Wind Power in the United States: Technology, Economic, and Policy Issues

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Summary

Rising energy prices and concern over greenhouse gas emissions have focused congressional attention on energy alternatives, including wind power. Although wind power currently provides only about 1% of U.S. electricity needs, it is growing more rapidly than any other energy source. In 2007, over 5,000 megawatts of new wind generating capacity were installed in the United States, second only to new natural gas-fired generating capacity. Wind power has become "mainstream" in many regions of the country, and is no longer considered an "alternative" energy source.

Wind energy has become increasingly competitive with other power generation options, although the impacts of the current financial crisis are uncertain. Wind technology has improved significantly over the past two decades. CRS analysis presented here shows that wind energy still depends on federal tax incentives to compete, but that key uncertainties like climate policy, fossil fuel prices, and technology progress could dominate future cost competitiveness.

A key challenge for wind energy is that electricity production depends on when winds blow rather than when consumers need power. Wind's variability can create added expenses and complexity in balancing supply and demand on the grid. Recent studies imply that these integration costs do not become significant (5%-10% of wholesale prices) until wind turbines account for 15%-30% of the capacity in a given control area. Another concern is that new transmission infrastructure will be required to send the wind-generated power to demand centers. Building new lines can be expensive and time-consuming, and there are debates over how construction costs should be allocated among end-users and which pricing methodologies are best.

Opposition to wind power arises for environmental, aesthetic, or aviation security reasons. New public-private partnerships have been established to address more comprehensively problems with avian (bird and bat) deaths resulting from wind farms. Some stakeholders oppose the construction of wind plants for visual reasons, especially in pristine or highly-valued areas. A debate over the potential for wind turbines to interfere with aviation radar emerged in 2006, but most experts believe any possible problems are economically and technically manageable.

Federal wind power policy has centered primarily on the production tax credit (PTC), a business incentive to operate wind facilities. The PTC is currently set to expire on December 31, 2009. Analysts and wind industry representatives argue that the on-again off-again nature of the PTC is inefficient and leads to higher costs for the industry. A federal renewable portfolio standard—which would mandate wind power levels—was rejected in the Senate in late 2007; its future is uncertain.

If wind is to supply up to 20% of the nation's power by 2030, as suggested by a recent U.S. Department of Energy report, additional federal policies will likely be required to overcome barriers, and ensure development of an efficient wind market.

Contents

Introduction 1
Background 2
The Rise of Wind 2
Benefits and Drawbacks of Wind Power 4
Wind Resources and Technology 7
Wind Power Fundamentals 7
Physical Relationships 7
Wind Resources 8
Offshore Wind 9
Wind Power Technology 10
Types of Wind Turbines 11
Capacity Factor 13
Wind Research and Development Emphasis 13
Wind Industry Composition and Trends 14
Wind Turbine Manufacturers and Wind Plant Developers 17
International Comparisons 18
Wind Power Economics 21
Cost and Operating Characteristics of Wind Power 21
Wind Operation and System Integration Issues 23
Levelized Cost Comparison 24
Wind Policy Issues 30
Siting and Permitting Issues 30
Transmission Constraints 33
Federal Renewable Transmission Initiatives 36
Renewable Production Tax Credit 36
PTC Eligibility: IOUs vs. IPPs 37
Specific PTC Legislative Options 37
Carbon Constraints and the PTC 38
Alternatives to the PTC 39
Renewable Portfolio Standards 39
Federal RPS Debate 39
Conclusions 40

Figures

Figure 1. Cumulative Installed U.S. Wind Capacity 3
Figure 2. Wind Power Aerodynamics 7
Figure 3. U.S. Wind Resources Potential 9
Figure 4. Evolution of U.S. Commercial Wind Technology 11
Figure 5. Components in a Simplified Wind Turbine 12
Figure 6. Installed Wind Capacity By State in 2007 15
Figure 7. Existing and Planned North American Wind Plants by Size 16

Figure 8. U.S. Wind Turbine Market Share by Manufacturer in 2007 17
Figure 9. Global Installed Wind Capacity By Country 19
Figure 10. Component Costs for Typical Wind Plants 22

Tables

Table 1. Wind Energy Penetration Rates by Country 19
Table 2. Assumptions for Generating Technologies 25
Table 3. Economic Comparison of Wind Power with Alternatives 29
Table 4. Selected Wind Power Tax Incentive Bills Compared 38
Table A-1. Base Case Financial Factors 43
Table A-2. Base Case Fuel and Allowance Price Forecasts 44
Table A-3. Power Plant Technology Assumptions 45

Appendixes

Appendix. Financial Analysis Methodology and Assumptions 41

Contacts

Author Contact Information 46

Introduction

Rising energy prices and concern over greenhouse gas emissions have focused congressional attention on energy alternatives, including wind power. Although wind power currently provides only a small fraction of U.S. energy needs, it is growing more rapidly than any other electricity source. Wind energy already plays a significant role in several European nations, and countries like China and India are rapidly expanding their capacity both to manufacture wind turbines and to integrate wind power into their electricity grids.

This report describes utility-scale wind power issues in the United States. The report is divided into the following sections:

- Background on wind energy;
- Wind resources and technology;
- Industry composition and trends;
- Wind power economics; and
- Policy issues.

Three policy issues may be of particular concern to Congress:

- *Should the renewable energy production tax credit be extended past its currently scheduled expiration at the end of 2009, and, if so, how would it be funded?* The economic analysis suggests that the credit significantly improves the economics of wind power compared to fossil and nuclear generation.
- *Should the Congress pass legislation intended to facilitate the construction of new transmission capacity to serve wind farms?* As discussed below, sites for wind facilities are often remote from load centers and may require new, expensive transmission infrastructure. Texas and California have implemented state policies to encourage the development of new transmission lines to serve wind and other remote renewable energy sources. Legislation before the Congress would create a federal equivalent.
- *Should the Congress establish a national renewable portfolio standard (RPS)?* As discussed in the report, the economics of wind are competitive, but not always compelling, compared to fossil and nuclear energy options, and because wind power is dependent on the vagaries of the weather it is not as reliable as conventional sources. Some benefits of wind power cited by proponents, such as a long-term reduction in demand for fossil fuels, are not easily quantified. To jump-start wind power development past these hurdles, many states have instituted RPS programs that require power companies to meet minimum renewable generation goals. A national RPS requirement has been considered and, to date, rejected by Congress.

Other policy questions, such as federal funding for wind research and development, and siting and permitting requirements, are also outlined.

Background

The modern wind industry began in the early 1980s when the first utility-scale turbines were installed in California and Denmark.[1] Wind power then, as today, was driven by high energy prices, energy insecurity, and concern about environmental degradation. Early wind turbines, installed primarily at Altamont Pass outside of San Francisco in California, were primitive compared to today's machines, and suffered from poor reliability and high costs. Like most new technology, early wind turbines had to go through a process of "learning by doing," where shortcomings were discovered, components were redesigned, and new machines were installed in a continuing cycle.

Today's wind industry is notably different from that in the early 1980s. Wind turbines now are typically 100 times more powerful than early versions and employ sophisticated materials, electronics, and aerodynamics. Costs have declined, making wind more competitive with other power generation options. Large companies and investment banks now drive most wind power activity compared to the early days of collaborating scientists, inventors, and entrepreneurs.[2]

From the mid-1980s to the late 1990s the U.S. wind industry stagnated due to low energy prices and the technology's reputation for high cost and low reliability. But researchers continued to make improvements in the technology, driving down costs and improving reliability. New federal and state incentives encouraged developers to focus on the production of electricity at wind plants (also known as wind farms) and not just installing the equipment.[3] In 1999, the U.S. industry began a period of rapid expansion, slowed occasionally by expiring federal incentives. Strong growth continues to this day, but whether that growth will continue in the face of the current financial crisis is unclear.

The Rise of Wind

Wind power is no longer an "alternative" source of energy in many regions of the country.[4] It is the fastest growing source of new power generation in the United States. Between 2004 and 2007, installed wind turbine generating capacity increased by 150% (see **Figure 1**), and power generation from wind turbines more than doubled.[5]

[1] T. Gray, *Proceedings of the Wind Energy and Birds/Bats Workshop: Understanding and Resolving Bird and Bat Impacts*, American Wind Energy Association and American Bird Conservancy, September 2004, p. 6.

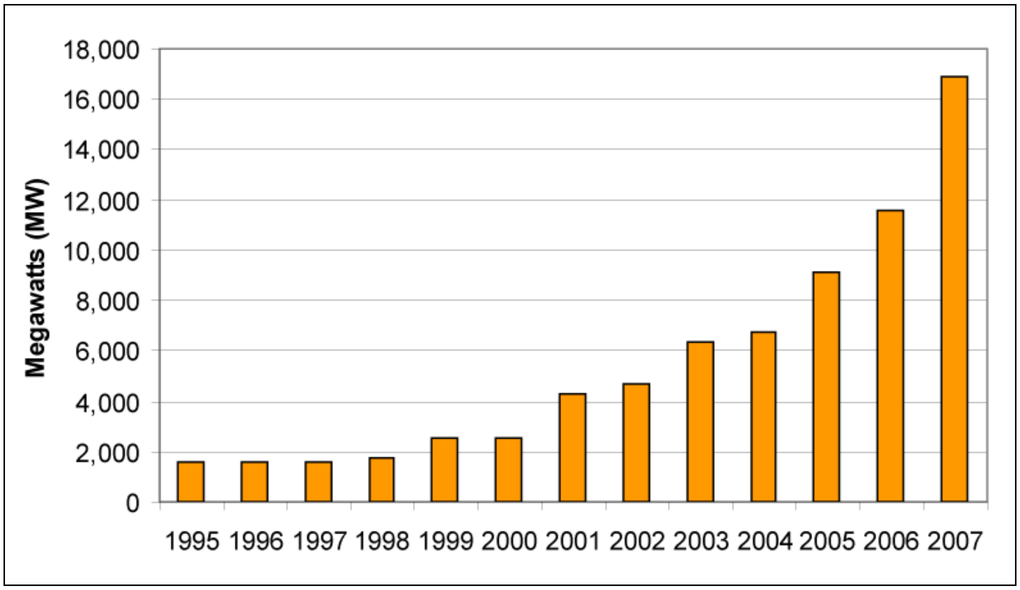
[2] R. Wiser and M. Bolinger, *Annual Report on U.S. Wind Power Installation, Cost and Performance Trends: 2007*, U.S. Department of Energy (DOE), May 2008, p.14.

[3] Investment tax credits in the 1980s offered incentives for the installation of wind equipment. They did not reward wind project developers for actually generating electricity. From the 1990s through today, production tax credits have encouraged builders to maximize the output of wind electricity since they earn credits for each kilowatt-hour generated.

[4] This statement is supported by the economic analysis presented later in the report; by the fact that wind accounts for over 6% of total in-state electricity generation in Minnesota, Iowa, Colorado and South Dakota; and by the amount of proposed wind power projects under development (225,000 megawatts) in 2007 compared to all other power plants (212,000 megawatts) combined. See R. Wiser and M. Bolinger, *Annual Report on U.S. Wind Power Installation, Cost, and Performance Trends: 2007*, DOE, May 2008, pp. 7-10.

[5] Electric generating capacity, measured in watts, is an expression of instantaneous power output. Electricity generation is measured in watt-hours and is an expression of energy produced over time. For example, a 1,000 watt generator that operates all day would produce 24,000 watt-hours (24 kilowatt-hours) of energy. Prefixes kilo (thousand), mega (million), giga (billion), and tera (trillion) are often used with these units. Capacity references are from: Energy (continued...)

Figure 1. Cumulative Installed U.S. Wind Capacity



Source: U.S. Department of Energy, Wind Powering America Program, 2008.

Only the amount of new natural gas-fired generating capacity installed during this period exceeded that of wind.[6] In 2007 the U.S. wind power industry brought over 5,000 megawatts of new generating capacity on-line, the largest annual increase ever by any country.[7] The United States was not alone in strong growth for wind power in 2007: global installations rose by 27% to reach a total of 94,123 megawatts.[8] Only Germany, with 22,247 megawatts, has more wind power capacity than the United States.[9]

Wind power's growth is driven by a combination of the following:

- improvements in wind energy technology,
- high and volatile fossil fuel prices,
- the federal wind production tax credit (PTC) incentive,[10]
- state renewable portfolio standards (RPS),[11]

(...continued)

Efficiency and Renewable Energy, "Wind Powering America Program," DOE, January 2008. http://www.eere.energy.gov/windandhydro/windpoweringamerica/wind_installed_capacity.asp. Generation references are from: Energy Information Administration (EIA), *Supplement to the Electric Power Monthly March 2008*, Table ES.1.B, DOE, April 2008; and EIA, *Electric Power Monthly March 2005*, Table ES.1.B., DOE, April 2005.

[6] New wind plants accounted for roughly 30% of total new power plant capacity installed in the United States in 2007. "Installed U.S. Wind Power Capacity Surged 45% in 2007," American Wind Energy Association, January 17, 2008.

[7] *Global Wind 2007 Report*, Global Wind Energy Council, 2008, p.64.

[8] *Global Wind 2007 Report*, Global Wind Energy Council, 2008, p. 6.

[9] *Global Wind 2007 Report*, Global Wind Energy Council, 2008, pp.8-10.

[10] The PTC is an incentive for business developers of wind farms and other renewable energy projects that produce electricity. It is discussed in the Policy Issues section later in this report. Also see CRS Report RL34162, *Renewable Energy: Background and Issues for the 110th Congress*, by (name redacted).

[11] Twenty-six states and the District of Columbia currently have mandatory RPS programs, requiring utilities to provide (continued...)

- difficulty siting and financing new coal-fired power plants given expectation of a future carbon constraint, and
- consumer preference for renewable energy.

However, wind power still accounts for only about 1% of the total electricity generated in the United States.[12] In some regions, a lack of transmission capacity is already beginning to constrain further growth in the wind power sector. And in states like Iowa, Texas, and Minnesota, where wind power has achieved a higher share of total electricity generation, there are concerns that additional wind power could lead to higher prices or threaten grid security. Finally, there is currently a shortage of wind turbine components and a backlog in scheduling transmission interconnection, leading to delays and rising costs.

Benefits and Drawbacks of Wind Power

There are frequently noted benefits and drawbacks to wind energy. **Text Box 1** and **Text Box 2** summarize selected problems and benefits, respectively, for wind power.

Drawbacks

A key challenge for wind energy is that electricity production depends on when and how consistently winds blow rather than when consumers most need power. This variability can create added expenses and complexity in balancing supply and demand on the grid.[13] Several recent studies note that system integration costs do not become significant ($3 to $5 per megawatt-hour) until wind turbines account for 15-30% of the capacity in a control area.[14] These apparently modest cost estimates have yet to be confirmed within the context of the U.S. electricity system.

Text Box 1. Selected Problems Facing Wind Power

- Power output depends on when the wind blows, not when users need electricity.

- New transmission infrastructure is often required.

- Depends on inconsistent federal incentives.

- Causes bird and bat deaths.

- Considered unsightly by some.

- Can interfere with radar in some cases.

Another concern is that new transmission infrastructure may be required to send the wind-generated power to where it is needed. This can be an expensive and time-consuming effort. There are debates over how construction costs should be allocated among end users and which pricing methodologies are most economically efficient. Although transmission

(...continued)

a minimum percentage of their electricity from approved renewable energy sources. Five others have non-binding goals. These numbers are reported by the Federal Energy Regulatory Commission (FERC) and can be accessed at http://www.ferc.gov/market-oversight/mkt-electric/overview/elec-ovr-rps.pdf.

[12] Wind farms in the United States generated approximately 32 billion kilowatt-hours in 2007 compared to total power sector generation of 4,160 billion kilowatt-hours. EIA, *Electric Power Monthly*, DOE, March 2008 Edition, Table ES1.B. The American Wind Energy Association forecasts that the U.S. wind industry will generate 48 billion kilowatt-hours of electricity in 2008.

[13] These issues are further discussed in the Wind Operation and Systems Integration Issues section of this report.

