Chapter 4

WIND ENERGY

Introduction

The use of wind as an energy source has its roots in antiquity. At one time wind was the major source of power for pumping water, grinding grain and long distance transportation (sailing ships). The farm windmill was instrumental in the settlement of the Plains of Texas. The advantages of wind are: renewable, ubiquitous, and does not require water for the generation of electricity. The disadvantages are: variable and low density, which means high initial costs. In general windy areas are distant from load centers, which means transmission is a problem. The installation of wind farms in Texas (estimated to total approximately 8,800 megawatts by the end of 2008) has been the major change since the previous Texas Renewable Energy Resource Assessment in 1995. In 2006, Texas surpassed California and became number one in the United States in installed wind capacity.

Farm Windmill

The farm windmill proves that wind power is a valuable commodity. Although the peak use of farm windmills was in the 1930's and 1940's when over 6 million were in operation, these windmills are still being manufactured and are being used to pump water for livestock and residences. In Texas, there are an estimated 30,000 to 40,000 operating farm windmills. Even though the power output of each is low—equivalent to 0.2 to 0.5 kilowatt (kW)—collectively they provide up to 20 million watts (20 MW) of power. If these windmills for pumping water were replaced by electricity from the grid, it would require 60 MW of thermal power from a conventional generating station, not to mention an extensive investment in transmission lines, electric pumps and other equipment. This says nothing of the energy (and money) saved by not using fossil fuels to satisfy this energy need (equivalent to 80,000 barrels of oil per year).

Small Systems (up to 100 kW)

During the 1930's, small wind power systems (100 Watts to 1 kW) with batteries were installed in rural areas, however these units were supplanted with power from rural electric cooperatives. After the first oil crisis in 1973, there was a resurgence interest in small systems. Today there are around 600,000 small wind units installed in the world, with the majority in China. The small wind industry in the United States is dominated by Southwest Windpower and Bergey Windpower, manufacturing units from 200 W to 10 kW. A small number of 50 kW units are also produced. However due to the high price of oil, Entegrity Wind expects to produce up to one hundred 50 kW units in 2008.

Future Uses

One development is the wind electric-to-electric water pumping system[1]. The wind turbine is coupled directly to an electric generator, just as in larger systems. The generator is then connected directly to a motor, which is connected to centrifugal, or turbine pump. This is a better match between the characteristics of the wind rotor and the load. This results in an overall efficiency of 12 to 15 percent for pumping water, double the performance of the standard farm windmill. The costs of the two systems are almost the same, however the wind-electric system pumps more water from the same depth. Large wind-electric systems can pump enough water for small communities or for low volume irrigation. Wind has been and will continue to be a major source of energy for pumping water for livestock in Texas.

If economical energy storage becomes feasible, then wind will be even more valuable. The three main possibilities are batteries[2], hydrogen production[3] and compressed air[4]. The Xcel project in Minnesota to store wind energy consists of twenty, 50-kW battery modules to store about 7.2 MWh of electricity. Another example to increase firm power is a proposed hybrid offshore wind-hydrokinetic ocean current project off the Texas coast (www.hydrogreen.com and www.windenergypartners.biz/home.html).

When carbon dioxide trading becomes part of the energy policy in the United States, wind energy will also be more valuable (a 2¢ to 3¢ per kWh increase). This is based on the average equivalent carbon produced per kWh at conventional fossil fuel power plants and a metric ton of carbon having a value of $30/ton or greater.

Development Issues: Considerations for Large Scale Use

Wind Farms

The three main considerations for development of wind farms are: 1) windy land, 2) access to transmission and 3) a power purchase agreement. Power purchase has been driven by Federal (today, the production tax credits) and State regulations (renewable portfolio standards).

The development of wind farms began in the early 1980's in California with the installation of wind turbines ranging from 25 to 100 kW. Today, wind turbines are available in megawatt sizes with rotor diameters of 60 to over 100 meters and installed on towers of 60 to over 100 meters. At the end of 2007, there were 94,200 MW of installed capacity in the world, with the majority in Europe (**Exhibit 4-1**) followed by the United States (**Exhibit 4-2**).

As of 2007, there were 31 wind farms in Texas (**Exhibit 4-3**), with an installed capacity of 4,494 MW **(Exhibit 4-4)** from 3210 wind turbines. The estimated numbers by the end of 2008 are 56 wind farms, 8,876 MW, and 5877 wind turbines. By the end of 2008 there will be five wind farms in Texas ranging in size from 523 to 782 MW.

The renewable portfolio standard (RPS) for Texas (1999) in conjunction with the Federal production tax credit (1992) gave rise to the wind farm boom in Texas. Notice that in the 2000, 2002, and 2004 there was no installation of wind power due to the late passage of extension of the production tax credit. The last four years show that the RPS and consistent production tax credit have driven the uninterrupted growth of wind farms in Texas to number one in the United States.

Exhibit 4-1 Installed capacity of wind farms in the world.

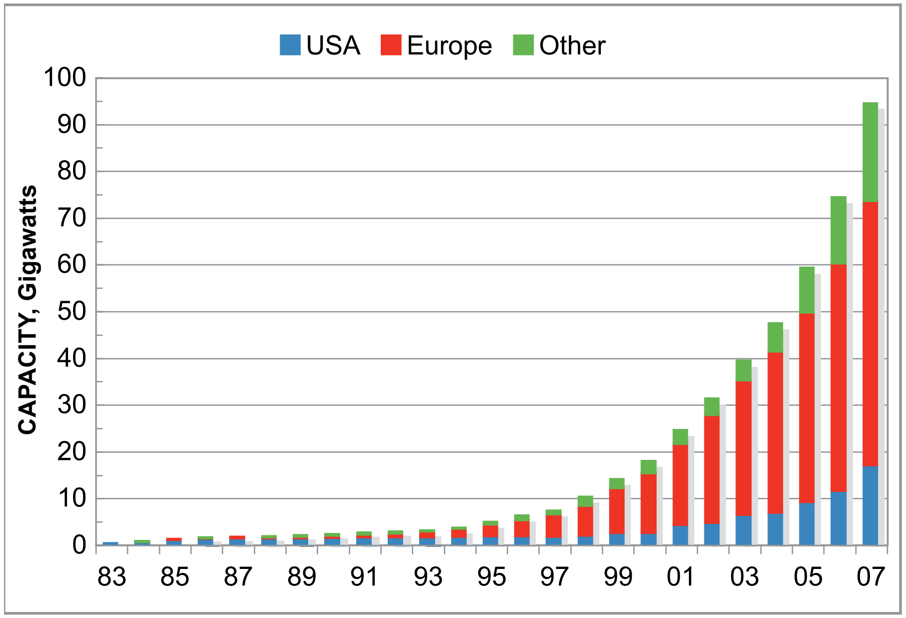


Exhibit 4-2 Installed capacity of wind farms in the United States.

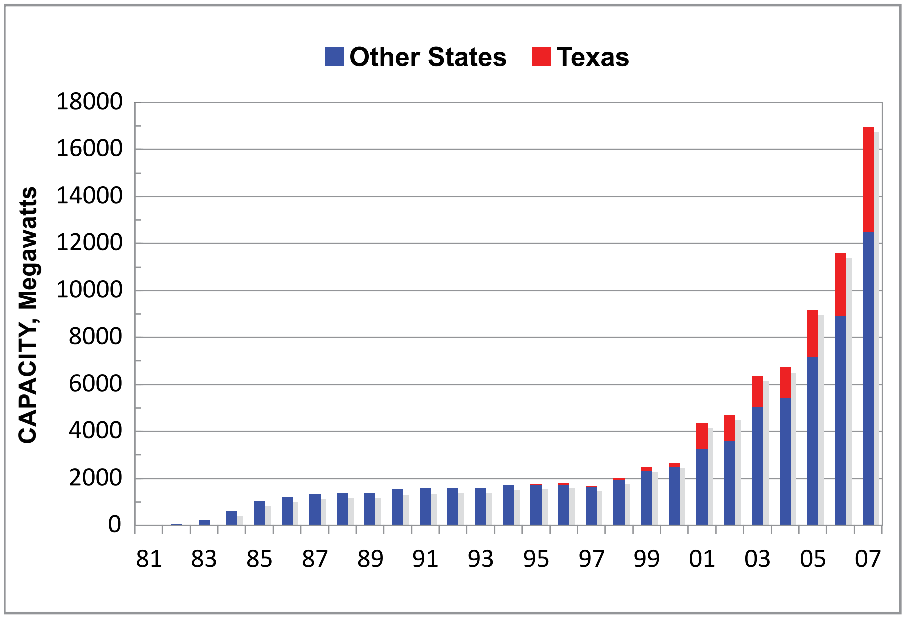
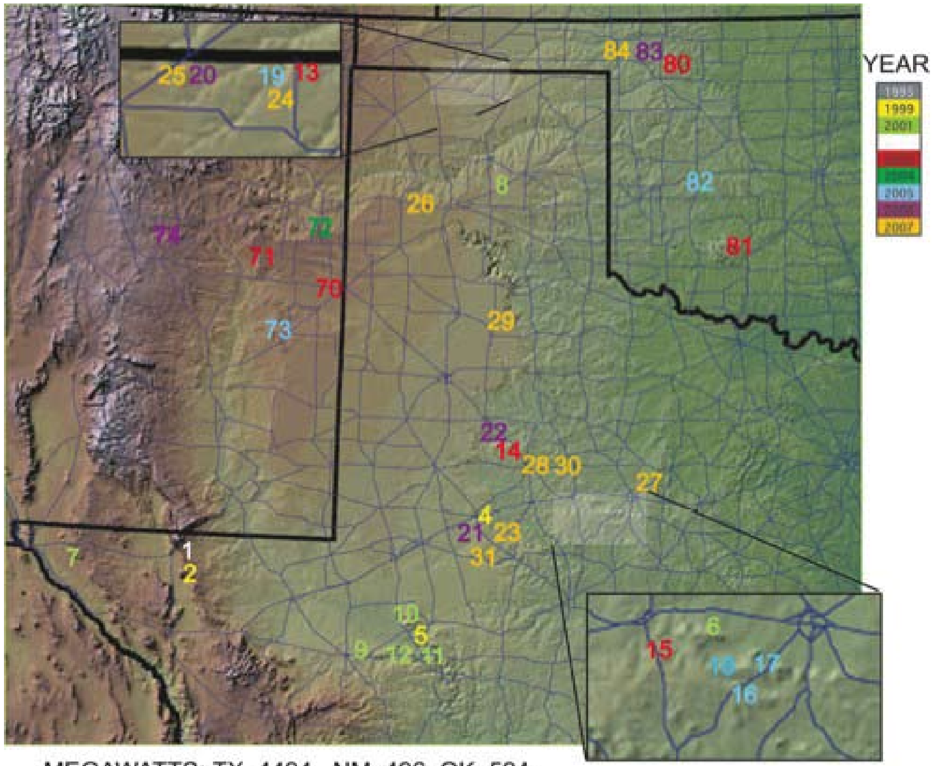


Exhibit 4-3 Location of wind farms (2007) in Texas, New Mexico and Oklahoma.



