

## Renewable Energy Fact Sheet: Wind Turbines

### DESCRIPTION

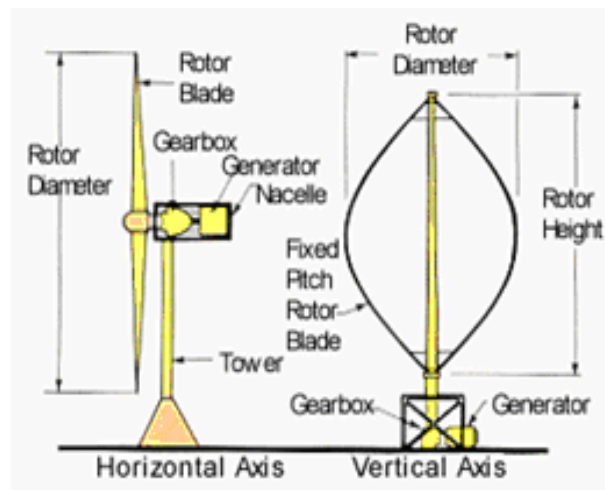
Wind turbines can be used as Auxiliary and Supplemental Power Sources (ASPSs) for wastewater treatment plants (WWTPs). A wind turbine is a machine, or windmill, that converts the energy in wind into mechanical energy. A wind generator then converts the mechanical energy to electricity<sup>1</sup>. The generator is equipped with fan blades and placed at the top of a tall tower. The tower is tall so that high wind velocities can be easily harnessed without being affected by turbulence caused by obstacles on the ground, such as trees, hills, and buildings. Individual wind turbines are typically grouped together to give rise to a wind farm (*Figure 1*). A single wind turbine can range in size from a few kilowatts (kW) for residential applications to more than 5 Megawatts (MW)<sup>2</sup>. Many wind farms are producing energy on a megawatt (MW) scale, ranging from a few MW to tens of MW.



**Figure 1: Wind turbine farms.**

There are primarily two types of wind turbines which are based on the axis about which the turbine rotates<sup>3</sup>. The more commonly used horizontal axis wind turbine (HAWT), which rotates around a horizontal axis, and the vertical-axis turbine (VAWT), which is less frequently used (*Figure 2* the two types of rotation).

HAWTs typically have three blades and are operated with the blades facing the wind (upwind). The wind rotates the blades which in turn spin a shaft attached to a generator. A gear box connects the low-speed turbine shaft to the high-speed generator shaft. These gears increase the rotational speeds from about 30 to 60 rotations per minute (rpm) in the turbine shaft to about 1,200 to 1,500 rpm (the rotational speed required by most generators) in the generator shaft. The rotational energy produced by the shaft spins copper coils within a magnet housed in the generator. This magnet excites the electrons in the wire, producing electricity. The quantity of electricity depends on how fast the shaft can spin in the magnetic field, the strength of the magnetic field, and the quantity and arrangement of the copper coils.



**Figure 2: Two Wind Turbine Configurations.**

To produce electricity at relatively low costs, the shaft must rotate at high speeds. HAWTs also include a computer operated yaw drive that turns the rotor so that the turbines are always facing the wind as wind direction changes.

Vertical axis wind turbines (VAWTs) are not widely used because they produce pulsating torque during each revolution and provide a level of difficulty when being mounted vertically on the tower (*Figure 2*).

Commercially available wind turbines range between 5 kW for small residential turbines and 5 MW for large scale utilities. Wind turbines are 20% to 40% efficient at converting wind into energy. The typical life span of a wind turbine is 20 years, with routine maintenance required every six months. Wind turbine power output is variable due to the fluctuation in wind speed; however, when coupled with an energy storage device, wind power can provide a steady power output.

Wind turbines, called variable-speed turbines, can be equipped with control features that regulate the power at high wind velocities. These variable-speed turbines can optimize power output without exceeding the turbine's performance limits. Common variable-speed wind turbines include pitch-controlled, stall-controlled, and active stall-controlled. An electronic controller checks the power output several times per second. When power output becomes too high, pitch-controlled turbines turn the rotor blades slightly out of the wind's path protecting the system from excessive stress. The blades are then turned back into the wind whenever the wind speed drops<sup>4</sup>.