[14] This is about 5-10% of the price of typical wholesale electric power, according to CRS calculations. R. Wiser and M. Bolinger, *Annual Report on U.S. Wind Power Installation, Cost and Performance Trends: 2006*, U.S. DOE, May 2007, p. 20.

constraints face all new power generating options, wind power is especially handicapped because wind resources are often far from demand centers and do not usually use the full capacity of the transmission line due to the variable output. Texas is analyzing new transmission capacity to send wind-generator power from West Texas to the more populated northern and eastern sections of the state that could cost from $3 billion to over $6 billion.[15] On a national scale, the U.S. Department of Energy (DOE) states that the most cost-effective way to meet a 20% wind energy target by 2030 would be by constructing over 12,000 miles of new transmission lines at a cost of approximately $20 billion.[16] (See the section on "Transmission Constraints" for more on this issue.)

Wind power is supported by federal and state incentives. In 2007, the Energy Information Administration (EIA) of DOE estimated that federal incentives for wind—primarily the PTC—totaled $724 million.[17] In 2008, incentives could exceed $1 billion if wind generation expands from 32 billion kilowatt-hours to 48 billion kilowatt-hours as estimated by the American Wind Energy Association (AWEA), a national trade association promoting wind. Costs to states using RPS policies are difficult to estimate because they are mandated requirements. Some believe that these are high costs to pay for a relatively small amount of energy. Others note that wind energy is an evolving technology and additional breakthroughs are possible. Many in the industry believe that the on-again, off-again nature of the federal PTC incentives harm rational development of the sector.[18]

Among some critics, wind power also results in unacceptable bird and bat deaths. To others, it is the visual impacts that wind turbines have on the landscape, or the noise that causes objection. Finally, increasingly tall wind turbines have interfered with military and airport radar. These issues are discussed in a later section of the report.

Benefits

Wind turbines have no direct emissions of air pollutants, including oxides of sulfur and nitrogen, mercury, particulates, and carbon dioxide.[19] They also offset the need to mine, process, and ship coal and uranium; drill and transport natural gas (and to a much lesser degree, oil); and construct or maintain hydroelectric dams. As noted previously, wind power contributed approximately 32 billion kilowatt-hours of electricity to the U.S. electricity grid in 2007; if that electricity had been generated using the average mix of power plants in the United States, an additional 19.5 million tons of carbon dioxide would have been released that year.[20]

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[15] "ERCOT Files Wind Transmission Options with Commission," Electric Reliability Council of Texas (ERCOT) Press Release, April 2, 2008.

[16] Energy Efficiency and Renewable Energy, *20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply*, U.S. DOE, May 2008, p. 95.

[17] EIA, *Federal Financial Interventions and Subsidies in Energy Markets 2007*, U.S. DOE, April 2008, Table ES5.

[18] M. Barradale, "Impact of Policy Uncertainty on Renewable Energy Investment: Wind Power and PTC," U.S. Association for Energy Economics Working Paper No. 08-003, January 2008.

[19] Wind power does have "lifecycle emissions" associated with the materials that go into turbine and transmission line construction, operation and maintenance activities, and decommissioning. A study by the International Energy Agency estimated lifecycle carbon dioxide emissions for wind power at 7-9 grams of CO_2 per kilowatt-hour. For comparison, coal- and natural gas-fired plants released 955 and 430 grams per kilowatt-hour, respectively. International Energy Agency, *Benign Energy?: The Environmental Implications of Renewables*, Table 3-1 and 3-2, 1998.

[20] CRS calculation based on EIA data for 2006 and estimates for 2007. EIA, *Electric Power Monthly*, U.S. DOE, April (continued...)

Given rising prices for coal, natural gas, and nuclear fuel, power suppliers are drawn to the certainty that wind—while variable—is inexhaustible and has no fuel cost. By displacing coal-fired and gas-fired generation, wind power would reduce the demand for these fuels, perhaps moderating future prices and price volatility.

Wind plants can catalyze rural development because farmers and ranchers receive royalty payments from wind developers who lease their land; the vast majority remains available for crops or grazing. Farmers and ranchers typically receive from project developers $2,000-5,000 per year for each turbine on their land.[21] The land taken out of production for wind turbine pads, access roads, and ancillary equipment reduces income for corn farmers, for example, by about $165 per turbine.[22]

Text Box 2. Selected Benefits of Wind Power

- Operations do not produce carbon dioxide or other air pollutants.
- Reduces power market exposure to volatile fuel prices.
- Assists rural development by giving landowners income from land leases.
- May provide more "green jobs" than other power generation options.
- Offers shorter construction lead time than some other options.
- Provides competitive electricity, especially at peak times.
- Does not require water for operations.

Wind energy provides an additional source of revenue for local governments in the form of property taxes on wind plant owners. Wind turbines—unlike fossil and nuclear power plants—do not require water for cooling, a potentially important issue in areas with scarce water resources. Also, the lead time for planning and constructing wind plants is shorter than that for nuclear and coal, assuming transmission access is not an issue.

Finally, wind power proponents argue that wind energy creates "green collar" manufacturing and field service jobs rather than traditional carbon-intensive employment.[23] A study by Navigant Consulting in February 2008 estimated that 76,000 U.S. jobs in the wind industry were at risk if the PTC is not renewed well before its expiration in December 2008.[24] It is unclear how many U.S. jobs are at risk if traditional power plants are not built.

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15, 2008, Table ES1.B. For comparison, total U.S. electric power sector emissions of carbon dioxide in 2006 were over 2,500 million tonnes. EIA, *Electric Power Annual,* U.S. DOE, Table 5.1, October 2007.

[21] "Wind Power's Contribution to Electric Power Generation and Impact on Farms and Rural Communities," Government Accountability Office, GAO-04-756, September 2004, p. 1.

[22] According to the U.S. Department of Agriculture (USDA), projected revenue in 2008-09 for corn grown in the United States is $846 per acre. (See *World Agricultural Supply and Demand Estimates*, USDA, May 9, 2008, p. 12.) Total expenses per acre to produce this corn in 2006 were $410 (See "Commodity Costs and Returns: U.S. and Regional Cost and Return Data," USDA Economic Research Service, available at http://www.ers.usda.gov/Data/CostsAndReturns/data/current/C-Corn.xls. Expenses for 2008-09 have increased due to higher fuel and fertilizer costs. Assuming these expenses to be 25% higher in 2008-09 leads to $513 per acre, and net income of $333 per acre. According to NREL, about 0.5 acres of land is removed from production for each turbine, leading to a loss of corn production of about $165 dollars per turbine. (See "Power Technologies Energy Data Book: Wind Farm Area Calculator," NREL. Available at http://www.nrel.gov/analysis/power_databook/calc_wind.php.)

[23] S. Greenhouse, "Millions of Jobs of a Different Collar," *New York Times*, March 26, 2008.

[24] "Economic Impacts of Tax Credit Expiration," Navigant Consulting, prepared for the American Wind Energy Association and the Solar Energy Research and Education Foundation, February 2008, p. 21.

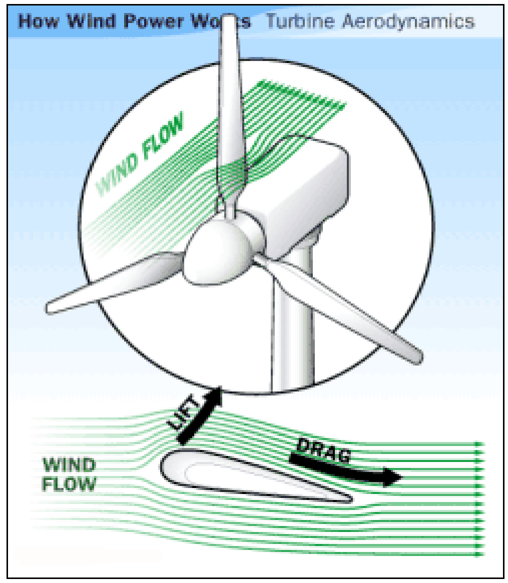
Wind Resources and Technology

This section begins with a description of how wind turbines work. It then provides information on wind resources in the United States, both on and offshore. Finally, the section outlines technology trends in the wind power sector.

Wind Power Fundamentals

Unequal solar heating of the Earth's atmosphere and oceans creates wind. Wind turbine blades, like airplane wings, produce lift when air passes over one side of their shaped surface more rapidly than another (**Figure 2**). This lift spins the turbine blades and rotor, which is connected to a generator through a gearbox inside the housing. The generator, and accompanying power conditioning equipment, then delivers electricity to the transmission grid at the appropriate voltage and frequency. The process is roughly opposite to a common household fan, which uses electricity to turn the blades and create air motion.

Figure 2. Wind Power Aerodynamics



Source: How Stuff Works, 2006.

Wind turbines can stand alone or be integrated into wind farms with power generating capacity equaling that of a traditional power plant.[25] This report focuses only on large, utility-scale wind turbines. Smaller, off-grid wind power applications are also growing rapidly, although their aggregate impact is limited.[26]

Physical Relationships

The evolution of wind power technology and market development has been influenced by three physical relationships. First, a wind turbine's power output varies with the cube of wind speed.[27] Thus, all else held constant, if wind velocity doubles, power output increases eight-fold. Wind power developers, therefore, face the challenge of finding where winds blow best. Winds at 250

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25 Typical new U.S. wind plants ranged from 100 to 300 megawatts of installed capacity in 2007. Horse Hollow (Texas) is the largest U.S. wind plant, at 736 megawatts. Although some wind plants have capacity on par with traditional fossil fuel power plants, they produce comparatively less electricity because winds blow inconsistently.

26 See Energy Efficiency and Renewable Energy, *Small Wind Electric Systems: A U.S. Consumer's Guide*, DOE, March 2005.

27 Cubing a number requires multiplying it by itself 2 additional times (i.e, $2^3 = 2x2x2 = 8$). The mathematical formula for wind turbine power output (P), usually measured in watts, is

$$P = k\,\rho A V^3,$$

where k is a constant that depends on turbine design characteristics and physical limitations, ρ is the density of air, A is the area swept out by the turbine rotor blades (namely, πr^2, with r being the length of the rotor blade), and V is the wind velocity.

feet in altitude are stronger and steadier than those closer to the ground; this factor explains why wind turbine towers are placed high in the air.

Second, power output varies with the area swept out by the turbine blades during their rotation. Doubling a turbine blade's length will yield a quadrupling of power output. Today's utility-scale wind turbine blades are commonly 130 feet long or more in an attempt to harness more energy. Turbine manufacturers have devoted attention over the past two decades to finding materials strong and durable enough to handle the twisting forces that are transmitted from the longer blades through the rotor and gearbox in fluctuating winds.

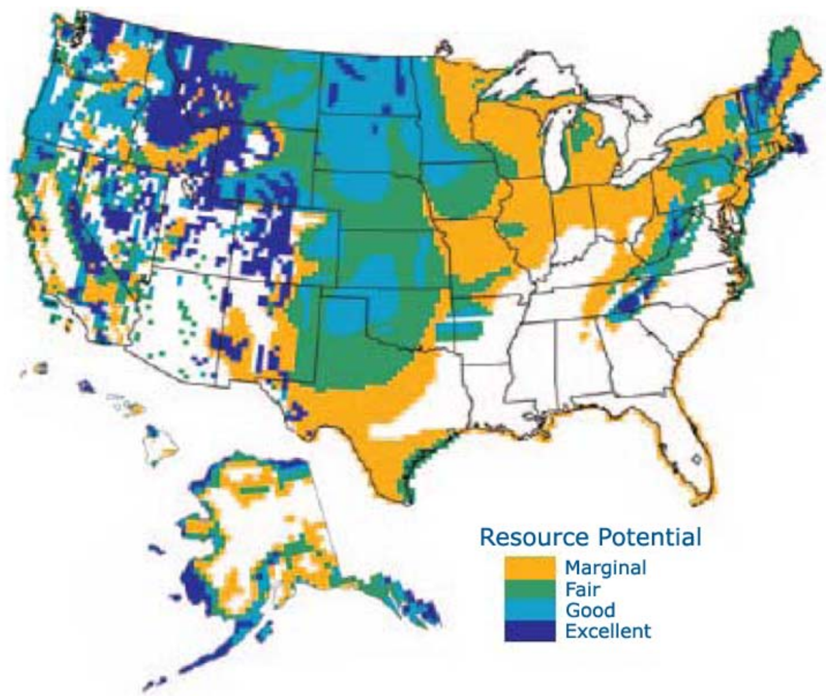
Finally, power output increases directly with air density. Density is typically higher in winter months and at low altitudes, and lower in summer months and at high altitudes. Winds near the cold Scandinavian seas, for example, contain more exploitable energy than those of the hot, high-altitude desserts of the American Southwest.

Wind Resources

Wind resources in the United States, and elsewhere, have been studied for decades. The National Renewable Energy Laboratory (NREL) has produced national and state wind resource maps that indicate areas with promising winds (**Figure 3**).[28] "Excellent" winds mean those that average about 17 miles per hour or above at 150 feet in altitude. Additional mapping efforts characterize seasonal and even daily variations in average wind speed. After using these maps to identify promising regions, wind plant developers must still study and document local conditions carefully—often for 12 months or longer—to ensure potential financiers that revenue streams will be sufficient and stable.

[28] For wind mapping resources, see NREL website http://www.nrel.gov/wind.

Figure 3. U.S. Wind Resources Potential



Source: National Renewable Energy Laboratory.

DOE estimates that total U.S. wind energy potential is over 10,000 billion kilowatt-hours annually—more than twice the total electricity generated from all sources in America today.[29] While this potential is not realistically achievable, wind power advocates, supported by a recent DOE study, believe that wind power could realistically contribute 20% of the nation's total electricity generation by the year 2030.[30] The U.S. Great Plains states contain most of the best onshore wind resources.[31] The main drawback to these rich wind resources is that they are located far from densely populated areas and thus require the construction of transmission lines to send the electricity to the load. Building these lines is often expensive, time consuming, and controversial.[32]

Offshore Wind

The U.S. Department of the Interior (DOI) estimates that over 90,000 megawatts of wind resource potential lies off the coasts of New England and the Mid-Atlantic states in waters less than 100 feet deep.[33] Offshore sites generally have higher quality winds and are located closer to

[29] This is the theoretical potential. Energy Efficiency and Renewable Energy, *Wind Powering America: Clean Energy for the 21st Century*, DOE, September 2004.

[30] Office of Energy Efficiency and Renewable Energy, *20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply*, DOE, May 2008.

[31] The U.S. Great Plains states include parts of Colorado, Kansas, Montana, Wyoming, North Dakota, South Dakota, Nebraska, Oklahoma, New Mexico, and Texas. From a geographical standpoint the region extends into the Canadian provinces of Alberta, Manitoba, and Saskatchewan.

[32] See CRS Report RL33875, *Electric Transmission: Approaches for Energizing a Sagging Industry*, by (name redacted).

[33] This estimate excludes two-thirds of the offshore areas ranging from 5 to 20 nautical miles from the shoreline to account for shipping lanes and wildlife, and view shed concerns; and one-third of the areas from 20 to nautical 50 miles (continued...)

population centers, but their development costs are significantly higher. Offshore wind projects have been slow to develop in the United States due to these high costs and public opposition. In Europe, a total of 1,099 megawatts of offshore wind had been installed by the end of 2007.[34]

The 420 megawatt Cape Wind project near Cape Cod, Massachusetts, is the largest proposed U.S. offshore wind project to date and is currently awaiting a permit from the DOI's Minerals Management Service (MMS).[35] During the 109th Congress, a debate erupted over the project's safety, cost, and environmental impact.[36] Cape Wind and other proponents say the project is a safe, clean way to develop renewable energy and create jobs. Opponents of the project have collaborated to create the Alliance to Protect Nantucket Sound. According to the Alliance, the project poses threats to the area's ecosystem, maritime navigation, and the Cape Cod tourism industry.

MMS released a Draft Environmental Impact Statement (EIS) for the Cape Wind project in March 2008.[37] The draft EIS did not indicate any critical factors that could derail the project. A final EIS is expected later in 2008. Other offshore U.S. wind projects have been proposed in Delaware (Bluewater) and Texas (Galveston).[38]

Wind Power Technology

Commercial, utility-scale wind turbines have evolved significantly from their early days in the 1980s and 1990s (**Figure 4**). They are larger, more efficient, and more durable. How wind technology evolves in the future could be influenced by congressional policy, both in research and development funding, and through regulatory frameworks that influence market behavior.

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out. See *Technology White Paper: Wind Energy Potential on the U.S. Outer Continental Shelf*, DOI, May 2006, pp. 1-2.