MEGAWATTS: TX 4494, NM 496, OK 594
Alternative Energy Institute, West Texas A&M University

The Texas Legislature passed Senate Bill 20 (SB 20) in 2005 in order to increase Texas' goal for renewable energy and to set up a process to facilitate the construction of electrical transmission facilities to interconnect a significantly larger amount of wind power. SB 20 increased Texas' mandated Goal for Renewable Energy to 5,880 MW in 2015 and set a target of 10,000 MW of wind power for 2025. Texas has already met the 2015 goal and is on track to meet the 2025 goal by 2010.

Through 2007, there were seven manufacturers represented in Texas with General Electric Wind having the largest number of turbines installed, followed by Siemens (**Exhibit 4-5**). Kenetech is no longer manufacturing wind turbines. Wind turbines installed in 2007 ranged from 1 to 3 MW (average size1.8 MW), 60-96 meters in diameter and on 60-105 meter towers. Wind turbines from these six manufacturers will account for most of the installations in Texas in 2008, estimated at 2,667 turbines with a capacity of 4,292 MW.

Exhibit 4-4 Installed capacity of wind farms in Texas.

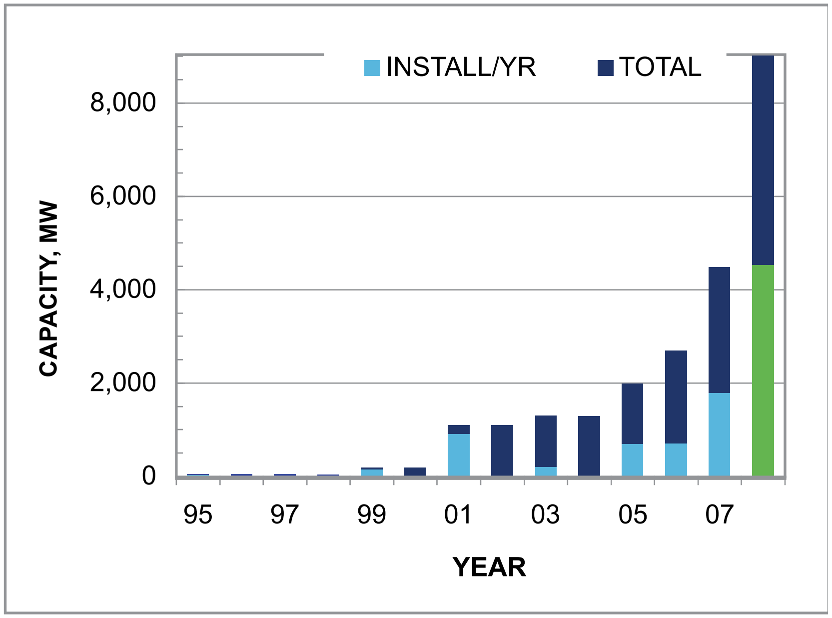
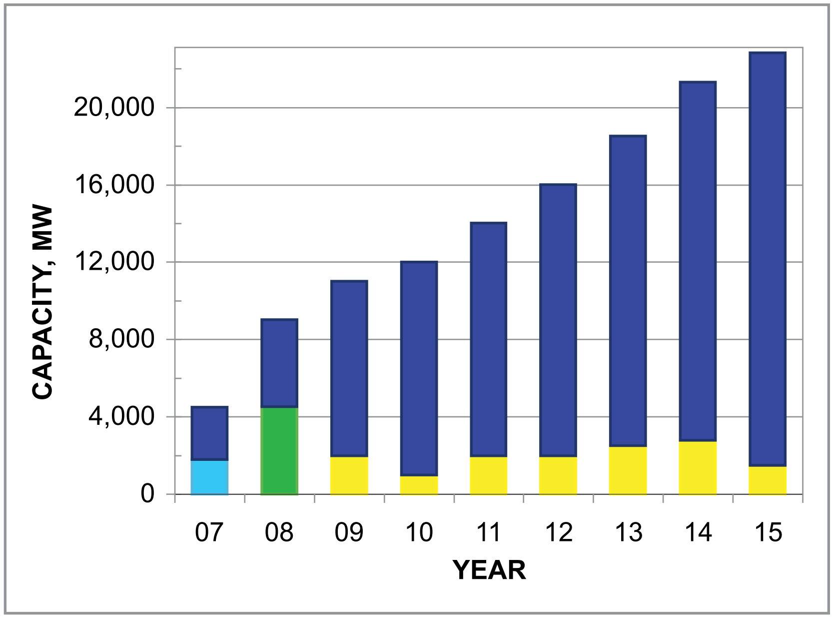


Exhibit 4-5 Manufacturers and number of turbines installed on wind farms in Texas, 2007.

	# turbines	MW
GE/Enron/Zond	1229	1815
Siemens/Bonus	640	1258
Vestas/NEG-Micon	612	542
Mitsubishi	375	375
Gamesa	167	367
Suzlon	78	98
Kenetech	109	39 (36)
Total	3210	4494

Texas Wind Power Project (Kenetech), rerated 2005.

Exhibit 4-6 Speculation on future installed capacity of wind farms in Texas.



Further wind farm development in Texas will still be driven by the production tax credit, the date of its extension, and availability of transmission line capacity. The "mid case" (**Exhibit 4-6**) makes the following assumptions; production tax credit extended to 2011, transmission upgrades in West Texas by 2010, national carbon trading by 2010, construction of transmission from the Panhandle to the ERCOT by 2012, and a national RPS by 2012. The installed capacity in Texas is projected to reach 12,000 MW by 2010 and could easily reach 22,000 MW by 2015. Note that the projected installed capacity per year is below the large installed capacity of 4,800 MW in 2008. A feasible goal for wind is 25,000 MW, which could be reached before 2020. The 25,000 MW represents a 25% penetration of peak electric load.

ERCOT and the Southwest Power Pool (SPP) in the Texas Panhandle have a large number of interconnection requests for wind generation. As of August 2008, ERCOT was tracking 243 active generation interconnection requests, which included 46,000 MW of wind. As of May 29, 2008 the Southwest Power had over 8,000 MW of active requests of wind generation interconnection in the Texas Panhandle. Of course there are many interconnection requests for wind generation that will not ultimately be constructed.

Exhibit 4-7 Capacity (MW) of new CREZ wind by scenario[9].

Wind Zone	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Panhandle A	1,442	3,191	4,960	6,660
Panhandle B	1,067	2,293	3,270	0
McCamey*	829	1,859	2,890	3,190
Central	1,358	3,047	4,735	5.615
Central West	474	1.063	1,651	2,051
Total**	12,053	18,456	24,859	24,419

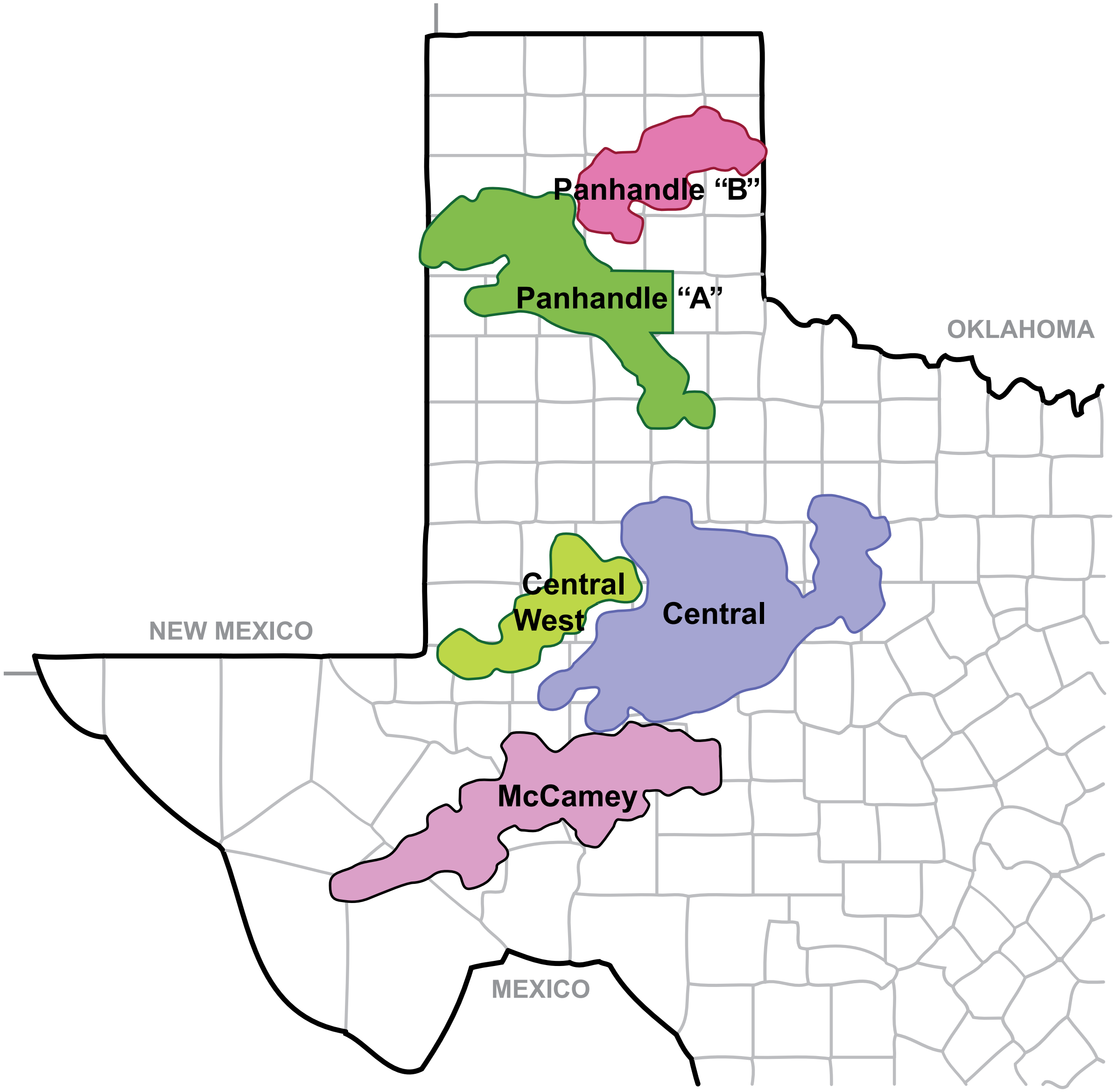
* The McCamey Area includes two CREZ areas
** Assumes 6,903 MW of existing wind capacity

