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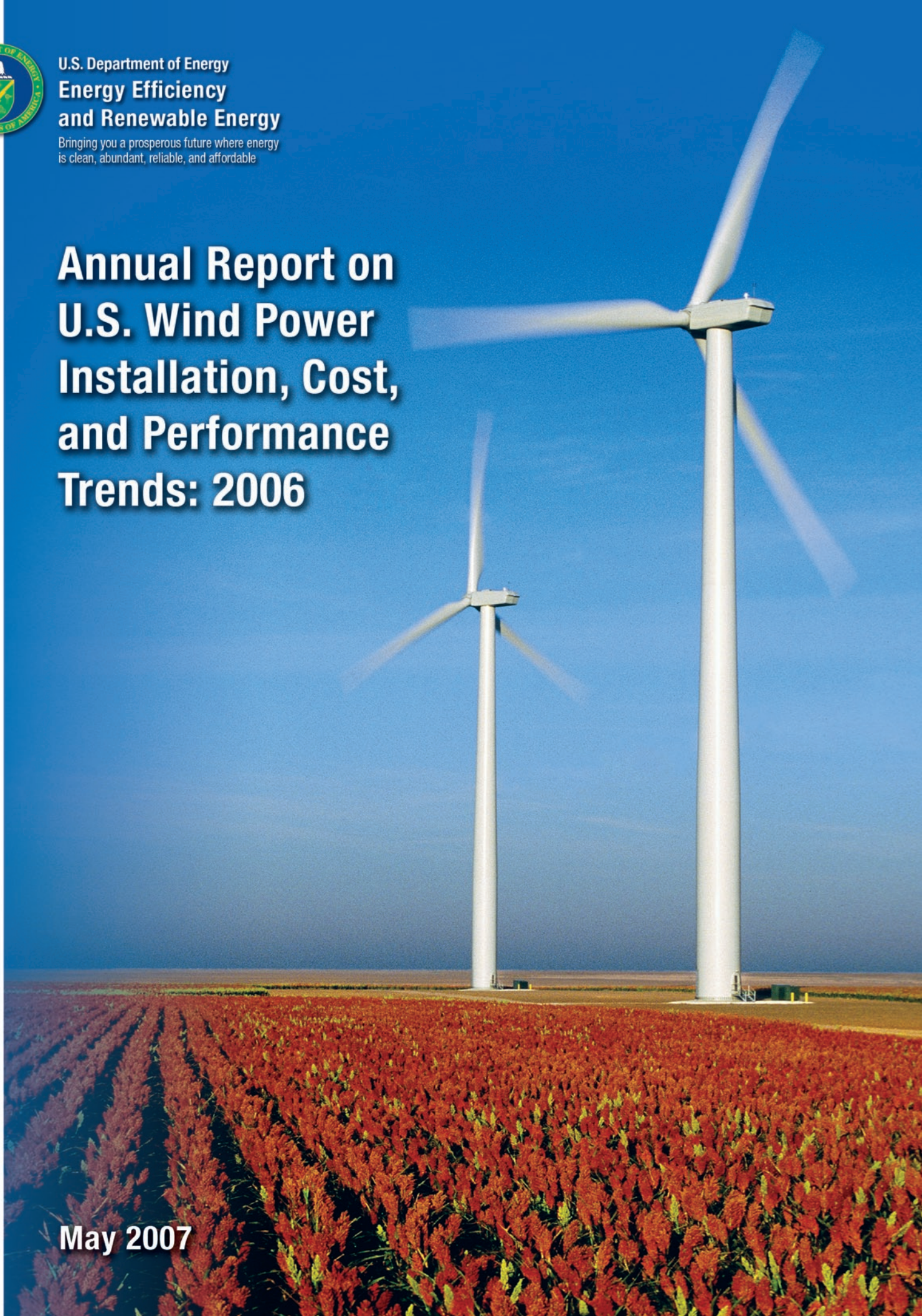
Annual Report on U.S. Wind Power Installation, Cost, and Performance Trends: 2006



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Annual Report on U.S. Wind Power Installation, Cost, and Performance Trends: 2006

Primary authors

Ryan Wiser
Lawrence Berkeley National Laboratory

Mark Bolinger
Lawrence Berkeley National Laboratory

With contributions from

Galen Barbose (Berkeley Lab), Kathy Belyeu (AWEA), Maureen Hand (NREL), Donna Heimiller (NREL), Debra Lew (NREL), Michael Milligan (NREL), Andrew Mills (Berkeley Lab), Alejandro Moreno (U.S. DOE), Walt Musial (NREL), Ric O'Connell (Black & Veatch), Kevin Porter (Exeter Associates), and Zack Subin (U.C. Berkeley)

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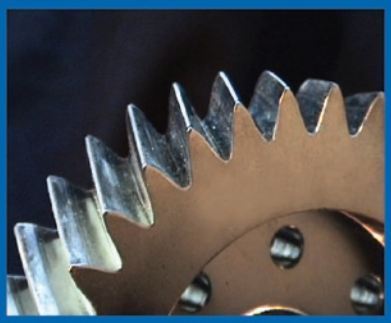


Introduction

The wind power industry is in an era of substantial growth, both globally and in the United States. With the market evolving at such a rapid pace, keeping up with trends in the marketplace has become increasingly difficult. Yet, the need for timely, objective information on the industry and its progress has never been greater. This report – the first in what is envisioned to be an ongoing annual series – attempts to fill this need by providing a detailed overview of developments and trends in the U.S. wind power market, with a particular focus on 2006.

The report begins with an overview of key wind development and installation-related trends, including trends in capacity growth, turbine make and model, and among developers, project owners, and power purchasers. It then reviews the price of wind power in the market, and how those prices compare to wholesale power prices. The report then turns to a review of trends in installed wind project costs, wind turbine transaction prices, project performance, and operations and maintenance expenses. Finally, the report examines other factors impacting the domestic wind power market, including grid integration costs, transmission issues, and policy drivers. The report concludes with a brief preview of possible developments in 2007.

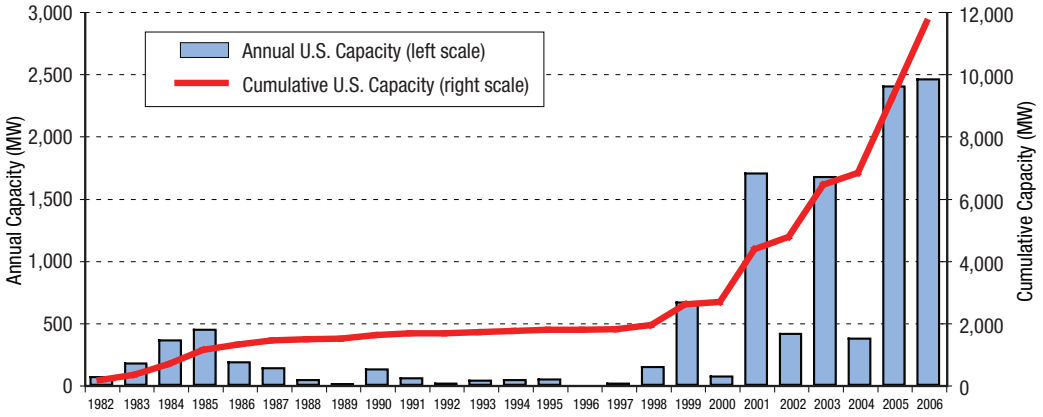
A note on scope: This report concentrates on larger-scale wind applications, defined here as individual turbines or projects that exceed 50 kW in size. The U.S. wind power sector is multifaceted, and also includes smaller, customer-sited wind applications used to power the needs of residences, farms, and businesses. Data on these applications, if they are less than 50 kW in size, are not included here. Much of the data included in this report were compiled by Berkeley Lab in multiple databases that contain historical information on wind power purchase prices, capital costs, turbine transaction prices, project performance, and O&M costs for many of the wind projects in the United States. The information included in these databases comes from a variety of sources (see the Appendix), and in many cases represents only a sample of actual wind projects installed in the U.S. As such, we caution that the data are not always comprehensive or of equal quality, so emphasis should be placed on overall trends in the data, rather than individual data-points. Finally, each section of this document focuses on historical market data or information, with an emphasis on 2006; we do not seek to forecast future trends.

U.S. Wind Power Capacity Increased by 27% in 2006

The U.S. wind power market continued its rapid expansion in 2006, with 2,454 MW of new capacity added, for a cumulative total of 11,575 MW (Figure 1). This growth translates into more than $3.7 billion (real 2006 dollars) invested in wind project installation in 2006, for a cumulative total of more than $18 billion since the 1980s.[1]

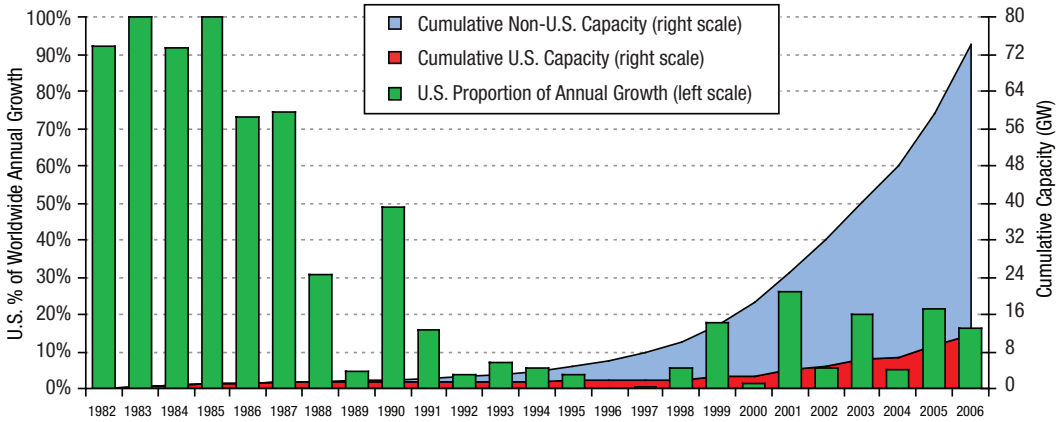
The yearly boom-and-bust cycle that characterized the U.S. wind market from 1999 through 2004 – caused by periodic, short-term extensions of the federal production tax credit (PTC) – ended in 2006, with two consecutive years of sizable growth. In fact, 2006 was the largest year on record in the U.S. for wind capacity additions, barely edging out year-2005 additions. Federal tax incentives, state renewable energy standards and incentives, and continued uncertainty about the future cost and liabilities of conventional natural gas and coal facilities helped spur this growth.

Also for the second consecutive year, wind power was the second-largest new resource added to the U.S. electrical grid in terms of nameplate capacity, well behind the more than 9,000 MW of new natural gas plants, but ahead of new coal, at 600 MW. New wind plants contributed roughly 19% of new nameplate capacity added to the U.S. electrical grid in 2006, compared to 13% in 2005.



Source: AWEA/GEC database.

Figure 1. Annual and Cumulative Growth in U.S. Wind Power Capacity



Source: Earth Policy Institute; BTM Consult; AWEA/GEC dataset

Figure 2. The United States' Contribution to Global Wind Capacity

The United States Leads the World in Annual Capacity Growth

On a worldwide basis, more than 15,000 MW of wind capacity was added in 2006, up from roughly 11,500 MW in 2005, for a cumulative total of more than 74,000 MW. For the second straight year, the United States led the world in wind capacity additions (Table 1), with roughly 16% of the worldwide market (Figure 2). Germany, India, Spain, and China round out the top five (Table 1). In terms of cumulative installed wind capacity, the U.S. ended the year with 16% of worldwide capacity, in third place behind Germany and Spain. So far this century (i.e., over the past seven years), wind power capacity has grown on average by 24% per year in the U.S., compared to 27% worldwide.[2]

Table 1. International Rankings of Wind Power Capacity

Cumulative Capacity (end of 2006, MW)		Incremental Capacity (2006, MW)	
Germany	20,652	**US**	**2,454**
Spain	11,614	Germany	2,233
US	**11,575**	India	1,840
India	6,228	Spain	1,587
Denmark	3,101	China	1,334
China	2,588	France	810
Italy	2,118	Canada	776
UK	1,967	UK	631
Portugal	1,716	Portugal	629
France	1,585	Italy	417
Rest of Wold	11,102	Rest of World	2,305
TOTAL	**74,246**	**TOTAL**	**15,016**

Source: BTM, 2007; AWEA/GEC dataset for U.S. cumulative capacity.

[1] These investment figures are based on an extrapolation of the average project-level capital costs reported later in this report. Annual O&M, R&D, and manufacturing expenditures would add to these figures.

[2] Yearly and cumulative installed wind capacity in the U.S. is from the AWEA/GEC database, while global wind capacity largely comes from BTM Consult (but updated with the most recent AWEA/GEC data for the U.S.). Modest disagreement exists among these data sources and others, e.g., *Windpower Monthly* and the Global Wind Energy Council.

Several countries have achieved high levels of wind power penetration in their electricity grids. Figure 3 presents data on end-of-2006 installed wind capacity, translated into projected annual electricity supply based on assumed country-specific capacity factors, and divided by projected 2007 electricity consumption. Using this rough approximation for the contribution of wind to electricity consumption (which, for example, ignores transmission losses), and focusing only on the ten countries with the most wind capacity, end-of-2006 installed wind is projected to supply more than 20% of Denmark's electricity demand, roughly 9% of Spain's, and 7% of Portugal's and Germany's. In the U.S., on the other hand, the cumulative wind capacity installed at the end of 2006 would, in an average year, be able to supply roughly 0.8% of the nation's electricity consumption[3] – just below wind's estimated 0.9% contribution to electricity consumption on a worldwide basis.

Texas, Washington, and California Lead the U.S. in Annual Capacity Growth

New large-scale[4] wind turbines were installed in 22 states in 2006. As shown in Table 2 and Figure 4, leading states in terms of 2006 additions include Texas, Washington, California, New York, and Minnesota. As for cumulative totals, Texas surpassed California in 2006, and leads the nation with 2,739 MW, followed by California, Iowa, Minnesota, and Washington. Twenty states had more than 50 MW of wind capacity as of the end of 2006, with 16 of these states achieving more than 100 MW and six topping 500 MW. Although all wind power development in the U.S. to date has been onshore, offshore development activities continued in 2006 (see Text Box 1).