34 R. Wiser and M. Bolinger, *Annual Report on U.S. Wind Power Installation, Cost and Performance Trends: 2007*, U.S. Department of Energy, May 2008, p. 9.

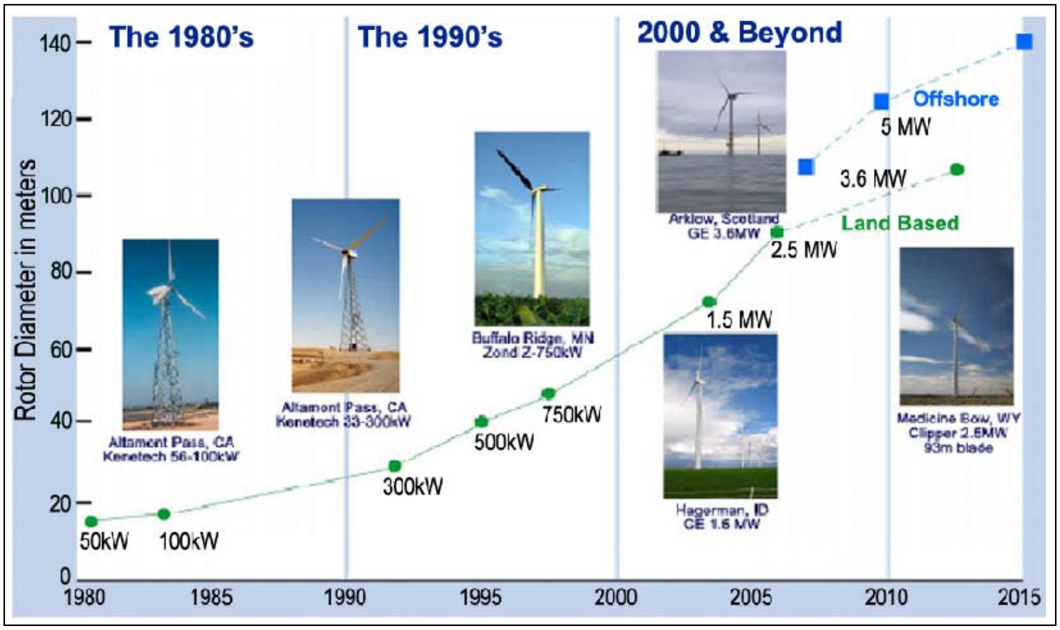
35 MMS manages the nation's Outer Continental Shelf oil, natural gas, and other mineral resources. The Energy Policy Act of 2005 (EPACT05) granted MMS additional authority to act as the lead federal agency for offshore renewable energy projects. EPACT05 §388 stipulates that MMS authority does not supercede the existing authority of any other agency for project permitting, so a wind project on the OCS may also require other permits to operate, although leasing and environmental review would be conducted by MMS.

36 In 2006, the Senate considered a provision to the Coast Guard appropriations bill giving the governor of Massachusetts authority to veto the Cape Wind project. A compromise was reached that gave the Coast Guard greater authority over navigational safety related to the project, but denied gubernatorial veto power. See §414 of P.L. 109-241.

37 See http://www.mms.gov/offshore/RenewableEnergy/RenewableEnergyMain.htm.

38 See Offshore Wind Energy website http://www.offshorewindenergy.org.

Figure 4. Evolution of U.S. Commercial Wind Technology



Source: L. Flowers, "Wind Energy Update," National Renewable Energy Lab, February 2008.

Utility-scale wind turbines have grown in size from dozens of kilowatts in the late 1970s and early 1980s to a maximum of 6 megawatts in 2008.[39] The average size of a turbine deployed in the United States in 2007 was 1.6 megawatts, enough to power approximately 430 U.S. homes.[40] The average size of turbines continues to expand as units rated between 2 and 3 megawatts become more common. Larger turbines provide greater efficiency and economy of scale, but they are also more complex to build, transport, and deploy.

Types of Wind Turbines

Industrial wind turbines fall into two general classes depending on how they spin: horizontal axis and vertical axis, also known as "eggbeater" turbines. Vertical axis machines, which spin about an axis perpendicular to the ground, have advantages in efficiency and serviceability since all of the control equipment is at ground level. The main drawback to this configuration, however, is that the blades cannot be easily elevated high into the air where the best winds blow. As a result, horizontal axis machines—which spin about an axis parallel to the ground rather than perpendicular to it—have come to dominate today's markets.[41]

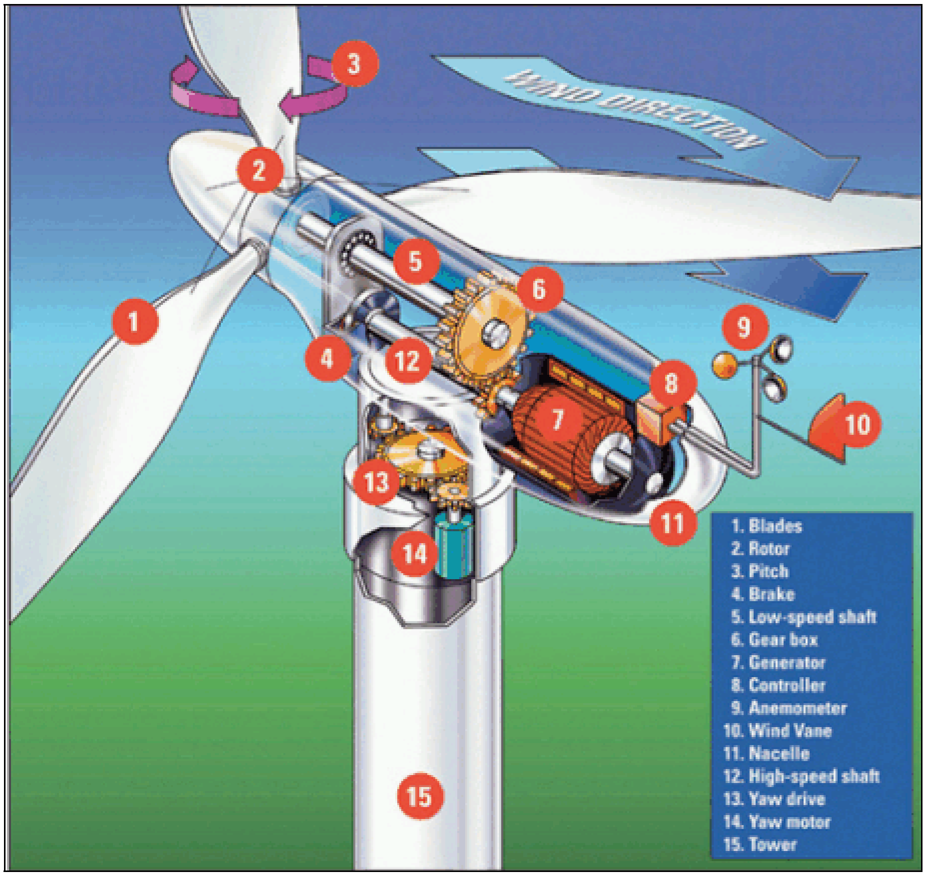
[39] The German company Enercon is testing two different 6 megawatt turbines, although they are not yet available on commercial markets. The largest commonly used commercial wind turbines are the 3.6 megawatt offshore units produced by Siemens and General Electric.

[40] This assumes a capacity factor (see following subsection) of 34% and an EIA estimate of the average U.S. household consumption of 11,000 kilowatt-hours per year.

[41] Horizontal turbines are further divided into classes depending on generator placement, type of generator, and blade control. For example, downwind turbines have their blades behind the generator and upwind turbines, in front. Generators can be asynchronous with the grid, or operate at the same frequency. Blade speed can be fixed or variable, and controlled through pitch or stall aerodynamics. For a more complete discussion of wind turbine technical issues, see P. Carlin, A. Laxson, and E. Muljadi, *The History and State of the Art of Variable-Speed Wind Turbines*, NREL, February 2001.

A simplified diagram of a typical horizontal axis wind turbine is shown in **Figure 5**. The blades connect to the rotor and turn a low-speed shaft that is geared to spin a higher-speed shaft in the generator. An automated yaw motor system turns the turbine to face the wind at an appropriate angle.[42]

Figure 5. Components in a Simplified Wind Turbine



There are barriers to the size of wind turbines that can be efficiently deployed, especially at onshore locations. Wind turbine components larger than standard over-the-road trailer dimensions and weight limits face expensive transport penalties.[43]

Other barriers to increasingly large turbines include (1) potential for aviation and radar interference, (2) local opposition to siting, (3) erection challenges (i.e., expensive cranes are needed to lift the turbine hubs to a height of 300 feet or more), and (4) material fatigue issues. Some of these issues are discussed in more detail later.

[42] Generally, the yaw control will position the turbine to face the wind at a perpendicular angle. The turbine can avoid damage from excessive wind speeds by yawing away from the wind or applying the brake.

[43] The standard trailer for an 18-wheel tractor trailer is approximately 12.5 feet high and 8 feet wide. Gross vehicle weight limitations are 80,000 pounds, corresponding to a cargo weight of 42,000 pounds. According to NREL, the trailer limitations have the greatest impact on the base diameter of wind turbine towers. R. Thresher and A. Laxson, "Advanced Wind Technology: New Challenges for a New Century," NREL, June 2006.

Capacity Factor

As noted above, a wind turbine's power output depends on wind speed. Capacity factor—a measure of how much electricity a power plant actually produces compared to its potential running at full load over a given period of time—is a useful tool to summarize average annual wind availability and speed for wind projects. The capacity factor a wind plant achieves strongly influences the cost of electricity produced and the profitability of the project. (See the "Wind Power Economics" section later in this report.)

Capacity factors for power generation technologies vary considerably. Nuclear plants run nearly continuously at full load and only shut down under normal conditions to be refueled. The industry-wide average capacity factor for U.S. nuclear power plants has been about 90% in recent years. Coal plants average a capacity factor of 70%, but individual plants can have a much higher or lower utilization rate. Wind plants, on the other hand, have capacity factors typically ranging from 20% to 40%.[44] Wind turbines usually spin 65% to 90% of the time, but only at their full rated capacity about 10% of the time. A recent study pegs the typical capacity factor for wind turbines at 34%.[45] Offshore wind turbines generally have higher capacity factors than onshore units because ocean winds are steadier than those over land.

A high capacity factor helps lower a plant's levelized, or annualized, cost of electricity (see section on "Wind Power Economics"). While a low capacity factor may result in relatively high costs per kilowatt-hour, a complete economic analysis would depend on when the electricity was produced. Since electricity is valued at different prices according to daily and seasonal demand profiles, when a wind turbine actually produces electricity can be as important as its overall capacity factor.

Wind Research and Development Emphasis

Future advances in wind turbine technology are likely to be evolutionary rather than revolutionary.[46] According to the NREL, which carries out much of DOE's wind research and development (R&D) program, current efforts to improve wind power technology and reduce costs includes:

- offshore turbine deployment,
- drivetrain (gearbox) innovation,
- blade design innovation,
- mechanical and power controls,
- low wind speed turbine development,

[44] Renewable Energy Research Laboratory, "Wind Power: Capacity Factor, Intermittency, and What Happens When the Wind Doesn't Blow?," University of Massachusetts at Amherst, p. 1, November 2004.

[45] *Comparative Costs of California Central Station Electricity Generation Technologies*, California Energy Commission, Appendix B, December 2007, p. 67.

[46] B. Parsons, "Grid-Connected Wind Energy Technology: Progress and Prospects," NREL, 1998, p. 5.

- manufacturing economies of scale, and
- system integration improvement.[47]

Another general area of R&D activity is in energy storage. Energy storage does not increase power output—in fact, energy conversion always results in lost power—but storage can make wind power available when it is most needed. Currently, most energy storage options are expensive and still under development.

The most common energy storage method is hydroelectric pumped storage. During periods of strong winds and low power demand, wind turbine output can be used to pump water into a reservoir at a higher elevation. The water can be released through a hydroelectric generator later when the power is most needed. Many countries have only limited pumped storage capacity and may have already exploited what exists. In the United States, pumped storage accounts for several percent of conventional hydroelectric power generation,[48] but probably does not have potential to grow significantly since many of the most economic sites have already been developed and the public opposes new large-scale hydroelectric projects.

Other energy storage options such as compressed air energy storage and advanced batteries face technical hurdles and high costs. Public and private sector R&D is underway to bring down costs for these options, not just for the benefit of wind power, but other variable energy sources as well.[49] A technological breakthrough in one of these storage options could enhance the ability of wind energy to supply large quantities of electricity on demand, but whether such breakthroughs are forthcoming is unpredictable.[50]

Wind Industry Composition and Trends

Within the United States, Texas is now the dominant state for wind power, followed by California, Minnesota, Iowa, Washington, and Colorado. Total installed wind capacity for each state at the end of 2007 is shown in **Figure 6**. California's early lead in wind power has been eclipsed by rapid growth in Texas. Wind power installations are also growing rapidly in the Pacific Northwest states of Washington and Oregon, as well as in Colorado, Minnesota, Iowa, Illinois, and the Dakotas. Most of these states have good wind resources, renewable portfolio standards, and local government proponents to help overcome construction barriers. These state and local incentives supplement the federal production tax credit incentive. The Southeastern region of the United States is noticeably empty of wind power projects due primarily to poor wind resources. This issue may also influence the region's general opposition to a national RPS.

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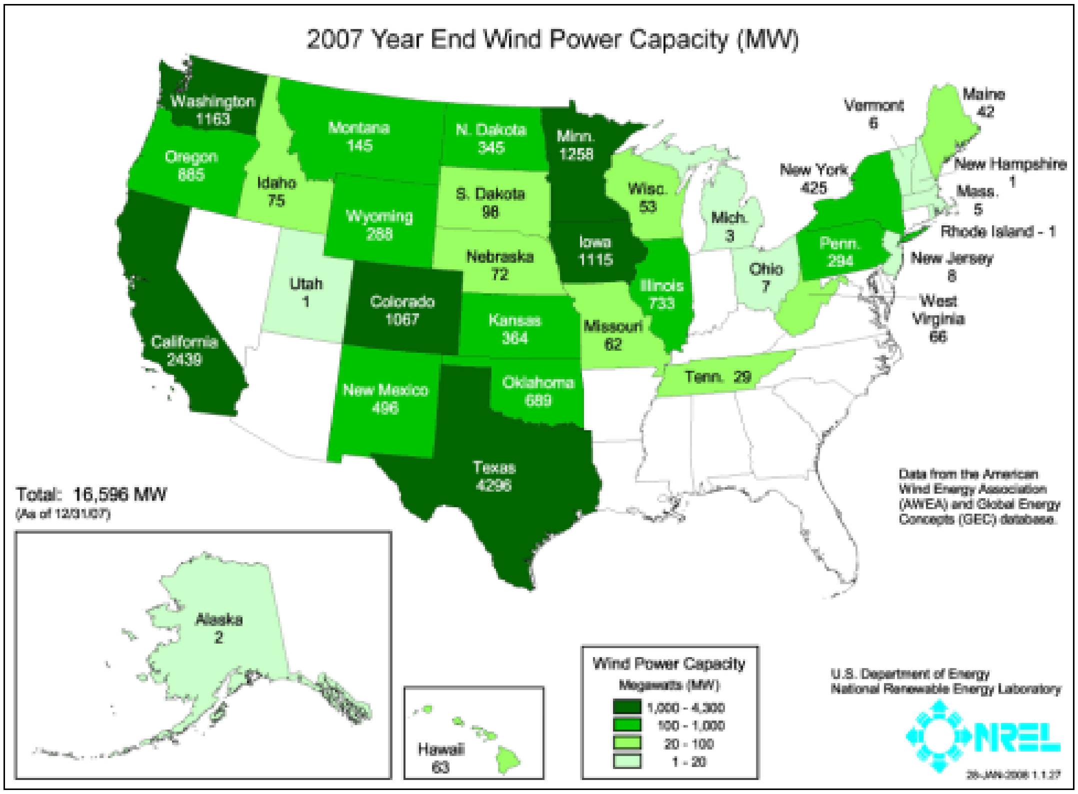
[47] S. Butterfield, "Technology Overview: Fundamentals of Wind Energy," NREL, 2005.