Institutional Issues

Environmental issues associated with wind generation are related to birds, bats, noise and visual impacts. In California there was a problem with raptors, especially with truss towers as perches, however after numerous studies this problem has been alleviated[5]. In West Virginia there was a problem with bats. The US Fish and Wildlife Service is developing a comprehensive set of national guidelines for siting and constructing wind energy facilities to help protect wildlife resources, streamline the site selection and design process and to assist in avoiding post-construction environmental concerns[6]. They have just established an advisory committee for wind turbines.

Noise from gearboxes and blades has been reduced to less than ambient noise. It is still noticeable at the tower because the wind turbine noise is not random. Then the other major problem is that some people do not like the visual impact of wind turbines, especially if they are on ridges and mountains.

Exhibit 4-8 Competitive Renewable Energy Zones selected by ERCOT.



Problems

Texas has a huge amount of windy land and most of that land is flat, so siting is not a major problem. The environmental issues and regulatory framework, along with impact analysis and mitigation are covered in the AWEA Siting Handbook[7]. Permits and archeology issues on private land are more lenient in Texas than in other states. In general around one to two acres per wind turbine are removed from production, primarily for roads.

However the major problem is that most of the windy land is not close to the major load centers so the electric transmission system needs to be upgraded in ERCOT. Another part of the problem is that the Texas Panhandle is not a part of ERCOT. Competitive Renewable Energy Zones (CREZ) were selected for the state, based on areas of the state with the highest wind potential and the transmission of wind power to the load centers in ERCOT[8]. Eight zones were selected and ultimately combined into five zones (**Exhibit 4-8**) from the original 24 potential zones. Different transmission scenarios (**Exhibit 4-7**) have been proposed which include construction of transmission loops into the Panhandle for power to ERCOT (**Exhibit 4-9**). The PUC selected Scenario 2 in July 2008, which would increase the amount of wind power in ERCOT by around 10,000 MW. The estimated costs are summarized in **Exhibit 4-10**. Current wind farm operators and developers have even offered to build transmission lines into the Panhandle and in 2008 T. Boone Pickens purchased 1000 MW of wind turbines as the first phase of a 4000 MW wind farm in the Panhandle. He has proposed to build a transmission line to ERCOT, using a water district board to obtain the right of way for the transmission line.

Exhibit 4-9 Scenario 2 transmission lines for CREZ.

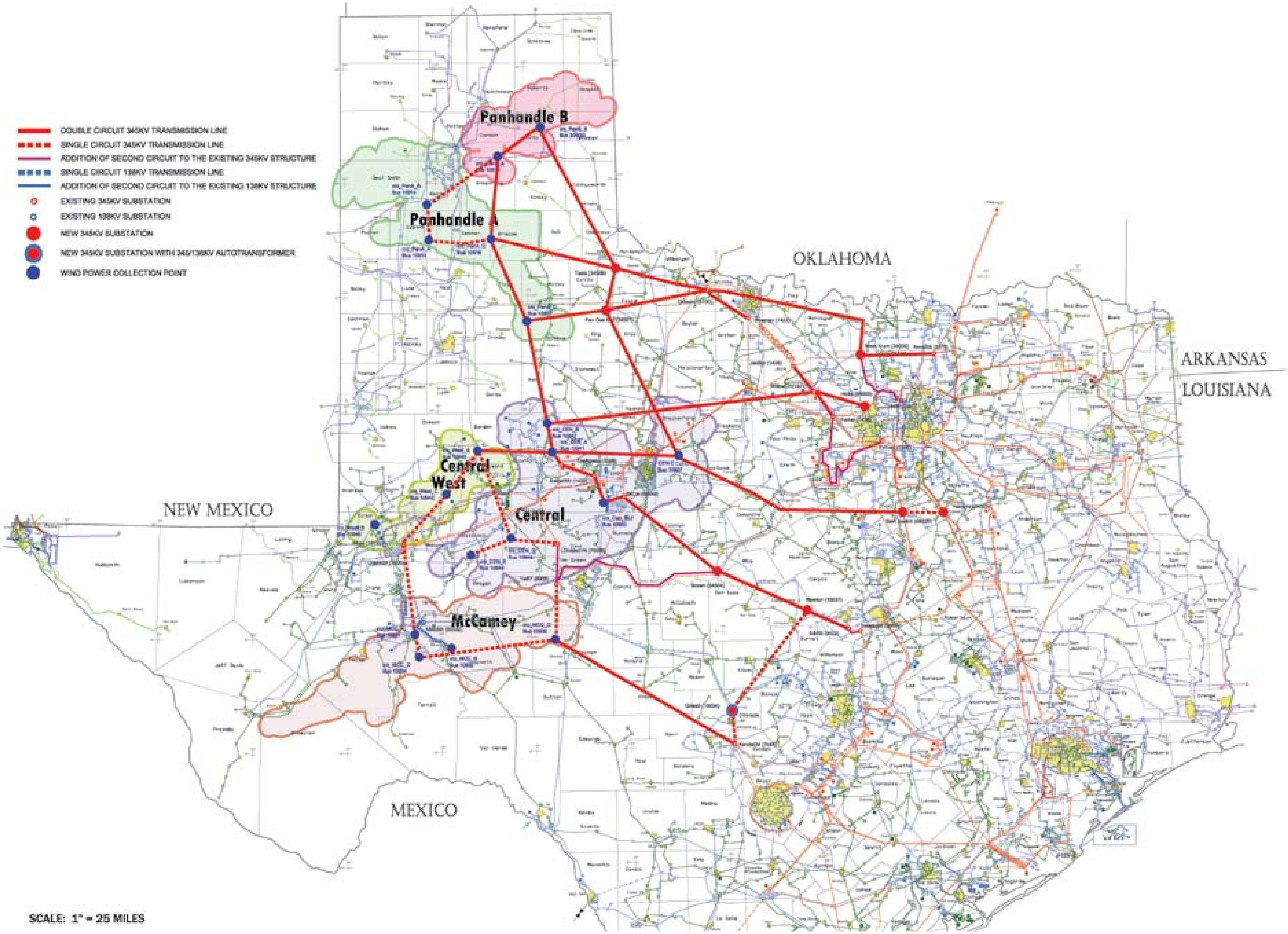


Exhibit 4-10 Estimated cost summary and miles of transmission lines for the CREZ scenarios.

Scenario	Wind Installed MW	Transmission Cost $B	Collection Cost $B	Total New ROW miles
1 A	12,053	2.95	9.35-0.41	1,638
1 B	12,053	3.78	0.41-0.53	1,831
2	18,456	4.93	0.58-0.82	2,376
3	24,859	6.38	0.72-1.03	3,036
4	24,419	5.75	0.67-0.94	2,489

Areas not included in the five zones will continue to have growth of wind power, so the estimations for installed capacity are probably on the low side. The CREZ designations have no implication for wind power potential for areas outside the five zones, for example those areas in the Panhandle that were not selected have equal or better wind potential. The zones were partially selected on the basis of transmission constraints for transporting power to the major load centers in ERCOT.

The Southwest Power Pool is the electric reliability council that covers the Panhandle, and there are only a couple of small AC to DC to AC interconnections to the ERCOT grid. Therefore existing transmission lines in the Panhandle are not large enough and the connections are not large enough to transmit substantial power to ERCOT. However SPP proposed two plans to interconnect 1,500 to 4,500 MW of new wind capacity and provide firm delivery to North Texas. By the end of 2008, Southwestern Public Service (part of Xcel Energy) will have approximately 850 MW of wind on their system. With that growth and requested interconnections for wind, the Southwest Power Pool has revised their estimate of the amount of wind power[10] and the need for high voltage transmission lines.

Most farmers and ranchers want wind farms on their land, as it is a long-term source of income. However there are residents who are opposed, the not in my backyard group. For example, in Jack County, about 10 percent were in favor, 10 percent were opposed, and the rest were neutral to the installation of the Barton Chapel wind farm. This means more emphasis is needed on public outreach on the cost/benefits of wind farms, and this needs to be done early in the project development.

There are ancillary costs for utilities as wind farms are connected to the utility grid: 1) spinning reserve, 2) system stability, and 3) penetration of wind farms. The cost and who pays for new transmission lines is a concern. As a general rule, up to 20% penetration of peak capacity does not present any major problems. However, in the Southwestern Public Service service area, their average load is around 3,600 MW, and now there are 622 MW of wind farms. In spring at night with a low load of 2,500 MW, they already can have 25 percent penetration on their system and in spring 2009, it will be 36 percent. However, unlike ERCOT, which has limited electrical connections with other transmission systems, SPP is part of a much larger transmission network.