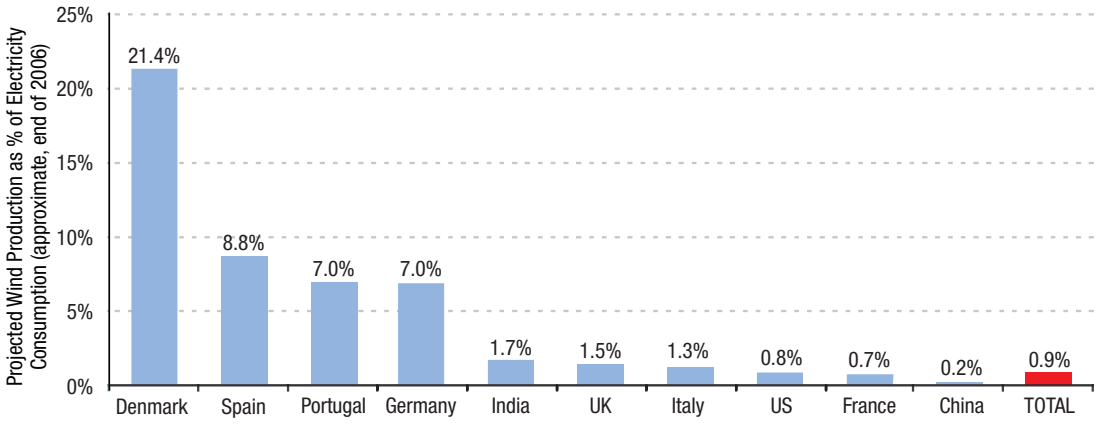
Assuming (inaccurately) that all in-state wind is used in-state, New Mexico could meet more than 7% of its total retail electricity sales with wind power installed as of the end of 2006 (Table 2). End-of-2006 installed wind capacity could serve more than 5% of the electricity needs of Iowa, North Dakota, and Wyoming. Twelve states had enough in-state wind capacity at the end of 2006 to meet more than 2% of in-state retail electricity sales.[5]

Text Box 1. Offshore Wind Development Activities

In Europe, nearly 900 MW of wind had been installed offshore by the end of 2006, typically in water depths of 25 meters or less. In contrast, all wind projects built in the U.S. to date have been sited on land. Due to permitting constraints and transmission bottlenecks for land-based projects, however, as well as advances in technology and potentially superior capacity factors for offshore facilities, there is some interest in offshore wind in several parts of the United States.

The table below provides a listing, by state, of active offshore project proposals in the U.S. as of the end of 2006 (note that these projects are in various stages of development, and that a certain amount of subjectivity is required in the definition of "active"). As shown, offshore interest exists off of the Atlantic Coast and Texas. In addition, though no projects have been officially announced, some interest has been expressed in the Great Lakes area.

State	Proposed Offshore Wind Capacity
Massachusetts	735 MW
Texas	650 MW
Delaware	600 MW
New Jersey	300 MW
New York	160 MW
Georgia	10 MW
TOTAL	**2,455 MW**



Source: Berkeley Lab estimates based on data from BTM and elsewhere.

Figure 3. Approximate Wind Power Penetration in Countries with the Most Installed Wind Capacity

[3] In terms of actual 2006 deliveries, wind represented 0.64% of electricity generation in the U.S., and roughly 0.67% of national electricity consumption. These figures are below the 0.8% figure provided above, because 0.8% is a projection based on end-of-year 2006 wind capacity.

[4] We define "large-scale" turbines consistently with the rest of this report – over 50 kW.

[5] Here we present wind generation as a percentage of retail electricity sales, rather than total electricity consumption. Wind generation on this basis represents 0.85% of U.S. sales, slightly higher than the 0.81% of nation-wide electricity consumption presented in Figure 3.

Table 2. United States Wind Power Rankings: The Top 20 States

Cumulative Capacity (end of 2006, MW)		Incremental Capacity (2006, MW)		Approximate Percentage of Retail Sales*	
Texas	2,739	Texas	774	New Mexico	7.3%
California	2,376	Washington	428	Iowa	6.0%
Iowa	931	California	212	North Dakota	5.1%
Minnesota	895	New York	185	Wyoming	5.1%
Washington	818	Minnesota	150	Minnesota	3.8%
Oklahoma	535	Oregon	101	Oklahoma	3.5%
New Mexico	496	Kansas	101	Montana	3.3%
Oregon	438	Iowa	99	Kansas	3.1%
New York	370	New Mexico	90	Oregon	2.4%
Kansas	364	North Dakota	80	Texas	2.3%
Colorado	291	Oklahoma	60	Washington	2.3%
Wyoming	288	Colorado	60	California	2.1%
Pennsylvania	179	Pennsylvania	50	Colorado	1.7%
North Dakota	178	Hawaii	41	South Dakota	1.5%
Montana	146	Montana	9	Nebraska	1.0%
Illinois	107	Maine	9	Hawaii	1.0%
Idaho	75	Massachusetts	2	Idaho	0.7%
Nebraska	73	New Hampshire	1	New York	0.6%
West Virginia	66	Rhode Island	0.7	West Virginia	0.6%
Wisconsin	53	Ohio	0.2	Pennsylvania	0.3%
Rest of U.S.	156	Rest of U.S.	0.3	Rest of U.S.	0.02%
TOTAL	**11,575**	**TOTAL**	**2,454**	**TOTAL**	**0.85%**

*Assumes that wind installed in a state serves that state's electrical load; ignores transmission losses.

Source: AWEA/GEC database and Berkeley Lab estimates.

GE Wind Is the Dominant Turbine Manufacturer, with Siemens Gaining Market Share

GE Wind remained the dominant manufacturer of wind turbines supplying the U.S. market in 2006, with 47% of domestic installations (down from 60% in 2005, and similar to its 46% market share in 2004).[6] Siemens and Vestas also had significant U.S. installations, with Mitsubishi, Suzlon, and Gamesa playing lesser roles (Figure 5). Siemens' move to the number two wind turbine supplier is particularly noteworthy, given that it delivered no turbines to the U.S. market the previous year, after its acquisition of Bonus in 2004. In part as a result, Vestas (along with GE Wind) lost market share between 2005 (29%) and 2006 (19%) in the U.S. market.

U.S.-based manufacturing of wind turbines and components remained somewhat limited, in part because of the uncertain continued availability of the federal production tax credit

[6] Market share reported here is in MW terms, and is based on project installations in the year in question, not turbine shipments or orders.

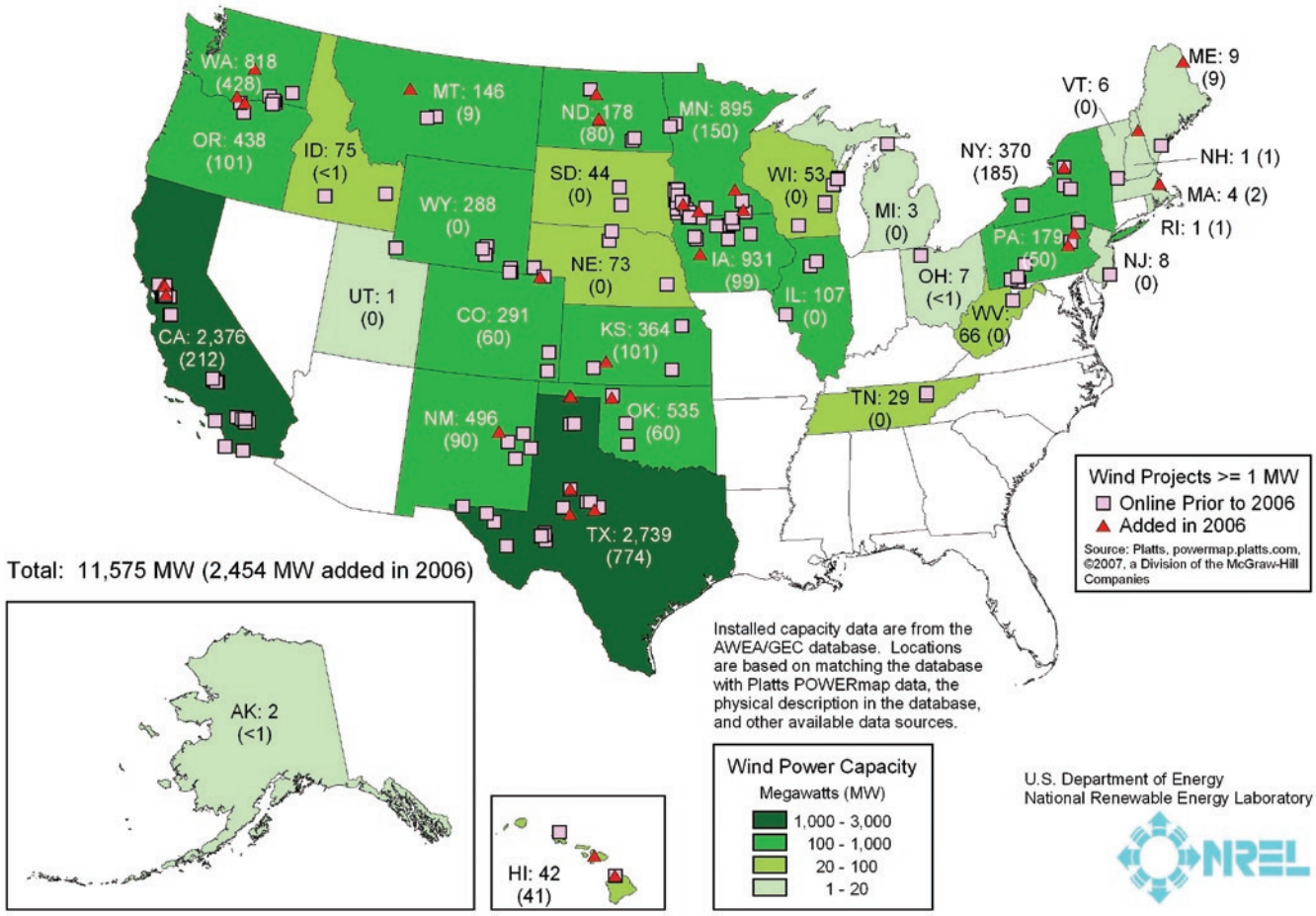
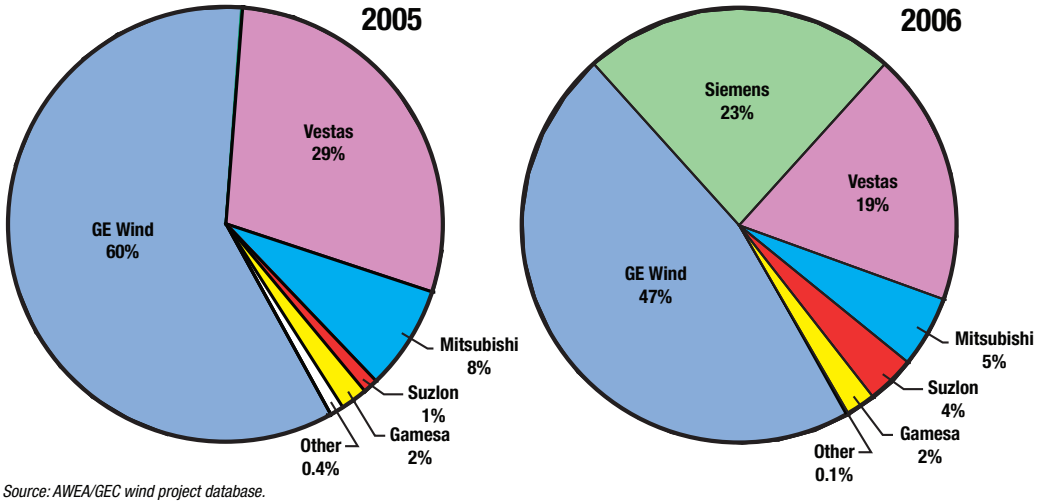


Figure 4. Size and Location of Wind Power Development in the U.S.

(PTC). That said, a new U.S.-based manufacturer – Clipper Windpower – is in the process of significant expansion, and a growing list of foreign turbine manufacturers have begun to localize some of their manufacturing in the United States. In 2006, for example, new manufacturing plants sprung up in Iowa (Clipper), Minnesota (Suzlon), and Pennsylvania (Gamesa). GE has also maintained a significant, domestic wind turbine manufacturing presence, in addition to its international facilities that serve both the U.S. and global markets.

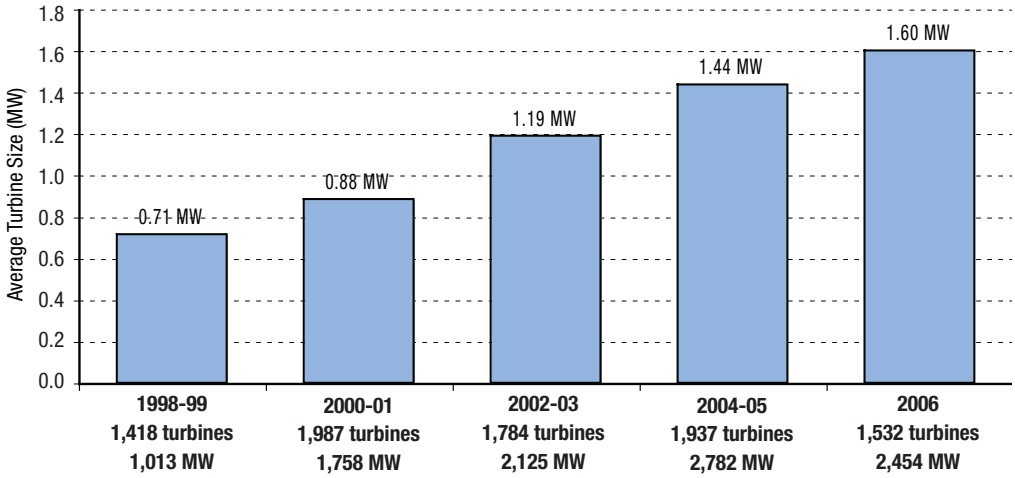


Source: AWEA/GEC wind project database.

Figure 5. Annual U.S. Market Share of Wind Turbine Manufacturers by MW, 2005 and 2006

Average Turbine Size Continues to Increase

The average size of wind turbines installed in the U.S. in 2006 increased to roughly 1.6 MW (Figure 6). Since 1998-99,[7] average turbine size has increased by 124%. Table 3 shows how the distribution of turbine size has shifted over time; nearly 17% of all turbines installed in 2006 had a nameplate capacity in excess of 2 MW, compared to just 0.1% of turbines installed in 2002 through 2003 and 2004 through 2005. GE's 1.5-MW wind turbine remained the nation's most-installed turbine in 2006.



Source: AWEA/GEC project database.

Figure 6. Average Turbine Size Installed During Period

Table 3. Size Distribution of Number of Turbines over Time

Turbine Size Range	1998-99 1,013 MW 1,418 turbines	2000-01 1,758 MW 1,987 turbines	2002-03 2,125 MW 1,784 turbines	2004-05 2,782 MW 1,937 turbines	2006 2,454 MW 1,532 turbines
0.00 to 0.5 MW	1.3%	0.4%	0.5%	1.9%	0.7%
0.51 to 1.0 MW	98.4%	73.9%	44.2%	17.6%	10.7%
1.01 to 1.5 MW	0.0%	25.4%	42.8%	56.6%	54.2%
1.51 to 2.0 MW	0.3%	0.4%	12.3%	23.9%	17.6%
2.01 to 2.5 MW	0.0%	0.0%	0.0%	0.1%	16.3%
2.51 to 3.0 MW	0.0%	0.0%	0.1%	0.0%	0.5%

Source: AWEA/GEC project database.

[7] Except for 2006, Figure 6 (as well as Figures 10, 22, 25 and 26, and Tables 3 and 5) combines data into two-year periods in order to avoid distortions related to small sample size in the PTC lapse years of 2000, 2002, and 2004. Though not a PTC lapse year, 1998 sample size is also small, and is therefore combined with 1999.