[48] EIA, *Annual Energy Review 2006*, U.S. DOE, 2007, Table 8.2a.

[49] For more information, see U.S. Climate Change Technology Program: *Technical Options for the Near and Long Term*, August 2005. http://www.climatetechnology.gov

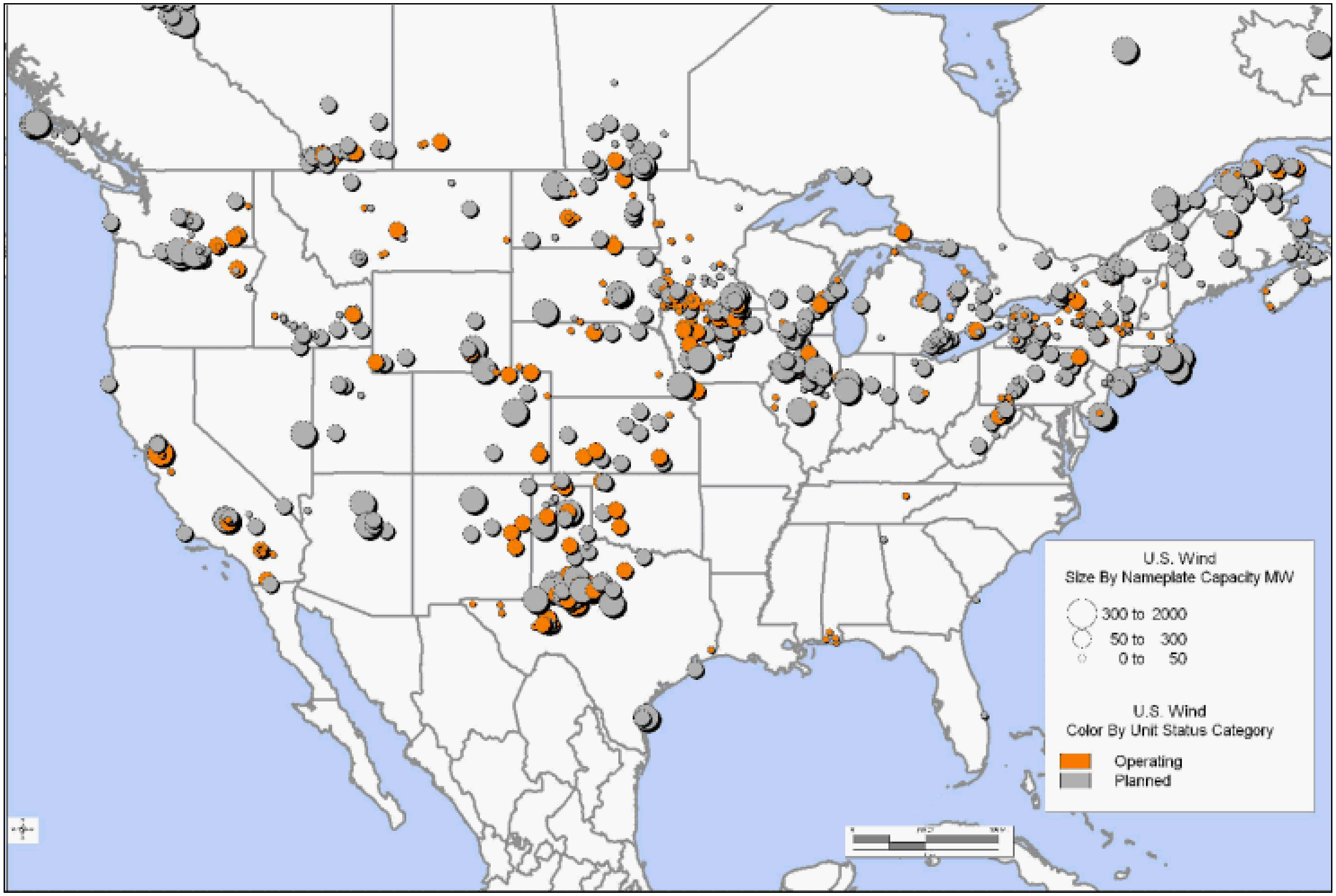
[50] For more information on U.S. R&D on wind power, see *20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply*, DOE, May 2008.

Figure 6. Installed Wind Capacity By State in 2007



A more detailed map showing the location of each existing and planned wind plant in North America by size is presented in **Figure 7**. Although planned wind projects far surpass the number of existing ones, there is no guarantee that they will all be constructed. Comparing wind resources from **Figure 3** with existing and planned wind plants in **Figure 7** shows significant potential to continue tapping some of the best wind sites in the upper Great Plains region. Limited transmission capacity is one of the reasons high-quality wind regions like this are not seeing greater wind plant development.

Figure 7. Existing and Planned North American Wind Plants by Size



Source: Ventyx Energy, the Velocity Suite. Data reportedly updated through June 5, 2008.

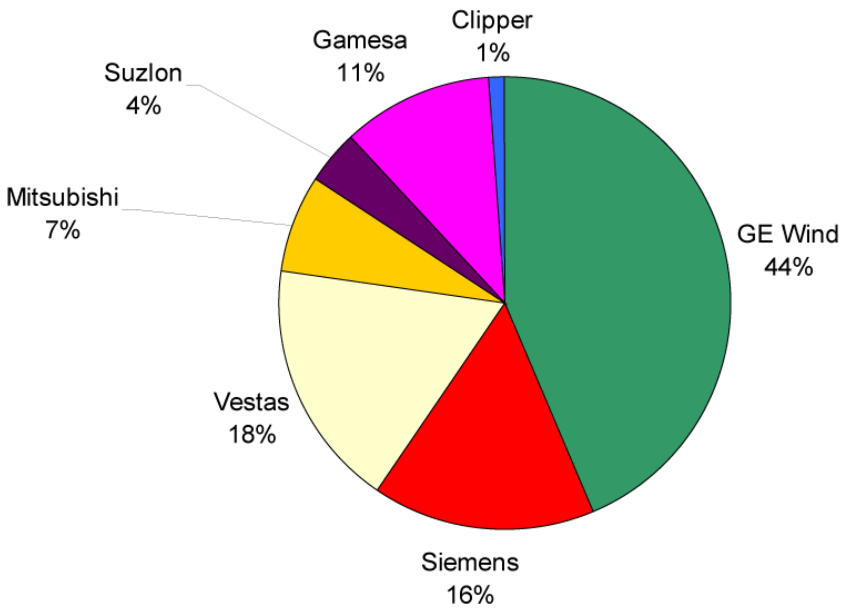
Note: Data for wind plants in Hawaii and Alaska are not available for this map.

Wind Turbine Manufacturers and Wind Plant Developers

The major wind turbine suppliers to wind plants in the United States include General Electric (GE) Wind, Siemens, Vestas, Mitsubishi, Suzlon, and Gamesa.

The 2007 U.S. market share for each of these suppliers is shown in **Figure 8**. The GE 1.5 megawatt turbine was the most commonly installed unit in 2007. Vestas, Siemens, and Gamesa—European manufacturers with an increasing number of production facilities in the United States—account for a combined market share roughly equivalent to that of GE. Suzlon, an Indian manufacturer and the world's fifth largest turbine producer, may face new challenges after having to recall many of the turbine blades it sold into the U.S. market due to premature cracking.[51] Other new manufacturers are also entering the field. Clipper Windpower is gaining market share as manufacturing capacity grows for its new 2.5 megawatt turbines. According to the Global Wind Energy Council, two Chinese firms, Gold Wind and Sinovel, are also likely to enter international markets in 2009 with low-cost turbines.

Figure 8. U.S. Wind Turbine Market Share by Manufacturer in 2007



Source: R. Wiser and M. Bolinger, *Annual Report on U.S. Wind Power Installation, Cost and Performance Trends*, U.S. DOE, p. 10.

Because shipping large wind turbine parts is expensive, suppliers build manufacturing facilities close to where wind plants will be installed. According to AWEA, wind industry manufacturing facilities in the United States grew from a small base in 2005 to over 100 in 2007. New wind turbine component manufacturing facilities opened in Illinois, Iowa, South Dakota, Texas, and Wisconsin in 2007, while seven other facilities were announced in Arkansas, Colorado, Iowa,

[51] T. Wright, "India Windmill Empire Begins to Show Cracks," *Wall Street Journal*, April 18, 2008, P. A1.

North Carolina, New York, and Oklahoma.[52] Expanding production and operations in the United States is especially attractive to European companies given the current value of the euro to the dollar. Despite the expansion in turbine manufacturing facilities in the United States, Europe, and Asia, demand continues to exceed supply.[53] The financial crisis that hit U.S. and global markets in late summer 2008 has at least temporarily dampened the availability of debt financing for many infrastructure projects, including wind power, but the long-term impacts remain to be seen.

Most wind plants in the United States are built and operated by independent power producers (IPPs), also known as merchant providers, that are not regulated utilities. IPPs have the most flexibility in taking advantage of the renewable tax incentives since regulated utilities cannot claim the renewable PTC. Still, investor-owned utilities do build and operate some wind plants; one estimate states that utilities built just over 10% of the total new capacity in wind electricity in 2007.[54]

Dozens of companies from around the world develop and operate wind plants in the United States. Selected examples of active developers and operators in early 2008 include Acciona, AES, Babcock & Brown, Edison Mission, FPL Energy, Gamesa Energy, Horizon, Invenergy, John Deere, Noble Environmental, PPM Energy, and RES Americas.[55] According to DOE, consolidation among companies remains strong, including the purchase of Horizon Wind by Energias de Portugal (from Portugal) and the acquisition of Airtricity North America by E.ON AG (from Germany).[56]

International Comparisons

The United States led the world in wind power deployment until 1996 when it was surpassed by Germany (**Figure 9**). Strong U.S. growth in new wind capacity pushed the United States into the number two spot ahead of Spain in 2007, and the Global Wind Energy Council (GWEC) expects the United States to become the world leader in installed capacity again by the end of 2009.[57]

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[52] *Wind Power Outlook 2008*, AWEA, 2008, p. 4.

[53] According to one report, in early 2008 General Electric had a backlog of wind turbines on order equal to $12 billion, more than twice the backlog in early 2007. M. Kanellos, "GE Confirms That Wind Turbine Supply Is Getting Worse," *CNet News.com*, April 13, 2008.

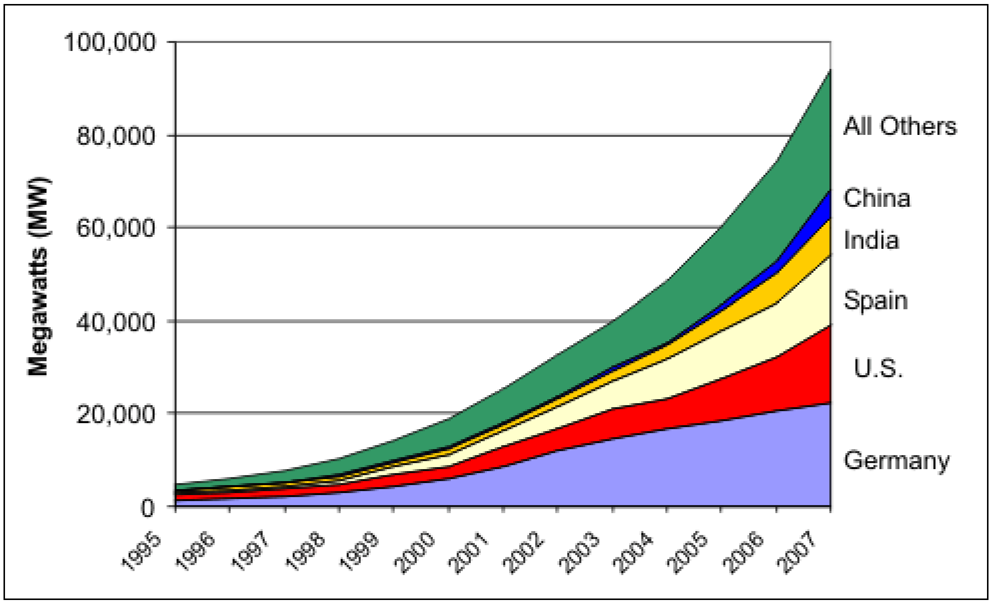
[54] R. Wiser and M. Bolinger, Annual Report on U.S. Wind Power Installation, Cost, and Performance Trends: 2007, DOE, May 2008, p. 15.

[55] *AWEA 2007 Market Report*, AWEA, January 2008, pp. 9-11.

[56] R. Wiser and M. Bolinger, *Annual Report on U.S. Wind Power Installation, Cost and Performance Trends: 2007*, DOE, May 2008, p. 13.

[57] *Global Wind 2007 Report*, Global Wind Energy Council, 2008, p. 6.

Figure 9. Global Installed Wind Capacity By Country



Source: Adapted from J. Dorn, "Global Wind Power Capacity Reaches 100,000 Megawatts," Earth Policy Institute, March 2004.

As countries deploy increasing quantities of wind capacity, new operational issues need to be addressed. Grid operators must become accustomed to dealing with the variability of wind in order to operate the system efficiently and reliably. Despite the near parity in total wind generating capacity among the top three countries, the United States has a much lower percentage penetration rate of actual wind power generation than Denmark, Spain, Portugal, Ireland, and Germany (**Table 1**). These European countries have gained experience operating their electricity grids at higher wind integration rates.

Table 1. Wind Energy Penetration Rates by Country

Country	Wind Energy Penetration Rate (%)
Denmark	20
Spain	12
Portugal	9
Ireland	8
Germany	7
United States	1

Source: R. Wiser and M. Bolinger, *Annual Report on U.S. Wind Power Installation, Cost, and Performance Trends: 2007*, U.S. DOE, May 2008, p. 6.

Note: Wind energy penetration is defined here as the ratio of wind-generated electricity to the total electricity generated by all sources.

China has the most rapidly growing wind sector in the world, but started from a very low base. New wind power additions in China are dwarfed by the amount of new coal-fired power plant construction.[58] Chinese leaders are reportedly considering a new wind power target of 100,000 megawatts by 2020, five-fold the previous target.[59] The German experience with wind power is highlighted in **Text Box 3**.

In summary, wind technology has evolved over the past two decades, resulting in larger, more reliable machines. Manufacturing capacity in the United States has expanded significantly. These advances have led to increasingly competitive wind electricity costs, the topic of the next section.

[58] According to GWEC, installed wind power capacity in China grew by an average annual rate of 56% between 2001 and 2007. Approximately 3,500 megawatts of new wind were installed in 2007. (*Global Wind 2007 Report*, GWEC, April 2008, p. 28.) According to a statement by Zhang Guobao, Vice Premier of the National Development and Reform Commission, China installed approximately 70,000 megawatts of new coal-fired generating capacity in 2007 as reported in Y. Wang, "China May Boost Power Capacity 40% in 3 Years as Demand Rises," *Bloomberg*, May 12, 2008.

[59] C. Fu, "Fanning Wind Power Capacity," *Shanghai Daily*, April 28, 2008.

Text Box 3. Focus on Wind Power in Germany

Germany is the world leader in installed wind power capacity. Given the country's relatively modest wind and solar resources, it has ambitious plans for renewable energy, including a goal that renewable energy meet 20% of total energy needs by 2020.

The primary driver of wind power growth in Germany is the country's "feed-in tariff" policy that gives producers of wind power a guaranteed constant minimum price over a maximum term of 20 years. The amount of the tariff depends on the location of the wind turbine and the specific year. The average 2007 payment was about 12.9 U.S. cents/kWh and is scheduled to slowly decline to about 10.9 cents/kWh by 2015.[a] Electricity in Germany is relatively expensive; the wind industry's impact on overall electricity price is not clearly known.[b]

Wind accounts for about 18% of installed capacity and generates 7% of the country's electricity. Most of Germany's wind farms lie in the northern Baltic coast region where wind resources are superior. Wind plants are widely deployed in Germany and few onshore areas with good wind resources remain to be developed. The shortage of onshore sites is leading Germany to replace older, less efficient wind turbines with larger, more powerful models.

The shortage of high-quality onshore sites is also leading to an expansion of offshore wind plants. In 2006, the federal government passed a law stating that grid operators must bear the costs for connecting to offshore wind plants as soon as they are ready to begin producing power. At the end of 2007, Germany had installed only seven megawatts of offshore wind generating capacity, although it had hundreds of megawatts more under development.