During times of high wind speeds, stall-controlled turbines create turbulence on the side of the rotor blade which is not facing the wind. This stall prevents the lifting force of the rotor blade from acting on the rotor. About two thirds of the wind turbines currently being installed in the world today are stall-controlled turbine<sup>5</sup>. The active stall-controlled turbines, which is more common among larger wind turbines (1 MW and up), will increase the angle of attack of the rotor blades causing the blades go into a deeper stall (killing the lift force of the blade), thus wasting the excess energy in the wind<sup>6</sup>. Other power control methods include ailerons (flaps) to control the power of the rotor and to yaw (swing) the rotor partly out of the wind to decrease power. Yaw control is used only for tiny wind turbines (1 kW or less)<sup>7,8</sup>. These

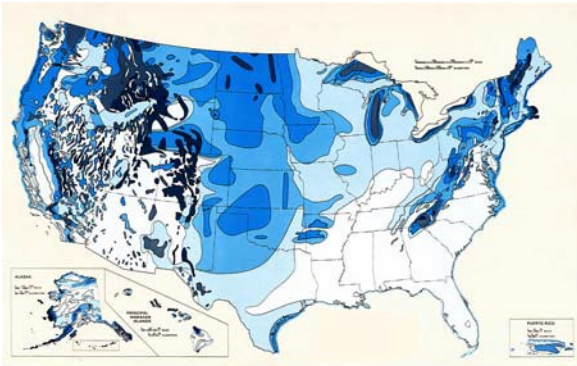
control mechanisms allow the turbine to operate with the greatest aerodynamic efficiency, and reduces excessive loads on the drive train, providing reduced maintenance and longer turbine life.

## **ADVANTAGES AND DISADVANTAGES**

There are several advantages associated with the use of wind power to generate electricity. Depending on the size of the wind farm, energy production can be inexpensive when compared to conventional power production methods. The cost to generate the electricity decreases as the size of the farms increase. Wind turbine power is an infinitely sustainable form of energy that does not require any fuel for operation and generates no harmful air or water pollution—produces no green house gases and toxic or radioactive waste. In addition, the land below each turbine can still be used for animal grazing or farming.

Disadvantages of using wind turbines include the need for more land space to support a wind farm and the difficulty in having a location with enough wind to produce maximum efficiency and power (*Figure 3*). The placement of turbines in areas of high population density can also result in aesthetic problems. Other drawbacks include death of birds and bats due to collision with spinning turbine blades and turbine obstruction in their flight paths<sup>9,10</sup>. Studies are being conducted to improve turbine design so as to reduce wildlife contact and mortality rates. In cold climates, ice and rime formation on turbine blades can result in turbine failure<sup>12</sup>

A heating system or a special coating of the blade's surface can reduce the risk of failure. However, the potential for ice to be thrown great distances during windy conditions is a potential health hazard. A recommended safety zone area should be factored into the design specification to reduce public access, potential risks, and sound.



Wind Power Class	10 m (33 ft) <sup>a</sup>		50 m (164ft) <sup>a</sup>	
	Wind Power W/m <sup>2</sup>	Speed <sup>b</sup> m/s mph	Wind Power W/m <sup>2</sup>	Speed <sup>b</sup> m/s mph
1	0	0 0	0	0 0
2	100	4.4 9.8	200	5.6 12.5
3	150	5.1 11.5	300	6.4 14.3
4	200	5.6 12.5	400	7.0 15.7
5	250	6.0 13.4	500	7.5 16.8
6	300	6.4 14.3	600	8.0 17.9
7	400	7.0 15.7	800	8.8 19.7
	1000	9.4 21.1	2000	11.9 24.4

Ridge Crest Estimates (Local relief >1000 ft).

<sup>a</sup> Vertical extrapolation of wind speed based on the 1/7 power law.

<sup>b</sup> Mean wind speed is based on Rayleigh speed distribution of equivalent mean wind power density. Wind speed is for standard sea-level conditions.

**Figure 3: U.S. Annual Average Wind Power - Classes of Wind Power Density<sup>9</sup>.**

## COST

The 2007 U.S. Department of Energy (DOE) Annual Report on the development and trends of wind power reports that the cost of wind power is nearly very competitive with those of conventional power technologies. And this does not account for the environmental and health benefits of using a non-polluting source of energy. It is expected that over time, wind energy cost will decrease as most conventional generation technology costs continue to increase. Since 2002, the cost of turbines has been on the rise because of increase cost of input material, energy prices, and in some cases, shortages in certain turbine components<sup>13</sup>.