Developer Consolidation Accelerates

As demonstration of a growing and maturing domestic wind industry, and as a result of the increased globalization of the wind sector and the need for capital to manage wind turbine supply constraints, consolidation on the development end of the business continued the strong trend that began in 2005, with a large number of significant acquisitions, mergers, and investments. Table 4 provides a listing of acquisition and investment activity among U.S. wind developers in the 2002 through 2006 timeframe. In summary, 13 transactions totaling roughly 35,000 MW of in-development wind projects (also called the development "pipeline") were announced in 2006, up from nine transactions totaling nearly 12,000 MW in 2005, and only four transactions totaling less than 4,000 MW from 2002 through 2004.[8]

A number of large companies have entered the wind development business in recent years, including AES, Goldman Sachs, Shell, BP, and John Deere, some through acquisitions and others though their own development activity, or through joint development agreements with others. Other active wind development companies include (but are not limited to) FPL Energy, PPM Energy, Iberdrola, Babcock & Brown, Airtricity, RES, UPC Wind, Invenergy, Edison Mission, enXco, Clipper, Acciona, Enel, NRG Energy (Padoma), Gamesa, Cielo, Noble Environmental Power, Exergy, U.S. Wind Force, Wind Capital Group, Foresight, Western Wind, and Midwest Wind Energy.

Table 4. Merger and Acquisition Activity among U.S. Wind Development Companies*

Investor	Transaction Type	Developer	Announced
EDF (SIIF Energies)	Acquisition	enXco	May-02
Gamesa	Investment	Navitas	Oct-02
AES	Investment	US Wind Force	Sep-04
PPM Energy	Acquisition	Atlantic Renewable Energy Corp.	Dec-04
AES	Acquisition	SeaWest	Jan-05
Goldman Sachs	Acquisition	Zilkha (Horizon)	Mar-05
JP Morgan Partners	Investment	Noble Power	Mar-05
Arclight Capital	Investment	CPV Wind	Jul-05
Diamond Castle	Acquisition	Catamount	Oct-05
Pacific Hydro	Investment	Western Wind Energy	Oct-05
Greenlight	Acquisition	Coastal Wind Energy LLC	Nov-05
EIF U.S. Power Fund II	Investment	Tierra Energy, LLC	Dec-05
Airtricity	Acquisition	Renewable Generation Inc.	Dec-05
Babcock & Brown	Acquisition	G3 Energy LLC	Jan-06
Iberdrola	Acquisition	Community Energy Inc.	Apr-06
Shaw/Madison Dearborn	Investment	UPC Wind	May-06
NRG	Acquisition	Padoma	Jun-06
CPV Wind	Acquisition	Disgen	Jul-06
BP	Investment	Clipper	Jul-06
BP	Acquisition	Greenlight	Aug-06
Babcock & Brown	Acquisition	Superior	Aug-06
Enel	Investment	TradeWind	Sep-06
Iberdrola	Acquisition	Midwest Renewable Energy Corp.	Oct-06
Iberdrola	Acquisition	Gamesa's U.S. project pipeline	Oct-06
Iberdrola	Acquisition	PPM (Scottish Power)	Dec-06
BP	Acquisition	Orion Energy	Dec-06

* Select list of announced transactions; excludes joint development activity.

Source: Berkeley Lab and Black & Veatch.

[8] Consolidation and investment continues in 2007 – as of May, an additional four transactions, totaling more than 15,000 MW of wind project pipeline, have been announced (most prominently, these transactions include Goldman Sachs' sale of Horizon Wind to EDP).

Innovation and Competition in Non-Utility Wind Financing Persists

A variety of innovative ownership and financing structures have been developed by the U.S. wind industry in recent years to serve the purpose of allowing equity capital to fully access federal tax incentives. The two most common structures employed in 2006 were corporate balance-sheet finance (e.g., that used by FPL Energy) and so-called "flip" structures involving institutional "tax equity" investors (e.g., the "Babcock & Brown model").[9] Both of these structures typically involve no debt at the project level, though some project developers involved in flips are increasingly employing so-called "back leverage" to debt-finance their own equity stake in the project (likewise, FPL Energy and others may finance portions of their balance sheet with debt). Although these all-equity project structures dominated the market in 2006, term debt still played a role in several new project financings, as well as in refinancings of existing projects and portfolios. Debt providers also offered shorter-term turbine supply loans, construction debt, and back leverage (i.e., at the sponsor, rather than project, level).

The year 2006 saw a continued expansion of the number of equity and debt providers to wind projects: there were at least a dozen tax-equity investors involved in 2006 projects (up from just three a few years ago), and eleven banks acting as lead debt arrangers (up from just a few several years ago). This ongoing infusion of willing capital has continued to drive down the cost of both equity and debt: anecdotal information suggests that the cost of tax equity for high-quality, well-structured deals has declined by approximately 300 basis points (3%) in the past four years, while interest rate margins on debt transactions have declined by approximately 50 basis points (0.5%) over the same period. This trend towards cheaper capital has helped to dampen the impact of recently-rising wind turbine costs on wind power prices.

Utility Interest in Wind Asset Ownership Strengthens; Community Wind Grows Modestly

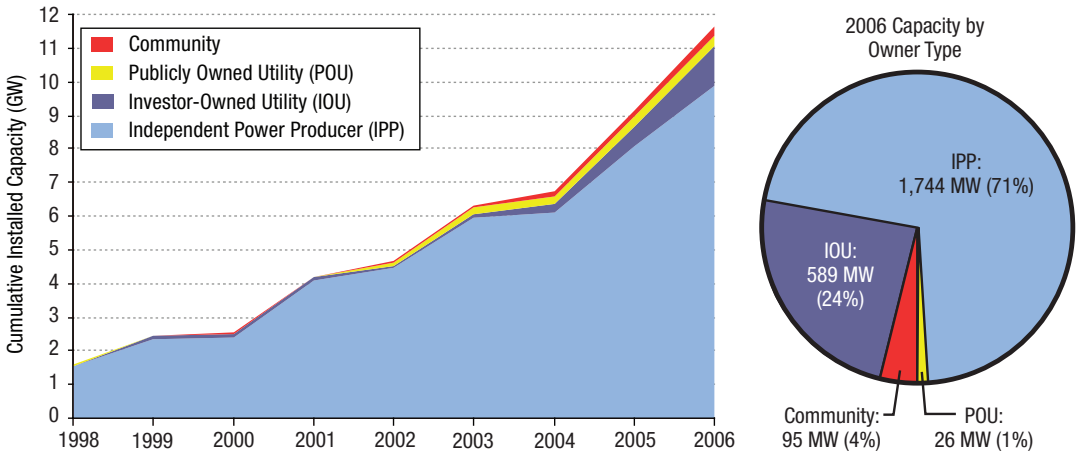
Another sign of the increased maturity and acceptance of the wind sector is that electric utilities have begun to express greater interest in owning wind assets. As shown in Figure 7, private independent power producers (IPPs) continued to dominate the wind industry in 2006, owning 71% of all new capacity. As demonstration of a growing trend, however, 25% of total wind additions in 2006 are owned by local electrical utilities, the vast majority of which are investor-owned utilities (IOUs), as opposed to publicly owned utilities (POUs). Community wind power projects – defined here as projects owned by towns, schools, commercial customers, and farmers, but excluding publicly owned utilities – constitute the remaining 4% of 2006 projects. Of the cumulative 11,575 MW of installed wind capacity at the end of 2006, IPPs owned 85% (9,817 MW), with utilities contributing 13% (1,190 MW for IOUs and 309 MW for POUs), and community ownership just 2% (258 MW).

Though still a small contributor overall, community wind power projects have grown from just 0.2% of total cumulative U.S. wind capacity as recently as 2001 to 2.2% at the end of 2006. This growth has come despite sizable barriers, including the challenge of securing small turbine orders in the midst of the current turbine shortage. However, with help from both state and federal policies that specifically or differentially support community wind power projects, including USDA Section 9006 grants, community-scale wind continues to fare well in certain states, including Minnesota and Iowa.

Merchant Plants and Sales to Power Marketers Are Significant

Investor-owned utilities (IOUs) continue to be the dominant purchasers of wind power, with 47% of new 2006 capacity and 58% of cumulative capacity selling power to IOUs (see Figure 8). Publicly owned utilities (POUs) have also taken an active role, purchasing the output of 14% of both new 2006 and cumulative capacity.

The role of power marketers – defined here as corporate intermediaries that purchase power under contract and then re-sell that power to others, sometimes taking some merchant risk[10] – in the wind power market has increased dramatically since 2000. As of the end of 2006, power marketers were purchasing power from 16% of the installed wind power capacity in the U.S., though these entities purchased the output of just 7% of the new projects built in 2006.



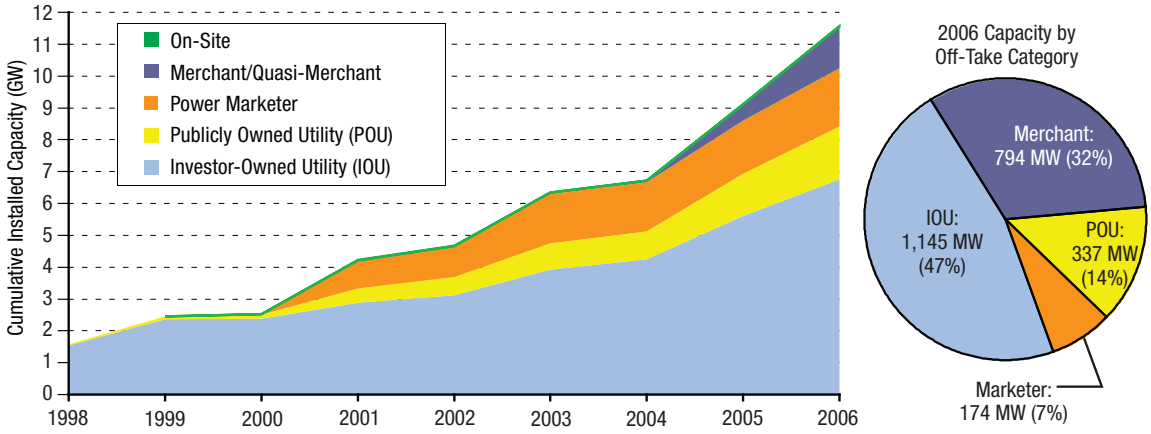
Source: Berkeley Lab estimates based on AWEA/GEC wind project database.

Figure 7. Cumulative and Annual (2006) Wind Capacity Categorized by Owner Type

[9] These two structures, along with five others currently used by the U.S. wind power industry, are examined in a forthcoming Berkeley Lab report.

[10] Here we define power marketers to include not only traditional marketers such as PPM Energy, but also the wholesale power marketing affiliates of large investor-owned utilities (e.g., PPL Energy Plus in PJM or TXU Wholesale in Texas), which may buy wind power on behalf of their load-serving affiliates.

Increasingly, owners of wind projects are taking on some merchant risk, meaning that some portion of their electricity sales revenue is tied to short-term or spot market sales.[11] The owners of 32% of the wind power capacity added in 2006, for example, are accepting some merchant risk, bringing merchant/quasi merchant ownership to 11% of total cumulative U.S. wind capacity. The majority of this activity exists in Texas and New York – both states in which wholesale spot markets exist, where wind power may be able to compete with these spot prices, and where additional revenue is possible from the sale of renewable energy certificates (RECs).



Source: Berkeley Lab estimates based on AWEA/GEC wind project database.

Figure 8. Cumulative and Annual (2006) Wind Capacity Categorized by Power Off-Take Arrangement

Wind Power Prices Are Up in 2006

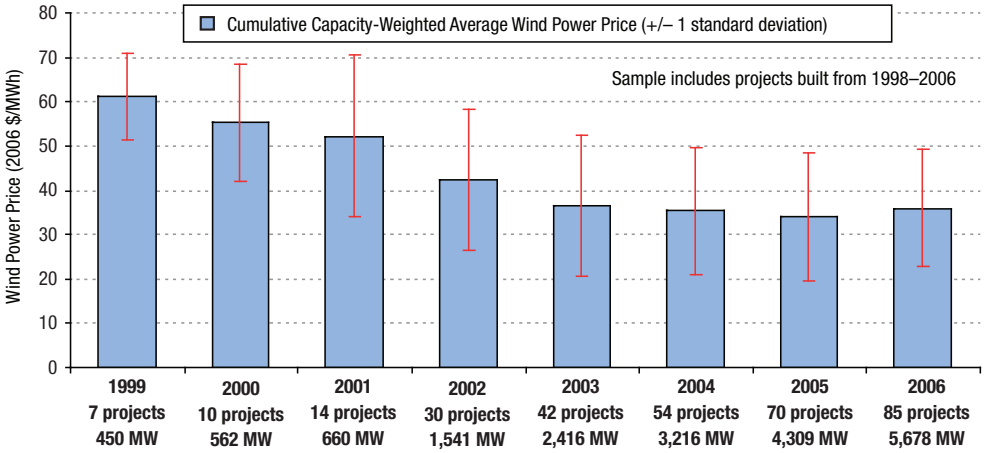
Although the wind industry appears to be on solid footing, the weakness of the dollar, rising materials costs, a concerted movement towards increased manufacturer profitability, and a shortage of components and turbines continued to put upward pressure on wind turbine costs, and therefore wind power prices in 2006.

Berkeley Lab maintains a database of wind power sales prices, which currently contains price data for 85 projects installed between 1998 and the end of 2006. These wind projects total 5,678 MW, or 58% of the incremental wind capacity in the U.S. over the 1998 through 2006 period.

The prices in this database reflect the price of electricity as sold by the project owner, and might typically be considered busbar energy prices.[12] These prices are reduced by the receipt of any available state and federal incentives (e.g., the PTC), and by the value that might be received through the separate sale of renewable energy certificates (RECs).[13] As a result, these prices do not represent wind energy generation costs, and generation costs cannot be derived by simply adding the PTC's value to the prices reported here.

Based on this database, the cumulative capacity-weighted average power sales price from our sample of post-1997 wind projects remains low by historical standards. Figure 9 shows the cumulative capacity-weighted average wind power price (plus or minus one standard deviation around that price) in each calendar year from 1999 through 2006. Based on our limited sample of 7 projects built in 1998 or 1999 and totaling 450 MW, the weighted-average price of wind in 1999 was just under $61/MWh (2006 dollars). By 2006, in contrast, our cumulative sample of projects built from 1998 through 2006 had grown to 85 projects totaling 5,678 MW, with an average price of $36/MWh (with the one standard deviation range extending from $23/MWh to $49/MWh). Although Figure 9 does show a slight increase in the cumulative weighted-average wind power price in 2006, reflecting rising prices from projects built in 2006, the cumulative nature of the graphic mutes the degree of increase.

To better illustrate the 2006 price increase and, more generally, changes in the price of power from newly built wind projects over time, Figure 10 shows average wind power sales prices in 2006, grouped by each project's initial commercial operation date (COD). Although our limited project sample and the considerable variability in prices across projects installed in a given time period



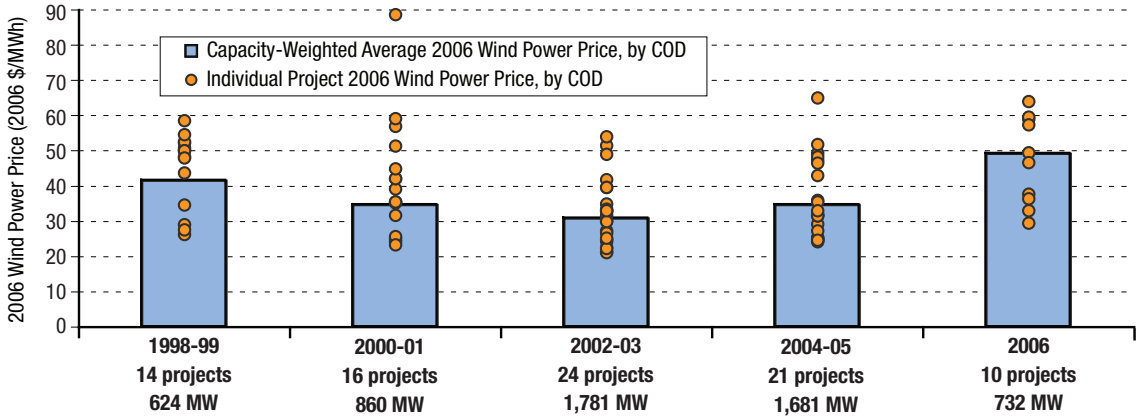
Source: Berkeley Lab database.