The German wind industry is not without critics. As elsewhere, critics state that wind energy depends on expensive subsidies, especially the feed-in tariff and grid connection requirements. As Germany is a relatively mature wind user, much of the countryside is dotted with wind plants. Some Germans oppose the visual impact these wind plants create and are concerned that they may impact the tourism industry. Finally, a recent study by the German Energy Agency claimed that wind power is an expensive way to lower carbon dioxide emissions compared with other options.[c]

a. German Energy Agency, Planning of the Grid Integration of Wind Energy in Germany Onshore and Offshore up to the Year 2020, February, 2005. The exchange rate used in this conversion was 1.55 U.S. dollars per euro.

b. The impact of growing wind use on Germany's electricity prices is obscured by larger restructuring and liberalization within the sector. B. Odent, "Les factures d'électricité germaniques se shootent à la libéralisation," l'Humanité, June 29, 2007.

c. Project Steering Group, "Planning of the Grid Integration of Wind Energy in Germany Onshore and Offshore Up to the Year 2020," German Energy Agency, March 2005.

Wind Power Economics

Numerous complex variables affect the economics of wind power. This section includes a financial analysis that compares the cost of building and operating wind plants with competing technologies (coal, natural gas, and nuclear power). The financial analysis provides an indicative picture of how the economics of wind compare with other bulk power sources. A comprehensive analysis for a specific project would take many other factors into consideration, including the cost of any necessary transmission upgrades and other options (e.g., purchased power or demand reduction). The following analysis was conducted before the financial crisis hit in late summer 2008.

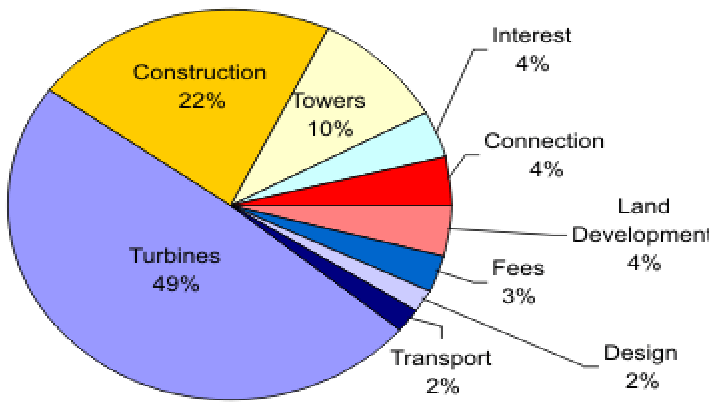
Cost and Operating Characteristics of Wind Power

Wind power is characterized by low variable costs and relatively high fixed costs. Wind turbines have, of course, no fuel costs, and minimal variable operations and maintenance (O&M)

expense.[60] In addition to having no direct expense for fuel, wind also does not incur the ancillary expenses associated with fossil fuel combustion, such as air pollution control equipment and allowances needed to comply with current law and, possibly, future carbon controls. Wind also does not incur the waste disposal costs associated with conventional generation, such as scrubber sludge disposal for coal plants and radioactive waste storage for nuclear plants.

As reported in 2005, the initial cost of wind turbines is about half of total wind plant development costs (**Figure 10**).[61]

Figure 10. Component Costs for Typical Wind Plants



Source: National Renewable Energy Laboratory, 2005.

Although wind plants have low variable costs, the fixed O&M costs are relatively high, and wind power plants are capital intensive.[62] As with other generation technologies, the cost of building a wind plant has increased in recent years. The reported unit cost of wind projects constructed in the United States declined steadily through the 1990s and, according to one study, bottomed out at about $1,400 per kilowatt of capacity in the 2000-2002 time period.[63]

Subsequently, project costs have risen steadily and averaged over $1,700 per kilowatt in 2007. Higher input prices (steel, cooper, concrete), a shortage of skilled workers, unfavorable currency exchange, and shortages in key wind turbine components and manufacturing capacity explain much of the overall cost increase.[64] Rapidly rising costs have also been experienced by all other utility-scale generation technologies.[65] In the case of wind, some analysts believe that the lapses

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[60] Variable O&M costs vary with the output of a generating station, such as the cost of the consumables used by pollution control equipment. Fixed O&M, which is insensitive to the level of plant output, includes such costs as the salaries of plant staff and scheduled maintenance.

[61] S. Butterfield, "Fundamentals of Wind Technology," NREL, presentation at American Wind Energy Association conference, May 15, 2005.

[62] Capital intensive means that compared to some other generating sources, such as gas-fired plants, wind plants require a relatively large initial outlay to build the plant. This large outlay also translates into higher fixed costs, in the form of repayment of the debt portion of construction financing.

[63] These data were gathered by analysts at Lawrence Berkeley National Lab from 227 completed wind projects totaling 12,998 megawatts of capacity. Reported in R. Wiser and M. Bolinger, *Annual Report on U.S. Wind Power Installation, Cost, and Performance Trends: 2007*, U.S. DOE, May 2008, pp. 21.

[64] L. Flowers, "Wind Energy Update," NREL, February 2008.

[65] According to Cambridge Energy Research Associates, coal, gas, wind, and nuclear power plants were, on average, (continued...)

in the production tax credit contributed to boom-and-bust cycles in the sector and discouraged steadier investment in new production capacity.[66]

Wind Operation and System Integration Issues

Operators try to maximize the power output from units with high fixed costs so that those costs can be spread over as many kilowatt-hours of electric generation as possible. This reduces the average cost of power from the unit and makes the unit's power more economical for consumers (and more marketable if the unit is operating in a competitive market).

Wind plants, however, cannot run as baseload units (i.e., continuously operating) because generation is subject to wind variability. Like solar power, wind is a source of *variable renewable power* that is dependent on daily, seasonal, and locational variations in the weather. Geographic diversity—that is, installing wind turbines over a large area—may compensate to some degree for local variations in wind conditions, but ultimately wind power cannot achieve the same degree of reliability or continuous operation as fossil or nuclear technology. The combination of the relatively low capacity factor of wind plants and high fixed costs drives up the cost of wind-generated electricity.

The variable nature of wind power has an additional cost implication. Electric power systems must be able to reliably meet all firm customer loads at all times. For this reason power systems are built around generating technologies that are dispatchable and predictable—that is, units that can be reliably turned on or off, or have their output ramped up or down, as needed to meet changes in load. However, because a wind turbine is weather dependent it is not dispatchable or as predicable as a fossil or nuclear unit. As noted previously, energy storage can help address this shortcoming in wind energy, although it also results in higher costs.

When a power system is dependent on only small amounts of wind generation to meet load, the variations in wind output can be absorbed by the system's existing buffer capacity. This capacity is either fossil fuel, nuclear, or dispatchable renewable energy (e.g., hydroelectric, geothermal, and biomass). However, when wind constitutes a large part of the system's total generating capacity, perhaps 10% to 15% or greater, the system must incur additional costs to provide reliable backup for the wind turbines. For example, in 2007 a utility in Montana built a gas-fired plant for the primary purpose of compensating for wind power variability.[67] Various estimates have been made of the cost of integrating large blocks of wind capacity into a power system. Estimates for integration costs range from $1.85 to $4.97 per megawatt-hour.[68] In 2008, the

(...continued)

131% more expensive to build in late 2007 compared to 2000. Sector-specific cost increases include wind 108%, nuclear 173%, coal 78% and gas 92%. See "Costs to Build Power Plants Pressure Rates," *Wall Street Journal*, May 27, 2008.

[66] R. Wiser, M. Bolinger, and G. Barbose, "Using the Production Tax Credit to Build a Durable Market for Wind Power in the United States," Lawrence Berkeley National Laboratory, 2007.

[67] Mike Mercer, "Power for a Calm Day," *Diesel & Gas Turbine Worldwide*, October 2007. The station is Northwestern Energy's Basin Creek plant, a 51.8 MW plant consisting of 9 gas-fired diesel generators.

[68] B. Parsons, M. Milligan, et al. "Grid Impacts of Wind Power Variability: Recent Assessments from a Variety of Utilities in the United States," conference paper presented at the European Wind Energy Conference. Athens, Greece, 2006 http://www.nrel.gov/docs/fy06osti/39955.pdf, p. 9.

Bonneville Power Administration established a wind integration charge of $2.82 per megawatt-hour.[69] (See **Text Box 4** for a description of a recent system integration issue in Texas.)

In summary, wind power has the economic advantage of zero fuel costs and no costs for the pollution controls associated with the consumption of fossil and nuclear fuel. However, wind plants have relatively high fixed costs, and the plants cannot be operated as intensively as fossil or nuclear plants due to the variability of the wind. Wind variability also creates system integration costs at high levels of wind penetration. These cost disadvantages are partly offset by the federal renewable production tax credit (discussed below) and also, in effect, by state renewable portfolio standards that mandate the use of renewable power.

Text Box 4. Electricity Curtailment Event in Texas

A recent event in Texas serves to illustrate the challenge of integrating wind power into existing electricity grids. At 6:41 p.m. on February 26, 2008, the Electric Reliability Council of Texas (ERCOT, the manager of most of the electric power grid in Texas) activated its emergency electric curtailment plan due to low frequency on the electricity grid. The emergency measure cut power to customers who had agreed in advance to such action in order to prevent more serious grid problems from occurring. The frequency drop was caused by an unplanned shortfall in available generation sources (primarily wind) at the same time demand was increasing. According to ERCOT's summary report, wind generator availability dropped from 1,700 megawatts three hours before the event to about 300 megawatts at the point the emergency procedures were activated.

An action item ERCOT took from the event is to accelerate plans to implement an improved wind forecasting system. The summary report is available at http://interchange.puc.state.tx.us/WebApp/Interchange/Documents/27706_114_577769.PDF.

Levelized Cost Comparison

Although wind power is not dispatchable, it is often seen as a replacement or supplement for conventional baseload power plants. This is because when wind conditions are favorable a wind turbine is used like a baseload plant: the wind turbine is run at full load as continuously as possible. The following economic analysis therefore compares wind power to the primary baseload alternative technologies using coal, nuclear power, or natural gas. Each technology is described briefly in **Text Box 5**.

The generation costs of these technologies and wind power are compared using the financial analysis technique of levelized costs, which summarizes the estimated lifetime costs of each system as a levelized ("annualized") cost per megawatt-hour of generation. This analysis is for plants entering commercial service in 2015, and costs are measured in constant 2008 dollars. The financial methodology and the key assumptions concerning plant costs and operations are described in the Appendix. The current estimate of "overnight" construction costs for each technology—that is, the cost that would be incurred if a plant could be built instantly—are summarized in **Table 2**, along with the assumed capacity factor. **Table 2** also indicates the type of entity assumed to build each kind of plant. Coal and nuclear plants are assumed to be constructed by regulated utilities that have the financial resources and regulatory support to undertake these very large and expensive projects. The natural gas combined-cycle plant is assumed to be built by an independent power producer (IPP). IPPs generally prefer gas-fired projects because of their relatively low capital costs and risk profiles. The wind plant is also assumed to be an IPP project

69 This is equivalent to 0.282 cents per kilowatt-hour. Gail Kinsey Hill, "BPA Calculates Administrative Costs of Wind Power," *The Oregonian*, March 29, 2008.

because regulated utilities normally cannot make use of the production tax credit.[70] Again, the estimates in **Table 2** do not include the impacts of the financial crisis that began in late summer 2008.

Text Box 5. Description of Primary Power Generation Technologies

- **Conventional (pulverized) coal.** This is the conventional technology used in most existing coal-fired power plants. Coal is ground to a fine powder, and then burned in a boiler to create steam which drives a generator. Modern coal plants are equipped with environmental control equipment that can greatly reduce air emissions, with the exception of carbon dioxide. No pulverized coal plants—or, for that matter, any other kind of fossil-fueled power plant—have been built with carbon control technology.
- **Natural Gas Combined Cycle.** This is a standard technology widely used to generate electricity. Natural gas is burned in a combustion turbine (the same type of technology used in a jet engine) to rotate a generator and produce electricity. The waste heat, in the form of exhaust gases, from the combustion turbine is then captured and used to produce steam, which drives a second generator to produce more electricity. Combined cycle plants are relatively inexpensive to build and very efficient, but use expensive natural gas as the fuel.
- **Nuclear Power.** These plants use heat from nuclear fission to produce steam for power generation. This report uses projected costs and performance for next generation nuclear plants characterized, for example, by simplified designs and modularized construction techniques.

Table 2. Assumptions for Generating Technologies

Technology	Overnight Cost in 2008 (2008$ per Kilowatt of Capacity)	Assumed Capacity Factor	Type of Project Developer
Wind	$1,900	34%	IPP
Coal	$2,600	85%	Utility
Nuclear	$3,700	90%	Utility
Natural Gas	$1,200	70%	IPP

Sources: Overnight capital costs estimated by CRS based on a review of published information on recent power projects. Capacity factor for coal plants is from Massachusetts Institute of Technology, *The Future of Coal*, 2007, p. 128. Natural gas plants are assumed to operate as baseload units with a capacity factor of 70%. Capacity factor for wind from California Energy Commission, "Comparative Costs of California Central Station Electricity Generation Technologies," December 2007, Appendix B, p. 67. Nuclear plant capacity factor reflects the recent industry average performance as reported in EIA, *Monthly Energy Review*, Table 8.1. Also see the **Appendix** to this report.

Note: IPP = Independent Power Producer.

Costs were estimated for six cases intended to illustrate some of the important economic, operational, and government incentive factors that influence the relative economics of wind power.[71] The **Base Case** (Case 1) assumes continuation of the renewable production tax credit as

[70] Assuming the natural gas combined cycle was built by a utility reduces the estimated cost in the Base Case by about $4 per megawatt-hour. This is due to the lower financing costs available to regulated utilities compared to IPPs. If the wind plant is built by a utility the estimated cost increases by about $1 per megawatt-hour. This is the net effect of the lower financing costs and the loss of the production tax credits. The renewable production tax credit applies to sales of electricity by the wind plant owner to another entity. A utility which operates a wind plant to serve its own load cannot take the credit. See 10 C.F.R. § 451.4.

[71] Other factors, combinations of factors, and alternative cost forecasts could be evaluated. The economic analyses presented here consider just one subset of many potential alternative assumptions. The subset was chosen to highlight some of the important determinants of the competitiveness of wind power.

currently formulated. It also assumes the nuclear plant qualifies for the nuclear production tax credit (at an effective rate of $12 per megawatt-hour)[72] and loan guarantee program established by the Energy Policy Act of 2005. No carbon costs are assumed. The five alternative cases have the following characteristics (each is identical to the Base Case except as indicated):

- **Case 2: Reduced Incentives**. The renewable production tax credit is assumed to terminate and is not renewed. The nuclear plant is assumed to not receive a loan guarantee.[73]
- **Case 3: High Natural Gas Prices**. Natural gas prices are assumed to be 50% higher than the current EIA forecast used in the Base Case.
- **Case 4: Carbon Costs**. This case assumes the imposition of controls on carbon emissions from fossil fueled power plants. An illustrative allowance price of $25 per metric ton of carbon dioxide is assumed, escalating at a real rate of one percent per year, first imposed in 2013.[74]
- **Case 5: Wind Capacity Factor**. This case assumes that the wind plant has a capacity factor of 44% rather than the 34% used in the Base Case. The higher capacity factor could be the result of improved technology or a better-than-average location.[75]
- **Case 6: Wind Integration Cost**. A system integration charge is added to the cost of wind power. The assumed cost is the Bonneville Power Administration charge of $2.82 per megawatt-hour. This cost is assumed to remain constant in real dollar terms for the forecast period.

The results for the six cases are summarized in **Table 3**. These estimates should be viewed as indicative and not definitive, and are subject to a high degree of uncertainty. As shown in the table:

- In Case 1, the levelized cost of wind power is a few percent higher than coal or gas-fired power; given the range of uncertainty in the assumptions, the costs of these options are essentially similar. Nuclear power, which is assumed to benefit from the full range of federal incentives (a production tax credit and loan

[72] The nominal value of the nuclear production tax credit of $18 per megawatt-hour will be reduced if more than 6,000 megawatts of new nuclear capacity qualify for the credit. The Base Case follows EIA's long-term forecast assumption that the effective rate will be reduced to $12 per megawatt-hour because 9,000 megawatts of new nuclear capacity will qualify. See EIA, *Annual Energy Outlook 2007, pp. 20-21.*

[73] The status of the renewable PTC is discussed elsewhere in this report.