On February 26, 2008, the ERCOT transmission system experienced a problem that required system operators to declare an emergency electric curtailment[11]. The curtailment followed a sudden drop in system frequency that occurred as the result of a mismatch between load and generation. The magnitude of this event caused ERCOT to implement the second stage of its Emergency Electric Curtailment Plan (EECP). Under EECP Stage 2, system operators activated a demand response program, in which large industrial and commercial users are paid to curtail their electricity use as needed for reliable grid operation. This measure added approximately 1,100 MW of resources within a 10-minute period and successfully restored system frequency in 3 minutes. Most of the interruptible loads were restored in 90 minutes and no other customers in the ERCOT region lost power due to the event. In explaining the causes of this event, ERCOT reported that its day-ahead forecast had led to a resource plan that indicated 1,000 MW of wind that ultimately was not available. According to ERCOT, discrepancies between forecast and actual load of this magnitude are not unusual. A new wind forecasting system, that will be included in the new nodal wholesale market, had predicted the actual wind generation situation very accurately.

The Electric Reliability Council of Texas (ERCOT) implemented the second stage of its emergency grid procedures Tuesday evening following a sudden drop in the system frequency. Preliminary reports indicate the frequency decline was caused by a combination of events including a drop in wind energy production at the same time the evening electricity load was increasing, accompanied by multiple power providers falling below their scheduled energy production. In addition, the drop in wind energy led to some system constraints in moving power from the generation in the north zone to load in the west zone, resulting in limitations of balancing energy availability. The wind production dropped from over 1700 megawatts (MW) three hours before the event, down to 300 MW at the point the emergency procedures were activated." (ERCOT press release, February 27, 2008, http://www.ercot.com/news/press_releases/2008/nr02-27-08)

Another view of the event is available from the American Wind Energy Association, www.awea.org/utility/pdf/ERCOT_Backgrounder.pdf. Over the 40-minute period preceding the start of load curtailment, wind generation declined by 80 MW relative to its schedule, non-wind generation decreased by 350 MW relative to its schedule, and load rapidly increased to a level that was 1,185 MW more than forecast.

ERCOT contracted with General Electric (GE) for an analysis of wind generation impact on ERCOT ancillary requirements. The objectives were to determine the level, type, and cost of additional ancillary services that might be required to maintain the reliability of the ERCOT System with increasing levels of wind generation. The Study was intended to inform both the current operation of the ERCOT System and the policy discussion associated with the Competitive Renewable Energy Zone (CREZ) process. The study used the 2006 load and weather patterns and used 5,000, 10,000 and 15,000 MW of wind power to drive the simulations. Some key conclusions of the study are:

- With 15,000 MW of installed wind capacity in ERCOT, the operational issues posed by wind generation will become a significant focus in ERCOT system operations. However, the impacts can be addressed by existing technology and operational attention, without requiring any radical alteration of operations.
- ERCOT's Regulation procurement methodology can be improved by including wind forecast information and wind capacity growth.
- Inclusion of wind forecasting in operations planning is critical.
- ERCOT's unit commitment may need to be altered to provide ancillary services.
- Variation of wind tends to be or out of phase with the daily load curve, but the errors in load and wind forecast are virtually independent. That means that it is improbable for the most severe load and wind forecast errors to occur in the same hour.
- Energy production from wind tends to be offset primarily by reduction in production from combined-cycle natural gas plants.
- The cost of the additional ancillary services will be small relative to the cost savings from the additional wind generation.

It was estimated that total system energy production costs decreased by approximately $54/MWh for each MWh of wind energy produced.

The GE Study addressed the impact of extreme weather events on wind generation output, noting that changes in wind output are almost always due to predictable weather phenomena. However, the study found that the frequency and severity of extreme short-term wind generation output changes increase at a faster rate with increasing wind generation capacity. GE estimated the maximum 30-minute drop in wind generation to be 2,836 MW for the 15,000 MW scenario, with a mean recurrence of once every three to five years, but noted that a 2,400 MW drop might occur once per year. The GE Study suggested that, although the timing and magnitude of extreme weather events may not be precisely predictable it is possible to predict periods of risk when weather conditions are likely to result in drastic changes in wind

For summer peak capacity, ERCOT counts 8.7 percent of wind nameplate capacity in accordance with ERCOT's stakeholder-adopted methodology, based on a study of the effective load serving capability of wind.

Small and Distributed Systems

The large-scale use of small wind systems depends primarily on economics. For wide spread use, life cycle costs will need to be comparable to costs from the utility. In some states there are credits and/or subsidies for purchase of small wind systems. Presently there is net energy billing for systems 50 kW and smaller in Texas, however this has not increase the use of small wind systems.

In Texas, so far there has not been any development of distributed, cooperative and/or community wind systems. A couple of school districts have installed 50 kW units and there is a 660 kW unit at the American Wind Power Center and Museum in Lubbock. A cottonseed oil plant in Lubbock installed ten 1 MW wind turbines and it is anticipated that all energy will be used on site.

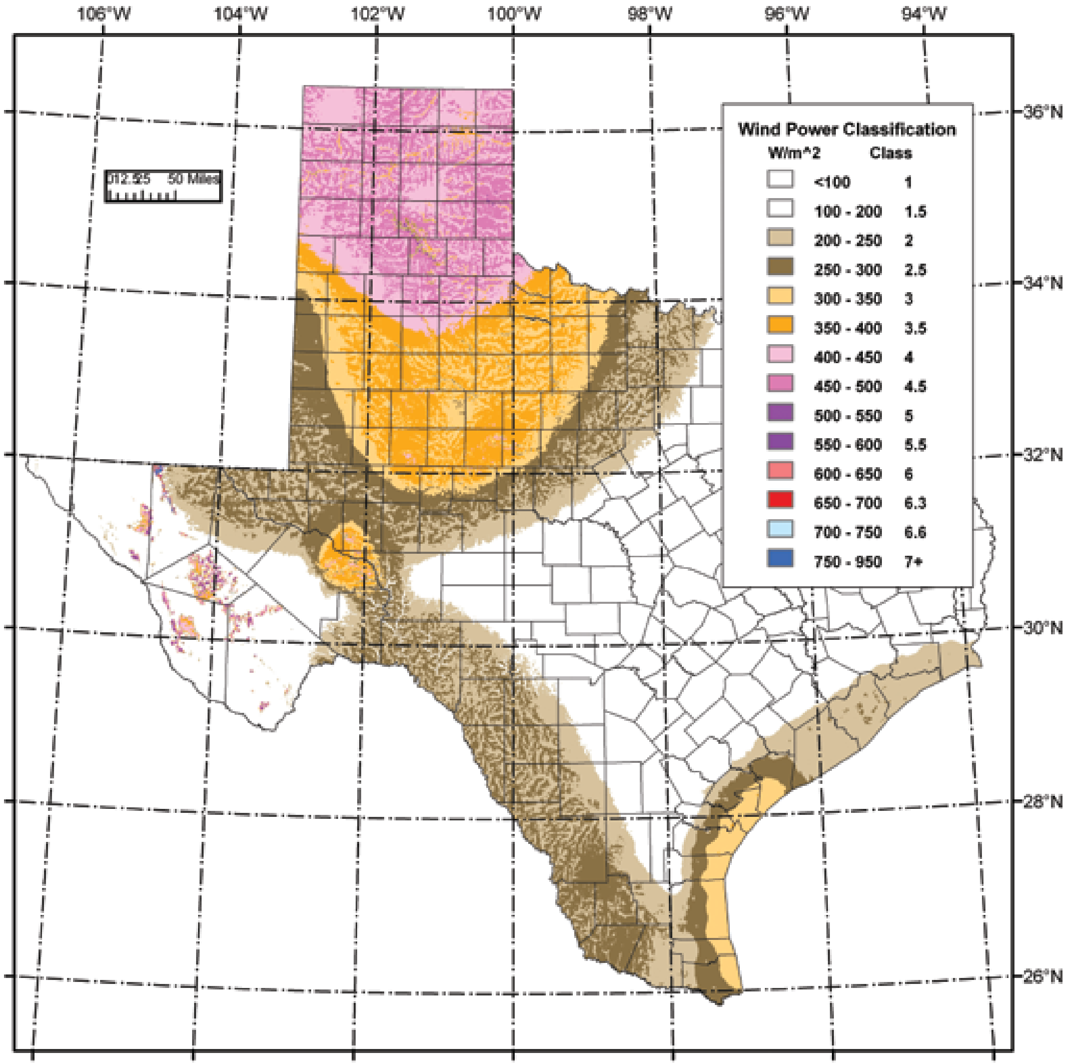
Resource

Texas has the best wind resource (**Exhibit 4-11**) in the United States with the amount of wind power at a height of 50 meters estimated to be 723,000 MW, and the capturable wind power estimated at 223,000 MW (**Exhibit 4-12**). This changes the rank of an earlier estimate, which had North Dakota number one with 138,400 MW and Texas with 136,100 MW. Offshore refers to the area from the coast out to a distance of 10 miles (16 km). The "capturable power" is based on Wind Class 3 and above and excludes the following land: 1) urban, 2) highways (does not include county roads), 3) parks, wetlands, wildlife refugees, rivers and lakes, and 4) slopes greater than 10 degrees. The estimated maximum capacity is based on 1 MW wind turbines, 60 meters in diameter (D), with a spacing of 7D within a row and 9D between rows, and a 30 percent capacity factor for Wind Class 3 land and a 35 percent capacity factor for Wind Class 4 and above land. In reality, the numbers would be even larger as the selected spacing is larger than that of actual wind farms. Of course the current numbers for estimated capacity are larger than the 1995 estimate, since the previous estimate was based on land within 10 miles of major transmission lines (69 kV and greater) and did not include the offshore area.

Another general way to estimate the installed wind power for Wind Class 3 and above is to use 15 MW per sq mile or 6 MW per sq km (for flat areas, 4D by 8D spacing) and 18 MW per linear mile or 11 MW per km for ridges, small mesas and hilltops (2 to 3D spacing). Using this method, the estimated installed capacity would be around 983,000 MW.

Because the wind resource is so large compared to the electrical generation capacity of the State (approximately 100,000 MW in 2008), a feasible goal for wind power for the State would be 25 percent penetration of peak load, which would be 25,000 MW by 2020. By end of 2008, Texas will already have an installed wind power capacity of over 8000 MW, which is 30 percent of that amount. The main short-term problems are transmission from windy areas to the load centers and the amount of penetration into the utility grid[12]. There are wind farms now being constructed in the upper Wind Class 2 areas, which are closer to major load centers.

