Off-Shore Wind Blue Ribbon Panel
Energy and Wind Systems 101
The Basics

This Report is a summary of the general energy generation information and general information on wind energy systems. For more detailed information on offshore wind – *New Jersey Offshore Wind Energy : Feasibility Study* May 2004 provides on overview of the technology and subsystems.

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1. What are the basic measurements in energy production?

The capacity of an electric generating unit and the load for electricity use is measured in watts. Watts are relative small power units. 1000 watts is equal to a *kilowatt* (kW, 1,000 watts), a *megawatt* is 1000 kWs (MW, 1 million watts), and a *gigawatt* is 1000 MW (pronounced "jig-a-watt," GW, 1 billion watts). These terms are most commonly used to describe the capacity of generating units like wind turbines or other power plants.

Electricity production and consumption are most commonly measured in *kilowatt-hours (kWh).* A kilowatt-hour means one kilowatt (1,000 watts) of electricity produced or consumed for one hour. 1000 kilowatt-hours is a *megawatt-hour (MWh)* and 1000 megawatt-hours is a *gigawatt-hour* (GWh).

As an example of capacity/load and production/consumption of electricity: One 100-watt light bulb left on for 10 hours consumes one kilowatt-hour of electricity (100 watts x 10 hours = 1,000 watt-hours or 1 kilowatt-hour). At the average retail cost for electricity of $0.11 per kilowatt-hour this would cost 11 cents. One thousand 100 watt light bulbs operating for ten hours would consume one MWh of electricity and cost $110.00. A one MW EGU like a wind power plant must operate one-hour (while the wind is blowing) to generate one MWh of electricity.

The electric energy from the generator must get from the EGU to the user. This happens through a system of high voltage transmission wires and local lower voltage distribution systems. The movement or flow of electricity through these wires results in losses from resistance in the wires. In order to get a MWh of energy from an EGU to a users the generator must account for these losses and generate additional energy.

In addition to consuming electricity in kilowatt-hours a home or businesses is measure as a load in kWs or MWs. A typical home has a load of 3 to 4 kilowatts and a business could have a load from several kilowatts to several megawatts. Since all the electric equipment in a home or business does not run all the time, the electricity that it uses is equal to its load (kilowatts) times the number of hours that the equipment runs. This is the electric energy use of the home or business that is measured in kilowatt-hours. Similarly, an EGU whose capacity is measured in kilowatts or megawatts does not run all the time and the electricity it produces is equal to the capacity of the generator times its run time generating electricity.

In managing the overall electrical energy system, the energy production and the consumption must be balanced in order to keep the frequency of the system (60 Hertz) within allowable or acceptable limits. An unbalanced system could cause a shutdown of the grid. This is what happened in the 2003 blackout. This balance for New Jersey's electric energy system is maintained by the Pennsylvania-Maryland-Jersey (PJM) LLC. PJM manages the grid or electric network which includes the dispatching of which electric energy generators (including utility-scale wind energy systems) operate and the transmission systems to deliver that energy. PJM must mange the intermittency of the wind energy system in balance with the grid. PJM does not currently manage BTM energy systems or the local distribution systems.

2. *Wind energy systems: what they are and how they work?*

A wind energy system transforms the kinetic energy of the wind into mechanical or electrical energy that can be harnessed for practical use. A mechanical energy wind system is most commonly used for pumping water in rural or remote locations. An electrical energy wind system, a wind turbine, generates electricity for homes and businesses.

There are two basic designs of wind energy turbines: vertical-axis, or "egg-beater" style, and horizontal axis machines. Horizontal-axis wind turbines are most common today, constituting nearly all of the "utility-scale" turbines in the global market.

In addition there are two basic wind energy systems: behind the meter (BTM) systems or utility-scaled wind power plants or wind farms. BTM systems are small systems from 20 watts to 250 kilowatts. In New Jersey we have defined net metering and local interconnection standards that establish the BTM limits at 2 MW and a peak load not to exceed 10 MW. In addition, BTM systems can not be larger than 125 percent of the customer's average electric use. BTM systems generate electrical energy for on-site use. BTM systems either allow the home or business to operate independent of the grid or off-set the use of electricity from the grid. Utility-scale wind power plants operate as typical electric generating unit (EGU). They generate electricity for use by consumers connected to the grid. These systems can vary in size from several hundred kW to several hundred MW.

As of 2004 there were 6,740 MW of installed onshore wind energy systems in the U.S. There is currently no installed offshore wind capacity in the U.S, although several offshore wind projects are in the planning stage in a number of states. The furthest along of these are the 140 MW system off the shore of Long Island proposed by LIPA and the Cape Wind 420 MW project in Nantucket Sound, MA.