[74] In 2008, the Congressional Budget Office (CBO) estimated the price of carbon dioxide allowances in 2013 at $30 per metric ton in nominal dollars. Given an estimated change in the implicit price deflator of 17.2% between 2005 and 2013, this converts to $25.60 per metric ton in constant 2005 dollars. This value was rounded to $26 per metric ton to simplify the presentation. See CBO, "Cost Estimate for S. 2191, America's Climate Security Act of 2007," April 10, 2008, p. 8.

[75] EIA assumes that a 44% capacity factor would be achievable by 2010 for a wind plant located in the northwest. The wind capacity factor for this region actually declines over time, to 41% by 2030, presumably because wind plants are increasingly located in less favorable locations. See EIA, *Assumptions to the Annual Energy Outlook 2007*, Table 73. Planning consultants to the utility Westar Energy assumed that wind plants located in Kansas could achieve capacity factors of 42%. See Direct Testimony of Michael Elenbaas on behalf of Westar Energy, before the Kansas State Corporation Commission, Docket 08-WSEE-309-PRE, October 1, 2007, pp. 11 and 13.

guarantee) is about 10% less expensive than wind and the least expensive of all the alternatives examined.

- In Case 2, reducing incentives significantly changes the results. If the renewable production tax credit is assumed to terminate, the cost of wind power increases by 10%. In this situation coal and gas have a 14% to 15% cost advantage over wind. However, the biggest impact of reducing incentives is on nuclear power. Assuming no loan guarantee, the cost of nuclear power increases by 28% (from $60 to $77 per megawatt-hour).[76] In this situation, wind power's cost (also without a production tax credit) is essentially similar (slightly lower) than nuclear power.
- Natural gas prices have historically been difficult to forecast and often underestimated.[77] When gas prices are assumed to be 50% higher than in the Base Case, wind has an 18% cost advantage over gas-fired electricity (Case 3).
- The imposition of an illustrative cost of $25 per metric ton of carbon dioxide on fossil-fired generation (Case 4) has the greatest impact on the relative competitiveness of wind with coal. The carbon cost takes coal from a 4% cost advantage over wind in the Base Case to a 19% disadvantage. The impact on gas-fired power is significant, but less dramatic; gas goes from a 6% cost advantage to a 4% disadvantage when carbon costs are imposed.[78]
- As discussed above, the combination of high capital costs and relatively low utilization rates, as measured by the capacity factor, creates a cost disadvantage for wind power. The importance of utilization is illustrated by Case 5, which assumes a wind capacity factor of 44%, compared to the 34% rate used in the Base Case. With a high capacity factor, wind has the lowest cost of the alternatives examined, and in particular is over 25% less costly than coal or gas.
- The final case (Case 6) assumes the imposition of a system integration charge of $2.82 per Mwh on wind generation. As Table 5 shows, costs under this case and the Base Case are similar.

In summary, the financial analysis suggests the following:

- Given the Base Case assumptions, including continuation of the renewable production tax credit, the cost of wind power is comparable to coal and gas. The

[76] The loan guarantee allows the nuclear plant to be financed with 80% debt at a low interest rate. In the absence of the loan guarantee the cost of debt increases and the debt portion of the financial structure drops to 50%. The balance of the financing is equity, which is more expensive than debt. Eliminating the loan guarantee, therefore, has a major impact on the cost of a nuclear project. The chief nuclear officer for Exelon, the power company with the largest fleet of nuclear reactors in the United States, stated that constructing new nuclear plants will be "impossible" in the absence of loan guarantees (S. Dolley, "Nuclear Power Key to Exelon's Low-Carbon Plan," *Nucleonics Week*, February 14, 2008). For further discussion of the importance of loan guarantees, see Tom Tiernan, "Nuclear Interests, Wall Street Concerned about Loan Guarantee Program, Legislation," *Electric Utility Week*, August 20, 2007. Wind power is not eligible for the loan guarantees provided in EPACT05 because it is not considered a commercial technology.

[77] For example, see EIA, *Annual Energy Outlook Retrospective Review: Evaluation of Projections in Past Editions (1982-2006)*, pp. 2, 3, and 5.

[78] Carbon costs have less impact on the gas plant because gas emits about half as much carbon dioxide per unit burned than coal, and a combined cycle gas-fired plant requires less fuel to produce a unit of electricity than a pulverized coal plant.

addition of an illustrative system integration charge, to account for large-scale wind penetration of a utility system, does not greatly change these results.

- Federal financial incentive policies have a significant impact on the financial analysis. The economics of wind are materially worse when the production tax credit is eliminated, and materially improved versus nuclear power when nuclear incentives are reduced.
- Improved technology or prime locations that allow wind projects to achieve high rates of utilization would significantly lower the cost of wind power.
- Assuming higher natural gas prices than the current EIA reference forecast, or the imposition of carbon charges on coal and gas, greatly enhances the cost competitiveness of wind.

Table 3. Economic Comparison of Wind Power with Alternatives

(New Plants Entering Commercial Service in 2015,
Levelized 2008$ Per Megawatt-hour and Percent Difference)

	Levelized Cost of Power, 2008$ per megawatt-hour				Wind Cost Advantage (Disadvantage) Comparison, Percent Difference		
Case	**Wind**	**Pulverized Coal**	**Nuclear**	**Natural Gas CC**	**Pulverized Coal**	**Nuclear**	**Natural Gas CC**
1. Base Case	$67	$64	$60	$63	(4%)	(10%)	(6%)
2. Reduced Incentives	$74	$64	$77	$63	(14%)	4%	(15%)
3. High Natural Gas Prices	$67	$64	$60	$79	(4%)	(10%)	18%
4. Carbon Cost	$67	$80	$60	$70	19%	(10%)	4%
5. Higher Wind Capacity Factor	$50	$64	$60	$63	28%	20%	26%
6. Wind Integration Cost	$69	$64	$60	$63	(7%)	(13%)	(9%)

Sources: See main body of the report and **Appendix**.

Notes: CC = Combined Cycle. PTC = production tax credit. These estimates are approximations subject to a high degree of uncertainty over such factors as future fuel and capital costs. The rankings of the technologies by cost are therefore also an approximation and should not be viewed as a definitive estimate of the relative cost-competitiveness of each option.

Wind Policy Issues

This section of the report discusses government policy issues related to wind power. Some issues, such as permitting, are primarily state and local issues, but still may be a concern to congressional constituents. Other issues, such as the extension of the renewable production tax credit, are clearly federal issues.

Siting and Permitting Issues

Like other electric power projects, wind energy projects built and operated in the United States must comply with applicable federal, state, and local requirements. Most wind energy projects in the United States today are built on private land. As a result, local and state jurisdictions play the most important role in siting and permitting wind energy projects.[79] These projects, however, usually must also meet certain federal requirements such as those in the Endangered Species Act (U.S.C.§1531-1544), Migratory Bird Treaty Act (U.S.C.§§703-711), or Hazard Determination by the Federal Aviation Administration (FAA).[80] Key siting and permitting issues are discussed below.[81]

Wildlife Constraints

The main environmental objection to wind power is concern about bird and bat collisions with wind turbines. A National Academy of Sciences report states that, "Out of a total of perhaps 1 billion birds killed annually as a result of human structures, vehicles and activities, somewhere between 20,000 and 37,000 died in 2003 as a result of collisions with wind-energy facilities."[82] Although this is a small percentage of total birds killed, the impact on particular species could be significant, especially if wind power continues to expand rapidly.

Early wind turbines in California killed birds—especially raptors (hunting birds like hawks, eagles, and owls, some of which are protected under the Endangered Species Act)—and catalyzed opposition to wind power among bird enthusiasts.[83] Although bird concerns remain, today's turbines kill far fewer birds per unit of electricity generated than early models, especially in California.[84] More recently, a relatively large number of bat fatalities have occurred at wind plants

[79] Energy projects built on private land that receive federal grants or use federal transmission lines must also meet federal requirements in the National Environmental Policy Act (42 U.S.C. §4321).

[80] Others might include the Bald and Golden Eagle Protection Act (16 U.S.C. §§668-668d), National Historic Preservation Act (16 U.S.C. §470), Clean Water Act (33 U.S.C. §1251), Rivers and Harbors Act of 1899 (33 U.S.C. §401), Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or Superfund, 42 U.S.C. §§9601-9675).

[81] More comprehensive information on federal, state and local regulations related to wind energy projects is found in: Energy Efficiency and Renewable Energy, "Federal Wind Siting Information Center," DOE http://www1.eere.energy.gov/windandhydro/federalwindsiting/, *Wind Energy Siting Handbook*, AWEA, 2008 and *Permitting of Wind Energy Facilities: A Handbook*, National Wind Coordinating Committee, Revised 2002.

[82] National Research Council, *Environmental Impacts of Wind-Energy Projects: Report in Brief*, The National Academy of Sciences, 2007, p. 2.

[83] These early turbines were not designed with avian populations in mind. The blades spun much more quickly than today's turbines and the towers were often constructed of lattice steel, an enticing nesting feature for birds.

[84] *Wind Power: Impacts on Wildlife and Government Responsibilities for Regulating Development and Protecting* (continued...)

in West Virginia, Pennsylvania, New York, Alberta, and elsewhere.[85] As a result, the wind industry and bat supporters formed a new organization, the Bats & Wind Energy Cooperative (BWEC) to fund studies designed to reduce bat mortality.[86]

Most experts concede that not enough is known about avian behavior to predict accurately what the affect on species will be if wind plants continue to expand. More collaborative study is underway to improve understanding of ways to minimize avian deaths.[87] Potential mitigation options include:

- Stopping wind plants during key migratory periods,
- Painting blades to improve visibility,
- Avoiding locations, such as some mountain passes, already known to be migration corridors,
- Employing acoustic deterrents, and
- Moving selected turbines.

In addition to birds and bats, wildlife protection experts are studying how wind plant construction and operation affects terrestrial animals.[88] Greater prairie chickens, for example, shy away from tall structures and may thus avoid living near wind plants.[89]

Federal agencies produced interim recommended guidelines in 2003 to assist project developers in considering and minimizing wildlife impacts.[90] The DOI (through Fish and Wildlife Services, FWS) has established a Wind Turbine Guidelines Advisory Committee to advise the Secretary on developing effective voluntary measures to minimize impacts to wildlife related to land-based wind turbines.[91] Early in the 110th Congress, Title VII of the New Direction for Energy Independence, National Security, and Consumer Protection Act (H.R. 3221) had required formation of such a committee, but the provision was removed when the bill was merged with H.R. 6. As noted previously, Congress gave MMS primary authority over most aspects of siting off-shore wind plants through the Energy Policy Act of 2005 (EPACT05).

(...continued)

Wildlife, Government Accountability Office, GAO-05-906, September 2005, pp. 10-13.

85 J. Layke, K. Porter, and A. Perera, "Diversifying Corporate Energy Purchasing with Wind Power," World Resources Institute, February 2008, p. 14.

86 BWEC includes AWEA, Bat Conservation International, the U.S. Fish and Wildlife Service, and the U.S. Department of Energy's National Renewable Energy Laboratory. "Wind Energy and Wildlife: Frequently Asked Questions," AWEA, 2008, p. 2.

87 See, for example, "Bats and Wind Energy Cooperative" http://www.batsandwind.org/.

88 See, for example, National Research Council, *Environmental Impacts of Wind-Energy Projects: Report in Brief*, The National Academy of Sciences, 2007

89 J. Layke, K. Porter, A. Perera, "Diversifying Corporate Energy Purchasing with Wind Power," World Resources Institute, 2008, p. 9.

90 See "Interim Guidelines to Avoid and Minimize Wildlife Impacts from Wind Turbines," U.S. Department of the Interior, Fish and Wildlife Service, 2003, http://www.fws.gov/habitatconservation/wind.pdf.

91 The Charter describing the committee's formation is available on the FWS website at http://www.fws.gov/habitatconservation/Advisory_Committee_Charter_3_20_07.pdf.

Aesthetic and Social Issues

Some landowners object to the visual impact that wind turbines create, especially near shore, mountainous, forested, protected, or other "valuable" areas. They view wind turbines as an unacceptable human or industrial fingerprint on lands that should remain natural. These objections are reflected in the offshore Cape Wind project, where opponents argue that natural "landscapes" (or seascapes, in this case) will be forever altered by the wind turbines.

In addition to the visual impacts, there are other objections. All wind turbines produce mechanical and aerodynamic noise. Noise is thus a siting criterion for regulatory purposes. Early wind turbine models were often loud, especially downwind versions (blades behind the generator). Newer models are designed to minimize noise.[92] Like visual aesthetics, wind turbine noise is often a matter of individual preferences and tolerances. For residences over 1 kilometer (0.6 miles) from a wind turbine, noise is generally not an issue.

Shadow flicker, also know as shadow casting or blinking, is defined as alternating changes in light intensity caused by the moving blades casting shadows on the ground or objects. No flicker shadow will be cast when the sun is obscured by clouds or when the turbine is not rotating. This phenomenon can be annoying for residents who live very close to turbines. Computer simulations can help project developers position turbines so that flicker does not interfere with nearby residences. Shadow flicker generally does not affect residences located 10 rotor diameters or more (about 0.5 miles) from the turbine, except possibly early in the morning or late in the evening when shadows are long.[93]

Radar Issues

Wind turbines can interfere with civilian and military radar at some locations. The potential interference occurs when wind turbines reflect radar waves and cause ghosting (false readings) or shadowing (dead zones) on receiving monitors. Radar interference thus raises national security and safety concerns.[94]

Concern over wind power and radar interference appeared to peak after Congress enacted the National Defense Authorization Act for Fiscal Year 2006 (P.L. 109-163) on January 3, 2006. Section 358 of the law required the Department of Defense (DOD) to submit to Congress within 120 days a report on the impacts of wind plants on military readiness. In response, DOD and the Department of Homeland Security (DHS) issued a temporary ruling on March 21, 2006, contesting the construction of any wind plant within radar line of sight of key military radar facilities until the report could be completed. AWEA stated in a June 2006 fact sheet that the *de facto* moratorium on billions of dollars worth of wind investment in parts of the country was inappropriate.[95] The temporary ruling was clarified on July 10, 2006, in a joint DOD-DHS memo

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[92] A. Rogers, J. Manwell, and S. Wright, *Wind Turbine Acoustic Noise*, University of Massachusetts at Amherst, Renewable Energy Research Laboratory, June 2002.

[93] B. Voll, "Black Springs Wind Farm Shadow Flicker Study," Energreen Wind, 2006, p. 6.

[94] See also M. Brenner, et al., *Wind Farms and Radar*, The MITRE Corporation, JSR-08-126, January 2008.

[95] AWEA, "Wind Turbines and Radar: An Informational Resource," June 2, 2006 http://www.awea.org/pubs/factsheets/060602_Wind_Turbines_and%20_Radar_Fact_Sheet.pdf.

to the FAA,[96] calling for a case-by-case evaluation of the potential of wind projects on radar systems. Permitting resumed for most of the affected projects later that year.

The DOD impacts report[97] concluded that wind farms located within radar line of sight of an air defense radar have the potential to degrade the ability of that radar to perform its intended function. It also noted that currently proven mitigation options to completely prevent any degradation in primary radar performance of air defense radars are limited to methods that avoid locating wind turbines within their radar line of sight. DOD has initiated research efforts to develop additional mitigation approaches that in the future could enable wind turbines to be placed within radar line of sight of air defense radars without impacting their performance.[98]

The FAA has oversight over any object that could have an impact on communications in navigable airspace, either commercial or military. DOD participates in the FAA review and evaluation of applications for potential impacts to its ability to defend the nation. The FAA requires that a Notice of Proposed Construction or Alteration be filed for any project that would extend more than 200 feet above ground level (or less in certain circumstances, for example if the object is closer than 20,000 feet away from a public-use airport with a runway more than 3,200 feet long).[99]

Although the DOD report noted limited options to "completely prevent" the degradation of any performance of air defense radar systems, DOE believes that practical solutions to radar interference are achievable. DOE notes that in the majority of cases, interference is either not present, is not deemed significant, or can be readily mitigated.[100] Potential interference is highly site specific and depends on local features, type of radar, and wind plant characteristics. In most cases, radar interference can be corrected with software that deletes radar signals from stationary targets.