Exhibit 4-11 Wind power map for Texas, Alternative Energy Institute, WTAMU.



Source: Alternative Energy Institute 2008

Exhibit 4-12 Land area suitable for wind power, estimated installed wind capacity and capturable wind capacity at 50 m height.

	Area, km2	%	Area, km2	%	Capacity	Capturable	Capacity
Class	No Exclusion	State	Exclusion	State	MW	MW	MW
3	91,000	13	80,000	12	355,000	106,000	483,000
4	80,000	12	74,000	11	324,000	114,000	441,000
5	700	0	100	0	400	140	600
6-7	200	0	100	0	400	140	600
3-5	Offshore		9,600		42,328	3,010	57,600
	Total		164,000	23	723,000	223,000	983,000

1 square mile = 2.5 square kilometers

Wind Characteristics

The main difference between wind and solar is that the power per area in the wind is proportional to the cube of the wind speed.

$$P/A = 0.5 \rho v^3 \qquad W/m^2$$

where ρ is the density of air. In general the air density decreases around 10% for each 1000 meter increase in elevation. The wind power potential will vary by year, season, month and day. In general the winds are high in the spring with the lowest months being July and August. More detail information on wind characteristics can be found in reports and books[13].

Measurement and Histograms

Data loggers at meteorological stations collect data from two to three levels of sensors (anemometers and wind vanes) on towers at least 40 to 60 meters in height. One reason towers higher than 62 meters are more expensive is the requirement of lights by the FAA. Temperature and pressure data are also needed, although an average pressure can be derived from elevation or weather station data. Sensors are sampled every second and then averaged for 10 minutes (or in the past, 1 hour). Data are generally sent to a base station, weekly by cell phone, or data cards are exchanged monthly. Data are then checked for quality assurance, with a goal of 95 percent or greater data recovery. Information on data collection and analysis is available[14, 15]. Wind speeds and wind direction are placed in histograms for the month and wind speeds and power are calculated for an average day for the month. Wind shear is then calculated from the average day wind speeds. Finally annual average values are calculated. That general data is valuable for potential wind farm developers and for landowners. Meteorological station costs are around $28,000 for the first year and then $6,000 per year (**Exhibit 4-5**).

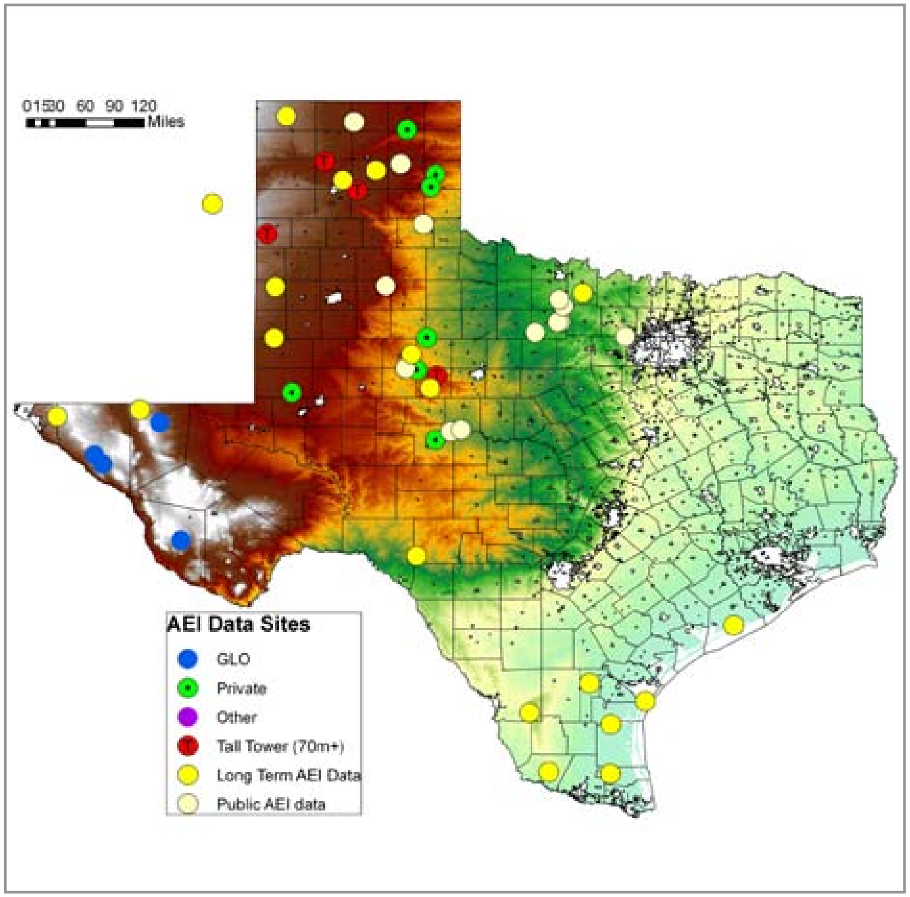
Exhibit 4-13 Estimated costs ($ 2008) for met station, 60 m pole tower, 3 levels of sensors, and call-in datalogger.

Tower, datalogger, sensors	$19,500
Installation	5,000
Yearly	6,000
O&M	2,000
Equipment replacement (10%/yr)	1,000
Data collection & analysis	3,000

Texas Winds

The wind power map was modified with data from the Alternative Energy Institute (AEI) meteorological sites with 40 meter and higher towers (**Exhibit 4-14**), again using terrain enhancement[16] to revise the Wind Classes. The wind power map for 50 meter height (see **Exhibit 4-14**) is available online with a zoom feature with a resolution of one square km[17]. As an example, a regional map shows the mesas (**Exhibit 4-15**) and now there are wind farms on many of the mesas, especially in the Pecos area, (see **Exhibit 4-3**).

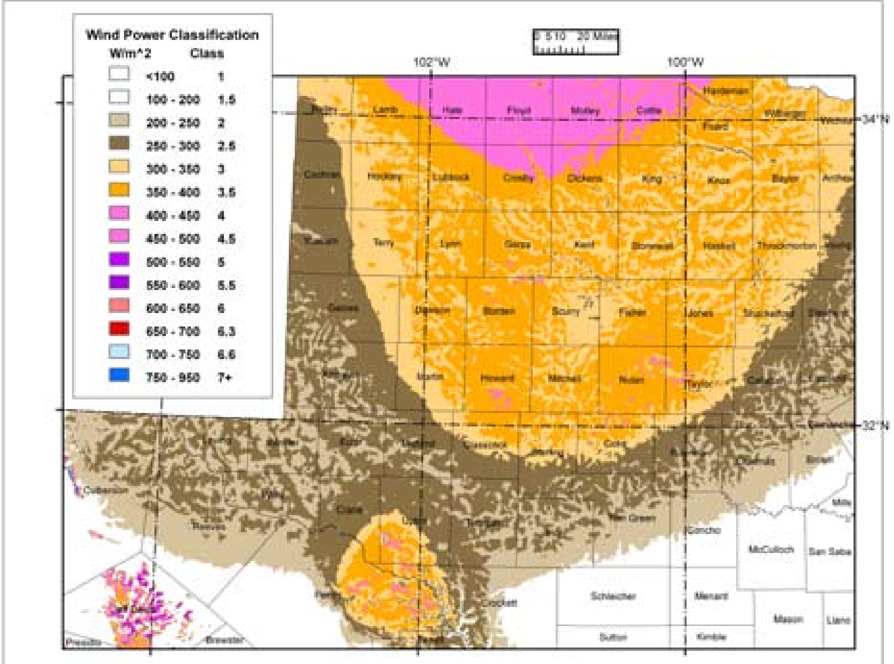
Exhibit 4-14 Location of met sites with towers 40 m and higher, Alternative Energy Institute, WTAMU.



Ocean winds from satellite data (radar reflection from waves) show that the Gulf of Mexico has Class 3 winds[18]. However the satellite data are not useful within 25 miles of the shore due to reflection from the ocean floor. A meso scale model for the Gulf Coast of Texas indicates Class 3 to 5 winds at a height of 50 meters (**Exhibit 4-16**)[19]. Two wind farms (487 MW total) next to the coast are under construction (2008) south of Corpus Christi in Kenedy County.

Winds are high in the spring with July and August being the low months. Notice that the yearly variations are essentially the same over the State (**Exhibit 4-17**). The annual wind speeds by hour (**Exhibit 4-18**) for five regions of Texas, High Plains, Mid Plains, Coastal, Rio Grande Valley, and Trans Pecos.

Exhibit 4-15 Wind power map of the West Central Texas, showing mesas with a higher wind class.



Source: Alternative Energy Institute 2008

EXHIBIT 4-16 Texas offshore wind power potential, W/m2, at 50 m height.