Figure 9. Cumulative Capacity-Weighted Average Wind Power Price over Time

[11] Though, even in these cases, hedging transactions are commonly used to mitigate price risk.

[12] These prices will typically include interconnection costs and, in some cases, transmission expansion costs that are needed to ensure delivery of the energy to the purchaser.

[13] Only 9 of the 85 projects in our sample appear to receive additional revenue (beyond the bundled power price reported) for the sale of RECs. See Figure 11 for more information on these 9 projects.



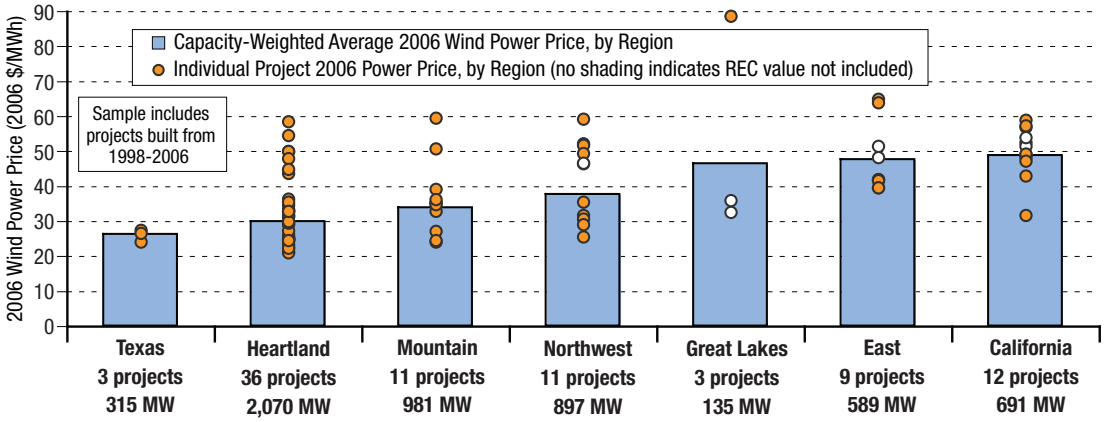
Source: Berkeley Lab database.

Figure 10. 2006 Wind Power Price by Commercial Operation Date (COD)

complicate analysis of national price trends (with averages subject to regional and other factors), the general trend exhibited by the capacity-weighted-average prices (i.e., blue columns) nevertheless suggests that, following a general decline since 1998, prices bottomed out for projects built in 2002 and 2003, and have since risen.[14]

Specifically, the capacity-weighted average 2006 sales price for projects in our sample built in 2006 was roughly $49/MWh (with a range of $30 to $64/MWh), up from an average of around $35/MWh (with a range of $24 to $65/MWh) for our sample of projects built in 2004 and 2005, and $31/MWh (with a range of $21 to $54/MWh) for our sample of projects built in 2002 and 2003.[15] Moreover, because recent turbine price increases are not fully reflected in 2006 wind project prices – many of these projects had locked in turbine prices and/or negotiated power purchase agreements as much as 18 to 24 months earlier – prices from projects being built in 2007 and beyond may be higher still.

The underlying variability in our price sample is caused in part by regional factors, which may affect not only project performance (depending on the strength of the wind resource in a given region), but also development and installation costs (depending on a region's physical geography, population density, or even regulatory processes).[16] Figure 11 shows individual project and average 2006 wind power prices by region for our sample of wind projects installed after 1997, with regions as defined in Figure 12. Although sample size is problematic in some regions (e.g., Texas and the Great Lakes), Texas and the Heartland region appear to be among the lowest cost on average, while California, the Great Lakes, and East regions are the three highest-cost regions (though data in the Great Lakes region in particular are not robust, with one higher cost outlier). These regions would appear even costlier if the value of RECs were included for the nine non-shaded projects (REC value appears to be bundled into the prices reported for all of the shaded projects – see Text Box 2 on page 12 for more on RECs). In general, this regional ranking is not particularly surprising, as Texas and the Plains states are widely considered to be low-cost wind regions, with development along the East and West coasts being costlier.



Source: Berkeley Lab database.

Figure 11. 2006 Wind Power Price by Region

[14] Although it may seem counterintuitive, the weighted-average 1999 price (for 1999) shown in Figure 9 (~$61/MWh) is significantly higher than the weighted-average 1999 price (for 2006) shown in Figure 10 (~$41.6/MWh) for three reasons: (1) our sample size is larger in Figure 10, due to the fact that we are pulling 2006 prices, rather than 1999 prices as in Figure 9; (2) two of the larger projects built in 1998 and 1999 (for which we have both 1999 and 2006 prices, meaning that these projects are represented within both figures) have nominal PPA prices that actually decline, rather than remaining flat or escalating, over time; and (3) inflating all prices to constant 2006 dollar terms impacts older (i.e., 1999) prices more than it does more recent (i.e., 2006) prices.

[15] If the federal PTC was not available, wind power prices for 2006 projects would range from approximately $50/MWh to $85/MWh, with an average of roughly $70/MWh.

[16] It is also possible that regions with higher wholesale power prices will, in general, yield higher wind contract prices due to arbitrage opportunities on the wholesale market. We do not test that theory here.

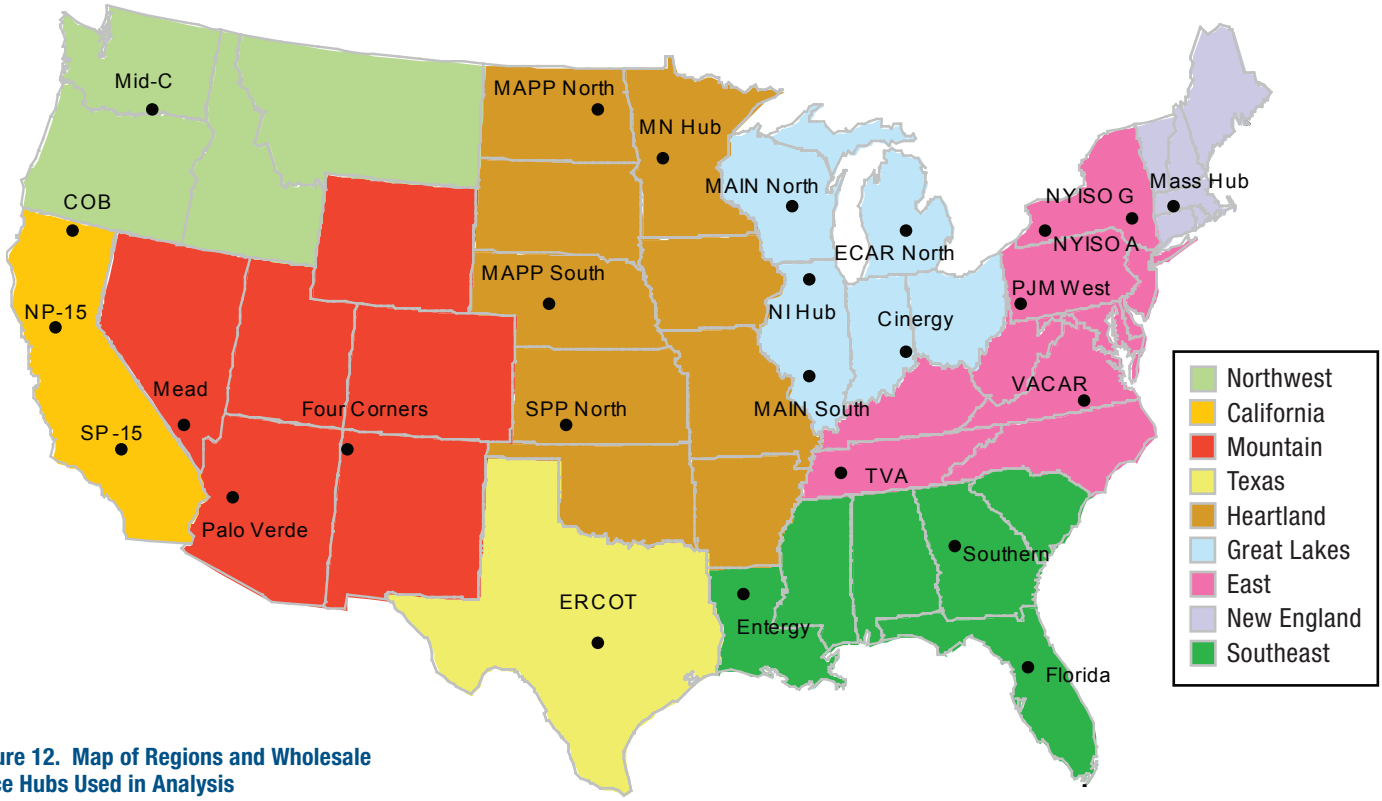
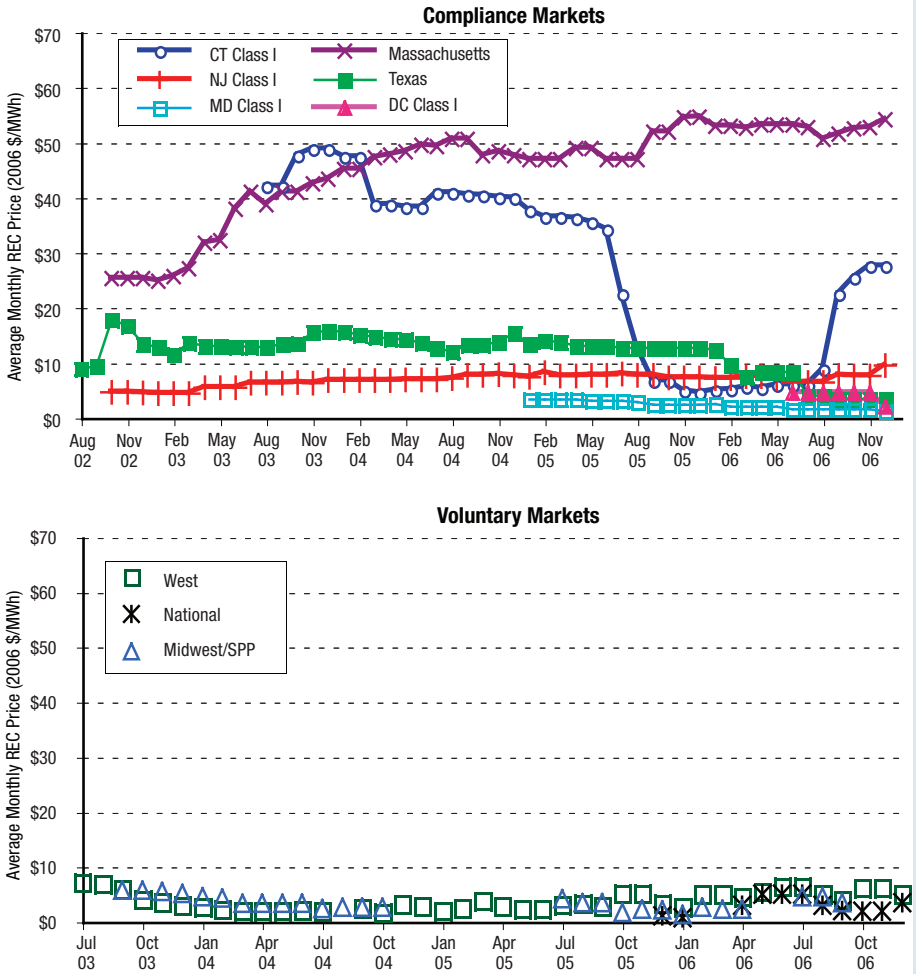


Figure 12. Map of Regions and Wholesale Price Hubs Used in Analysis

Text Box 2. REC Markets Remain Fragmented

Most of the wind power transactions identified in Figures 9 through 11 reflect the sale of both electricity and renewable energy certificates (RECs), but for at least 9 of these projects, RECs are or can be sold separately to earn additional revenue. REC markets are highly fragmented in the U.S., but consist of two distinct segments: compliance markets in which RECs are sold to meet state RPS obligations, and green power markets in which RECs are sold on a voluntary basis. Electronic REC tracking systems exist in New England, the PJM Interconnection, Texas, and Wisconsin, with such tracking systems under development in the West, Midwest, and New York.

The figures at right present monthly data on REC prices in compliance and voluntary markets. Key trends in 2006 compliance markets include continued high prices to serve the Massachusetts RPS, dramatically increasing prices under the Connecticut RPS, and declining prices in Texas. Despite declining prices in Texas, the combination of high wholesale power prices and the possibility of additional REC revenue increased merchant wind activity in that state in 2006. RECs offered in voluntary markets continued to fetch under $5/MWh in 2006.

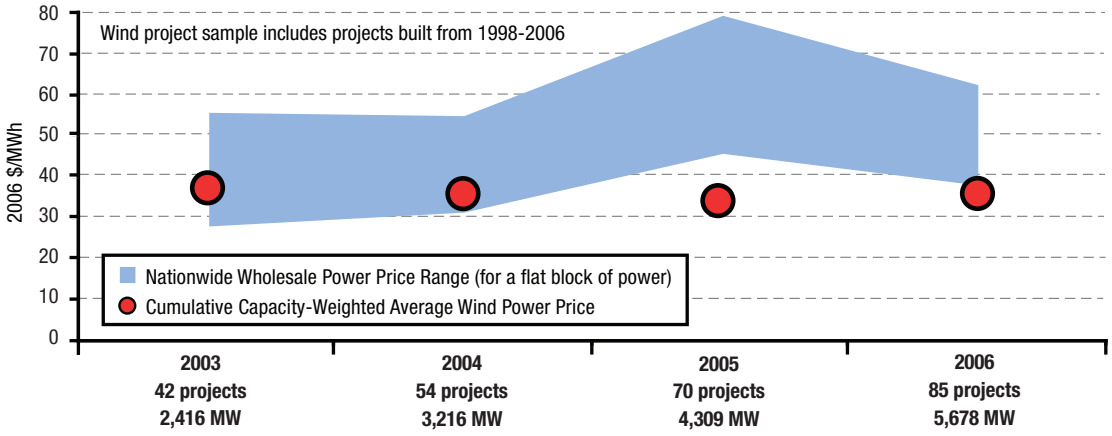


Source: Evolution Markets

Wind Appears Competitive in Wholesale Power Markets, but Rising Costs Are Starting to Erode that Value

The wind power prices presented in the previous section do not encompass the full costs or benefits of wind power. As mentioned, the prices do not universally include the value of RECs, and are also suppressed by virtue of federal and, in some cases, state tax and financial incentives. Furthermore, these prices, which typically represent only the busbar cost of energy, do not fully reflect integration or transmission costs, or the value of wind power in reducing carbon emissions and fuel price risk.