Large-scale wind farms can be installed for between \$1,000 and \$2,000 per kilowatt. The cost of electricity produced from wind farms can be attributed to the annual capacity factor, location, wind quality, and installation and maintenance costs. The cost per kilowatt for small-scale wind turbines is still relatively high, with costs up to

\$3,000 per kilowatt. However, the cost per kW decreases as the size of the turbine increases.

Wind availability at a site also influences cost. Wind turbines installed in very windy locations generate less expensive electricity than the same unit installed in a less windy location. It is therefore important to assess wind speeds at the potential site during the planning stage (See Figure 3).

## APPLICATIONS OF WIND POWER AT WASTEWATER TREATMENT PLANTS

Wind power use in the U.S. constitutes about 16% of the world's wind capacity. It is the second largest new resource added to the U.S. electrical grid (in terms of nameplate capacity)<sup>13</sup>. In 2006, new wind plants contributed roughly 19% of new nameplate capacity, compared to 13% in 2005. Wind turbines have been installed in 22 states, with Texas, California, and Iowa leading the nation in annual capacity growth<sup>13</sup>.

The 40 MGD Atlantic County Utilities Authority (ACUA) Wastewater Treatment Facility in Atlantic City, New Jersey, supplements its energy needs using wind turbines<sup>14</sup> (Figure 4). When operating at design wind speeds of over 12 mph, the five 1.5 MW wind turbines at this facility are capable of producing up to 7.5 MW of electrical energy. Since this is much more than the average 2.5 MW of power needed each day by this facility, the remaining energy is sold to the local power grid.

Power production occurs only when wind speed is greater than 7 mph and shuts down at speeds in excess of 45 mph to protect the machinery inside. Therefore, on an annual basis, the ACUA wind farm can supply more than 60% of the electricity required by the plant. The remaining electricity can be bought from the local power grid when windmills are not at peak capacity (during calm or gusty weather). The cost of wind generated electricity is 7.9¢ per kWh delivered for the next 20 years, while the current cost delivered by the electrical grid is 12¢ per kWh and rising. The estimated cost of the 7.5 MW wind farm was \$12.5 million with an expected cost saving of \$350,000 per year<sup>15</sup>





**Figure 4: ACUA Wastewater Treatment Plant wind farm in Atlantic City, New Jersey.**

To encourage the use of renewable energy resources, the town of Browning, Montana, and the Blackfeet Indian Tribe have installed four Bergey Excel 10 kW wind turbines adjacent to the town's sewage treatment plant. The turbines provide about one-quarter of the plant's electricity, displacing energy bought from the grid. In the City of Fargo, North Dakota, the installation of a 1.5 MW wind turbine to provide 85% of the annual electricity used by the city's wastewater treatment plant is being considered. The Fargo wind turbine is estimated to cost \$2.4 million and could save the plant about \$203,000 in energy costs annually<sup>16</sup>.

The Lynn wastewater treatment plant in Massachusetts, that services the counties of Lynn, Saugus, Swampscott, and Nahant, is considering the installation of one or more wind turbine generators to supply a substantial portion of the plant's electricity. As of May 2007, information is being collected on possible wind turbine model options that comply with the Federal Aviation Administration (FAA) height restrictions of 254 feet (77 meters) above ground level; and each model's estimated energy production, setback requirements, and potential sound impacts<sup>17</sup>.

Several other WWTPs throughout the U.S. have installed or are considering the installation of wind turbines to temper the rising costs of electricity.

