* (EIA 2007; see sections B.1, B.2, and B.4.2).

areas critical to this endeavor: Technology and Applications, Manufacturing and Materials, Environmental and Siting Impacts, Electricity Markets, Transmission and Integration, and Supporting Analysis. These teams conducted in-depth analyses of potential impacts, using related studies and various analytic tools to examine the benefits and costs. (See Appendix D for the task force participants.)

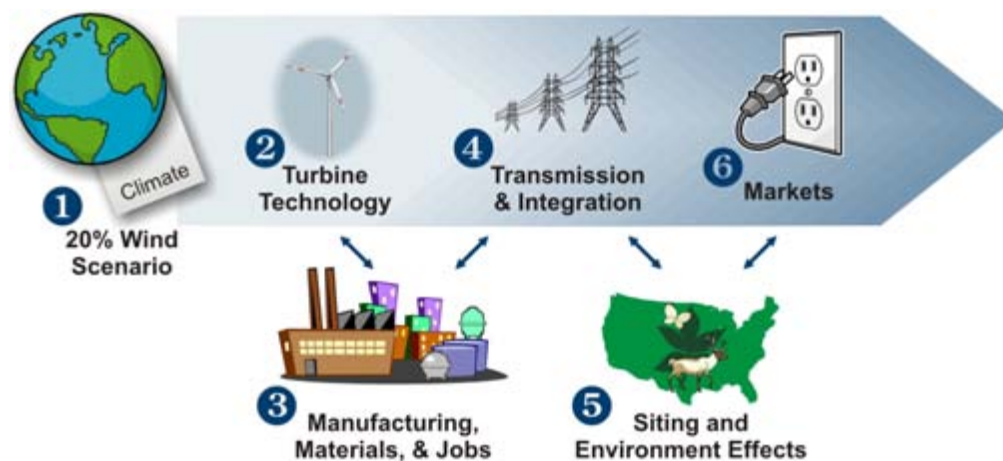
NREL's Wind Deployment System (WinDS) model³ was employed to create a scenario that paints a "picture" of this level of wind energy generation and evaluates some impacts associated with wind. Assumptions about the future of the U.S. electric generation and transmission sector were developed in consultation with the task forces and other parties. Some assumptions in this analysis could be considered optimistic. Examples of assumptions used in this analysis are listed in the text box and are presented in detail in Appendix A and B. For comparison, the modeling team contrasted the 20% Wind Scenario impacts to a reference case characterized by no growth in U.S. wind capacity or other renewable energy sources after 2006.

In the course of the examination, two workshops were held to define and refine the work plan, present and discuss preliminary results, and obtain relevant input from key stakeholders external to the report preparation effort.

1.1.4 REPORT STRUCTURE

A 20% wind energy scenario in 2030 would require improved turbine technology to generate wind power, significant changes in transmission systems to deliver it through the electric grid, and large expanded markets to purchase and use it. In turn, these essential changes in the power generation and delivery process would involve supporting changes and capabilities in manufacturing, policy development, and environmental regulation. As shown in Figure 1-1, the chapters of this report address some of the requirements and impacts in each of these areas. Detailed discussions of the modeling process, assumptions, and results can be found in appendices A through C.

Figure 1-1. Report chapters



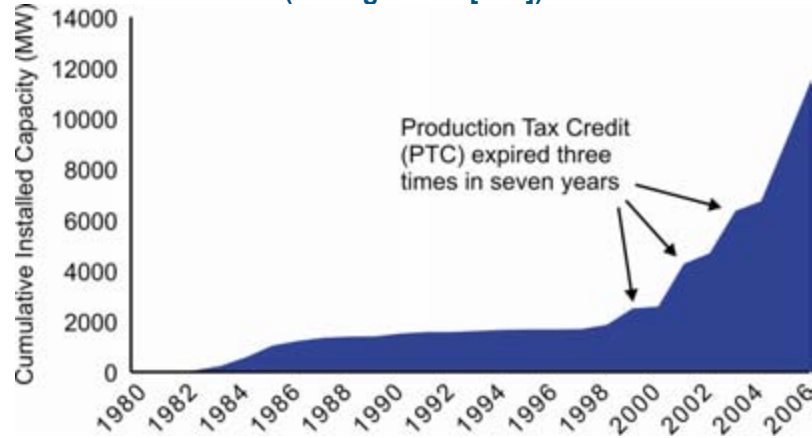
³ The model, developed by NREL's Strategic Energy Analysis Center (SEAC), is designed to address the principal market issues related to the penetration of wind energy technologies into the electric sector. For additional information and documentation, see text box entitled "Wind Energy Deployment Model Assumptions," Appendices A and B, and <http://www.nrel.gov/analysis/winds/>

1.1.5 SETTING THE CONTEXT: TODAY'S U.S. WIND INDUSTRY

After experiencing strong growth in the mid-1980s, the U.S. wind industry hit a plateau during the electricity restructuring period in the 1990s, then regained momentum in 1999. Industry growth has since responded positively to policy incentives when they are in effect (see Figure 1-2). Today, the U.S. wind industry is growing rapidly, driven by sustained production tax credits (PTCs), rising concerns about climate change, and renewable portfolio standards (RPS) or goals in roughly 50% of the states.

U.S. turbine technology has advanced steadily to offer improved performance. In 2006 alone, average turbine size increased by more than 11% over the 2005 level to an average size of 1.6 MW. In addition, average capacity factors have improved 11% over the past two years. To meet the growing demand for wind energy, U.S. manufacturers have expanded their capacity to produce and assemble the essential components. Despite this growth, U.S. components continue to represent a relatively small share of total turbine and tower materials, and U.S. manufacturers are struggling to keep pace with rising demand (Wiser & Bolinger, 2007).

Figure 1-2. Cumulative U.S. wind capacity, by year (in megawatts [MW])



Initiatives to Improve Wind Turbine Performance

Avoid problems before installation

- Improve reliability of turbines and components
- Full-scale testing prior to commercial introduction
- Development of appropriate design criteria, specifications and standards
- Validation of design tools

Monitor Performance

- Monitor and evaluate turbine and wind-plant performance
- Performance tracking by independent parties
- Early identification of problems

Rapid Deployment of Problem Resolution

- Develop and communicate problem solutions
- Focused activities with stakeholders to address critical issues, e.g., Gearbox Reliability Collaborative

In 2005 and 2006, the United States led the world in new wind installations. By early 2007, global wind power capacity exceeded 74 GW, and U.S. wind power capacity totaled 11.5 GW. This domestic wind power has been installed across 35 states and delivers roughly 0.8% of the electricity consumed in the nation (Wiser and Bolinger, 2007).

A Brief History of the U.S. Wind Industry

The U.S. wind industry got its start in California during the 1970s, when the oil shortage increased the price of electricity generated from oil. The California wind industry benefited from federal and state investment tax credits (ITCs) as well as state-mandated standard utility contracts that guaranteed a satisfactory market price for wind power. By 1986, California had installed more than 1.2 GW of wind power, representing nearly 90% of global installations at that time.

Expiration of the federal ITC in 1985 and the California incentive in 1986 brought the growth of the U.S. wind energy industry to an abrupt halt in the mid-1980s. Europe took the lead in wind energy, propelled by aggressive renewable energy policies enacted between 1974 and 1985. As the global industry continued to grow into the 1990s, technological advances led to significant increases in turbine power and productivity. Turbines installed in 1998 had an average capacity 7 to 10 times greater than that of the 1980s turbines, and the price of wind-generated electricity dropped by nearly 80% (AWEA 2007). By 2000, Europe had more than 12,000 MW of installed wind power, versus only 2,500 MW in the United States, and Germany became the new international leader.