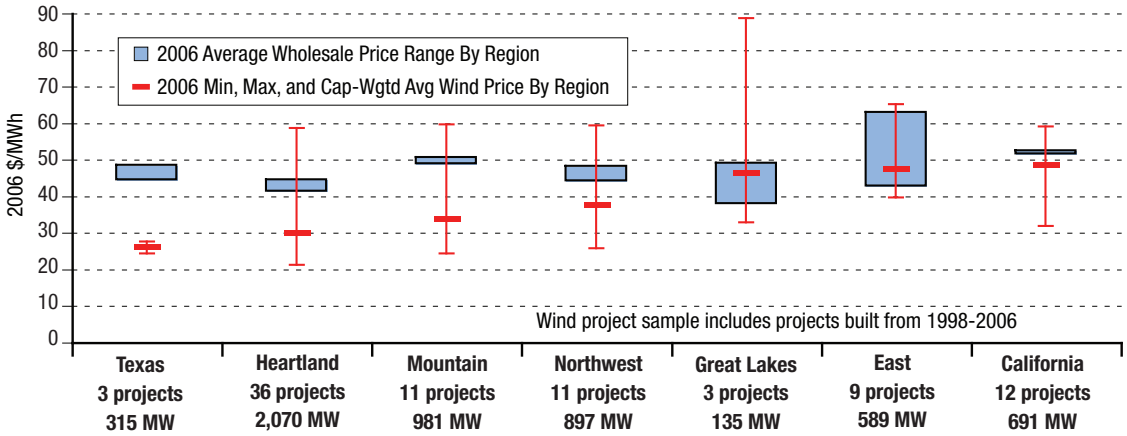
Nevertheless, a simple comparison of these prices with recent wholesale power prices throughout the United States demonstrates that wind power has generally provided good value in wholesale power markets over the past few years. Figure 13 shows the range of average annual wholesale power prices for a flat block of power[17] going back to 2003 at 26 different pricing hubs located throughout the country. Refer to Figure 12 for the names and approximate locations of the 26 pricing hubs represented by the blue-shaded area. The red dots show the cumulative capacity-weighted average price received by wind projects in each year among those projects in our sample with commercial operations dates of 1998 through 2006 (consistent with the data presented in Figure 9). At least on a cumulative basis within our sample of projects, wind has consistently been priced at or below the low end of the wholesale power price range.[18]



Source: FERC 2006 and 2004 "State of the Market" reports, Berkeley Lab database.

Figure 13. Average Cumulative Wind and Wholesale Power Prices over Time

Though Figure 13 suggests that wind projects installed from 1998 through 2006 have, since 2003 at least, been a good value in wholesale markets on a simple, nationwide basis, there are clearly regional differences in wholesale power prices and in the average price of wind power. These variations are reflected in Figure 14, which focuses on 2006 wind and wholesale power prices in the same regions shown earlier in Figures 11 and 12, again based on our entire sample of wind projects installed from 1998 through 2006. Although there is quite a bit of variability within some regions, in most regions the cumulative capacity-weighted average wind power price of our sample was below the range of average annual wholesale prices in 2006.



Source: FERC 2006 "State of the Market" report, Berkeley Lab database.

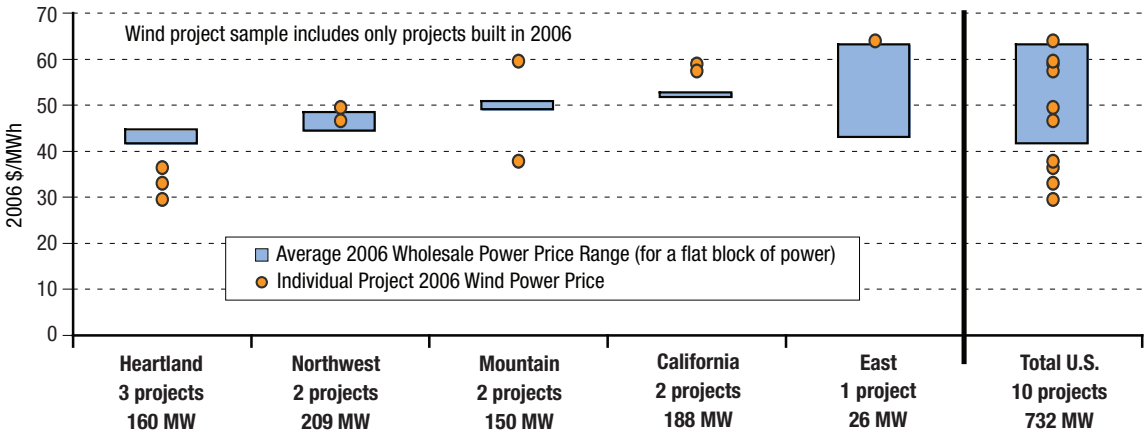
Figure 14. Average Cumulative Wind and Wholesale Power Prices by Region

Figures 13 and 14 use cumulative wind price data for projects installed from 1998 through 2006, but wind prices have risen in recent years, and especially in 2006.

[17] Though wind projects do not provide a perfectly flat block of power, as a common point of comparison, a flat block is not an unreasonable starting point. In other words, the time-variability of wind generation is often such that its wholesale market value is not too dissimilar from that of a flat block of (non-firm) power.

[18] It is worth noting that the comparison between wind power and wholesale prices in Figures 13-15 is, arguably, somewhat spurious for a number of reasons: (1) wholesale power prices do not always reflect both the capital and operating costs of new generation projects, whereas our wind prices represent all-in levelized costs; (2) in regions where capacity markets exist, wholesale prices presumably reflect only the value of energy, whereas wind projects may provide both energy and limited capacity value; and (3) we have ignored relative transmission and integration costs, and the environmental and risk-reduction benefits of wind power. Another way to think of Figures 13-15, however, is as representing the decision facing wholesale power purchasers – i.e., whether to contract long-term for wind power or buy a flat block of (non-firm) spot power on the wholesale market. In this sense, the costs represented in Figures 13-15 are reasonably comparable, in that they represent what the power purchaser would actually pay in either case for power.

Focusing just on those projects in our sample that were built in 2006 (as opposed to 1998 through 2006) tells a more cautious story. As shown in Figure 15, only in the Heartland region was our sample of projects installed in 2006 consistently priced below average regional wholesale prices in that year. The recent increase in wind power prices is clearly eroding, to a degree, the strong competitive position that wind held relative to wholesale power prices in the 2003 to 2005 timeframe.



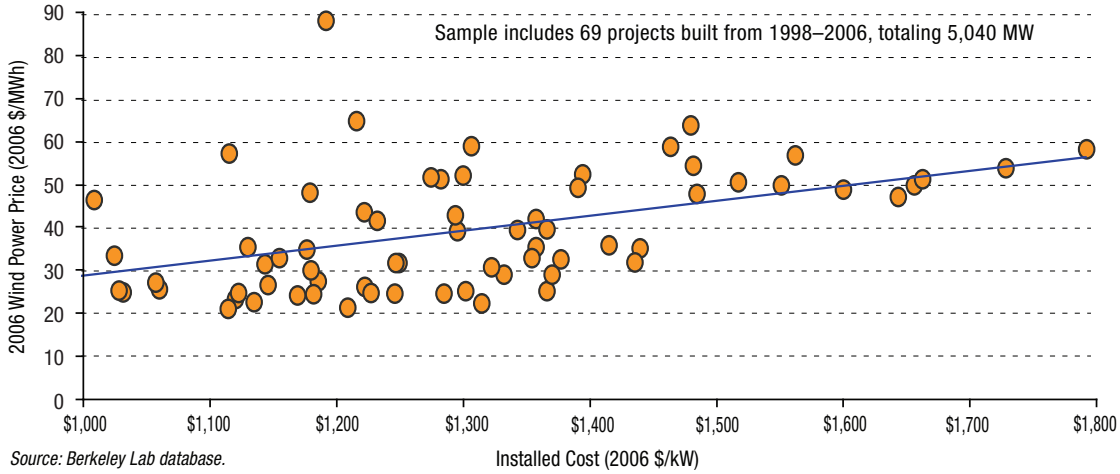
Source: FERC 2006 "State of the Market" report, Berkeley Lab database.

Figure 15. Wind and Wholesale Power Prices by Region: 2006 Projects Only

Project Performance and Capital Costs Drive Wind Power Prices

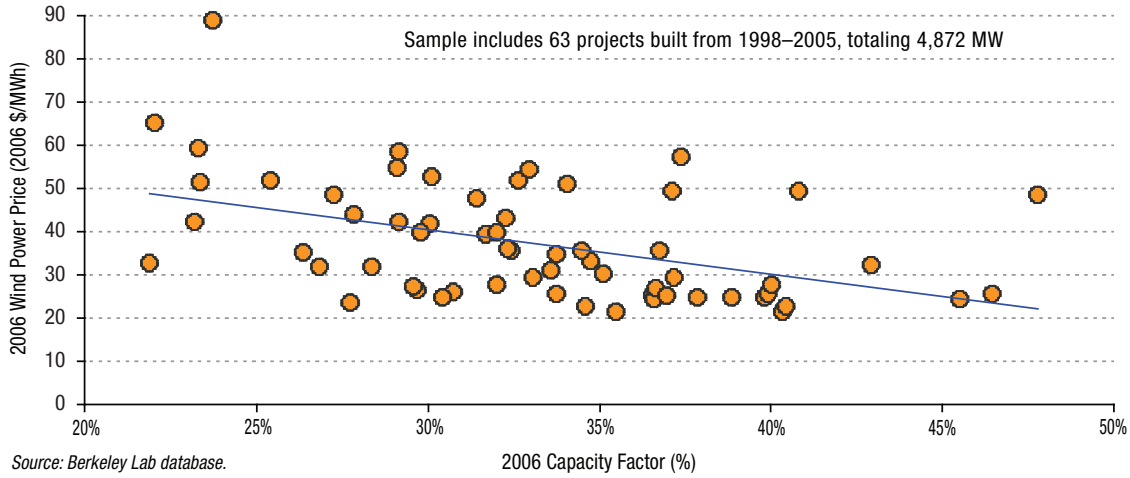
Wind power sales prices are affected by a number of factors, two of the most important being installed project costs and project performance.[19] Figures 16 and 17 illustrate the importance of these two variables.

Figure 16 shows a clear relationship between project-level installed costs and power sales prices for a sample of more than 5,000 MW of wind projects installed in the U.S. Figure 17, meanwhile, demonstrates a similarly striking (inverse) relationship between 2006 project-level capacity factors and 2006 power sales prices for a sample of nearly 4,900 MW of installed U.S. wind projects. The next few sections of this report explore trends in installed costs and project performance in more detail.



Source: Berkeley Lab database.

Figure 16. 2006 Wind Power Price as a Function of Installed Project Costs



Source: Berkeley Lab database.

Figure 17. 2006 Wind Power Price as a Function of 2006 Capacity Factor

[19] Operations and maintenance (O&M) costs are another important variable that affect wind power prices. A later section of this report covers trends in project-level O&M costs.

Installed Project Costs Are On the Rise, After a Long Period of Decline

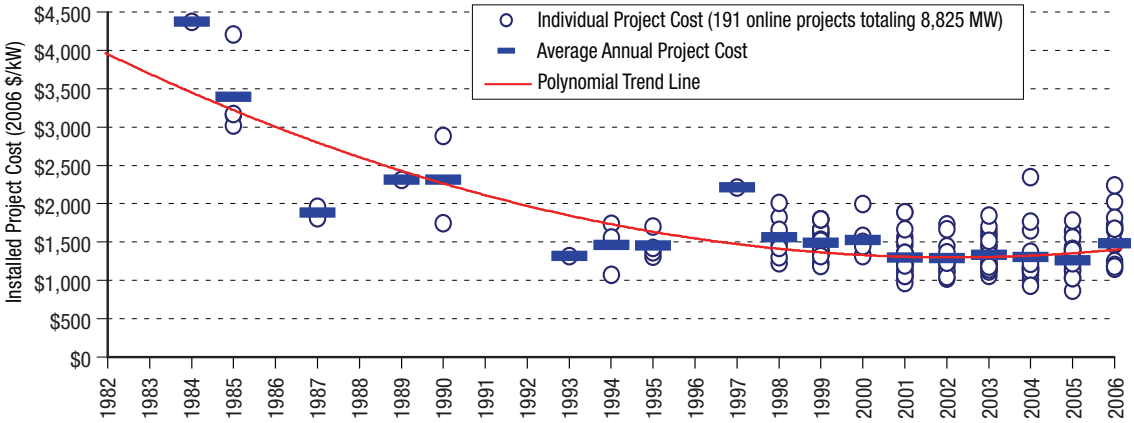
Berkeley Lab has compiled a sizable database of the installed costs of wind projects in the U.S., including data on 16 wind projects completed in 2006, totaling 1,326 MW, or 54% of the wind power capacity installed in that year. In aggregate, the dataset includes 191 completed wind projects in the continental U.S., totaling 8,825 MW, and equaling roughly 76% of all wind capacity installed in the U.S. at the end of 2006. The dataset also includes cost projections for proposed projects. In general, reported project costs reflect turbine installation, balance of plant, and any substation and/or interconnection expenses. Data sources are diverse, however, and are not all of equal credibility, so emphasis should be placed on overall trends in the data, rather than individual project-level estimates.

As shown in Figure 18, wind project installed costs declined dramatically from the beginnings of the industry in California in the 1980s to the early 2000s, falling by roughly $2,700/kW over this period (although limited sample size early on – particularly in the 1980s – makes it difficult to pin down this number with a high degree of confidence). More recently, however, costs have increased: among our sample of projects built in 2006, reported installed costs ranged from $1,150/kW to $2,240/kW, with an average cost of $1,480/kW – up $220/kW (18%) from $1,260/kW in 2005.

Moreover, there is reason to believe that recent increases in turbine costs did not fully work their way into installed project costs in 2006 – the average 2006 cost estimate for *proposed* projects in our sample (not shown in Figure 18) was $1,680/kW, or $200/kW higher than for projects completed in 2006. Anecdotal information from industry suggests that project costs may reach an average of $1,800/kW or higher in future years.

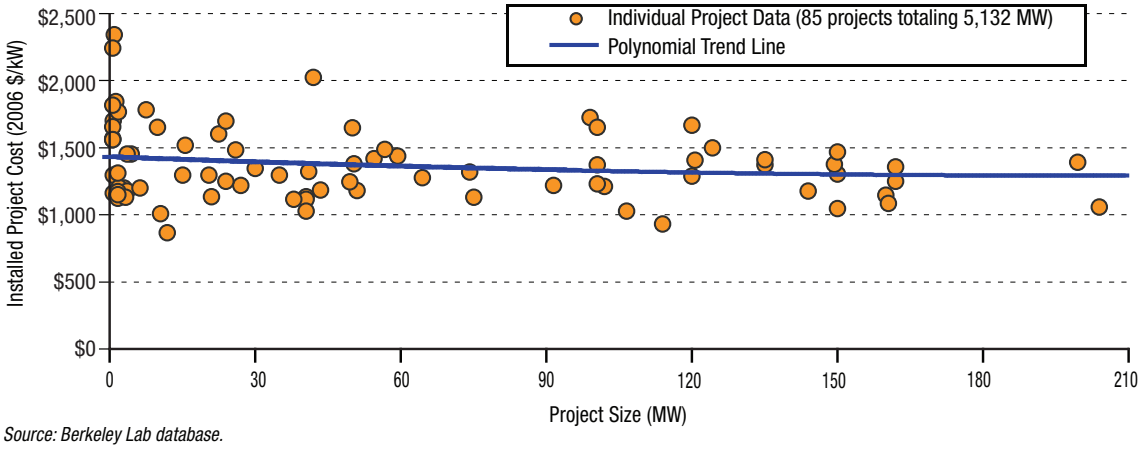
Project costs are influenced by numerous factors, including project size. Focusing only on those projects completed in 2003 through 2006, Figure 19 suggests that some economies of scale *may* exist, at least among the smaller projects in the sample. Given the wide spread in the data, however, and the apparently weak relationship between project size and cost, it is clear that other factors must play a major role in determining installed costs.