Europe currently (2003) has installed 28,706 MW in 29 countries of which over 500 MW are offshore wind energy systems in 16 countries. There is over 10,000 MW of new offshore wind energy systems in various stages of planning in these countries.

A wind turbine operates like a fan in reverse. Instead of using electricity to make wind like a fan, a wind turbine uses the wind to make electricity. The wind turns the blades, which spin a shaft, which is connected to a generator that makes electricity.

A wind turbine's subsystems include:

- a rotor, or blades, which convert the wind's energy into rotational shaft energy;
- a nacelle (enclosure) containing a drive train, usually including a gearbox and a generator;
- a tower, to support the rotor and drive train; and
- electronic equipment such as controls, electrical cables, transformers, ground support equipment, and interconnection equipment.

See Attachment A for a detail schematic of a wind turbine. These components are generally the same for a BTM system, and onshore utility-scale wind energy system and an offshore wind energy system.

3. How is the output of wind turbines determined?

The output of a wind turbine, the energy it generates, depends on the turbine's size and the wind's speed. Wind speed is a crucial element in projecting turbine performance, and a site's wind speed is measured through wind resource assessment prior to a wind system's construction. Generally, annual average wind speeds greater than four meters per second (m/s) or nine mph are required for small wind electric turbines (less wind is required for water-pumping operations). Utility-scale wind power plants require minimum average wind speeds of six m/s or 13 mph.

Wind power is characterized by a simple system that assigns the wind potential to one of seven wind classes. An area with an average annual wind speed of four m/s or nine mph is categorized as a Class 1 wind area. The wind potential in a Class 1 or 2 areas are low and are not deemed suitable for utility-scale wind energy power plants. A Class 2 area may be suitable for small wind systems or BTM systems. An area with an average annual wind speed of six m/s or 13 mph is categorized as a Class 5 wind area. A Class 5 wind area is suitable for utility-scale wind energy systems. Most of New Jersey is a Class 1 or Class 2 wind area. There are some Class 3 wind areas along the New Jersey coast and in the mountain ridges in the northwest portion of the state. There are Class 4, 5 and 6 wind areas off-shore. (See Attachment B for a copy of the New Jersey Wind Speed Map)

The power available in the wind is proportional to the cube of its speed, which means that doubling the wind speed increases the available power by a factor of eight. Thus, a turbine operating at a site with an average wind speed of 12 mph could in theory generate about 33 percent more electricity than one at an 11-mph site, because the cube of 12 (1,768) is 33% larger than the cube of 11(1,331). In the real world, the turbine will not produce quite that much more electricity, but it will still generate much more than the nine percent difference in wind speed. A small difference in wind speed can mean a large difference in available energy and in electricity produced, and therefore, a large difference in the cost of the electricity generated. The following formula illustrates factors that are important in the performance of a wind turbine:

$$\mathbf{P = k\, C_p\, \tfrac{1}{2}\, \rho\, A\, V^3}$$

Where:

P = Power output in kilowatts (kW)
C_p = Max. power coefficient ranging
From 0.25 to 0.45 (capacity factor)
ρ = Air density lb/ft3
A = Rotor swept area ft2
V = wind speed, mph
k = 0.000133 to convert to yield power in kW

4. What is the capacity of wind systems?

Capacity factor is one performance indicator in measuring the productivity of a wind turbine or any other power production facility. It compares the plant's actual production over a given period of time with the amount of power the plant would have produced if it had run at full capacity for the same amount of time as follows:

$$\textbf{Capacity Factor} = \frac{\textbf{Actual amount of power produced over time}}{\textbf{Power that would have been produced if turbine operated at maximum output 100\% of the time}}$$

A conventional utility power plant uses fuel, so it will normally run much of the time unless it is idled by equipment problems or for maintenance. A capacity factor for a baseload conventional coal or nuclear plant is greater than 90 percent.

A wind plant is "fueled" by the wind, which blows steadily at times and not at all at other times. Most modern utility-scale wind turbines operate with a capacity factor of 25 percent to 45 percent, although they may achieve higher capacity factors during windy weeks or months. The theoretical maximum capacity factor for a rotor wind turbine is 59 percent. It is possible to achieve much higher capacity factors by combining wind with a storage technology such as pumped hydro or compressed-air energy storage (CAES).

This means that in order for a wind energy power plant to generate the same amount of energy as a coal power plant a wind plant must be approximately 3 times as large. However, existing coal burning power plants are only approximately 33 percent efficient in converting the coal to electricity. A conventional gas fired power plant is approximately 55 percent efficient in convert the fuel to electricity. Capacity is a measure of the reliability of the power plant not its efficiency.