With low natural gas prices and U.S. utilities preoccupied by industry restructuring during the 1990s, the federal PTC enacted in 1992 (as part of the Energy Policy Act [EPAAct]) did little to foster new wind installations until just before its expiration in June 1999. Nearly 700 MW of new wind generation were installed in the last year before the credit expired—more than in any previous 12-month period since 1985. After the PTC expired in 1999, it was extended for two brief periods, ending in 2003. It was then reinstated in late 2004. Although this intermittent policy support led to sporadic growth, business inefficiencies inherent in serving this choppy market inhibited investment and restrained market growth.

Energy Policy Act of 1992

The PTC gave power producers 1.5 cents (increased annually with inflation) for every kilowatt-hour (kWh) of electricity produced from wind during the first 10 years of operation.

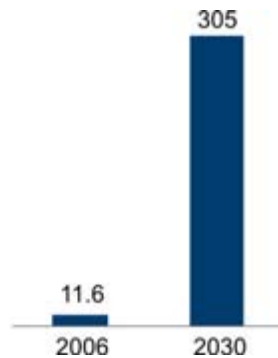
To promote renewable energy systems, many states began requiring electricity suppliers to obtain a small percentage of their supply from renewable energy sources, with percentages typically increasing over time. With Iowa and Texas leading the way, more than 20 states have followed suit with RPS, creating an environment for stable growth.

After a decade of trailing Germany and Spain, the United States reestablished itself as the world leader in new wind energy in 2005. This resurgence is attributed to increasingly supportive policies, growing interest in renewable energy, and continued improvements in wind technology and performance. The United States retained its leadership of wind development in 2006 and, because of its very large wind resources, is likely to remain a major force in the highly competitive wind markets of the future.

1.2 SCENARIO DESCRIPTION

The 20% Wind Scenario presented here would require U.S. wind power capacity to grow from the current 11.5 GW to more than 300 GW over the next 23 years (see Figure 1-3). This ambitious growth could be achieved in many different ways, with

Figure 1-3. Required growth in U.S. capacity (GW) to implement the 20% Wind Scenario



varying challenges, impacts, and levels of success. The 20% Wind Scenario would require an installation rate of 16 GW per year after 2018 (See Figure 1-4). This report examines one particular scenario for achieving this dramatic growth and contrasts it to another scenario that—for analytic simplicity—assumes no wind growth after 2006. The authors recognize that U.S. wind capacity is currently growing rapidly (although from a very small base), and that wind energy technology will be a part of any future electricity generation scenario for the United States. At the

same time, a great deal of uncertainty remains about the level of contribution that wind could or is likely to make. In the 2007 *Annual Energy Outlook* (EIA 2007), an additional 7 GW beyond the 2006 installed capacity of 11.6 GW is forecast by 2030.⁴ Other organizations are projecting higher capacity additions, and it would be difficult to develop a “most likely” forecast given today’s uncertainties. The analysis presented here sidesteps these uncertainties and contrasts some of the challenges and impacts of producing 20% of the nation’s electricity from wind with a scenario in which no additional wind is added after 2006. This results in an estimate, expressed in terms of parameters, of the impacts and benefits associated with increased reliance on wind energy generation under given assumptions. The analysis was also simplified by assuming that the contributions to U.S. electricity supplies from other renewable sources of energy would remain at 2006 levels in both scenarios (see Figure A-6 for resource mix).

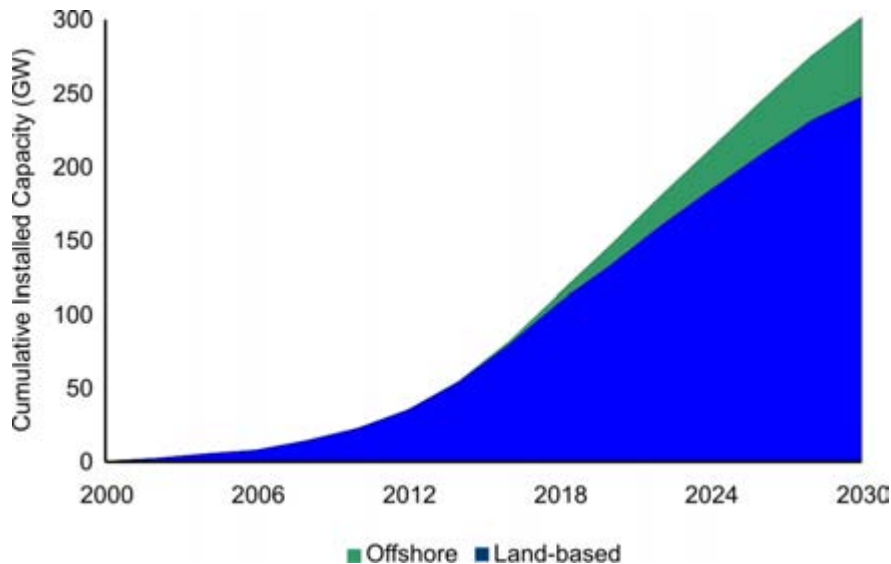
The 20% Wind Scenario has been carefully defined to provide a base of common assumptions for detailed analysis of all impact areas. Broadly stated, this 20% scenario is designed to consider incremental costs while recognizing realistic constraints and considerations (see the Considerations in the 20% Scenario sidebar in Appendix A). Specifically, the scenario describes the mix of wind resources that would need to be captured, the geographic distribution of wind power installations, estimated land needs, the required utility and transmission infrastructure, manufacturing requirements, and the pace of growth that would be necessary.

1.2.1 WIND GEOGRAPHY

The United States possesses abundant wind resources. As shown in Figure 1-5, current “bus-bar” energy costs for wind (based on costs of the wind plant only, excluding transmission and integration costs and the PTC) vary by type of location

⁴ AEO data from 2007 were used in this report. AEO released new data in March of 2008, which were not incorporated into this report. While new EIA data could change specific numbers in this report, it would not change the overall message of the report.

Figure 1-4. 20% Cumulative installed wind power capacity required to produce 20% of projected electricity by 2030