Differences in installed costs exist regionally due to differences in average project size (e.g., smaller projects in more-populous regions), as well as variations in development costs, siting and permitting requirements and timeframes, and balance-of-plant and construction expenditures. Considering projects in our sample



Source: Berkeley Lab database (some data points suppressed to protect confidentiality).

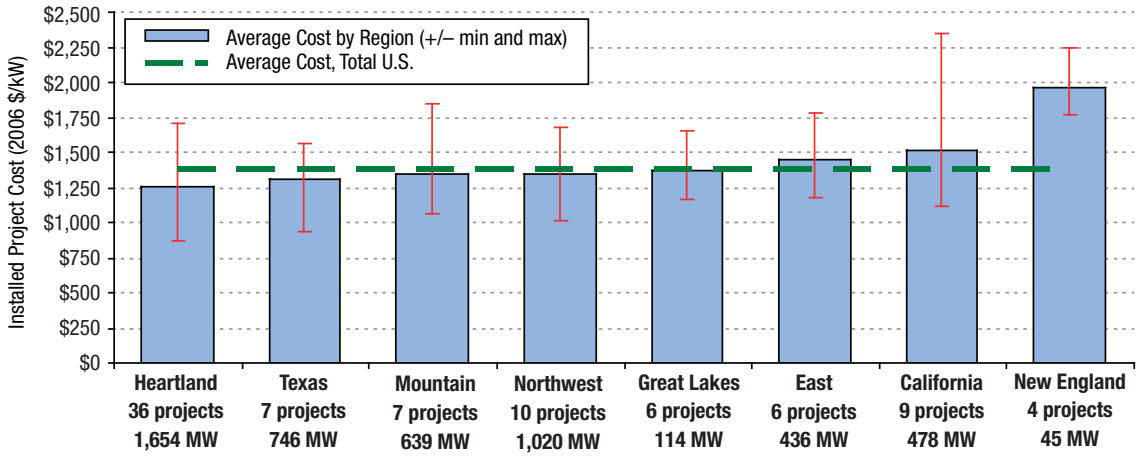
Figure 18. Installed Wind Project Costs over Time



Source: Berkeley Lab database.

Figure 19. Installed Wind Project Costs as a Function of Project Size: 2003 through 2006 Projects Only

installed in 2003 through 2006, Figure 20 shows that average costs equaled $1,365/kW nationwide, but vary by region. Higher cost regions are shown to include New England, California, and the East, while Texas and the Heartland are found to be the lowest cost regions.[20]

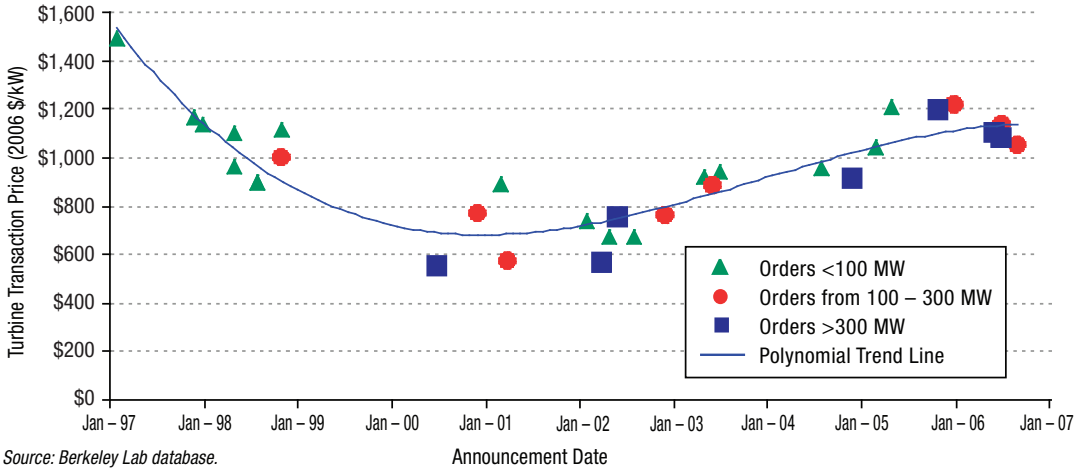


Source: Berkeley Lab database.

Figure 20. Installed Wind Project Costs by Region: 2003 through 2006 Projects Only

Project Cost Increases Are a Function of Turbine Prices

Increases in wind power prices and overall installed project costs, not surprisingly, mirror increases in the cost of wind turbines. Berkeley Lab has gathered data on 32 U.S. wind turbine transactions totaling 8,986 MW and spanning the 1997 through 2006 period. Sources of transaction price data vary, but most derive from press releases and press reports. Wind turbine transactions differ in the services offered (e.g., whether towers and installation are provided, the length of the service agreement, etc.), driving some of the observed intra-year variability in transaction prices. Nonetheless, most of the transactions included in the Berkeley Lab database likely include turbines, towers, erection, and limited warranty and service agreements; unfortunately, because of data limitations, we were to unable to determine the precise content of many of the individual transactions.



Source: Berkeley Lab database.

Figure 21. Reported U.S. Wind-Turbine Transaction Prices over Time

Despite these limitations, Figure 21 depicts reported wind-turbine transaction prices for U.S. turbine sales, from 1997 through 2006. Since hitting a nadir in the 2000 through 2002 period, turbine prices appear to have increased by more than $400/kW (60%), on average. Recent increases in turbine prices have likely been caused by several factors, including the declining value of the U.S. dollar relative to the Euro, increased materials and energy input prices (e.g., steel and oil), a general move by manufacturers to improve their profitability, shortages in certain turbine components, and an up-scaling of turbine size (and hub height) and sophistication.[21] The shortage of turbines has also led to a secondary market in turbines, through which prices may be even higher than those shown in Figure 21. Though by no means definitive, Figure 21 also suggests that larger turbine orders (> 300 MW) may have generally yielded somewhat lower pricing than smaller orders at any given point in time.

This trend of increasing turbine prices suggests that virtually the entire recent rise in installed project costs reported earlier has come from turbine price increases (recognizing that these prices reflect the cost of turbines, towers, and erection). In fact, because our sample of project-level costs has increased, on average, by just over $200/kW during the last several years, while turbine prices appear to have increased by $400/kW over the same time span, it appears as if further increases in project costs should be expected in the near future as the increases in turbine prices flow through to project costs.

[20] Graphical presentation of the data in this way should be viewed with some caution, as numerous factors influence project costs (e.g., whether projects are repowered vs. greenfield development, etc). As a result, actual cost differences among some regions may be more (or less) significant than they appear in Figure 20. Further statistical analysis of these project-level capital cost data will be made available later in 2007 in a forthcoming Berkeley Lab report, and those results should provide a better basis for inter-regional comparisons.

[21] More information on these factors will be available in a forthcoming Berkeley Lab report.

Wind Project Performance Is Improving Over Time

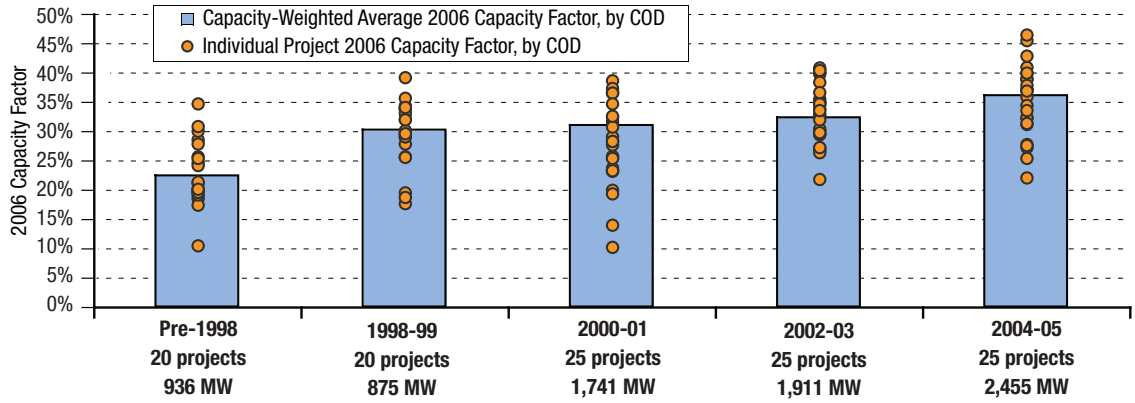
Though recent turbine and installed project cost increases have driven wind power prices higher, improvements in wind project performance have mitigated these impacts to some degree. In particular, capacity factors have increased for projects installed in recent years, driven by a combination of higher hub heights, improved siting, and technological advancements.

Figures 22 and 23, as well as Table 5, present excerpts from a Berkeley Lab compilation of wind project capacity-factor data. The sample consists of 115 projects built between 1983 and 2005 totaling 7,918 MW (87% of nationwide, installed wind capacity at the end of 2005).[22] Though capacity factors are not the ideal metric of project performance due to variations in the design and rating of wind turbines, absent rotor diameter data for each project, we are unable to present the arguably more relevant metric of electricity generation per square meter of swept rotor area. Both figures and the table summarize project-level capacity factors in the year 2006, thereby limiting the effects of inter-annual fluctuations in the nationwide wind resource.[23]

As shown in Figure 22, capacity-weighted average 2006 capacity factors in the Berkeley Lab sample increased from 22.5% for wind projects installed before 1998, to roughly 30% to 32.5% for projects installed from 1998 through 2003, and to roughly 36% for projects installed in 2004 through 2005. The average capacity factor of projects installed in 2004 through 2005 (36%) is approximately 20% greater than that of the 1998 through 1999 vintage projects in our sample (30%).[24]

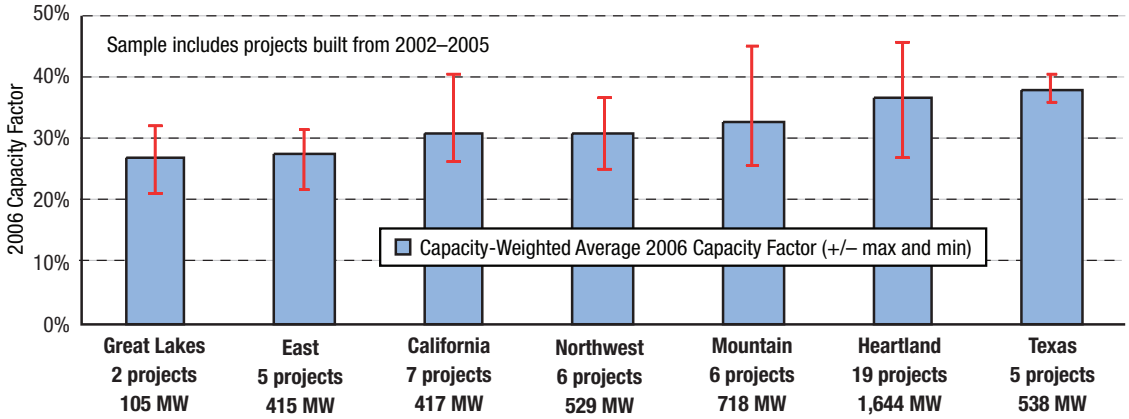
Though the overall trend is towards improved performance for more-recently installed projects, Figure 22 also illustrates a considerable spread in project-level capacity factors among projects installed within a given time period. Some of this spread is attributable to regional variations in wind resource quality. Figure 23 shows the regional variation in 2006 capacity factors, based on a sub-sample of wind projects built from 2002 through 2005. For this sample of projects, capacity factors are the highest in Texas and the Heartland (above 35% on average), and lowest in the Great Lakes and the East (below 30% on average). Given the small sample size in some regions, however, as well as the possibility that certain regions may have experienced a particularly good or bad wind resource year in 2006, care should be taken in extrapolating these results.

Though limited sample size is again a problem for many regions, Table 5 illustrates trends in 2006 capacity factors over time, by region. In the Heartland and Texas, the two regions with the largest sample of projects in terms of installed MW, the average capacity factor of projects installed in 2004 through 2005 (39%) is approximately 30% greater than that of the 1998 through 1999 vintage projects in our sample (30%).



Source: Berkeley Lab database.

Figure 22. 2006 Project Capacity Factors by Commercial Operation Date



Source: Berkeley Lab database.

Figure 23. 2006 Project Capacity Factors by Region: 2002 through 2005 Projects Only

[22] Though some data for wind projects installed in 2006 are available, those data do not span an entire year of operations. As such, for the purpose of this section, we focus on project-level 2006 capacity factors for projects with commercial online dates of 2005 and earlier.

[23] Focusing just on 2006 means that the absolute capacity factors shown in Figure 22 may not be representative if 2006 was not a representative year in terms of the strength of the wind resource. Though we have not formally investigated this question, an informal survey of individual project data suggests that 2006 was a fairly good wind year, at least relative to 2005. Note also that by including only 2006 capacity factors, variations in the quality of the wind resource year in 2006 across regions could skew the regional results presented in Figure 23 and Table 5.

[24] Conventional wisdom holds that new-project capacity factors will eventually decline as the best sites are developed and only lower-value wind resource sites remain. Our data showing capacity factor improvements over time suggest that either we have not yet reached that point (i.e., excellent wind sites are still being developed) or else some combination of higher hub heights, better turbine designs, and improved micro-siting have outweighed the presumed trend towards lower-quality sites (or both). Though we have not formally investigated this issue, it seems likely that a combination of events – including all of those listed here -- are behind the apparent increase in capacity factors from more recent projects.