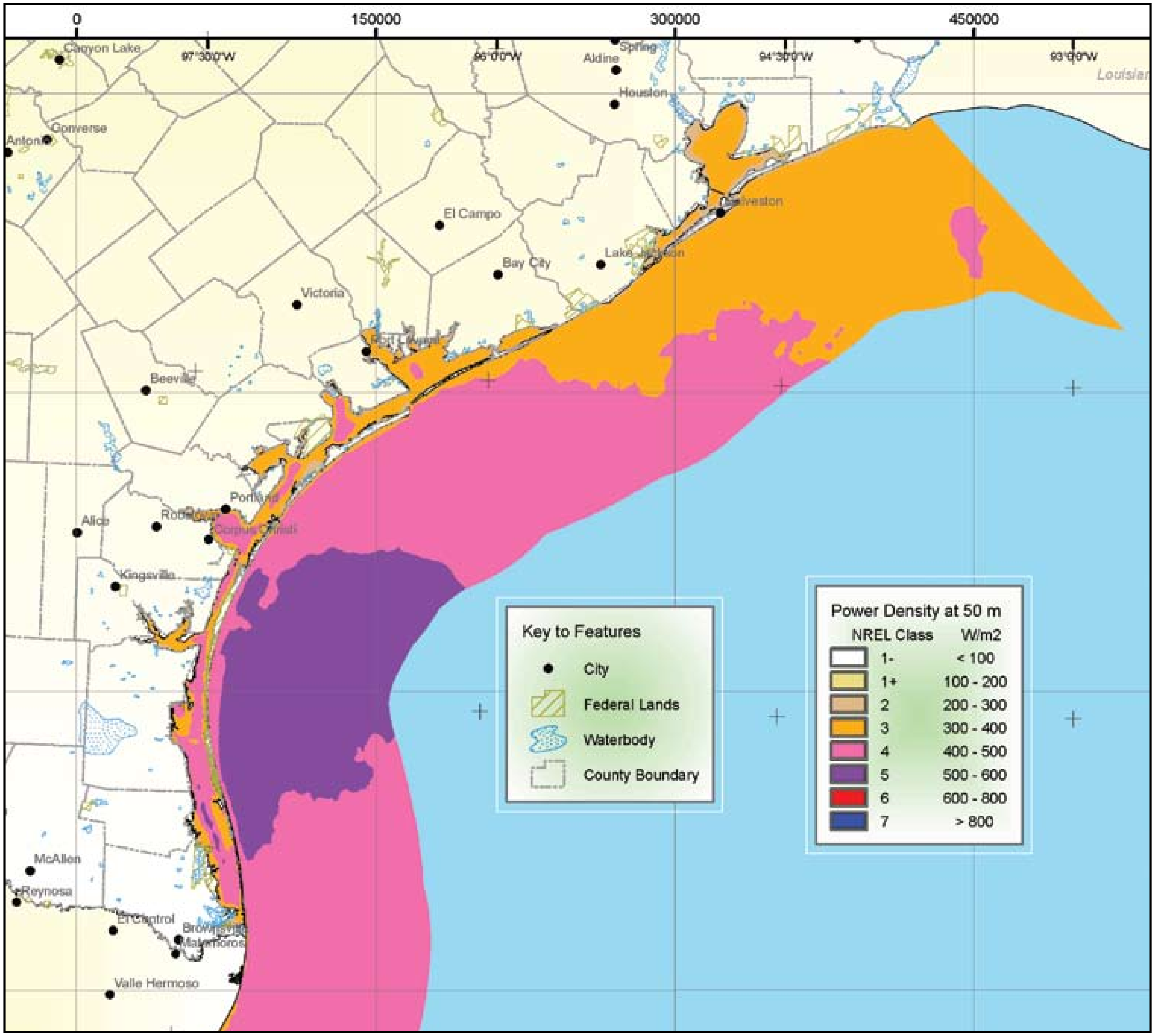


Exhibit 4-17 Yearly wind power potential at 50 m height for three sites.

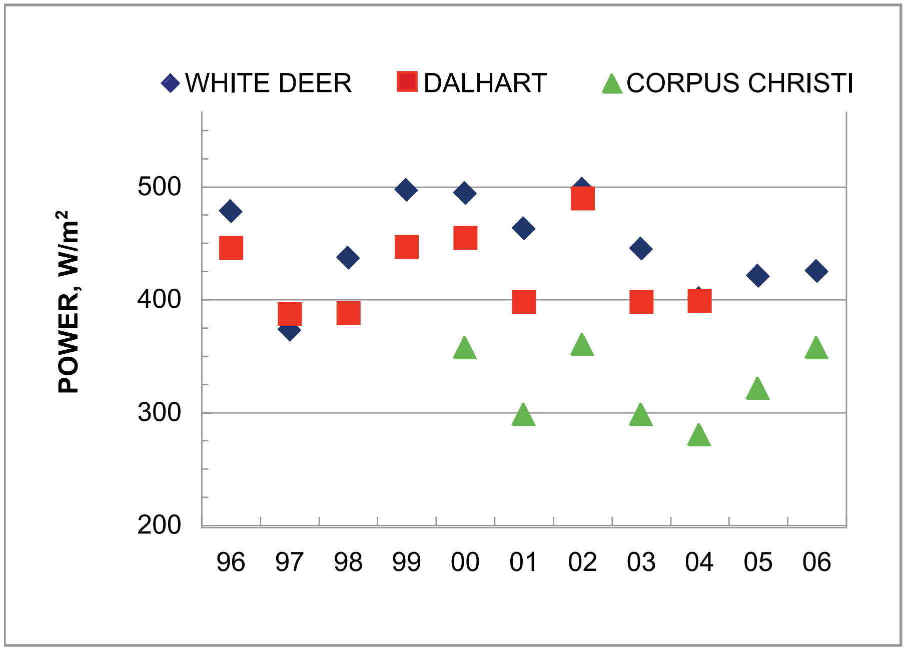
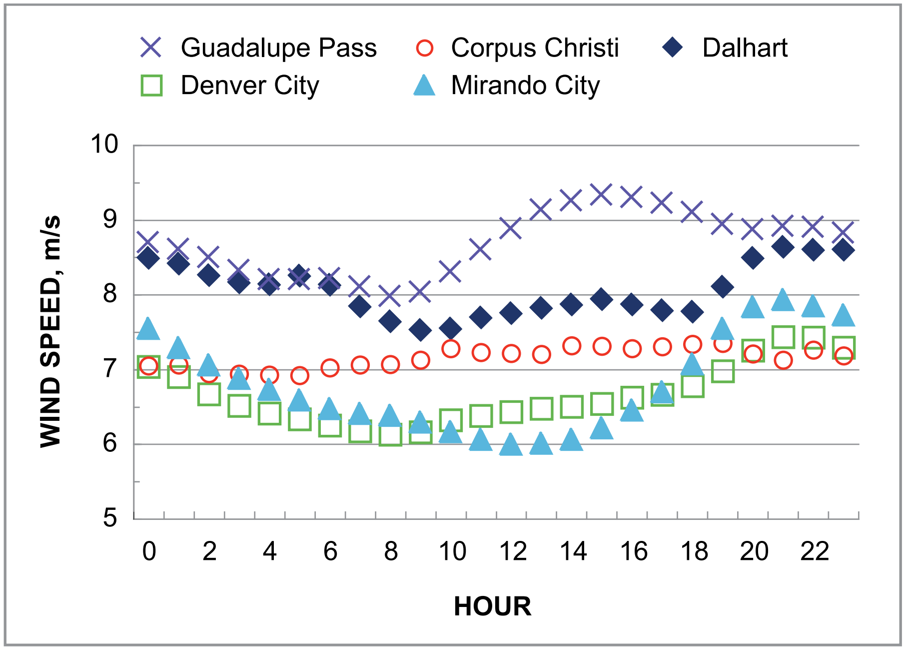


Exhibit 4-18 Yearly average wind speed by hour at 50 m, for representative sites in different regions.



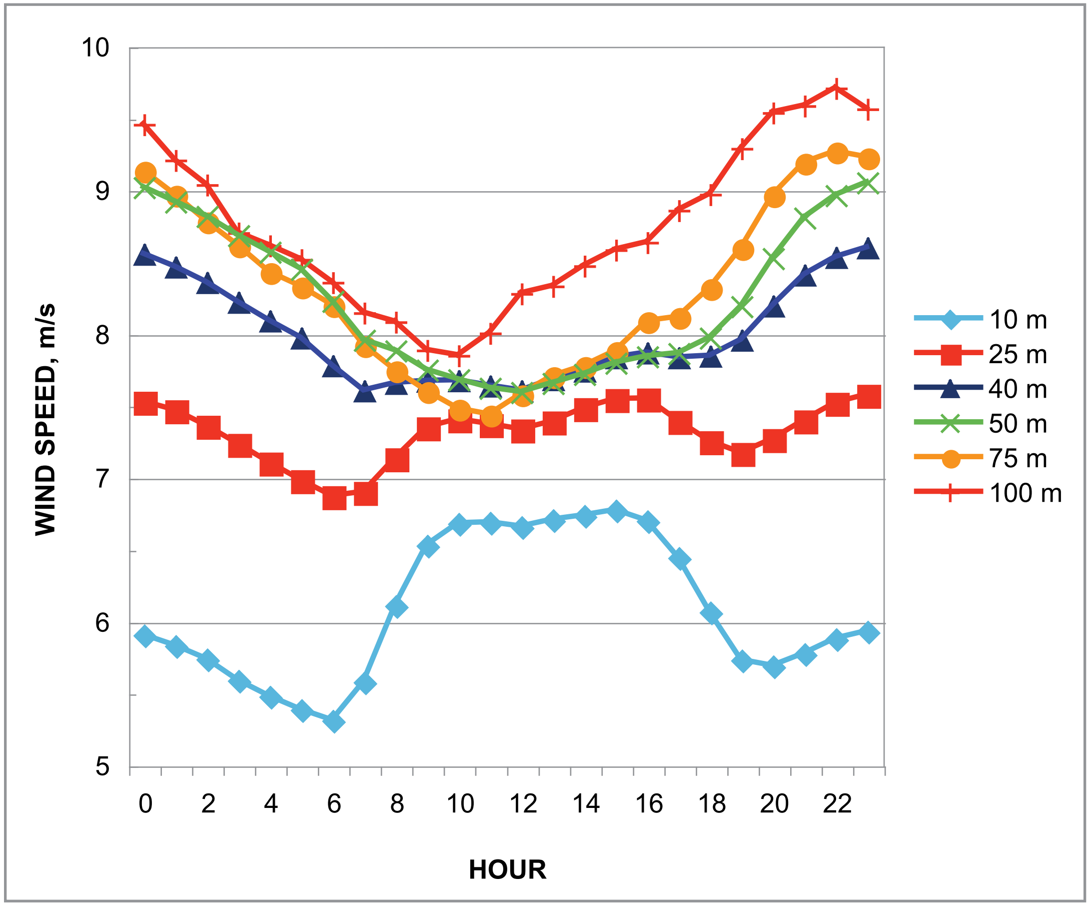
There is a change in the pattern of the daily winds at around 40 m, which continues to higher elevations for most of the State. Wind speed data for White Deer and Tall Tower North at Washburn show this pattern (**Exhibit 4-19**). White Deer and Tall Tower North meteorological towers are 25 miles apart. However data taken at 40 meters and 50 or 60 meters can be used to predict wind speeds and power at higher heights at the same location.