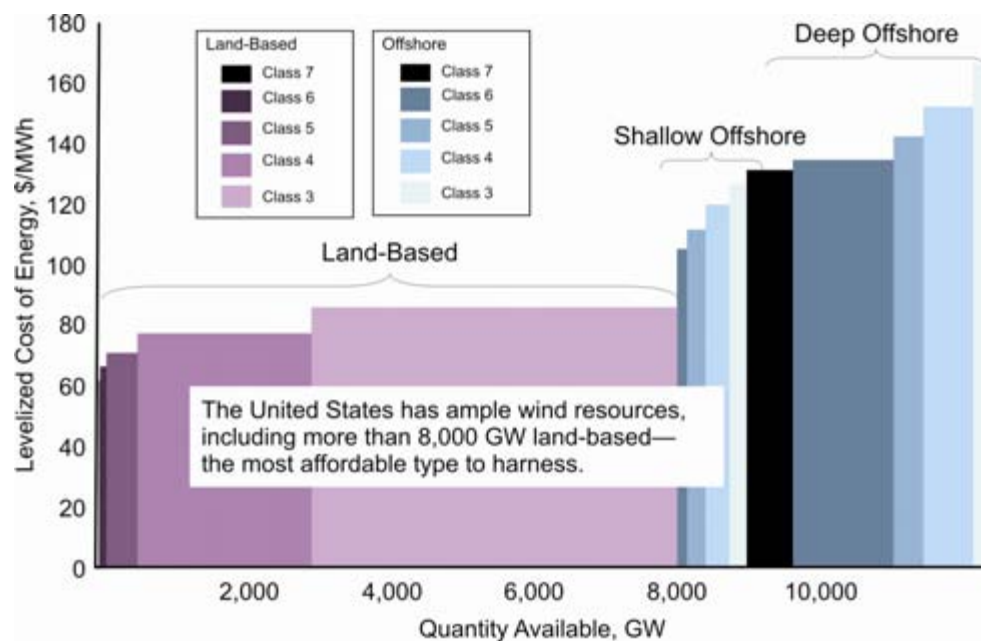


(land-based or offshore) and by class of wind power density (higher classes offer greater productivity). Transmission and integration will add additional costs which are discussed in Chapter 4. The nation has more than 8,000 GW of available land-based wind resources (Black and Veatch, forthcoming 2008) that industry estimates can be captured economically. NREL periodically classifies wind resources by wind speed which forms the basis of the Black and Veatch study. See

Appendix B for further details.

Electricity must, however, be transmitted from where it is generated to areas of high electricity demand, using the existing transmission system or new transmission lines where necessary. As shown in Figure 1-6 on the next page, the delivered cost of wind power increases when costs associated with connecting to the existing electric grid are included. The assumptions used in this report are different than EIA's assumptions and are documented in Appendix A & B. The cost and performance assumptions of the 20% Wind Scenario are based on real market data from 2007.

Figure 1-5. Supply curve for wind energy—current bus-bar energy costs



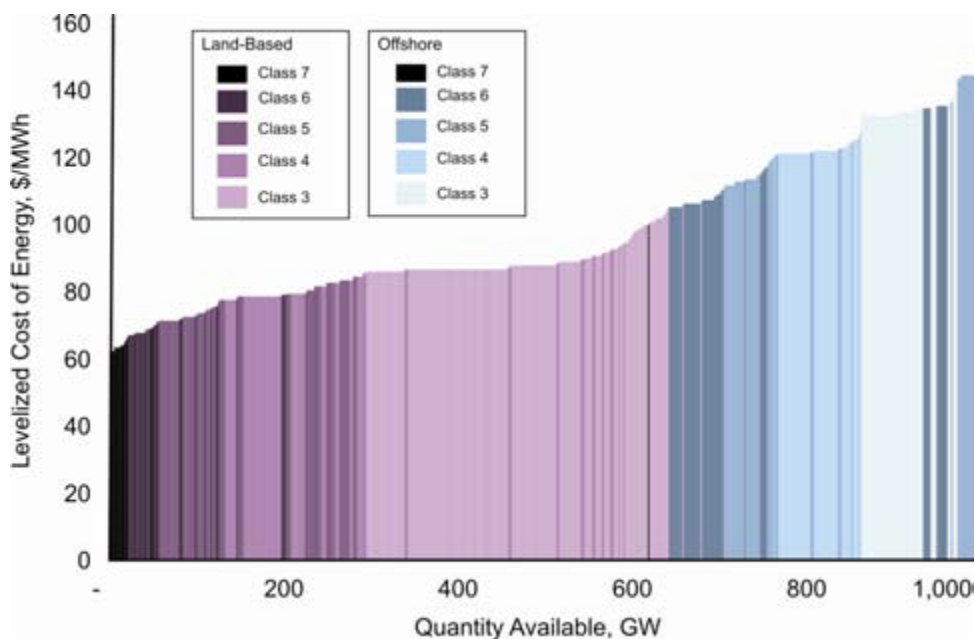
See Appendix B for wind technology cost and performance projections; PTC and transmission and integration costs are excluded.

Cost and performance for all technologies either decrease or remain flat over time. The models suggest that as much as 600 GW of wind resources could be available for \$60 to \$100 per megawatt-hour (MWh), including the cost of connecting to the existing transmission system. Including the PTC reduces the cost by about \$20/MWh, and costs are further reduced if technology improvements in cost and performance are projected. In some cases, new transmission lines connecting high-wind resource areas to load centers could be cost-effective, and in other cases, high transmission costs could offset the advantage of land-based generation, as in the case of large demand centers along wind-rich coastlines.

NREL’s WinDS model estimated the overall U.S. generation capacity expansion required to meet projected electricity demand growth through 2030. Both wind technology and conventional generation technology (i.e., coal, nuclear) were included in the modeling but other renewables were not. Readers should refer to Appendices A and B to see a more complete list of the modeling assumptions. Wind energy development for this 20% Wind Scenario optimized the total delivered costs, including future reductions in cost per kilowatt-hour for wind sites both near to and remote from demand sites from 2000 through 2030.⁵ Chapter 2 presents additional discussion of wind technology potential. Of the 293 GW that would be added, the model specifies more than 50 GW of offshore wind energy, mostly along the northeastern and southeastern seaboards.

Based on this least-cost optimization algorithm (which incorporates future cost per kilowatt-hour of wind and cost of transmission), the WinDS model further specified

Figure 1-6. Supply curve for wind energy—energy costs including connection to 10% of existing transmission grid capacity



Note: See Appendix B for wind technology cost and performance projections. Excludes PTC, includes transmission costs to access existing electric transmission within 500 miles of wind resource.

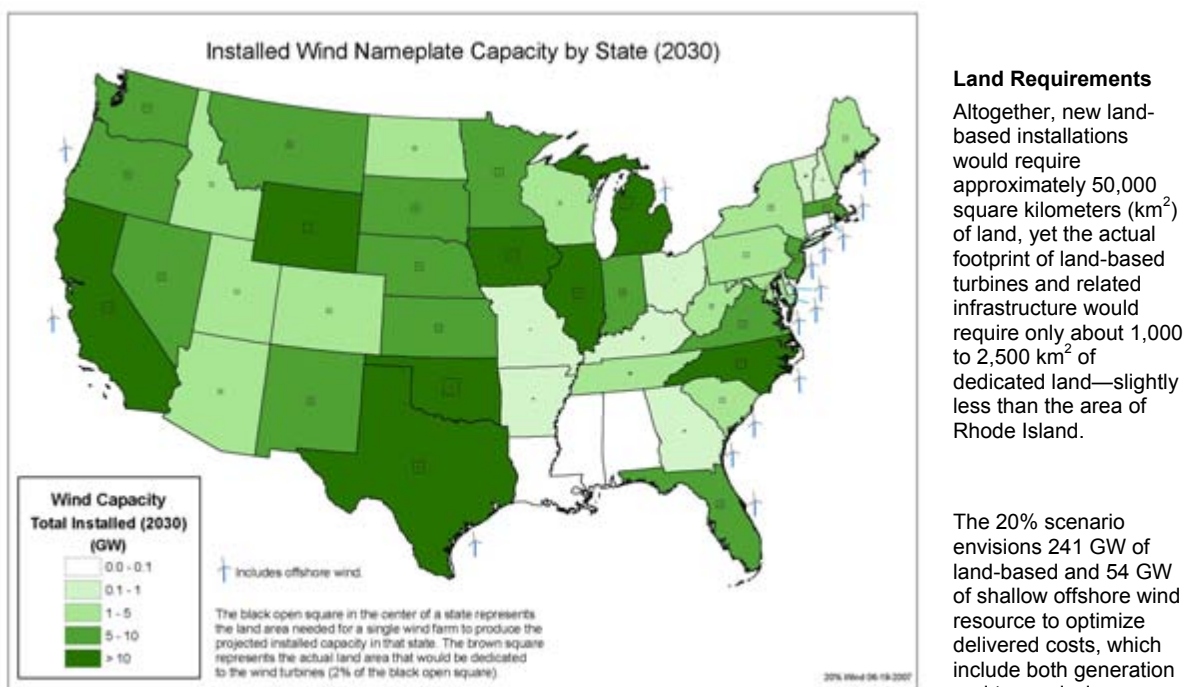
⁵ The modeling assumptions prescribed annual wind energy generation levels that reached 20% of projected demand by 2030 so as to demonstrate technical feasibility and quantify costs and benefits. Policy options that would help induce this growth trajectory were not included. It is assumed that a