Table 5. Capacity-Weighted Average 2006 Capacity Factors by Region and Commercial Operation Date

Capacity Factor	Heartland	Texas	California	Mountain	Northwest	East	Great Lakes	New England
Pre-1998	25.5%	19.6%	22.4%	—	—	—	—	20.2%
1998-99	30.1%	30.1%	30.0%	35.2%	30.1%	—	19.6%	—
2000-01	32.6%	31.8%	37.4%	30.1%	29.5%	22.2%	23.8%	—
2002-03	34.9%	37.0%	30.1%	30.3%	31.1%	30.3%	21.9%	—
2004-05	38.7%	38.9%	34.2%	41.0%	31.5%	26.7%	32.3%	—

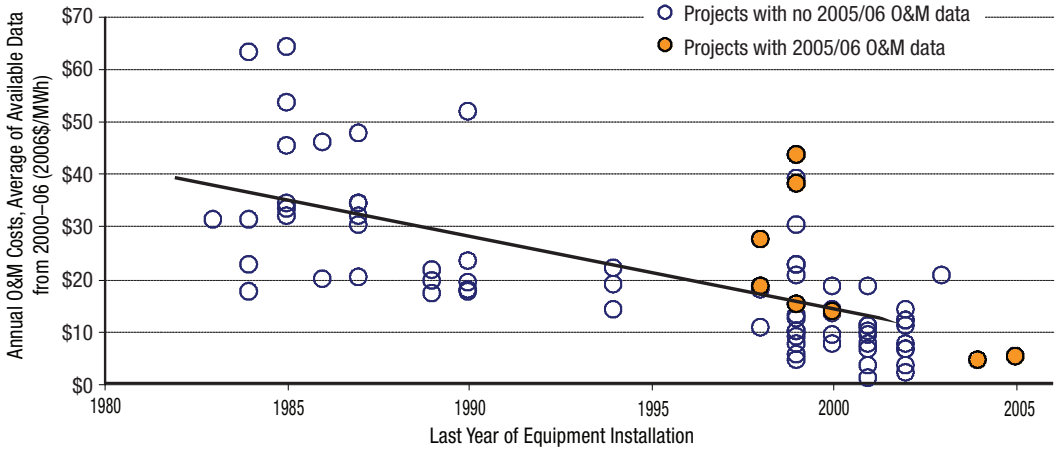
Sample	#	MW	#	MW	#	MW	#	MW	#	MW	#	MW	#	MW	#	MW
Pre-1998	1	26	1	34	17	870	—	—	—	—	—	—	—	—	1	6
1998-99	6	447	3	139	4	174	3	68	1	25	—	—	3	22	—	—
2000-01	4	197	7	911	1	67	4	123	3	338	5	76	1	30	—	—
2002-03	10	602	2	198	4	287	3	510	2	105	3	161	1	50	—	—
2004-05	9	1,042	3	341	3	130	3	208	4	424	2	255	1	54	—	—
Total	**30**	**2,314**	**16**	**1,622**	**29**	**1,528**	**13**	**909**	**10**	**891**	**10**	**491**	**6**	**157**	**1**	**6**

Operations and Maintenance Costs Are Affected by Project Age and Size, Among Other Factors

Operations and maintenance (O&M) costs are a significant component of the overall cost of wind projects, but can vary widely among projects. Market data on actual project-level O&M costs for wind plants are scarce. Even where these data are available, care must be taken in extrapolating historical O&M costs given the dramatic changes in wind turbine technology that have occurred over the last two decades, not least of which has been the up-scaling of turbine size (see Figure 6).

Berkeley Lab has compiled O&M cost data for 89 installed wind plants in the U.S., totaling 3,937 MW of capacity, with commercial operation dates of 1982 through 2005. These data cover facilities owned by both independent power producers and utilities, though data since 2004 is exclusively from utility-owned plants. A full time series of O&M cost data, by year, is available for only a small number of projects; in all other cases, O&M cost data are available for just a subset of years of project operations. Although the data sources do not all clearly define what items are included in O&M costs, in most cases, the reported values appear to include the costs of wages and materials associated with operating and maintaining the facility, as well as rent (i.e., land lease payments). Other ongoing expenses, including taxes, property insurance, and workers' compensation insurance, generally are not included. Given the scarcity and varying quality of the data, caution should be taken when interpreting the results shown below. Note also that we present the available data in $/MWh terms, as if O&M represents a variable cost. In fact, O&M costs are in part variable, and in part fixed.[25]

Figure 24 shows project-level O&M costs by year of project installation. Here, O&M costs represent an average of annual project-level data available for the years 2000 through 2006. For example, for projects that reach commercial operations in 2005, only year 2006 data are available, and that is what is shown in the figure.[26] Many other projects only have data for a subset of years during the 2000 through 2006 period, either because they were installed after 2000 or because a full time series is not available, so each data-point in the chart may represent a different averaging



Source: Berkeley Lab database; five data points suppressed to protect confidentiality.

Figure 24. Average O&M Costs for Available Data Years from 2000-2006, by Last Year of Equipment Installation

[25] Although not presented here, expressing O&M costs in units of $/kW-yr was found to yield qualitatively similar results.

[26] No 2006 projects are shown because we only use data from the first full year of project operations (and afterwards), which in this case would be year 2007 (for which data are not yet available). This makes projects that achieved commercial operations in 2005 the last in our series in this annual report (because full-year 2006 data are available in some cases).

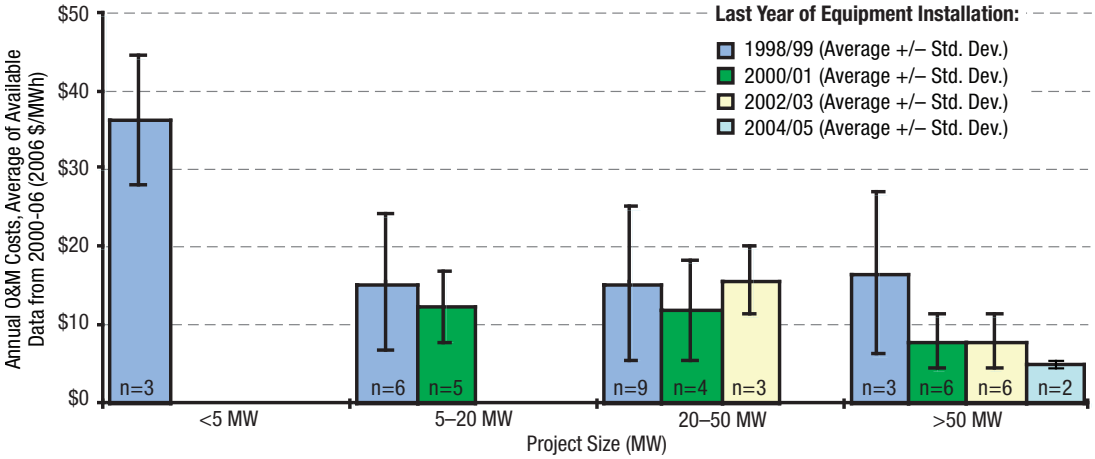
period over the 2000 through 2006 timeframe. The chart also identifies which of the data-points contain our most-updated data, from 2005 through 2006.

The data exhibit considerable spread, demonstrating that O&M costs are far from uniform across projects. However, Figure 24 suggests that projects installed more recently have, on average, incurred much lower O&M costs. Specifically, capacity-weighted average 2000 through 2006 O&M costs for projects in our sample constructed in the 1980s equal $30/MWh, dropping to $20/MWh for projects installed in the 1990s, and to $8/MWh for projects installed in the 2000s.[27] This drop in O&M costs may be due to a combination of at least two factors: (1) O&M costs generally increase as turbines age and component failures become more common; and (2) projects installed more recently, with larger turbines and more sophisticated designs, may experience lower overall O&M costs on a per-MWh basis. Given data limitations, we are unable to test the hypothesis that O&M costs have decreased as turbines have grown in size.

In addition to turbine size, another variable that may impact O&M costs is project size. Figure 25 narrows in on projects installed in 1998 or later, and presents average O&M costs for 2000 through 2006 (as in Figure 24) relative to project size.[28] Though substantial spread in the data exists and the sample is too small for definite conclusions, project size does appear to have some impact on average O&M costs, with higher costs typically experienced by smaller projects. More data would be needed to confirm this inference.

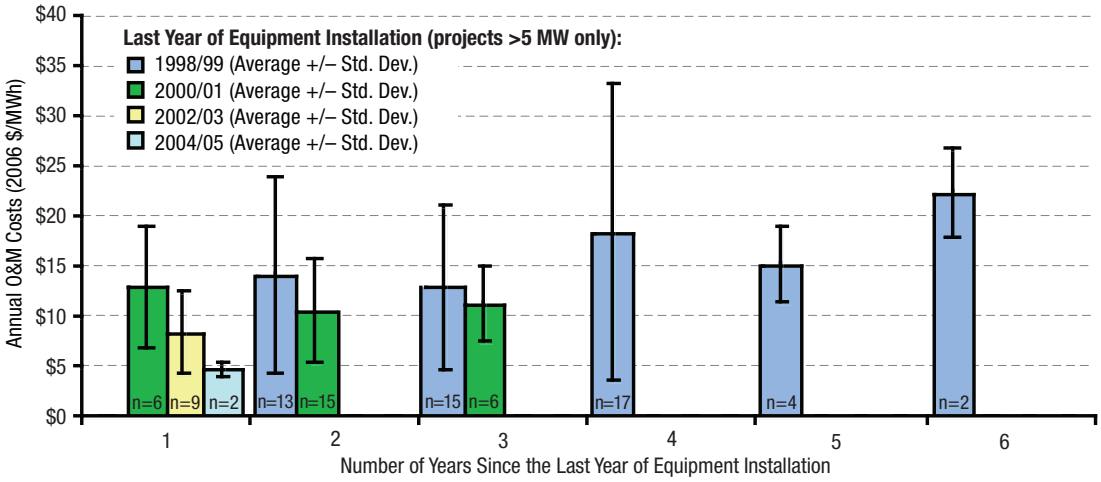
Finally, Figure 26 shows annual O&M costs over time, based on the number of years since the last year of equipment installation. Annual data for projects of similar vintages are averaged together, and data for projects under 5 MW in size are excluded (to avoid significant economies of scale impacts on the graphic). Note that, for each group, the number of projects used to compute the average annual values shown in the figure varies substantially (from 2 to 17 data points per project-year for projects installed in 1998 through 1999; from 6 to 15 data points per project-year for projects installed in 2000 through 2001; 9 data points for projects installed in 2002 through 2003; and 2 data points for projects installed in 2004 through 2005).[29] With this limitation in mind, the figure appears to show that projects installed in 2000 and later have lower O&M costs than those installed in 1998 and 1999, at least during the initial years of operation. In addition, the data for projects installed in 1998 through 1999 show a general upward trend in project-level O&M costs over the first 6 full years of project operation, though the sample size after year four is quite limited.

Though interesting, the trends noted above are not necessarily useful predictors of O&M costs for the latest turbine models. The U.S. DOE Wind Energy Program is currently funding additional efforts to better understand the drivers for O&M costs and component failures, and to develop models to project future O&M costs and failure events.



Source: Berkeley Lab database; averages shown only for groups of two or more projects.

Figure 25. Average O&M Costs for Available Data Years from 2000-2006, by Project Size



Source: Berkeley Lab database; averages shown only for groups of two or more projects.

Figure 26. Annual Average O&M Costs, by Project Age and Last Year of Equipment Installation

[27] Many of these latter projects may still be within their turbine manufacturer warranty period, in which case the O&M costs reported here may or may not include the costs of the turbine warranty, depending on whether the warranty is paid up-front as part of the turbine purchase, or is paid over time.

[28] Excluded from Figure 25 are average data bars that rely on just one data point.

[29] Excluded from Figure 26 are average data bars that rely on just one data point.

New Studies Find That Integrating Wind into Power Systems Is Manageable, But Not Costless

During the past several years, there has been a considerable amount of analysis on the potential impacts of wind energy on power systems, typically responding to concerns about whether the electrical grid can accommodate significant new wind additions, and at what cost. The sophistication of these studies has increased dramatically in recent years, resulting in a better accounting of wind's impacts and costs (recall that these "integration costs" were not included in the busbar wind power prices presented earlier).

Table 6. Key Results from Major Wind Integration Studies Completed 2003-2006

Date	Study	Wind Capacity Penetration	Cost ($/MWh)				
			Regulation	Load Following	Unit Commitment	Gas Supply	TOTAL
2003	Xcel-UWIG	3.5%	0	0.41	1.44	na	1.85
2003	We Energies	4%	1.12	0.09	0.69	na	1.90
2003	We Energies	29%	1.02	0.15	1.75	na	2.92
2004	Xcel-MNDOC	15%	0.23	na	4.37	na	4.60
2005	PacifiCorp	20%	0	1.6	3	na	4.60
2006	CA RPS (multi-year)	4%	0.45*	trace	na	na	0.45
2006	Xcel-PSCo	10%	0.2	na	2.26	1.26	3.72
2006	Xcel-PSCo	15%	0.2	na	3.32	1.45	4.97
2006	MN-MISO 20%	31%	na	na	na	na	4.41**

** 3-year average* *** highest over 3-year evaluation period*

Source: National Renewable Energy Laboratory.

Table 6 provides a selective listing of results from major wind integration studies completed from 2003 through 2006. Because methods vary and a consistent set of operational impacts has not been included in each study, results from the different analyses are not perfectly comparable. Nonetheless, the key findings of two major new studies completed in 2006 in Colorado and Minnesota are broadly consistent with those in earlier work, and (at a minimum) show that wind integration costs are generally approximately $5/MWh, or less, for wind *capacity* penetrations[30] up to about 15% of the local/regional peak load in which the wind power is being delivered.[31] Regulation and load-following impacts are generally found to be small, whereas the impacts of wind on unit commitment are more significant.[32]

Transmission Is an Increasingly Significant Barrier to Wind, but Solutions Are Emerging

Relatively little investment has been made in new transmission over the past 15 to 20 years, and in recent years it has become clear that lack of transmission access and investment are major barriers to wind development in the U.S. New transmission facilities are particularly important for wind resource development because of wind's locational dependence and distance from load centers. In addition, there is a mismatch between the short lead times for developing wind projects and the lengthier time often needed to develop new transmission lines. Furthermore, wind's relatively low capacity factor can lead to underutilization of new transmission lines that are intended to only serve wind. The question of "who pays?" for new transmission is also of critical importance to wind developers and investors. Transmission rate pancaking, charges imposed for inaccurate scheduling, and interconnection queuing procedures have also sometimes been identified as impediments to wind capacity expansion.

A number of developments occurred in 2006 that promise to help ease some of these barriers over time. The U.S. DOE issued a national transmission congestion study that designated southern California and the mid-Atlantic coastal area from New York City to northern Virginia as "critical congestion areas." Under the Energy Policy Act of 2005 (EPAct 2005), the U.S. DOE can nominate National Interest Electric Transmission Corridors, and the Federal Energy Regulatory Commission (FERC) can approve potential new transmission facilities in these corridors if states do not act within one year, or do not have the authority to act, among other conditions.[33] Separately, FERC issued a rule allowing additional profit incentives for transmission owners on a case-by-case basis, also as required by EPAct 2005, and thereby potentially encouraging greater transmission investment.

In the West, the Western Governors Association adopted a policy resolution through its Clean and Diversified Energy Advisory Committee that included a goal of 30,000 MW of clean energy by 2015, with potentially significant contributions from wind power. The recommendations of this committee to advance wind included

30 Wind penetration on a capacity basis (defined as nameplate wind capacity serving a region divided by that region's peak electricity demand) is frequently used in integration studies. For a given amount of wind capacity, penetration on a capacity basis is typically higher than the comparable wind penetration in energy terms.

31 The recently completed study in Minnesota found that a 25% wind penetration within the state, based on energy production (31% based on capacity), would cost $4.41/MWh or less. This low cost at such a high penetration rate is caused, in part, by the extensive interactions with the Midwest Independent System Operator (MISO) markets. The low cost found in the California study is partly a reflection of the limited number of cost factors that were considered in the analysis.

32 A number of additional wind integration analyses are planned for 2007, including a study of even-higher wind power penetrations in Colorado, the completion of the California Intermittency Analysis Project, and further work in the Pacific Northwest. Studies evaluating wind integration in the Southwest, and perhaps throughout the West, are also in the early planning stage.

33 The U.S. DOE has since issued draft National Interest Electric Transmission Corridor designations for the two regions identified above and, as of this writing, is receiving comments on this draft designation.

not only transmission expansion, but also more efficient use of the existing transmission grid through new transmission products such as "conditional firm" transmission service. Conditional firm service provides firm transmission service except during times of peak demand, when transmission could be curtailed.