Transmission Constraints

Transmission constraints are considered to be one of the biggest challenges facing the U.S. wind industry.

The electricity grid in the United States is aging and overloaded in some regions, and new investment is required to ensure reliable, efficient transmission of electricity.[101] Siting new transmission lines is an expensive, time consuming, and, often, controversial endeavor. Wind plant developers seek access to transmission capacity that allows them to send their electricity to market without having to build new lines, especially ones they need to pay for themselves. As noted previously, much of the nation's best wind resources are located in remote, lightly

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[96] K. Kinsmore, and R. Wright, "Intent of March 21, 2006 Memorandum," Department of Defense and Department of Homeland Security Joint Program Office, July 10, 2006.

[97] The report was issues on September 27, 2006 and is available at http://www.defense.gov/pubs/pdfs/WindFarmReport.pdf

[98] Office of the Director of Defense Research and Engineering, *The Effect of Windmill Farms on Military Readiness*, DOD, September 2006, pp. 56-57.

[99] FAA requirements on potential obstructions are discussed at https://oeaaa.faa.gov/oeaaa/external/portal.jsp.

[100] U.S. DOE, "Wind Powering America," available at http://www.eere.energy.gov/windandhydro/windpoweringamerica/ne_issues_interference.asp.

[101] See CRS Report RL33875, *Electric Transmission: Approaches for Energizing a Sagging Industry*, by (name redacted).

populated areas where little transmission capacity exists. Demand centers, where the electricity is consumed, can be hundreds of miles away. A 2006 estimate puts the cost of new transmission lines at $1.5-$2 million per mile, and costs may have increased since.[102]

Transmission constraints occur in at least 3 ways:

- **Limited transmission capacity,**
- **Scheduling difficulties** in using existing lines, and
- **Delays in interconnecting** new wind power sources to the grid.

Limited Transmission Capacity

Good sites for wind plants may be located in areas with limited available capacity on the transmission network, or the sites may be distant from any existing transmission lines. These capacity limits are the most fundamental constraint facing wind power project developers. It can take many years to plan and build new infrastructure. Wind plant developers who build in regions with limited or no transmission capacity may have to incur all construction costs for new or improved transmission infrastructure, an expensive proposition.

Texas is attempting to address its wind power transmission constraints through competitive renewable energy zones (CREZs), which attempt to optimize the linking of promising wind zones with demand centers and overcome the "chicken and egg" problem between wind plant developers and transmission providers. California is pursuing a similar CREZ policy, and other states, including New Mexico, Wyoming, and Colorado, are expanding transmission infrastructure to accommodate wind and other electricity options.[103]

Under EPACT05, in certain cases where transmission congestion exists, the Federal Energy Regulatory Commission (FERC) may use federal over-ride (eminent domain) authority to site new transmission lines when states have not acted to site those lines.[104] Also under EPACT05, FERC is authorized to approve a funding plan for new transmission that would charge the new generator for all costs associated with interconnection rather than socializing the interconnection costs over all users of the transmission network.[105] This type of funding could be cost prohibitive for small wind facilities.

Finally, EPACT05 also directed FERC to establish incentive rules to encourage greater investment in the nation's transmission infrastructure, promote electric power reliability, and lower costs for consumers by reducing transmission congestion. Order No. 679 allows a public utility to obtain incentive rate treatment for transmission infrastructure investments under certain conditions.

[102] Actual costs are location dependent. Northwest Power Pool, "Canada—Northwest—California Transmission Options Study," pp. 16-27, May 16, 2006.

[103] L. Chaset, "Comments of the Public Utility Commission of California," FERC Docket No. AD08-2-00, December 11, 2007; and S. Smith, "Wind on the Wires: Can Transmission Infrastructure Adapt?," *Utility Automation and Engineering T&D*, May 2008.

[104] P.L. 109-58, §1221.

[105] P.L. 109-58, §1242.

Scheduling Difficulties

Transmission scheduling difficulties for wind power can result because the original rules for access to transmission capacity were not designed with intermittent sources, like wind, in mind. As the electricity sector slowly transforms itself from one with several hundred vertically integrated utilities with their own transmission control areas to one with a combination of regional transmission organizations (RTOs) and traditional control centers, the rules are being rewritten. Under the old rules, economic penalties were applied to generators that did not meet their day-ahead schedule requirements. For wind power, this occurred frequently since power output varies with wind variability, making scheduling difficult. Wind developers claim that the old rules discriminated against intermittent sources. In February 2007, FERC issued Order No. 890 to allow greater access to transmission lines for power generators of all types, including renewable energy projects.[106]

Rate pancaking (using the transmission facilities of multiple operators and incurring access charges from each) is another scheduling barrier for wind power in some regions. Only large transmission systems acting as a single network resource allow wind plants to avoid pancaking. FERC tried to promote a Standard Market Design order in 2002-2003 that might have provided greater uniformity to transmission pricing, but the effort was dropped due to opposition.[107]

Transmission Interconnection

There are long queues (waiting lists) in some regions of the country for wind and other power plant developers to get approval to interconnect their new facilities with the grid.[108] FERC issued Orders 2003 and 661 to clarify transmission interconnection requirements and help address potential discrimination.[109] FERC is also preparing new guidance to help RTOs and independent system operators (ISOs) improve their queuing methodology.[110] As long as there is a shortage of transmission capacity, however, transmission interconnection queuing is likely to remain a problem.[111]

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[106] *Preventing Undue Discrimination and Preference in Transmission Service* (Order 890), Federal Energy Regulatory Commission, February 16, 2007.

[107] See CRS Report RS21407, *Federal Energy Regulatory Commission's Standard Market Design Activities*, by (nam e redacted).

[108] According to a recent DOE report, there were 225,000 megawatts of proposed wind power capacity in interconnection queues within 11 RTO, ISO, and utility regions at the end of 2007. As noted in the report, being in the queue does not guarantee that a project will be built; many are at an early stage of development and may never achieve commercial operations. For comparison, the report noted that about 212,000 megawatts of natural gas, coal, nuclear, solar, and "other" projects were also in queues. R. Wiser and M. Bolinger, *Annual Report on U.S. Wind Power Installation, Cost and Performance Trends: 2007*, U.S. Department of Energy, May 2008, pp. 9-10.

[109] *Standardization of Generator Interconnection Agreements and Procedures* (Order 2003), Federal Energy Regulatory Commission, July 24, 2003; *Interconnection for Wind Energy* (Order 661), Federal Energy Regulatory Commission, June 2, 2005.

[110] *Interconnection Queuing Practices* (Docket No. AD08-2-000), Federal Energy Regulatory Commission, March 20, 2008.

[111] For more information on recent electricity transmission issues that may relate to wind power, see CRS Report RL33875, *Electric Transmission: Approaches for Energizing a Sagging Industry*, by (name redacted); *20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply*, U.S. DOE, 2008.

Federal Renewable Transmission Initiatives

Two bills were introduced in the 110th Congress to address transmission of wind power and other renewable electricity. The Clean Renewable Energy and Economic Development Act (S. 2076), introduced in September 2007, would, among other things, amend the Federal Power Act to require national renewable energy zones. These zones would be specified areas that have the potential to generate 1,000 megawatts of electricity from renewable energy, a significant portion of which could be generated in a rural area or on federal land.

The legislation would also require FERC to promulgate regulations to ensure that (1) specified public utility transmission providers that finance renewable electricity connection facilities in such zones recover incurred costs and a reasonable return on equity associated with the new transmission capacity; and (2) not less than 75% of the capacity of specified high-voltage transmission facilities and lines is used for electricity from renewable energy. The legislation was referred to the Committee on Energy and Natural Resources, which held a hearing on transmission issues for renewable electricity resources on June 17, 2008.[112]

A similar bill in the House, the Rural Clean Energy Superhighways Act (H.R. 4059), was introduced in November 2007. It would also focus on creating national renewable energy zones under certain conditions. It requires the President to identify, and provide public notice of, additional renewable energy trunkline facilities and network upgrades required to increase substantially the generation of electricity from renewable energy within each potential zone. It directs FERC to pass regulations to ensure that a public utility that finances transmission capacity to transmit electricity from renewable energy from a zone to an electricity consuming area recovers through transmission service rates all prudently incurred costs and a reasonable return on equity associated with construction and operation of the new transmission capacity. It also directs FERC, in specified circumstances, to permit a renewable energy trunkline built by a public utility located in a zone to be initially funded through transmission charges imposed upon (1) all the utility's transmission customers in advance of significant generation interconnection requests; or (2) all the transmission customers of an RTO or independent system operator, if the trunkline is built in an area served by one or the other. Cost allocation procedures are prescribed for new projects and network upgrades. A federal power marketing administration, including the Tennessee Valley Authority, that owns or operates electric transmission facilities is required to finance a network upgrade or a renewable energy trunkline facility, if within a certain time frame no privately or publicly funded entity commits to do so.

Renewable Production Tax Credit

The renewable production tax credit is an incentive to business developers of wind plants and some other renewable energy projects that produce electricity. For each kilowatt-hour of energy produced, a developer can apply for a credit against taxes. In 2007, the credit stood at 2.0 cents per kilowatt-hour for claims against 2006 taxes. On October 3, 2008, the PTC was renewed for one year in the Emergency Economic Stabilization Act of 2008 until December 31, 2009. According to industry members, the PTC expirations in 2000, 2002, and 2004 have had a

[112] Testimony from this hearing is available at http://energy.senate.gov/public/index.cfm?FuseAction= Hearings.Hearing&Hearing_ID=7344491e-df7f-9a28-80ce-47fe52e63f1b.

negative impact on the U.S. wind industry's ability to invest in new production facilities efficiently.[113]

Proponents of extending the credit past 2009 argue that the PTC is merited because it corrects a market failure by providing economic value for the environmental benefits of "clean" energy sources. Also, they contend it helps "level the playing field," noting that there is an even longer history of federal subsidies for conventional energy.[114] For example, they point to the percentage depletion allowance for oil and natural gas that has been in place for many decades.[115]

Opponents of extending the production tax credit beyond the end of 2009 argue that generally there are no market failures that warrant special tax subsidies for particular types of renewable energy technologies. They argue further that subsidies generally distort the free market and that renewables should not get special treatment that exempts them from this principle. Also, regarding the concern about the environmental problems of conventional energy sources, they contend that the most cost-effective economic policy is to put a tax on the pollution from energy sources and let the free market make the necessary adjustments. Another argument against the PTC is that intermittent renewable energy production has a fluctuating nature that makes it less valuable than energy produced by conventional facilities.

PTC Eligibility: IOUs vs. IPPs

The renewable PTC is not available to investor owned utilities (IOUs), although utilities do finance and own wind plants. Typically, independent power producers (IPPs) build, finance, and own wind plants and sell power to regulated utilities. There are a number of financing mechanisms where other providers of capital assist with financing wind plants in exchange for a portion of the tax credits. One question for Congress is whether utilities should become eligible to receive the PTC. Doing so would allow them to finance wind plants at a lower cost since the interest rates they pay on debt is lower than what an IPP pays. This would reduce the cost of wind power. One impact of allowing utilities to receive the renewable tax credits is that they could become more competitive at producing wind than IPPs. This could threaten the growth of the dozens of companies that now build wind plants.

Specific PTC Legislative Options

During the 110th Congress, a variety of bills sought to extend or modify selected renewable energy and energy efficiency tax incentives, including wind power. Title IV of the Alternative Minimum Tax and Extenders Tax Relief Act (S. 2886), which was introduced on April 17, 2008,

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113 U.S. Congress, House Committee on Ways and Means, *Tax Credits for Electricity Production from Renewable Sources*. Hearing held May 24, 2005. Testimony of Dean Gosselin, FPL Energy. pp. 25-26. http://waysandmeans.house.gov/hearings.asp?formmode=detail&hearing=411.

114 Federal subsidies for conventional energy resources and technologies and for electric power facilities (including large hydroelectric power plants) have been traced back as far as the 1920s and 1930s. See DOE (Pacific Northwest Laboratory), *An Analysis of Federal Incentives Used to Stimulate Energy Production*, 1980. p. 300. EIA recently published the latest in a series on federal energy incentives and subsidies: EIA, *Federal Financial Interventions and Subsidies in Energy Markets 2007*, DOE, April 2008.

115 GAO. *Petroleum and Ethanol Fuels: Tax Incentives and Related GAO Work*. (GAO/RCED-00-301R) September 25, 2000. The report notes that from 1968 through 2000, about $150 billion (constant 2000 dollars) worth of tax incentives were provided to support the oil and natural gas industries.

would extend eight incentives. Title X of the Foreclosure Prevention Act (H.R. 3221), which passed the Senate on April 10, 2008, incorporates eight renewable energy and energy efficiency tax incentives from the Clean Energy Tax Stimulus Act (S. 2821). The Renewable Energy and Energy Conservation Tax Act (H.R. 5351), which passed the House on February 27, 2008, includes 16 incentives for renewable energy and energy efficiency. Features of these bills as they relate to the PTC for wind energy are summarized in **Table 4**. For updated status on legislation related to the PTC, see CRS Report RL33831, *Energy Efficiency and Renewable Energy Legislation in the 110th Congress*, by (name redacted), (name redacted), and (name redacted).

Table 4. Selected Wind Power Tax Incentive Bills Compared

	H.R. 6049	Senate Substitute to H.R. 6049	H.R. 5984, H.R. 3221 (S. 2821)
Renewable Energy			
Production Tax Credit Extension	1 year	1 year	1 year
Clean Renewable Energy Bonds	$2 billion	$2 billion	$400 million
Revenue Offsets			
Offsets from reduced oil and gas subsidies	yes	yes	no

On October 3, 2008, the PTC was extended for one year until the end of 2009 in the Emergency Economic Stabilization Act of 2008.

Carbon Constraints and the PTC

Climate change is almost certain to be an important topic in this and future Congresses. Most proposals call for a cap-and-trade system to reduce greenhouse gas emissions, although carbon taxes have also been proposed. Either way of constraining greenhouse gas emissions would create an effective cost on emissions. As noted in the Economics Section of this report, the Congressional Budget Office estimated the price of carbon dioxide allowances in S. 2091 at $30 per metric ton in 2013.[116] While this legislation did not pass, future versions of legislation are likely to have similar price levels on carbon dioxide allowances. According to the levelized cost analysis presented earlier, such a price would make wind power about 19% less expensive than power derived from coal. Even without the PTC, wind power would be more competitive than coal. For natural gas, the impact of carbon allowance costs would be less dramatic, although the levelized cost of wind as modeled here would be noticeably lower than natural gas power. Congress will need to reconsider the policy goal of the renewable PTC if and when a carbon constraint is imposed.

[116] CBO's analysis was performed in accordance with S. 2191 (the Lieberman-Warner Climate Security Act of 2008). See CRS Report RL34515, *Climate Change: Comparison of S. 2191 as Reported (now S. 3036) with Proposed Boxer Amendment*, by (name redacted) and (name redacted).

Alternatives to the PTC

One alternative to the PTC is the renewable energy payment system, also known as the feed-in tariff. This policy is widely used in Europe (see Text Box 1 for the German experience). It guarantees interconnection with the electricity grid and a premium price to renewable energy producers. Financing renewable energy projects under a renewable energy payment system is reportedly easier since there is a transparent source of revenue for a fixed period, usually 20 years. Even in Germany, however, critics claim that feed-in tariffs can be expensive. A summary of the Renewable Energy Jobs and Security Act, which incorporates renewable energy payments, was circulated in mid-June 2008.[117]

Renewable Portfolio Standards

In the late 1990s, many states began to restructure their electric utility industries to allow for increased competition. Some of these states established an RPS, in part, as a way to create a continuing role for renewable energy in power production.[118] An RPS requires utilities to provide a minimum percentage of their electricity from approved renewable energy sources. Some states without a restructured industry also adopted an RPS. The number of states with an RPS has grown steadily but without consistency—RPS requirements vary from state to state. In April 2008, FERC reported that 26 states and the District of Columbia had an RPS in place, collectively covering about 54% of the national electric load.[119] Mandatory state RPS targets range from a low of 2% to a high of 25% of electricity generation. However, most targets range from 10% to 20% and are scheduled to be reached between 2010 and 2025.