the wind capacity needed by state by 2030. As shown in Figure 1-6, most states would have the opportunity to develop their wind resources. Total land requirements are extensive, but only about 2% to 5% of the total would be dedicated entirely to the wind installation. In addition, the visual impacts and other siting concerns of wind energy projects must be taken into account in assessing land requirements. Chapter 5 contains additional discussion of land use and visual impacts. Again, the 20% Wind Scenario presented here is not a prediction. Figure 1-6 simply shows one way in which a 20% wind future could evolve.

1.2.2 WIND POWER TRANSMISSION AND INTEGRATION

Development of 293 GW of new wind capacity would require expanding the U.S. transmission grid in a manner that not only accesses the best wind resource regions of the country but also relieves current congestion on the grid including new transmission lines to deliver wind power to electricity consumers. Figure 1-7 conceptually illustrates the optimized use of wind resources within the local areas as well as the transmission of wind-generated electricity from high-resource areas to high-demand centers. This data was generated by the WinDS model given prescribed constraints. The figure does not represent proposals for specific

Figure 1-7. 46 States would have substantial wind development by 2030



Land Requirements

Altogether, new land-based installations would require approximately 50,000 square kilometers (km²) of land, yet the actual footprint of land-based turbines and related infrastructure would require only about 1,000 to 2,500 km² of dedicated land—slightly less than the area of Rhode Island.

The 20% scenario envisions 241 GW of land-based and 54 GW of shallow offshore wind resource to optimize delivered costs, which include both generation and transmission.

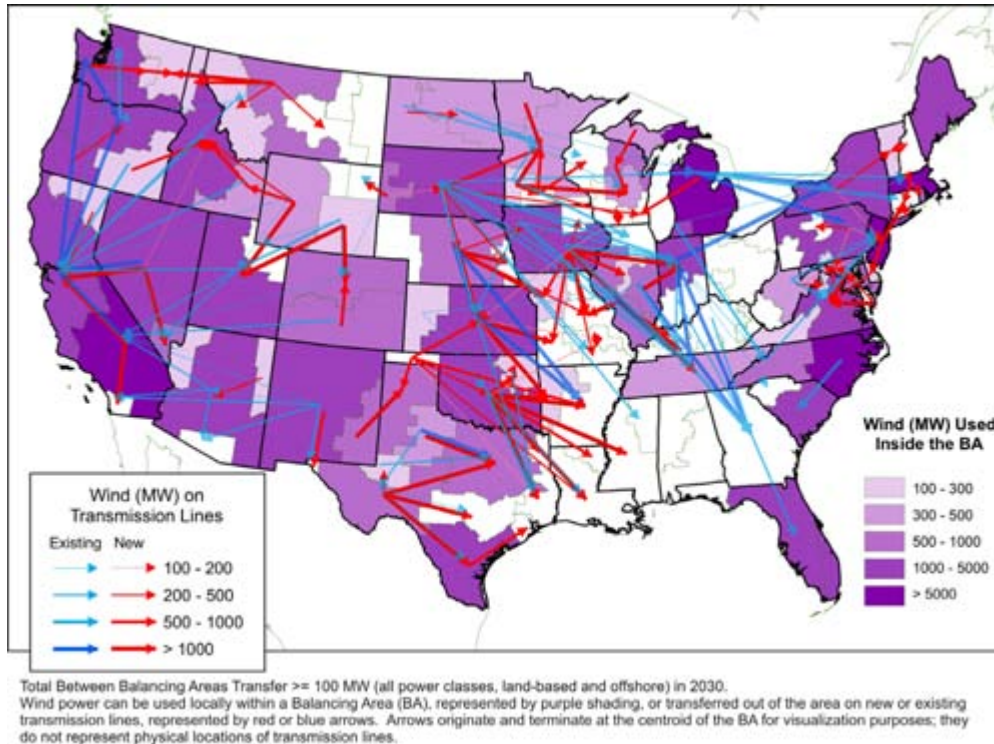
Wind capacity levels in each state depend on a variety of assumptions and the national optimization of electricity generation expansion. Based on the perspectives of industry experts and near-term wind development plans, wind capacity in Ohio was modified and offshore wind development in Texas was included. In reality, each state's wind capacity level will vary significantly as electricity markets evolve and state policies promote or restrict the energy production of electricity from wind and other renewable and conventional energy sources.

transmission lines.

stable policy environment that recognizes wind's benefits could lead to growth rates that would result in the 20% Wind Scenario.

Figure 1-8 displays transmission needs in the form of one technically feasible transmission grid as a 765 kV overlay. A complete discussion of transmission issues can be found in Chapter 4.

Figure 1-8. All new electrical generation including wind energy would require expansion of U.S. transmission by 2030

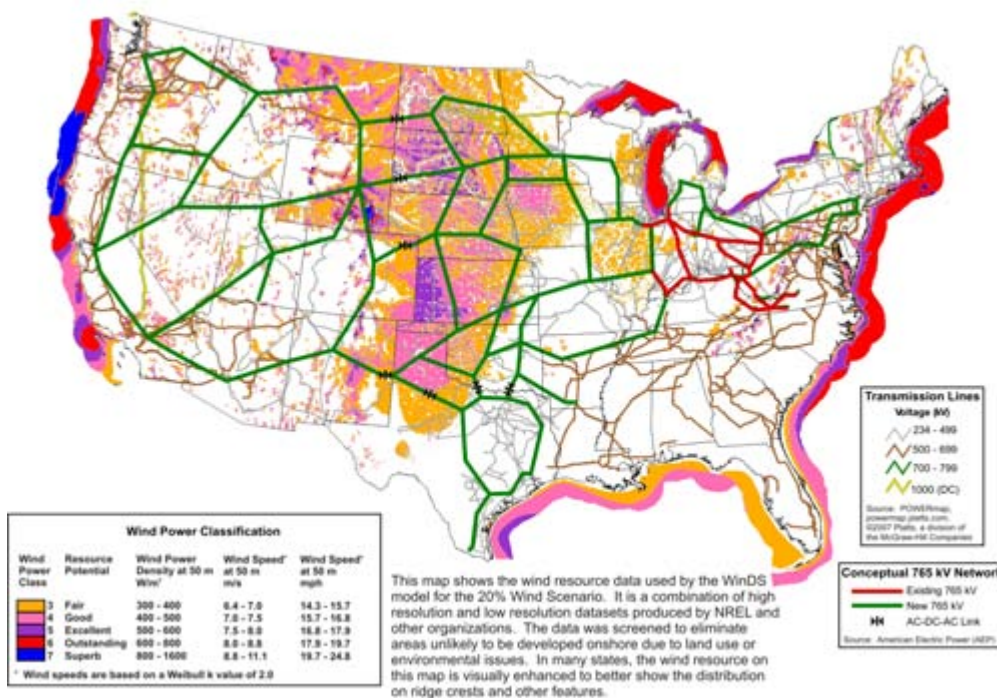


Until recently, concerns had been prevalent in the electric utility sector about the difficulty and costs of dealing with the variability and uncertainty of energy production from wind plants and other weather-driven renewable technologies. But utility engineers in some parts of the United States now have extensive experience with wind plant impacts, and their analyses of these impacts have helped to reduce these concerns. As discussed in detail in Chapter 4, wind's variability is being accommodated, and given optimistic assumptions, studies suggest the cost impact could be as little as the current level - 10% or less of the value of the wind energy generated.