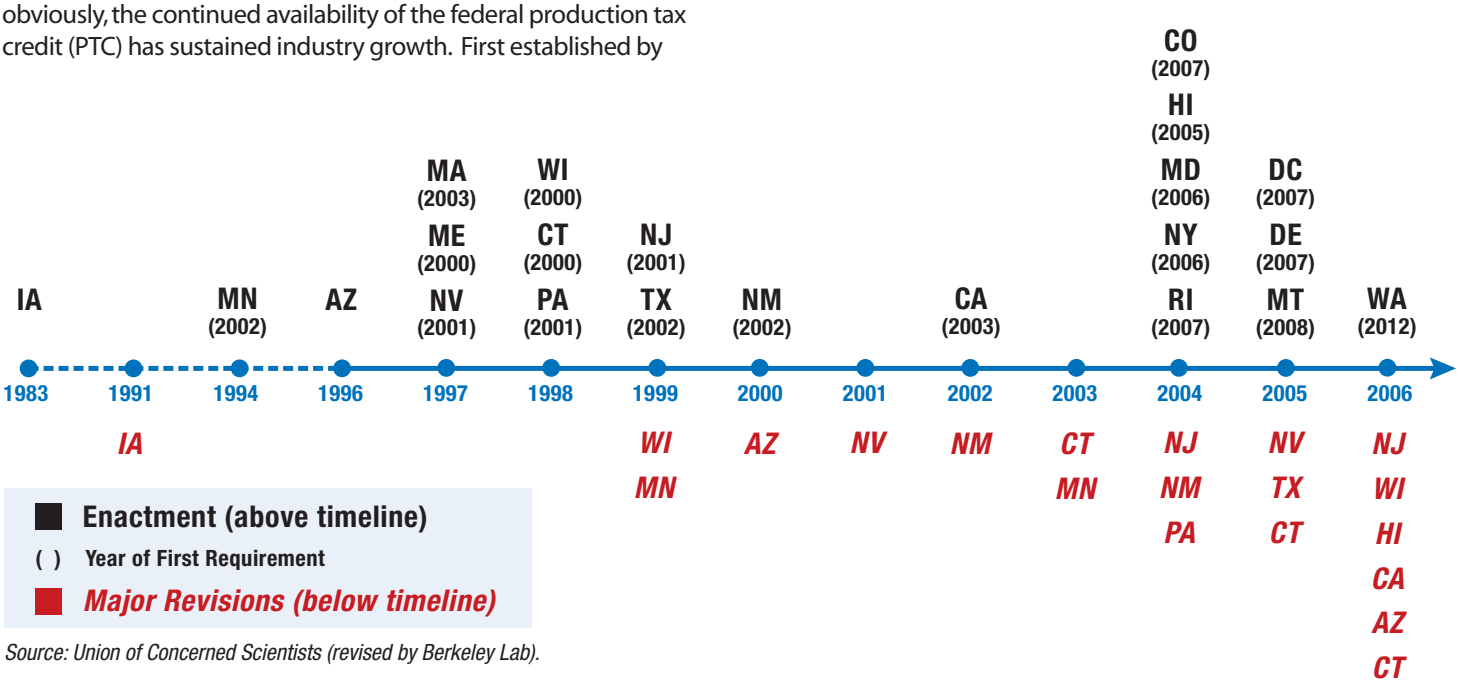
At the state level, several states are proactively developing the transmission infrastructure needed to accommodate increased wind development. In 2006, Texas began the process of identifying and creating Competitive Renewable Energy Zones: areas in which renewable resource availability is significant and to which transmission infrastructure would be built in advance of installed generation, with costs recovered through transmission tariffs. Meanwhile, in California, progress was made in developing elements of the Tehachapi transmission plan to access more than 4,000 MW of wind power. In the Midwest, utilities continued preparing permit applications to the Minnesota PUC for the first group of proposed transmission lines under the Capital Expansion by 2020 (CapX 2020) plan, a plan that would facilitate increased access to wind resources. Finally, a large number of transmission projects that may include delivery of wind power are in various stages of planning, including TransWest Express, Frontier, Northern Lights, TOT3, Seabreeze West Coast Cable, SunPath, and SunZia.[34]

Policy Efforts Continue to Drive Wind Development

A variety of policy drivers have been important to the recent expansion of the wind power market in the U.S. Perhaps most obviously, the continued availability of the federal production tax credit (PTC) has sustained industry growth. First established by the Energy Policy Act of 1992, the PTC provides a 10-year credit at a level that equaled 1.9¢/kWh in 2006 (adjusted upwards, in future years, for inflation). The importance of the PTC to the U.S. wind industry is illustrated by the pronounced lulls in wind capacity additions in the three years in which the PTC has lapsed: 2000, 2002, and 2004 (see Figure 1).

A number of other federal policies also support the wind industry. Wind power property, for example, may be depreciated for tax purposes over an accelerated 5-year period. Because tax-exempt entities are unable to take direct advantage of tax incentives, the Energy Policy Act of 2005 created the Clean Renewable Energy Bond (CREB) program, effectively offering interest-free debt to eligible renewable projects.[35] Finally, Section 9006 of the 2002 Farm Bill established the USDA's Renewable Energy and Energy Efficiency program to encourage agricultural producers and small rural businesses to use renewable and energy efficient systems.

State policies also continue to play a substantial role in directing the location and amount of wind development. Berkeley Lab has estimated that over the 2001 through 2006 timeframe, for example, approximately 50% of the wind power capacity built in the U.S. was motivated, to some extent at least, by state renewables portfolio standards (RPS); this proportion grew to 60% for installations in 2006. Utility resource planning requirements in Western and Midwestern states have also helped spur wind additions in recent years, as has growing voluntary customer demand for "green" power, especially among commercial customers. Additionally, state renewable energy funds provide support for wind projects, as do a variety of state tax incentives.



Source: Union of Concerned Scientists (revised by Berkeley Lab).

Figure 27. Timeline of State RPS Enactments and Revisions

[34] Important transmission developments have continued in 2007. In March 2007, FERC issued Order 890, which includes several provisions of importance to wind, such as reform of Order 888 energy imbalance penalties; establishment of a "conditional firm" transmission service; and requiring transmission providers to file transmission plans with FERC that meet certain principles. In April 2007, FERC approved in principle a proposal from the California ISO to establish a new transmission interconnection category aimed at large-scale development of renewable energy facilities in defined geographic areas (including, most immediately, Tehachapi). Finally, as already noted, in May 2007, DOE proposed two draft National Interest Electric Transmission Corridors, one in the Mid-Atlantic region and one in the Southwest.

[35] Such entities have also been eligible to receive the Renewable Energy Production Incentive (REPI), which offers a 10-year cash payment equal in face value to the PTC, but the need for annual appropriations and insufficient funding have limited the effectiveness of REPI.

Key policy developments in 2006 included:

- In December, the Tax Relief and Health Care Act of 2006 extended the in-service deadline for the PTC by one year, allowing wind projects that come on line through 2008 full access to the 10-year credit.
- In November, the IRS announced the distribution of the first $800 million in CREBs, including nearly $270 million for 112 wind power projects totaling roughly 200 MW. One month later, the Tax Relief and Health Care Act of 2006 added a second CREB allocation of $400 million, with applications due mid-2007.
- In August, a total of more than $17 million in grant awards were announced under the Section 9006 grant program, including $4.075 million for 14 wind projects totaling 28 MW in capacity.
- One new state (Washington) enacted an RPS, bringing the total to 21 states and Washington D.C. at the end of 2006. Several states revised their RPS requirements in 2006, in most cases making them more stringent (see Figure 27).[36]
- State renewable energy funds (in existence in more than 15 states), state tax incentives, utility resource planning requirements, green power markets, and growing interest in carbon regulations all helped contribute to wind expansion in 2006.

Coming Up in 2007

Though transmission availability, siting and permitting conflicts, and other barriers remain, 2007 is, by all accounts, expected to be another excellent year for the U.S. wind industry. With the PTC now extended through 2008, the American Wind Energy Association and BTM Consult expect robust 25 to 30% growth in wind power capacity in 2007, and strong growth should extend at least through 2008. With backing from industry and government, new efforts to seriously explore ambitious long-term targets for wind power commenced in 2006: a joint DOE-AWEA report that explores the possible costs, benefits, challenges, and policy needs of meeting 20% of the nation's electricity supply with wind power is planned for completion in 2007.

Appendix: Sources of Data Presented in this Report

Capacity Additions and Industry Trends

Data on wind power additions in the U.S. come from a database maintained by the American Wind Energy Association (AWEA) and Global Energy Concepts (GEC). Annual wind capital investment estimates derive from multiplying the wind capacity data from the AWEA/GEC dataset by weighted-average capital cost data, provided elsewhere in the report. Data on non-wind electric capacity additions come from the EIA. Data on active, proposed, offshore wind development activity in the U.S. were compiled by NREL, based on press reports and other data sources.

Global cumulative (and 2006 annual) wind capacity data come from BTM Consult, with cumulative data revised to include the most recent AWEA/GEC data on U.S. wind capacity. Historical cumulative capacity data come from BTM Consult and the Earth Policy Institute. Wind as a percentage of country sales is based on end-of-2006 wind capacity data and country-specific assumed capacity factors from BTM Consult's "World Market Update 2006," with the exception of the U.S., for which the underlying performance data presented in this report are used. Country-specific projected wind generation is then divided by projected electricity consumption in 2007, based on actual 2004 consumption and a country-specific growth rate assumed to be the same as the rate of growth from 2000 through 2004 (country-specific consumption and growth rates come from EIA's International Energy Outlook; except for the U.S., where we use projections from AEO 2007 for electricity consumption in 2007).

The wind project installation map of the U.S. was created by NREL, based in part on the AWEA/GEC dataset and in part on Platts data for the location of individual wind power plants. Effort was taken to reconcile the GEC/AWEA dataset and the Platts-provided project locations, though some discrepancies remain. Wind as a percentage contribution to statewide electricity sales is based on AWEA/GEC installed capacity data for the end of 2006 and the underlying wind project performance data presented in this report. Where necessary, judgment was used to estimate state-specific capacity factors. The resulting state wind generation is then divided by projected 2007 state retail electricity sales based on EIA-reported 2005 sales and EIA-projected regional consumption growth rates.

Turbine manufacturer market share and average turbine size are derived from the AWEA/GEC dataset, and are based on turbine installations in a given year (not turbine sales). Data on wind developer consolidation and investment trends were compiled by Berkeley Lab and Black & Veatch. Data on wind financing trends come from a forthcoming Berkeley Lab report. Wind project ownership and power purchaser trends are based on a Berkeley Lab analysis of the AWEA/GEC dataset.

Wind Power and Market Prices

Wind power price data are based on multiple sources, including prices reported in FERC Electronic Quarterly Reports (in the case of non-qualifying-facility projects), FERC Form 1, avoided cost data filed by utilities (in the case of some qualifying-facility projects), pre-offering research conducted by Standard & Poor's and other bond rating agencies, and a Berkeley Lab collection of power purchase agreements. To reduce the possibility of non-representative outliers, only wind power price data from the contiguous lower-48 states are included.

Wholesale power price data were compiled by Berkeley Lab from Table 3 of the FERC's "2006 State of the Markets Report" and Table 5 of the FERC's "2004 State of the Markets Report." For purposes of the regional graphs (Figures 14 and 15), the California-Oregon Border (COB) pricing hub is considered part of the Northwest, while the Texas wholesale price range considers prices in ERCOT as well as the Southwest Power Pool (SPP).

REC price data were compiled by Berkeley Lab based on a review of *Evolution Markets'* monthly REC market tracking reports.

[36] Through April 2007, several additional states have strengthened their RPS requirements, including Minnesota, New Mexico, and Colorado. Other states are considering enacting RPS policies in 2007, including New Hampshire and Oregon.

Installed Project and Turbine Costs

Berkeley Lab used a variety of public and some private sources of data to compile capital cost data for a large number of U.S. wind power projects. Data sources range from pre-installation corporate press releases to verified post-construction cost data. Specific sources of data include: EIA Form 412, FERC Form 1, various Securities and Exchange Commission filings, various filings with state public utilities commissions, *Windpower Monthly* magazine, AWEA's *Wind Energy Weekly*, DOE/EPRI's Turbine Verification Program, *Project Finance* magazine, various analytic case studies, and general web searches for news stories, presentations, or information from project developers. Some data points are suppressed in Figure 18 to protect data confidentiality. Because the sources are not equally credible, little emphasis should be placed on individual project-level data; instead, it is the trends in those underlying data that offer insight. Only wind power cost data from the contiguous lower-48 states are included.

Wind turbine transaction prices were also compiled by Berkeley Lab. Sources of transaction price data vary, but most derive from press releases and press reports. In part because wind turbine transactions vary in the services offered, a good deal of intra-year variability in the cost data is apparent.

Wind Project Performance

Wind project performance data were compiled overwhelmingly from two main sources: FERC Electronic Quarterly Reports and EIA Form 906. Where discrepancies exist among our data sources, those discrepancies are handled based on the judgment of Berkeley Lab staff. Only wind project performance data from the contiguous lower-48 are included.

Wind Project Operations and Maintenance Costs

Wind project operations and maintenance costs come primarily from two sources: EIA Form 412 data from 2001 to 2003 for private power projects and projects owned by POUs, and FERC Form 1 data for IOU-owned projects. Some data points are suppressed in Figure 24 to protect data confidentiality. Only O&M data from the contiguous lower-48 states are included.

Other

The wind integration table (Table 6) is an updated version of Table 2 in: Parsons, B., M. Milligan, et al. "Grid Impacts of Wind Power Variability: Recent Assessments from a Variety of Utilities in the United States" available at http://www.nrel.gov/docs/fy06osti/39955.pdf. Data provided in the transmission and policy sections of this paper were compiled by Berkeley Lab, NREL, and Exeter Associates.

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Key Program Contacts

Steve Lindenberg
Acting Program Manager
Office of Wind and Hydropower Technologies
Energy Efficiency and Renewable Energy
1000 Independence Ave., SW, Washington, D.C. 20585

Robert Thresher, Director
National Renewable Energy Laboratory
National Wind Technology Center (NWTC)
1617 Cole Blvd, MS. 3811
Golden, Colorado 80401

Brian Smith, Technology Manager
Wind and Hydropower Technologies
NWTC
1617 Cole Boulevard, Golden, CO 80401

Jose R. Zayas, Manager
Sandia National Laboratories
Wind Energy Technology Department
P.O. Box 5800, Albuquerque, NM 87185-1124

Ryan Wiser, Scientist
Lawrence Berkeley National Laboratory
1 Cyclotron Rd., MS-90-4000, Berkeley, CA 94720

Wind Energy Web Sites

U.S. DEPARTMENT OF ENERGY WIND AND HYDROPOWER TECHNOLOGIES PROGRAM
http://www1.eere.energy.gov/windandhydro/

AMERICAN WIND ENERGY ASSOCIATION
http://www.awea.org/
windmail@awea.org

LAWRENCE BERKELEY NATIONAL LABORATORY
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WIND POWERING AMERICA
http://www.eere.energy.gov/windandhydro/windpoweringamerica/

Key Report Contacts

For more information on this report, please contact:

Ryan Wiser, Lawrence Berkeley National Laboratory
510-486-5474; RHWiser@lbl.gov

Mark Bolinger, Lawrence Berkeley National Laboratory
603-795-4937; MABolinger@lbl.gov

Alejandro Moreno, U.S. Department of Energy
202-586-8171; Alejandro.Moreno@ee.doe.gov

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