## REFERENCES

1. U.S. Department of Energy (DOE). Energy Efficiency and Renewable Energy. Wind and Hydropower Technologies Program. [http://www.eere.energy.gov/windandhydro/wind\\_how.html](http://www.eere.energy.gov/windandhydro/wind_how.html). Retrieved July 9, 2007.
2. California Energy Commission. California Distributed Energy Resource Guide. <http://www.energy.ca.gov/distgen/equipment/wind/wind.html>. Retrieved August 21, 2007.
3. Wikipedia, the free encyclopedia. [http://en.wikipedia.org/wiki/Wind\\_turbine](http://en.wikipedia.org/wiki/Wind_turbine). Retrieved July 9, 2007.
4. Muljadi, E. and Butterfield, C.P. 2000. Pitch-Controlled Variable-Speed Wind Turbine Generation, NREL/CP-500-27143. Conference paper, presented at the 1999 IEEE Industry Applications Society Annual Meeting, Phoenix, Arizona October 3-7, 1999. <http://www.nrel.gov/docs/fy00osti/27143.pdf>. Retrieved August 21, 2007.
5. Muljadi, E., Pierce, K., and Migliore, P. 1998. Control Strategy for Variable-Speed, Stall-Regulated Wind Turbines. NREL/CP-500-24311- UC Category:1211. Conference paper, presented at American Controls Conference, Philadelphia, PA, June 26, 1998. <http://www.nrel.gov/docs/legosti/fy98/24311.pdf>. Retrieved August 21, 2007.
6. Polinder, H., Bang, D., van Rooij, R.P.J.O.M., McDonald, A.S., and Mueller, M.A. 2007. 10-MW Wind Turbine Direct-Drive Generator Design with Pitch or Active Speed Stall Control. Electric Machines & Drives Conference, 2007. IEMDC 2007. IEEE International, 2, 3-5, pp. 1390 – 1395.
7. Sathyajith, M. 2006. Wind Energy: Fundamentals, Resource Analysis, and Economics. Published 2006. Springer. ISBN 3540309055.

8. Danish Wind Industry Association. Power Control of Wind Turbines. <http://www.windpower.org/en/tour/wtrb/powerreg.htm>. Retrieved August 21, 2007.

9. Wind Energy Resource Atlas of the United States. <http://rredc.nrel.gov/wind/pubs/atlas/acknowledgment.html>

10. Nicholls, B. and Racey, P.A. 2007. Bats Avoid Radar Installations: Could Electromagnetic Fields Deter Bats from Colliding with Wind Turbines? PLoS ONE, 2, 3, e297.

11. Fielding, A.H., Whitfield, D.P. and McLeod, D.R. 2006. Spatial association as an indicator of the potential for future interactions between wind energy developments and golden eagles *Aquila chrysaetos* in Scotland. Biological Conservation, 131, 3, 359-369.

12. Henry Seifert, 2004 Technical Requirements for Rotor Blades Operating in Cold Climates, DEWI Magazin Nr. 24.

13. U.S. Department of Energy (DOE). 2007. Energy Efficiency and Renewable Energy. Annual Report on U.S. Wind Power Installation, Cost, and Performance Trends, 2006. DOE/GO-102007-2433. <http://www.nrel.gov/docs/fy07osti/41435.pdf>. Retrieved July 10, 2007.

14. Atlantic County Utilities Authority (AOUA), Atlantic City Wind Farm Project. [http://www.acuc.com/alternative/a\\_project\\_display.cfm?id=214](http://www.acuc.com/alternative/a_project_display.cfm?id=214) and <http://www.acua.com/files/windfacts607.pdf>. Retrieved July 9, 2007.

15. Wind Power for the Wastewater Treatment Plant in Browning, Montana. <http://www.browningmontana.com/wind.html>. Retrieved July 9, 2007.

16. Fargo, North Dakota. [http://www.prairiepublic.org/features/riverwatch/news/forum/04\\_25\\_06.html](http://www.prairiepublic.org/features/riverwatch/news/forum/04_25_06.html) and <http://www.uswaternews.com/archives/arcquality/6fargomigh4.html>. Retrieved July 9, 2007.

17. Update to Wind Feasibility Study for Lynn, Massachusetts, May 2007. [http://www.mtpc.org/Project%20Deliverables/Comm\\_Wind/Lynn/TurbineSitingMemoMay%20\\_2007.PDF](http://www.mtpc.org/Project%20Deliverables/Comm_Wind/Lynn/TurbineSitingMemoMay%20_2007.PDF). Retrieved July 9, 2007.

**Some of the information presented in this fact sheet was provided by the manufacturer or vendor and could not be verified by the EPA.**

**The mention of trade names, specific vendors, or products does not represent an actual or presumed endorsement, preference, or acceptance by the EPA or federal government.**

**Stated results, conclusions, usage, or practices do not necessarily represent the views or policies of the EPA.**

**Environmental Protection Agency  
Office of Wastewater Management  
EPA 832-F-13-017  
August 2013**