1.2.3 ELECTRICAL ENERGY MIX

The U.S. Energy Information Administration (EIA) estimates that U.S. electricity demand will grow by 39% from 2005 to 2030, reaching 5.8 billion MWh by 2030. The 20% Wind Scenario would require delivery of nearly 1.16 billion MWh of wind energy in 2030, altering U.S. electricity generation as shown in Figure 1-9. In this scenario, wind would supply enough energy to displace about 50% of natural gas electric utility consumption and 18% of coal consumption by 2030. This amounts to an 11% reduction in natural gas across all industries. (Gas-fired generation would probably be displaced first, because it typically has a higher cost.)

Figure 1-9. Conceptual transmission plan to accommodate 400 GW of wind energy (AEP 2007)

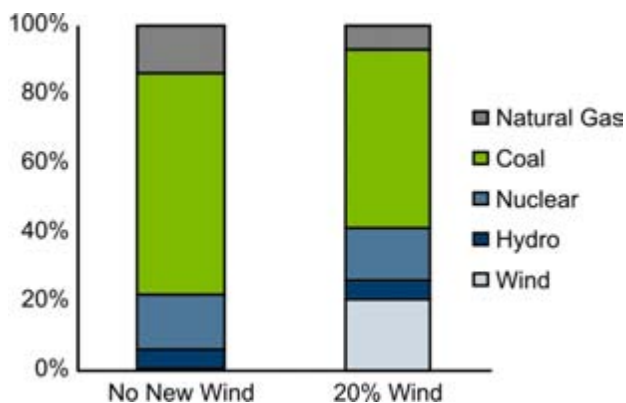


The increased wind development in this scenario could reduce the need for new coal and combined cycle natural gas capacity, but would increase the need for additional combustion turbine natural gas capacity to maintain electric system reliability. These units, though, would be run only as needed.⁶

1.2.4 PACE OF NEW WIND INSTALLATIONS

Manufacturing capacity would require some time to ramp up to support rapid growth in new U.S. wind installations. The 20% Wind Scenario estimates that the installation rate would need to increase from installing 3 GW per year today to more

Figure 1-10. U.S. electrical energy mix



than 16 GW per year by 2018 and continue at roughly that rate through 2030, as seen in Figure 1-10. This increase in installation rate, although quite large, is comparable to the recent annual installation rate of natural gas units, which totaled more than 16 GW in 2005 alone (EIA 2005).

The assumptions of the 20% Wind Scenario form the foundation for the technical analyses presented in the remaining chapters. This overview is provided as context for the potential impacts and technical challenges discussed in the next sections.

⁶ Appendix B presents a full analysis of changes in the capacity mix and energy generation under the 20% Wind Scenario.

1.3 IMPACTS

The 20% Wind Scenario presented here offers potentially positive impacts in terms of GHG reductions, water conservation, and energy security, as compared to the base case of no wind growth in this analysis. However, tapping this resource at this level would entail large front-end capital investments to install wind capacity and expanded transmission systems. The impacts described in this section are based largely on the analytical tools and methodology discussed in detail in appendices A, B, and C.

Wind power would be a critical part of a broad and near-term strategy to substantially reduce air pollution, water pollution, and global climate change associated with traditional generation technologies (see Wind versus Traditional Electricity Generation sidebar). As a domestic energy resource, wind power would also stabilize and diversify national energy supplies.

1.3.1 GREENHOUSE GAS REDUCTIONS

Supplying 20% of U.S. electricity from wind could reduce electric sector carbon dioxide (CO₂) emissions by 825 million metric tons.

The threat of climate change and the growing attention to it are helping to position wind power as an increasingly attractive option for new power generation. U.S. electricity demand is growing rapidly, and cleaner power sources (e.g., renewable energy) and energy-saving practices (i.e., energy efficiency) could help meet much of the new demand while reducing GHG emissions. Today, wind energy represents approximately 30% of new capacity additions (AWEA 2008). Greater use of wind energy, therefore, presents an opportunity for reducing emissions today as the nation develops additional clean power options for tomorrow.

Wind vs. Traditional Electricity Generation

Wind power avoids several of the negative effects of traditional electricity generation from fossil fuels:

- Emissions of mercury or other heavy metals into the air
- Emissions associated with extracting and transporting fuels.
- Lake and streambed acidification from acid rain or mining
- Water consumption associated with mining or electricity generation
- Production of toxic solid wastes, ash, or slurry
- Greenhouse gas (GHG) emissions

20% Wind Scenario: Projected Impacts

- **Environment:** Avoids air pollution, reduces GHG emissions, and reduces water use in electricity generation. Reduces electric sector CO₂ emissions by 825 million metric tons.
- **U.S. energy security:** Diversifies our electricity portfolio and represents an indigenous energy source with stable prices not subject to fuel volatility
- **Energy consumers:** Wind potentially reduces demand for fossil fuels, in turn reducing fuel prices and stabilizing electricity rates
- **Local economics:** Creates new income source for rural landowners and tax revenues for local communities in wind development areas.
- **American workers:** Generates well-paying jobs in sectors that support wind development, such as manufacturing, engineering, construction, transportation, and financial services. The new manufacturing will cause significant growth in the wind industry supply chain.
- **Water savings:** Reduce cumulative water use in the electric sector by 8% (4 trillion gallons)

20% Wind Scenario: Major Challenges

- Investment in the nation's transmission system so the power generated is delivered to urban centers that need the increased supply;
- Larger electric load balancing areas, in tandem with better regional planning, so that regions can depend on a diversity of generation sources, including wind power;
- Continued reduction in wind capital cost and improvement in turbine performance through technology advancement and improved manufacturing capabilities; and
- Addressing potential concerns about local siting, wildlife, and environmental issues within the context of generating electricity.

Concerns about climate change have spurred many industries, policy makers, environmentalists, and utilities to call for reductions in GHG emissions. Although the cost of reducing emissions is uncertain, the most affordable near-term strategy likely involves wider deployment of currently available efficiency and clean energy technologies. Wind power is one of the potential supply-side solutions to the climate change problem (Socolow and Pacala 2006).