The probability of extreme wind events[20] is of interest to wind farm developers. Tornadoes, hurricanes, thunderstorms and high winds (straight high winds and microbursts) can affect wind farms in two ways: (1) wind turbines do not produce power because winds are greater than the "cut-out" wind speed (most are 25 m/s, 60 mph); and (2) damage to wind turbines because gusts are above the survival wind speed (55 to 65 m/s, 120-145 mph). Tornadoes have the highest winds, however typical widths are around 50 m (150 ft) and typical lengths are 2 to 3 km (1 to 2 miles). Tropical storms and Category 1 and 2 hurricanes may be beneficial for wind farms as they increase wind speeds over fairly large areas, however Category 3-5 hurricanes have damaging wind speeds for wind farms located offshore and near the coast. Typical widths of hurricane eyes are 30 to 65 km (20 to 40 miles) and Category 3 to 5 hurricanes (Saffir-Simpson intensity scale) have wind speeds greater than 50 m/s (110 mph) over that width of 100 to 200 km (60 to 120 miles).

Data Sources

The longest-term source of wind data is the National Weather Service, hourly data, which is available in digital format. However that data at a height of 10 m is only useful as a broad indication of yearly winds (good, average, poor). Wind power maps are now derived from data collected at heights of 40 to 60 meters, and in some cases even to 100 meters.

Exhibit 4-19 Annual, average wind speed by hour for White Deer (10 to 50 m height) and Tall Tower North (75-100 m height); 3 to 6 years of data.



Wind power maps for others states[21] used a meso scale model, which includes effect of the terrain and with validation from ground data available. In any case, before a wind farm is installed, meteorological data is typically collected on site for one to three years. This is proprietary data and is not available to the public.

The Alternative Energy Institute (AEI) collected data at a number of sites across Texas and one site in New Mexico (see **Exhibit 4-14**), starting in 1995, with funding from the National Renewable Energy Laboratory (NREL), the Texas State Energy Conservation Office (SECO) and AEI. Most of the sites were dismantled after 2000. Report and data from these sites are available online[22]. The first two years of data from two tall tower sites (50 to 100 meters), near Amarillo and Sweetwater, are public and available from AEI.

AEI added other sites by using surplus met equipment for an anemometer loan program to individuals or counties. However AEI still served as the base station for data storage and analysis. The anemometer loan program was expanded with support from SECO, as more stand-alone dataloggers and sensors were purchased. For the anemometer loan program, the landowner furnishes the tower and monthly average values are available to AEI. In general, the data are public and available from AEI after two years. Two cases in the anemometer loan program are known where wind farms are now installed.

Other

Since wind farms have been installed and are under construction in Wind Class 2 areas, data need to be collected or proprietary data need to be obtained to verify the extent of Wind Class 2 areas and in order to update the Texas wind map. One possibility for accomplishing this is to use the annual kWh energy output reported to the ERCOT from individual wind farms and then use the characteristics of the turbines to make a backward estimation of the wind resource. Capacity factors by year for several years can also be calculated for wind farms, and would provide an indication of reliability. Data on wind energy and wind farms in Texas should be placed online, similar to the wind information that is available for California[23].

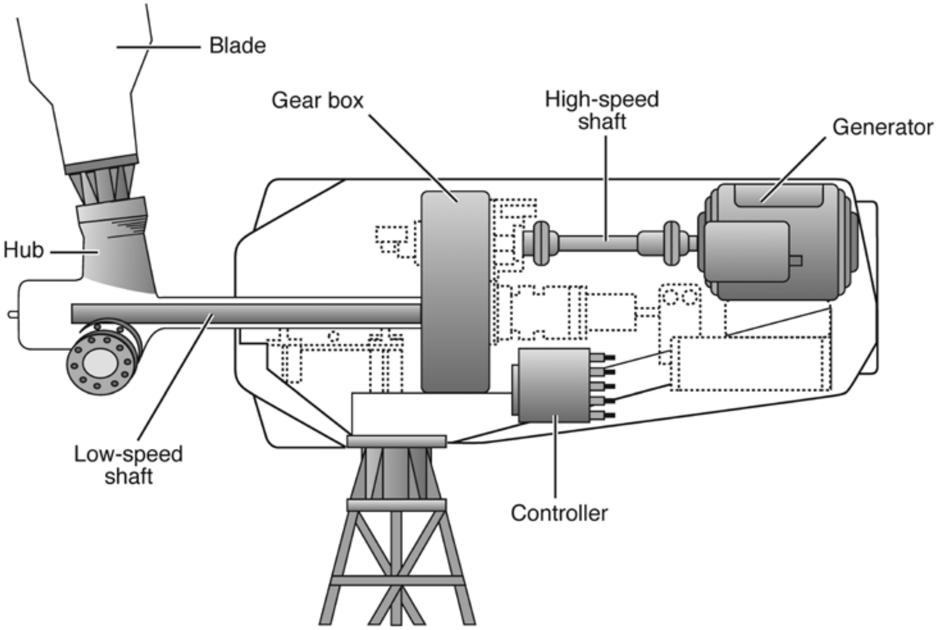
Technology

The general types of wind turbines are: (1) drag and (2) lift devices. Drag devices are where the blades or sail move parallel to the wind and they can never move faster than the wind. There are no commercial drag devices for generating electricity. Lift devices use blades, like propellers and airplane wings, which are perpendicular to the wind and can move faster than the wind. For wind turbines the speed of the tip of the blade divided by the wind speed (tip speed ratio) can be 5 to 8. Lift devices are also classified according to orientation of the rotor axis: (1) horizontal axis wind turbine (HAWT) and (2) vertical axis wind turbine (VAWT). Further the HAWT can be upwind and downwind, which is the relation of rotor and tower to the wind. A power curve is the power output of the wind turbine by wind speed. At this time there are no large commercial VAWTS.

Large Systems

Most of the large wind turbines are HAWT, upwind, 3 blades with full span pitch control, a gearbox to increase rpm, and an induction generator (**Exhibit 4-20**) with a variable speed range of around 40%. Enercon has large wind turbines with no gearbox, which requires a large generator. Permanent magnet generators in megawatt size are available. Power electronics, which convert variable frequency to constant frequency, allow wind turbines to operate at variable frequency for improved efficiency and reduction of power spikes as these can be absorbed by rotor inertia.

Exhibit 4-20 Electric generating wind turbine. The major components of this device are the blades, shaft, gearbox and generator. On large machines, additional controllers and drive motors ensure that the machine is positioned for optimal capture of the wind.



Source: http://www.infinitepower.org/newfact/96-817-No17.pdf

Exhibit 4-21 Annual capacity factor for wind farms with Mitsubishi (1 MW) wind turbines, White Deer D = 56 m D, Fluvana, 60 turbines D = 56 m, 100 turbines D = 61.4 m D, San Jon and Elida, D = 61.4 m. Capacity factors provided by Brian Vick, ARS, USDA, Bushland, TX.

	Annual Capacity Factor (%)					
Year	2002	2003	2004	2005	2006	2007
White Deer	39.5	38.4	37.4	35.1	36.2	33.8
Fluvanna			33.3	32.8	36.7	33.5
San Jon, NM				38.1	45.6	42.5
Elida, NM					38.9	36.8

"Capacity factor" is the average power divided by the rated power. Average power is generally calculated from the annual energy production, although monthly and seasonal capacity factors have been calculated. Wind turbines are now available with the same size generator but different diameter rotors for installation in different wind regimes. In Wind Class 3, capacity factors are 30 to 35 percent and in Wind Class 4 and above, capacity factors are 35 to 45 percent. A very general rule for capacity factor is to take the wind power potential at 50 m height and divide that number by 11. Capacity factors for wind farms are calculated from the annual energy production and number of turbines in the wind farm (**Exhibit 4-21**). If there are different types of turbines, or turbines with the same generators but different rotor diameters, than the individual contributions need to be estimated if individual data are not available.

"Availability" is the amount of time that a wind turbine is available for operation, regardless of whether the wind is blowing. For third generation wind turbines, availabilities of 98 percent are common.

Annual energy production can be estimated from (1) generator size, (2) rotor area and wind map value, (3) average wind speed and calculated energy using Rayleigh distribution and (4) manufacturer's power curve, and calculated energy production using wind speed histogram and power curve[24]. The last method is the one used for securing financing by wind farm developers with on site data referenced to the hub height of the selected wind turbine. The generator size method is the simplest.

Annual kWh = capacity factor*generator size (kW)* 8760 (hr).

For example, a 1 MW (1,000 kW) wind turbine should produce around 2,800,000 kWh in a mid Wind Class 3 area. Annual KWH = 0.32* (capacity factor) × 1,000 (kW) × 8760 (hours per year) = 2,803,200 kWh.

There have been economies of scale as turbines have increased in size, with the largest commercial unit now available being 6 MW, 126 meters in diameter. Ten megawatt units are in the design stage and the optimum size has not been determined as this depends on economics, as well as the difficulties in transportation and installation of these size units.

Small Systems

Small wind turbines with fixed pitch, stall control and permanent magnet alternators are available. Even though there are around 600,000 small wind turbines in the world, primarily 100 to 300 Watts, the costs per rated power are much higher than the large turbines installed in wind farms.

Innovative Systems

A number of innovative systems have been proposed [24]. None of these have gone beyond the conception, design or prototype stage.

Infrastructure Needs

The primary infrastructure requirement for wind power is electricity transmission from the windy areas to the load centers. Of course if cheap storage becomes available, no new power plants would be needed for fossil, nuclear, or renewable energy. Energy would be stored at night when demand is low and then used during the day when demand is high. Possible storage systems are large-scale batteries, compressed air, chemical, primarily hydrogen, superconducting magnets, and flywheels. If plug-in electric cars become wide spread, that makes wind power a better load match due to higher nighttime winds.