Most states include wind energy as an eligible resource and allow some form of trading between holders of the "renewable energy credits" that result from operating wind projects.[120] Non-compliance penalties imposed by states range from about 1.0 to 5.5 cents per kilowatt-hour. Many states in the Southeast and Midwest regions do not have an RPS requirement. Several states have broadened their RPS provisions to allow certain energy efficiency measures and technologies to help satisfy the requirement.

Federal RPS Debate

State RPS action has provided an experience base for the design of a possible national requirement. Proponents of a federal RPS contend that a national system of tradable credits would

[117] The summary is available at http://www.eesi.org/briefings/2008/061808_hboell_rep/Inslee_REJSA_061808.pdf.

[118] Section 210 of the Public Utility Regulatory Policies Act (PURPA) of 1978 had guaranteed a market for the purchase of electric power produced from small renewable energy facilities. PURPA let states determine the avoided cost pricing of the electricity production from renewable energy facilities. The effectiveness of this mechanism lessened with the advent of electric industry restructuring. Provided that certain conditions are met in any given state, Section 1253 of the Energy Policy Act of 2005 retrospectively terminates the PURPA mandatory purchase requirements.

[119] Federal Energy Regulatory Commission, *Renewable Energy Portfolio Standards (RPS)*, DOE. For a map showing the status of state action on RPS, see http://www.ferc.gov/market-oversight/mkt-electric/overview/elec-ovr-rps.pdf.

[120] Details about eligible resources and other provisions of state RPS programs are available from the online Database of State Incentives for Renewable Energy and Energy Efficiency, http://www.dsireusa.org/. See also R. Wiser and G. Barbose, *Renewables Portfolio Standards in the United States—A Status Report with Data Through 2007*, Lawrence Berkeley National Laboratory, April 2008; and A. Selting, *The Race for the Green: How Renewable Portfolio Standards Could Affect U.S. Utility Credit Quality*, Standard & Poors, March 2008.

enable retail suppliers in states with fewer resources to comply at the least cost by purchasing credits from organizations in states with a surplus of low-cost production. Opponents counter that regional differences in availability, amount, and types of renewable energy resources would make a federal RPS costly and unfair.

Efforts to include a federal RPS in the Energy Independence and Security Act (P.L. 110-140) were unsuccessful. In June 2007, S.Amdt. 1537 to H.R. 6 proposed a 15% federal RPS. Senate floor action on the proposal triggered a lively debate, but the amendment was ultimately ruled non-germane. In that debate, opponents argued that a national RPS would raise retail electricity prices and disadvantage Southeastern states because they lack sufficient renewable energy resources to meet a 15% RPS requirement. RPS proponents countered that an EIA report indicated that the South has sufficient biomass power potential from existing plants to meet a 15% RPS without becoming "unusually dependent" on other regions.[121] Further, EIA estimated that the 15% RPS would likely raise retail prices by slightly less than 1% over the 2005 to 2030 period, but would also be likely to cause retail natural gas prices to fall slightly over that period. In December 2007, the House approved H.R. 6 with a 15% RPS, but the Senate dropped the provision under threat of an Administration veto of the bill. The prospects for another federal RPS initiative in the 110th Congress are unclear.

Conclusions

Wind power in the United States is growing rapidly. Although it currently supplies only about 1% of the country's electricity needs, some states and regions have a much higher level of wind penetration. Furthermore, the amount of proposed new wind plants either under construction or waiting to be built is significant, and could soon make wind the largest source of new power supply at the national level. Continued expansion of wind power in the United States could be slowed by the current financial crisis, lack of transmission capacity, or expiration of the federal renewable production tax credit on December 31, 2009. On the other hand, federal policy on climate change, expected by many in the 111th Congress, would likely put a value on carbon dioxide emissions and give wind power additional advantages compared to coal- and natural gas-based electricity. Congress will need to carefully consider the interactive nature of energy and climate legislation when crafting future policy.

[121] EIA, *Impacts of a 15-Percent Renewable Portfolio Standard*, DOE, June 2007. 24 p.

Appendix. Financial Analysis Methodology and Assumptions

The financial analysis of power plant costs in this report estimates the operating costs and required capital recovery of each generating technology for an analysis period through 2050. Plant operating costs will vary from year to year depending, for example, on changes in fuel prices and the start or end of government incentive programs. To simplify the comparison of alternatives, these varying yearly expenses are converted to a uniform annual cost expressed as 2008 present value dollars.[122]

Similarly, the capital costs for the generating technologies are also converted to levelized annual payments. An investor-owned utility or independent power project developer must recover the cost of the investment and a return on the investment, accounting for income taxes, tax law (depreciation rates), and the cost of money. These variables are encapsulated within an annualized capital cost for a project computed using a "capital charge rate." The financial model used for this study computes a project-specific capital charge rate that reflects, for example, the assumed cost of money and the applicable depreciation schedule.

In the case of publicly owned utilities the return on capital is a function of the interest rate. A "capital recovery factor" reflecting each project's cost of money is computed and used to calculate a mortgage-type levelized annual payment.[123]

Combining the annualized capital cost with the annualized cash flows yields the total estimated annualized cost of a project. This annualized cost is divided by the projected yearly output of electricity to produce a cost per Mwh for each technology. By "annualizing" the costs in this manner it is possible to compare alternatives with different year-to-year cost patterns on an apples-to-apples basis.

Inputs to the financial model include financing costs, forecasted fuel prices, non-fuel operations and maintenance expense, the efficiency with which fossil-fueled plants convert fuel to electricity, and typical utilization rates (see **Table A-1, Table A-2**, and **Table A-3**). Most of these inputs are taken from published sources, such as EIA's assumptions used to produce its 2007 and 2008 long-term energy forecasts. Overnight power plant capital costs—that is, the cost to construct a plant before financing expenses—are estimated by CRS based on a review of public information on recent projects.

[122] Converting a series of cash flows to a financially-equivalent uniform annual payment is a two-step process. First, the cash flows for the project are converted to a 2008 "present value." The present value is the total cost for the analysis period, adjusted ("discounted" using a "discount factor") to account for the time value of money and the risk that projected costs will not occur as expected. This lump-sum 2008 present value is then converted to an equivalent annual payment using a uniform payments factor (the "capital recovery factor"). For a more detailed discussion of the levelization method see, for example, Chan Park, *Fundamentals of Engineering Economics*, 2004, Chapter 6; or Eugene Grant, et al., *Principles of Engineering Economy,* 6th Ed., 1976, Chapter 7.

[123] For additional information on capital charge rates see Hoff Stauffer, "Beware Capital Charge Rates," *The Electricity Journal*, April 2006. The capital recovery factor is equivalent to the PMT function in the Excel spreadsheet program. For additional information on the calculation of capital recovery factors see Chan Park, *Fundamentals of Engineering Economics*, 2004, Chapter 2; or Eugene Grant, et al., *Principles of Engineering Economy,* 6th Ed., 1976, Chapter 4.

Government incentives are also an important part of the financial analysis. EPACT05 created or extended federal incentive programs for coal, nuclear, and renewable technologies. This study assumes the following incentives:

- *A renewable energy production tax credit of 2.0 cents per kWh, with the value indexed to inflation*. The credit applies to the first 10 years of a plant's operation. The Base Case analysis assumes that the tax credit, which is currently scheduled to expire at the end of 2008, will be extended (as has happened in the past). The credit is available only to wind power production that is sold to an unaffiliated third party. Under most circumstances this requirement effectively limits the production tax credit to independent power producers. A utility that owns a wind plant and uses the power to serve its own load would not qualify.[124] The credit is currently available to new wind, geothermal, and several other renewable energy sources. New solar energy systems do not qualify, and geothermal systems can take the production tax credit only if they do not use the renewable investment tax credit (discussed below).
- *A nuclear energy production tax credit for new advanced nuclear plants of 1.8 cents per kWh.* The credit applies to the first eight years of operation. Unlike the renewable production tax credit described above, the nuclear credit is not indexed to inflation and therefore drops in real value over time. This credit is subject to several limitations:
    - It is available to plants that begin construction before January 1, 2014, and enter service before January 1, 2021.
    - For each project the annual credit is limited to $125 million per thousand megawatts of generating capacity.
    - The full amount of the credit will be available to qualifying facilities only if the total capacity of the qualifying facilities is 6,000 megawatts or less. If the total qualifying capacity exceeds 6,000 megawatts the amount of the credit available to each plant will be prorated. For example, EIA assumes in its 2007 *Annual Energy Outlook* that 9,000 megawatts of new nuclear capacity qualifies; in this case the credit amount drops to 1.2 cents per kWh.[125] The Base Case for this study follows EIA in using the 1.2 cent per kWh assumption for the effective value of the credit.
- *Loan guarantees for carbon-control technologies, including nuclear power.* Under final DOE rules, the loan guarantees can cover up to 80% of the cost of a project. Guarantees are made available based on a case-by-case evaluation of applicants and are dependent on congressional authority (in April 2008, the Department of Energy announced plans to solicit up to $18.5 billion in loan guarantee applications for nuclear projects[126]). Entities receiving loan guarantees must make a "credit subsidy cost" payment to the federal treasury that reflects the net anticipated cost of the guarantee to the government, including a

[124] See 10 CFR § 451.4.

[125] For a discussion of the credit see EIA, *Annual Energy Outlook 2007*, p. 21.

[126] *DOE Announces Plans for Future Loan Guarantee Solicitations*, Department of Energy press release, April 11, 2008. Loan guarantee authority of $18.5 billion for nuclear power plants is provided by P.L. 110-161.

probability of default. The guarantees are, under current rules, unlikely to be available to public power entities.[127]

- *Energy Investment Tax Credit*. Tax credits under this program are available to certain renewable energy systems, including solar and geothermal electricity generation, and some other innovative energy technologies. Wind energy systems do not qualify. The credit is 10% for systems installed after January 1, 2009. Geothermal projects that take the investment tax credit cannot take the renewable production tax credit.[128]

The results of the analysis are shown in the main body of the report. Note that these estimates are approximations subject to a high degree of uncertainty over such factors as future fuel and capital costs. The rankings of the technologies by cost are therefore also an approximation and should not be viewed as a definitive estimate of the relative cost-competitiveness of each option. Also note that site-specific factors would influence an actual developer's choice of generating technologies. For example, coal may be less costly if a plant is close to coal mines, and the economics of wind depend in part on the strength and consistency of the wind in a given area.

Table A-1. Base Case Financial Factors

Item	Value	Sources and Notes
Representative Bond Interest Rates		
Utility Aa	2010: 6.8% 2015: 7.0% 2020: 7.0%	When available, interest rates for investment grade bonds with a rating of Baa or higher (i.e., other than high yield bonds) are Global Insight forecasts. When Global Insight does not forecast an interest rate for an investment grade bond the value is estimated based on historical relationships between bond interest rates (the historical data for this analysis is from the Global Finance website). High yield interest rates are estimated based on the differential between Merrill Lynch high yield bond indices and corporate Baa rates, as reported by WSJ.com (Wall Street Journal website).
IPP High Yield	2010: 9.8% 2015: 10.0% 2020: 10.0%	
Public Power Aaa	2010: 5.1% 2015: 5.4% 2020: 5.4%	
Corporate Aaa	2010: 6.3% 2015: 6.5% 2020: 6.5%	
Cost of Equity—Utility	14.00%	California Energy Commission, "Comparative Cost of California Cental Station Electricity Generating Technologies," December 2007, Table 8.
Cost of Equity—IPP	15.19%	
Debt Percent of Capital Structure	Utility: 50% IPP: 60% Utility or IPP with	Northwest Power and Conservation Council, "The Fifth Northwest Electric Power and Conservation Plan," May

[127] Entities receiving loan guarantees must make a substantial equity contribution to the project's financing. Public power entities normally do not have the retained earnings needed to make such payments. The rules also preclude granting a loan guarantee if the federal guarantee would cause what would otherwise be tax exempt debt to become subject to income taxes. Under current law this situation would arise if the federal government were to guarantee public power debt. For further information on these and other aspects of the loan guarantee program see U.S. DOE, final rule, "Loan Guarantees for Projects that Employ Innovative Technologies," 10 C.F.R. § 609 (RIN 1901-AB21), October 4, 2007 http://www.lgprogram.energy.gov/keydocs.html.

[128] For additional information see the discussion of the investment tax credit in the federal incentives section of the Database of State Incentives for Renewable Energy website, http://www.dsireusa.org/.

Item	Value	Sources and Notes
	federal loan guarantee: 80% POU: 100%	2005, Table I-1.
Federal Loan Guarantees		
Cost of equity premium for entities using 80% financing.	1.75 percentage points	Congressional Budget Office, *Nuclear Power's Role in Generating Electricity*, May 2008, web supplement ("The Methodology Behind the Levelized Cost Analysis"), Table A-5 and page 9.
Credit Subsidy Cost	12.5% of loan value	
Long-Term Inflation Rate (change in the implicit price deflator)	1.9%	Global Insight
Composite Federal/State Income Tax Rate	38%	EIA, National Energy Modeling System Documentation, Electricity Market Module, March 2006, p. 85.

Notes: EIA = Energy Information Administration; IOU = Investor Owned Utility; POU = Publicly Owned Utility; IPP = Independent Power Producer. For a summary of bond rating criteria see http://www.bondsonline.com/Bond_Ratings_Definitions.php. "High yield" refers to bonds with a rating below Baa.

Table A-2. Base Case Fuel and Allowance Price Forecasts

	Delivered Fuel Prices, Constant 2008$ per Million Btus			Air Emission Allowance Price, 2008$ per Allowance	
	Coal	Natural Gas	Nuclear Fuel	Sulfur Dioxide	Nitrogen Oxides
2010	$1.93	$7.51	$0.58	$249	$2,636
2020	$1.80	$6.41	$0.67	$1,074	$3,252
2030	$1.87	$7.48	$0.67	$479	$3,360
2040	$1.96	$9.17	$0.65	$158	$3,180
2050	$2.06	$11.24	$0.63	$52	$3,009

Sources: Forecasts are from the assumptions to the Energy Information Administration's 2008 Annual Energy Outlook, which assumes implementation of current law and regulation. The original values in 2006 dollars were converted to 2008 dollars using the Global Insight forecast of the change in the implicit price deflator. The EIA forecasts are to 2030; the forecasts are extended to 2050 using the 2025 to 2030 growth rates. The sulfur dioxide and nitrogen oxides allowance forecasts are for the eastern region of the United States (allowance prices are expected to vary regionally under the Clean Air Interstate Rule).

Note: Btu = British thermal unit.

Table A-3. Power Plant Technology Assumptions

Energy Source	Technology	Overnight Construction Cost for Units Entering Service in 2015, 2008$ per kilowatt	Capacity (Megawatts)	Heat Rate for Units Entering Service in 2015 (Btus per kWh)	Variable O&M Cost, 2008$ per Mwh	Fixed O&M, 2008$ per Megawatt	Capacity Factor
Wind	Onshore	$1,900	50	Not Applicable	$0.00	$30,921	34%
Coal	Supercritical Pulverized Coal	$2,577	600	8,742	$4.46	$28,100	85%
Natural Gas	Combined Cycle	$1,186	400	6,506	$1.95	$11,936	70%
Nuclear	Generation III/III+	$3,682	1,350	10,400	$0.48	$69,279	90%

Sources: Heat rates, O&M costs, and nominal plant capacities are from the assumptions to EIA's 2007 and 2008 Annual Energy Outlooks. Capital cost estimates are based on a CRS review of public information on current projects. Capital costs and heat rates are adjusted based on the learning rates used by EIA in the Annual Energy Outlook. EIA costs are adjusted to 2008 dollars using Global Insight's forecast of the implicit price deflator. Capacity factor for coal plants is from Massachusetts Institute of Technology, *The Future of Coal*, 2007, p. 128. Natural gas plants are assumed to operate as baseload units with a capacity factor of 70%. Capacity factor for wind from California Energy Commission, "Comparative Costs of California Central Station Electricity Generation Technologies," December 2007, Appendix B, p. 67. Nuclear plant capacity factor reflects the recent industry average performance as reported in EIA, *Monthly Energy Review*, Table 8.1.

Notes: kWh = kilowatt-hour; O&M = operations and maintenance; Mwh = megawatt-hour.

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