Governments at many levels have enacted policies to actively support clean electricity generation, including the renewable energy PTC and state

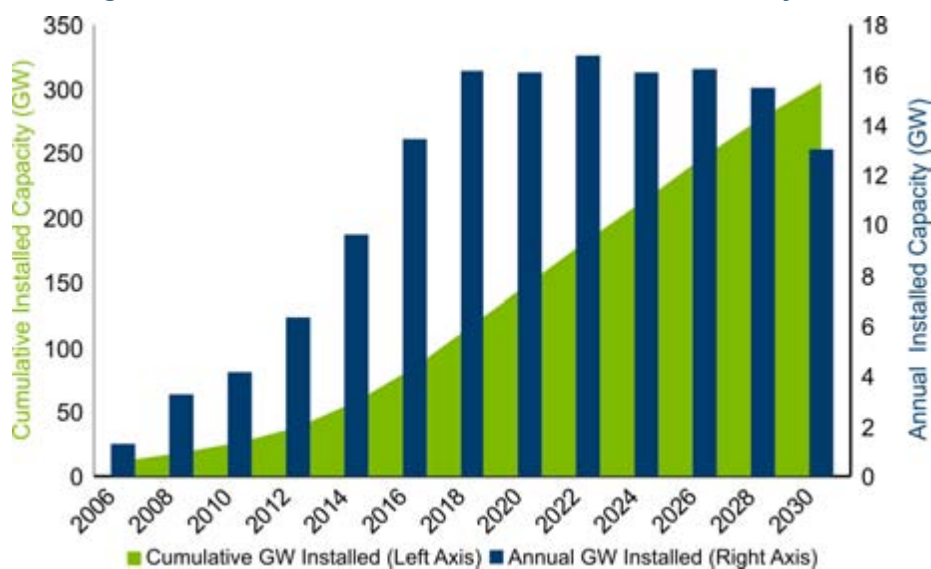
RPS. A growing number of energy and environmental organizations are calling for expanded wind and other renewable power deployment to try to reduce society's carbon footprint.

GHG Reduction

Under the 20% Wind Scenario, a cumulative total of 7,600 million tons of CO₂ would be avoided by 2030, and more than 15,000 million tons of CO₂ would be avoided through 2050.

According to EIA, The United States annually emits approximately 6,000 million metric tons of CO₂.⁷ These emissions are expected to increase to nearly 7,900 million metric tons by 2030, with the electric power sector accounting for approximately 40% of the total (AEO, 2007). As shown in Figure 1-11, based on the analysis completed for this report, generating 20% of U.S. electricity from wind could avoid approximately 825 million metric tons of CO₂ in the electric sector in 2030. The 20% scenario would also reduce *cumulative* emissions from the electric sector through that same year by more than 7,600 million metric tons of CO₂

Figure 1-11. Annual and cumulative wind installations by 2030



⁷C

carbon equivalent, not CO₂. In addition, the WinDS model projects higher CO₂ emissions than the EIA model because it assumes a higher share of coal-fired generation.

(2,100 million metric tons of carbon equivalent). See Figures 1-12 and 13. In general, CO₂ emission reductions are not only a wind energy benefit but could be achieved under other energy mix scenarios.

The Fourth Assessment Report of the United Nations Environment Programme and World Meteorological Organization’s Intergovernmental Panel on Climate Change (IPCC) notes that, “Renewable energy generally has a positive effect on energy security, employment, and air quality. Given costs relative to other supply options, renewable electricity can have a 30% to 35% share of the total electricity supply in 2030. Deployment of low-GHG (greenhouse gas) emission technologies... would be required for achieving stabilization and cost reductions” (IPCC 2007).

More than 30 U.S. states have created climate action plans. The Regional Greenhouse Gas Initiative (RGGI) is a 10-state collaborative in the Northeast to address CO₂ emissions. All of these state and regional efforts include wind energy as part of a portfolio strategy to reduce overall emissions from energy production (RGGI 2006).

Wind turbines typically have a service life of at least 20 years and transmission lines can last more than 50 years, meaning that investments in 20% wind by 2030 would continue to supply clean energy at least through 2050. As a result, cumulative climate change impacts could grow to more than 15,000 million tons of CO₂ avoided by mid-century (4,182 million metric tons of carbon equivalent).

The 20% Wind Scenario constructed here would displace a significant amount of fossil fuel generation. According to the WinDS model, by 2030, wind generation is projected to displace 50% of electricity generated from natural gas and 18% of that generated from coal. Coal displacement is of particular interest because the carbon emissions reduction opportunity is relatively higher. Recognizing that coal power will continue to play a major role in future electricity generation, a large increase in total wind capacity could potentially defer the need to build some new coal capacity, avoiding or postponing the associated carbon emissions. Current DOE projections anticipate construction of approximately 140 GW of new coal plant capacity by 2030 (EIA 2007); the 20% Wind Scenario could avoid more than 80 GW of new coal capacity.⁸

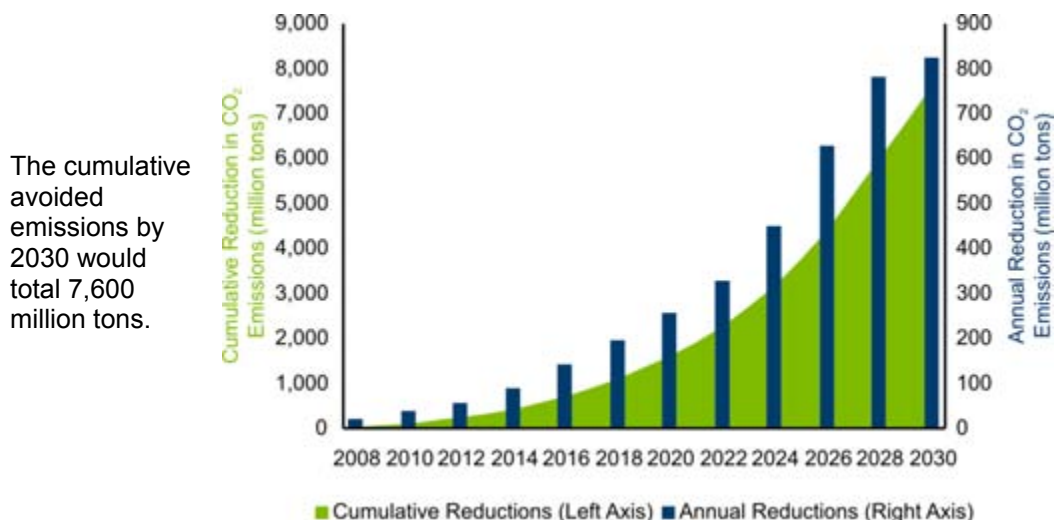
Wind energy that displaces fossil fuel generation can also help meet existing regulations for emissions of conventional pollutants, including sulfur dioxide, nitrogen oxides, and mercury.

1.3.2 WATER CONSERVATION

The 20% scenario would potentially reduce cumulative water consumption in the electric sector by 8% from 2007 through 2030, or 4 trillion gallons—significantly reducing water consumption in the arid states of the interior West. In 2030, annual water consumption in the electric sector would be reduced by 17%.

⁸ Carbon mitigation policies were not modeled in either the 20% wind or no new Wind Scenarios, which results in conventional generation mixes typical of current generation capacity. Under carbon mitigation scenarios, additional technologies could be implemented to reduce the need for conventional generation technology (see Appendix A).

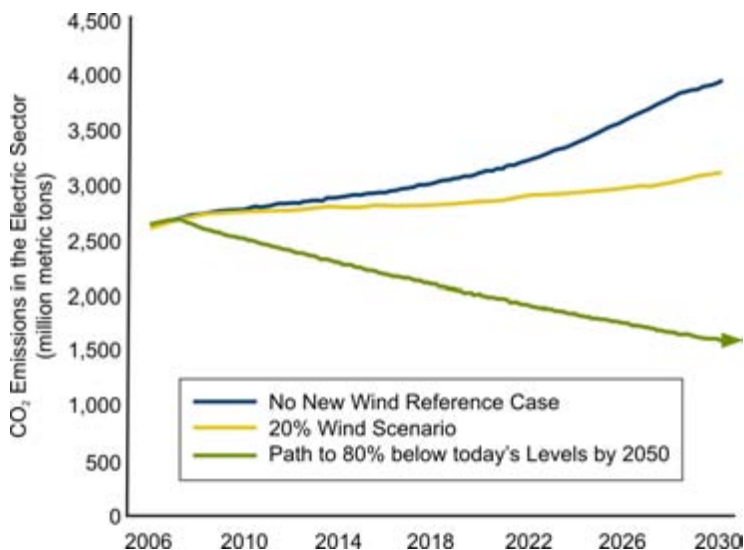
Figure 1-12. Annual CO₂ emissions avoided (vertical bars) would reach 825 million tons by 2030.