Economics

The levelized cost of energy for the 20 to 25 year life of a wind turbine is estimated from Electric Power Research Institute-Tag-Supply method. The big difference for renewable energy systems, there is no fuel cost in the formula.

$$\mathrm{COE} = \frac{(\mathrm{IC} * \mathrm{FOR}) + \mathrm{AOM} + \mathrm{LRC}}{\mathrm{AEP}}$$

where IC = initial installed cost, \$

FCR = fixed charged rate (cost of borrowing money)

AOM = annual operation & maintenance, \$/yr

LRC = levelized replacement costs, \$/yr

AEP = annual net energy production, kWh/yr

As an example, a 1 MW wind turbine, which produces 3,000,000 kWh per year. Installed costs are \$1,500,000, FCR = 10%, and AOM = \$0.01/kWh = \$30,000/yr, LRC = 10% of IC = \$15,000/yr. The installed cost is representative of wind farms installed in 2006 and 2007 and the fixed charge rate was chosen at 10%, which could be higher or lower depending on the present rate of borrowing money.

$$\mathrm{COE} = \frac{1{,}500{,}000 * 0.1 + 30{,}000 + 15{,}000}{3{,}000{,}000} = \frac{195{,}000}{3{,}000{,}000} = \$0.7/\mathrm{kWh}$$

The main drivers of the COE are the installed cost and the annual net energy production. The net energy production is primarily due to the Wind Class. Because of economies of scale the numbers are for 30 MW or greater wind farms. The COE for the John Deere wind farms (10 MW each, however 2 or more in same general area) will be a little less because they do not have a substation for connection to the grid.

Installed costs have increased from around \$1 million per MW in 2003 to \$1.8 to \$2 million in 2008, due to increase in the prices of steel, copper, and cement. An installed cost of \$2 million per megawatt in the above example would increase the COE by 1.3¢ per kWh. The price is also higher because of the demand for wind turbines is greater than the current production capacity. The installed cost for offshore wind farms is around 1.5 times larger.

The important number for a wind project is the sale price of electricity (power purchase agreement). For some older contracts for wind farms in Texas, the sale price of electricity was around \$0.025/kWh for a 20 year contract. The only way this could be achieved was with production tax credits, accelerated depreciation, tax abatements, and Renewable Energy Credits (RECs). In 2007, RECS were around \$0.005/kWh. For wind farms being installed today, the production tax credit is still the main driver of economic viability.

Today wind farms are receiving power purchase agreements in the range of \$0.03 to \$0.04 per kWh and some wind farms are selling electricity in the wholesale or merchant market, where the rate can range from \$0.03 to \$0.065 per kWh. However the ancillary costs for the utility are \$0.005 to 0.008/kWh. The Montana Public Service Commission set a rate up to \$0.00565/kWh for integrated wind power into the Northwestern Energy utility from a wind farm.

The cost of energy for small systems is higher, with some economies of scale (**Exhibit 4-22**). In general the AOM is around \$0.005/kWh.

EXHIBIT 4-22 Range of cost of energy for small systems, wind class 2-4 (capacity factors 25-35%).

System, kW	$/kWh
1	0.20-0.30
10	0.18-0.23
50	0.12-0.18

Benefits

Wind farms can provide rural economic development with the primary benefit being long-term stable income to the landowner. Representative economic values are for a 100 MW wind farm using capacity factors of 30% in Wind Class 3 and 35% in Wind Class 4. A 100 MW wind farm would require 6,000 acres, which can include 10 to 30 landowners (**Exhibit 4-23**). Around 1 to 3 percent of the land is removed from production, primarily for roads. The return on land removed from previous use is around \$4,000 per acre per year, a much greater return per acre than farming or ranching. During 2008, the 4,500 MW of wind power already installed in Texas will generate around \$18,000,000 for landowners.

Exhibit 4-23 Representative lease for wind farm.

Resource	0.5 to 3 yr
Flat fee	$10,000
acre/yr	$1-4
Contract	30 yr
option	2 (10 yr)
Construction, road, etc	$15 to 20/rod
or flat fee	$4,000/MW
Income	
royalty and/or	4%
per turbine (minimum)	$4,000/MW
Escalation	0.5% every 5 yr

A number of seminars for landowners have been presented across the State, and more information is available online [www.windenergy.org]. Some landowners have begun forming associations for dealing with wind farm developers. Wind turbines can be installed on land currently under the Conservation Reserve Program (CRP), however there may be a penalty or reimbursement, which is decided by the CRP district.

The benefit of rural economic development also includes construction and then operation. During construction there will be 100 to 200 jobs for 4 to 8 months for a 100 MW wind farm, around 1 man-year per MW. In 2008, the estimated installation of 4,000 MW in Texas will generate around an estimated $16 million payroll. The administration and operation and maintenance of wind farms proved 10 to 14 full time jobs per 100 MW. Installation of 20,000 MW of wind power by 2015, would lead to 2,000 or more full time jobs in rural areas. The economic impact of wind (2,500 MW) for just Nolan County[25] is estimated at $315 million for 2008 and $396 million for 2009. Cumulative school property taxes 2002 through 2007 were $22,670,680. Landowner royalties on 2,500 MW is estimated at $12,264,000 (annual) and is projected to increase to over $17 million by end of 2009.

Wind power also provides important environmental benefits. Wind generated electricity does not require water and does not emit gases such as CO^2, NOX, SOX and particulates. In Texas, fossil fuel power plants use 440 gallons of water per MWh of generation[26], which for 2003 amounted to 100 billion gallons. In 2008, the 4,500 MW of wind generation already installed in Texas will save 5 billion gallons of water per year. The anticipated installation of 20,000 MW of wind power by 2015 would save an estimated 20 billion gallons of water per year.

Coal and natural gas power plants emit an average of 700 kilograms (over 1,500 pounds) of CO^2 per MWh. In 2008, the 4,500 MW in Texas will reduce CO^2 emissions by 9 million metric tons per year. If 20,000 MW are installed by 2015, then the reduction in CO^2 emissions is estimated at 40 million metric tons per year. The present value for CO^2 trading in Europe is $30 per metric ton, which is equivalent to $20 per MWh.

When CO^2 trading becomes a national policy in the United States, the projected 20,000 MW of wind to be installed by 2015 will produce an additional value of approximately $1 billion per year. This could be used to offset the loss of the production tax credit after the initial 10 years and reduce the need for the PTC in the future.

Subsidies

The primary government subsidy for construction of wind farms is the federal production tax credit, which was set in 1992 at $0.015/kWh for 10 years with an inflation factor for installation in later years. The PTC has been extended a number of times and is now valid through 2009 at $0.02/kWh. Wind farm developers, like every other business want subsidies. The most common in Texas is tax abatement from 5 to 7 years. If a tax abatement is secured, the wind farm generally makes payment in lieu of taxes for education.

There is net metering (see Solar Chapter) in Texas for renewable energy systems up to 50 kW. If the renewable energy system produces more energy than is needed on site, the utility meter runs backward, and if the load on site is greater the meter runs forward. The bill is determined at the end of the time period, which is generally one month. If the renewable energy system produced more energy over the billing period than was used on site, the utility company pays the avoided cost. Most of the states have net metering which ranges from 10 to 1000 kW, with most in the 10 to 100 kW range. However net metering in Texas did not increase the implementation of small wind systems.

Key issues

The following are key issues, more or less in order of priority.

1. Utility transmission capacity, especially from Panhandle to ERCOT.

2. Subsidies – production tax credit, property tax exemption. If the PTC is not extended, the installation of wind farms will decrease significantly after 2009.

3. Penetration of wind power on the transmission grid in excess of 20% of peak load and associated utility ancillary costs. In Denmark in 2007, wind power provided 20 percent of their electricity, and during high winds penetration was way above 20%.

4. Forecasting winds 6 to 36 hours in advance.

5. Future income from emissions trading, including carbon dioxide.

6. Should electric cooperatives be required to accept wind farms, community wind turbines, and/or distributive wind turbines on their lines? In general, community and distributive wind turbines are one to ten wind turbines, ranging in size from 50 kW to a megawatt. Examples: The Shallowater Independent School District has five 50 kW wind turbines. The city of Lamar, Colorado has four 1.5 MW wind turbines.

Other issues that will affect the installation of wind systems are:

1. Siting and permitting which will become more of a challenge especially for areas like the hill country and offshore.

2. The treatment of various subsidies for small wind systems (up to 100 kW), and whether these are the same for all small renewable systems. There is a new Federal investment tax credit for small wind turbines for home, farm or business use installed from October 3, 2008 through December 31, 2016. Credit is for 30% of total installed cost (maximum of 100 kW capacity), maximum of $4,000. For homes, credit is limited to lesser of $4,000 or $1,000 per kW of capacity.

3. Whether renewable Energy Credits will be the same for all renewable systems.

4. The availability of net energy billing for small renewable energy systems without additional cost to the producer. Should net energy billing be for longer periods, up to a year?

5. Availability of wind turbines for wind farm construction through 2011.

Information Sources

There are numerous books, articles, and online information from general to technical on wind energy and wind turbines.

Alternative Energy Institute, West Texas A&M University, www.windenergy.org

Also at AEI, Texas Wind Power Map, plus data at 40 to 100 meters at different sites across Texas.

USDA, ARS, Conservation and Production Laboratory, www.cprl.ars.usda.gov

Texas State Energy Conservation Office, www.seco.cpa.state.tx.us/re_wind.htm

Texas General Land Office, www.glo.state.tx.us/energy/sustain/index.html

Texas Tech University, www.wind.ttu.edu

Texas National Large Wind Turbine Research and Test Center, www.egr.uh.edu/wind

Texas State Technical College West Texas, www.windenergyeducation.com

National Wind Technology Laboratory, NREL, www.nrel.gov/wind

Energy Efficiency and Renewable Energy, DOE, www1.eere.energy.gov/windandhydro

Also site of Wind Powering America

Electric Reliability Council of Texas, www.ercot.com

System Planning Division, Monthly Status Report, information on generation interconnection requests

Southwest Power Pool (SPP), www.spp.org

SPP Wind Integration, www.spp.org/publications/SPP_Wind_Integration_QA.pdf

SPP Generation Interconnection, https://studies.spp.org/GenInterHomePage.cfm

American Wind Energy Association, www.awea.org

American Wind Power Center and Museum, www.windmill.org

Global Wind Energy Council, www.gwec.net

Danish Wind Industry Association, guided tour, www.windpower.org/en/tour.htm

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