The cumulative avoided emissions by 2030 would total 7,600 million tons.

Water scarcity is a significant problem in many parts of the country. Even so, few realize that electricity generation accounts for nearly half of all water withdrawals in the nation, with irrigation coming in second at 34% (USGS 2005). Water is used for cooling of natural gas, coal, and nuclear power plants and is an increasing part of the challenge in developing those resources.

Figure 1-13. Avoided emissions would nearly level projected growth in CO₂ emissions from the electricity sector



Although a significant portion of the water withdrawn for electricity production is recycled back through the system, approximately 2% to 3% of the water withdrawn is consumed through evaporative losses. Even this small fraction adds up to approximately 1.6 to 1.7 trillion gallons of water consumed for power generation each year.

As additional wind generation displaces fossil fuel generation, each megawatt-hour generated by wind could save as much as

600 gallons of water that would otherwise be lost to fossil plant cooling.⁹ Because wind energy generation uses a negligible amount of water, the 20% Wind Scenario would avoid the consumption of 4 trillion gallons of water through 2030, with annual reductions shown in Figure 1-14. The annual savings in 2030 is approximately 450 billion gallons. This reduction would reduce the expected annual water consumption for electricity generation in 2030 by 17%. The projected water

⁹ See Appendix A for specific assumptions.

savings are dependant on future generation mix, which is discussed further in Appendix A.

Based on the WinDS modeling results, nearly 30% of the projected water savings from the 20% Wind Scenario would occur in western states, where water resources are particularly scarce. The Western Governors Association (WGA) highlights this concern in its Clean and Diversified Energy Initiative, which recognizes increased water consumption as a key challenge in accommodating rapid growth in electricity demand. In its 2006 report on water needs, the WGA states that “difficult political choices will be necessary regarding future economic and environmental uses of water and the best way to encourage the orderly transition to a new equilibrium” (WGA 2006).

Wind Reduces Vulnerability

Continued reliance on natural gas for new power generation is likely to put the United States in growing competition in world markets for liquefied natural gas (LNG)—some of which will come from Russia, Qatar, Iran, and other nations in less-than-stable regions.

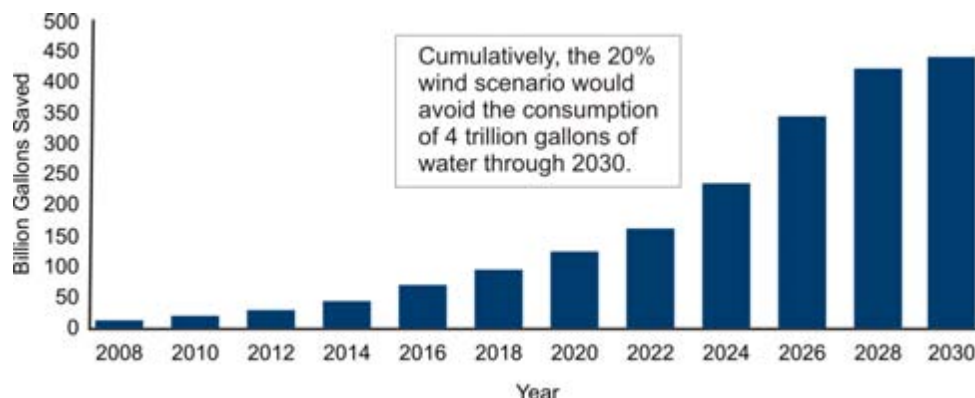
1.3.3 ENERGY SECURITY AND STABILITY

There is broad and growing recognition that the nation should diversify its energy portfolio so that a supply disruption affecting a single energy source will not significantly disrupt the national economy. Developing domestic energy sources with known and stable costs would significantly improve U.S. energy stability and security.

When electric utilities have a Power Purchase Agreement or own wind energy turbines, the price of energy is expected to remain relatively flat and predictable for the life of the wind project, given that there are no fuel costs and assuming that the machines are well maintained. In contrast, a large part of the cost of coal- and gas-fired electricity is in the fuel, for which prices are often volatile and unpredictable. Fuel price risks reduce security and stability for U.S. manufacturers and consumers, as well as for the economy as a whole. Even small reductions in the amount of energy available or changes in the price of fuel can cause large economic disruptions across the nation. This capacity to disrupt was clearly illustrated by the 1973 embargo imposed by the Organization of Arab Petroleum Exporting Countries (the “Arab oil embargo”); the 2000–2001 California electricity market problems; and the gasoline and natural gas shortages and price spikes that followed the 2005 hurricane damage to oil refinery and natural gas processing facilities along the Gulf Coast.

Using wind energy increases security and stability by diversifying the national

Figure 1-14. National water savings from the 20% Wind Scenario



electricity portfolio. Just as those investing for retirement are advised to diversify investments across companies, sectors, and stocks and bonds, diversification helps distribute the risks and stabilize rates for electricity consumers.

Wind energy reduces reliance on foreign energy sources from politically unstable regions. As a domestic energy source, wind requires no imported fuel, and the turbine components can be either produced on U.S. soil or imported from any friendly nation with production capabilities.

Energy security concerns for the electric industry will likely increase in the foreseeable future as natural gas continues to be a leading source of new generation supply. With declining domestic natural gas sources, future natural gas supplies are expected to come in the form of LNG imported on tanker ships. U.S. imports of LNG could quadruple by 2030 (EIA 2007). Almost 60% of uncommitted natural gas reserves are in Iran, Qatar, and Russia. These countries, along with others in the Middle East, are expected to be major suppliers to the global LNG market. Actions by those sources can disrupt international energy markets and thus have indirect adverse effects on our economy. Additional risks arise from competition for these resources caused by the growing energy demands of China, India, and other developing nations. Under the 20% scenario, according to the WinDS model results, wind energy could displace approximately 11% of natural gas consumption which is equivalent to 60% of expected LNG imports in 2030.¹⁰ This shift would reduce the nation's energy vulnerability to uncertain natural gas supplies. Please see Appendix A for gas demand reduction assumptions and calculations.

Continued reliance on fossil energy sources exposes the nation to price risks and supply uncertainties. Although the electric sector does not rely heavily on petroleum, which represents one of the nation's biggest energy security threats, diversifying the electric generation mix with increased domestic renewable energy would still enhance national energy security by increasing energy diversity and price stability.

1.3.4 COST OF THE 20% WIND SCENARIO

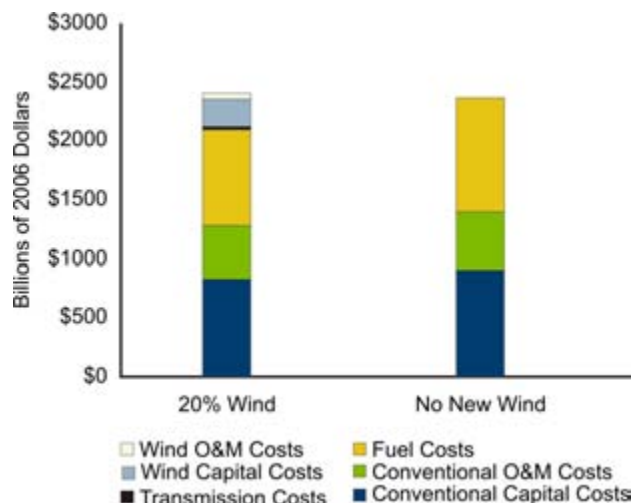
The overall economic cost of the 20% Wind Scenario accrues mainly from the incremental costs of wind energy relative to other generation sources. This is impacted by the assumptions behind the scenario, listed in table A-6. Also, some incremental transmission would be required to connect wind to the electric power system. This transmission investment would be in addition to the significant investment in the electric grid that will be needed to serve continuing load growth, whatever the mix of new generation. The market cost of wind energy remains higher than that of conventional energy sources in many areas across the country. In addition, the transmission grid would have to be expanded and upgraded from wind-rich areas and across the existing system to deliver wind energy to many demand centers.

Compared to other generation sources, the 20% Wind Scenario entails higher initial capital costs (to install wind capacity and associated transmission infrastructure) in many areas, yet offers lower ongoing energy costs than conventional power plants for operations, maintenance and fuel. Given the optimistic cost and performance assumptions of wind and conventional energy sources (detailed in Appendix B), the 20% Wind Scenario could require an incremental investment of as little as \$43 billion NPV more than the base-case no new Wind Scenario. This would represent

¹⁰ Compared to consumption of the high price scenario of EIA (2007), used in this report

less than 0.06 cent (6 one-hundredths of 1 cent) per kilowatt-hour of total generation by 2030, or roughly 50 cents per month per household. Figure 1-18 shows this cost comparison. The base-case costs are calculated under the assumption of no major

Figure 1-15. Incremental investment cost of 20% wind is modest; a difference of 2%



changes in fuel availability or environmental restrictions. In this scenario, the cost differential would be about 2% of a total NPV expenditure exceeding \$2 trillion.

This analysis intended to identify the incremental cost of pursuing the 20% Wind Scenario. In regions where the capital costs of the 20% scenario exceed those of building little or no additional wind capacity, the differential could be offset by the operating cost and benefits discussed earlier. For example, even though Figure 1-18 shows that under optimistic assumptions the 20% Wind Scenario could increase total capital cost by nearly \$197 billion, most of that cost would be offset by the nearly \$155 billion in decreased fuel expenditure, resulting in a net incremental cost of approximately \$43 billion in NPV. These monetary cost do not reflect other potential offsetting positive impacts.

An integrated approach to expanding the transmission system would need to include furnishing access to wind resources as well as meeting other system needs.

As estimated by the NREL WinDS model, given optimistic assumptions, the specific cost of the proposed transmission expansion for the 20% Wind Scenario is \$20 billion in NPV. The actual required grid investment could also involve significant costs for permitting delays, construction of grid extensions to remote areas with wind resources, and investments in advanced grid controls, integration and training to enable regional load balancing of wind resources.

The total installed costs for wind plants include costs associated with siting and permitting of these plants. It has become clear that wind power expansion would require careful, logical, and fact-based consideration of local and environmental concerns, allowing siting issues to be addressed within a broad risk framework. Experience in many regions has shown that this can be done, but efficient,

streamlined procedures will likely be needed to enable installation rates in the range of 16 GW per year. Chapter 5 covers these issues in more detail.

1.4 CONCLUSION

There are significant costs, challenges, and impacts associated with the 20% Wind Scenario presented in this report. There are also substantial positive impacts from wind power expansion on the scale and pace described in this chapter are not likely to be realized in a business-as-usual future. Achieving this scenario would involve a major national commitment to clean, domestic energy sources with minimal emissions of GHGs and other environmental pollutants.

1.5 REFERENCES AND OTHER SUGGESTED READING

AWEA 2007. American Wind Energy Association Web site, Oct.1, 2007:
<http://www.awea.org/faq/cost.html>.

BTM Consult. 2007. *International Wind Energy Development, World Market Update 2006*. Ringkøbing, Denmark: BTM.

Edmonds, J.A., M.A. Wise, J.J. Dooley, S.H. Kim, S.J. Smith, P.J. Runci, L.E. Clarke, E.L. Malone, and G.M. Stokes. 2007. *Global Energy Technology Strategy: Addressing Climate Change*. Richland, WA: Global Energy Strategy Technology Project.
http://www.pnl.gov/gtsp/docs/gtsp_2007_final.pdf

EIA (Energy Information Administration). 2005. *Electric Power Annual*. Washington, DC: EIA. Table 2.6.
<http://www.eia.doe.gov/cneaf/electricity/epa/epat2p6.html>.

EIA. 2007. *Annual Energy Outlook*. Washington, DC: EIA.
<http://www.eia.doe.gov/oiaf/aeo/index.html>.

IPCC (Intergovernmental Panel on Climate Change). 2007. *Climate Change 2007: Impacts, Adaptation and Vulnerability: Working Group II Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate change*. PCC Report presented at 8th session of Working Group II of the IPCC, April 2007, Brussels, Belgium. <http://www.ipcc.ch/ipccreports/ar4-wg2.htm>

Johnston, L., E. Hausman, A. Sommer, B. Biewald, T. Woolf, D. Schlissel, A. Roschelle, and D. White. 2006. *Climate Change and Power: Carbon Dioxide Emissions Costs and Electricity Resource Planning*. Cambridge, MA: Synapse Energy Economics, Inc.

O'Connell, R., R. Pletka, et al. 2007. *20% Wind Energy Penetration in the United States: A Technical Analysis of the Energy Resource*. Overland Park, KS: Black & Veatch.

RGGI (Regional Greenhouse Gas Initiative). 2006. "About RGGI."
<http://www.rggi.org/about.htm>.

Socolow, R.H., and S.W. Pacala. 2006. "A Plan to Keep Carbon in Check," *Scientific American*, September.

Teske, S., A. Zervos, and O. Schafer. 2007. *Energy [R]evolution: A Blueprint for Solving Global Warming*, USA National Energy Scenario. Amsterdam:

- Greenpeace International. <http://www.greenpeace.org/raw/content/usa/press-center/reports4/energy-r-evolution-introduc.pdf>
- USCAP (U.S. Climate Action Partnership). 2007. A Call for Action. <http://www.uscap.org/USCAPCallForAction.pdf>
- USGS (U.S. Geological Survey). 2005. *Estimated Use of Water in the United States in 2000*. <http://pubs.usgs.gov/circ/2004/circ1268/hdocs/figure01.html>
- WGA (Western Governors' Association). 2006. *Water Needs and Strategies for a Sustainable Future*, p. 4. <http://www.westgov.org/wga/publicat/Water06.pdf>
- Wiser, R., M. Bolinger, and M. St. Clair. 2005. *Easing the Natural Gas Crisis: Reducing Natural Gas Prices through Increased Deployment of Renewable Energy and Energy Efficiency*. Berkeley, CA: Berkeley Lab. Report No. LBNL-56756. <http://eetd.lbl.gov/EA/EMP/reports/56756.pdf>
- Wood Mackenzie. 2007. *Impact of a Federal Renewable Portfolio Standard*. Edinburgh, Scotland: Wood Mackenzie.