While the capacity factor is almost entirely a matter of reliability for a fueled power plant, it is not for a wind plant—for a wind plant, it is a matter of economical turbine design. With a very large rotor and a very small generator, a wind turbine would run at full capacity whenever the wind blew and would have a 60 to 80 percent capacity factor—but it would produce very little electricity. The most electricity per dollar of investment is gained by using a larger generator and accepting the fact that the capacity factor will be lower as a result. Wind turbines are fundamentally different from fueled power plants in this respect. A wind turbine typically operates about 65 percent of the time. However, much of the time it will be generating at less than full capacity, making its capacity factor lower.

Availability factor (or just "availability") is a measurement of the reliability of a wind turbine or other power plants. It refers to the percentage of time that a plant is ready to generate (that is, not out of service for maintenance or repairs). Modern wind turbines have an availability of more than 98 percent --higher than most other types of power plant. After two decades of constant engineering refinement, today's wind machines are highly reliable.

5. What determines the actual performance of wind systems?

There are a number of other factors that influence the performance of a wind energy system. These following factors can lower the overall performance of as wind system if not appropriately designed:

1. Roughness of the surrounding environment – friction imposed by trees, buildings and other structures causing wind shear;
2. Turbulence or irregular wind flow due to change in speed or direction;
3. Wake effect from other wind turbines; and
4. Tunnel effect or the increase in wind speed between two objects.

These factors are evident to a lesser degree offshore which coupled with higher wind speeds offshore increase the potential performance of offshore wind energy systems. Offshore shore wind ranges between Class 3 to Class 5 wind power areas while onshore winds are in the Class 1 to Class 3.

During the year there are times when the wind does not blow or blows at speeds below which the wind turbine will turn to produce energy (the cut in speed). A wind energy system does not produce energy all 8760 hours during the year. Even when the wind is blowing the wind energy system does not always produce energy at its full rated power.

However, wind energy is more steady and predictable offshore. Because of this fact, with equivalent onshore and offshore wind systems (same MW capacity), an offshore wind energy system will produce more energy over the year.

Though wind energy production is intermittent, it can be measured and forecasted with some degree of accuracy. The most significant technical characteristic of wind energy productivity is its variation over time. While wind varies with time, it is not completely random. A certain degree of wind forecasting is possible. With wind energy forecasting through modeling, wind energy production can be matched to a certain degree to electricity demand.

Over the year the wind speed offshore in New Jersey can vary between 5 to 9 meters per second (m/s). The offshore wind in New Jersey peaks between April to October and is highest in December/January. It is lowest in July/August. The wind speed offshore can varies roughly 1.5 m/s over the day. In addition during the warm summer months because of the thermal difference between the temperature of the water and the land a sea breeze circulation develops along the shore. The sea breeze can increase wind speeds between one M/s six miles offshore to 2 m/s one half a mile offshore.

6. How large are wind turbines?

Wind turbines vary in size. The following chart depicts the change in turbine technology over time in wind rotor size, the turbines capacity or power rating and the amount of electricity they are capable of generating.

	1981	1985	1990	1996	1999	2000
Rotor diameter in meters	10	17	27	40	50	71
Turbine capacity in kW(MW)	25	100	225	550 (.55)	750 (.75)	1,650 (1.6)
Electric energy in MWhs/yr	45	220	550	1,480	2,200	5,600
Total cost ($ 000)	$65					$1,300
Cost per kW	$2,600					$790

Today, GE Power manufactures offshore wind turbines with rated capacities of between 2.3 and 2.7 MW. These units have a rotor size of approximately 94 meters. GE Power also manufactures an offshore wind turbine with a rated capacity of 3.6 MW with a rotor diameter of 104 meters. As noted from the table above, these GE units will generate significantly more energy.

7. How many homes can be supplied by a wind system?

An average New Jersey household uses approximately 8,500 kilowatt-hours (kWh) of electricity each year. With the increasing size of homes with more electrical appliance this average is increasing. A 10-kW wind turbine can generate about 16,000 kWh annually, more than enough to power a typical household.

A one megawatt wind energy system can generate between 2.4 million and 3 million kWh annually. Therefore, a megawatt wind generates about as much electricity to power over 300 average New Jersey households. It is important to note that since the wind does not blow all of the time, it cannot be the only power source for that many households without some form of storage system. The "number of homes served" is just a convenient way to translate a quantity of electricity into a familiar term.

A 1.8-MW off shore wind turbine can produce more than 5.4 million kWh in a year--enough to power more than 600 households. A 3.6 MW GE turbine can produce more than 10.8 million kWh in a year – enough to power more than 1200 households.

8. Can wind energy systems meet consumer demand?

The independent system operator (ISO) of the transmission system must deliver enough power to meet expected customer electricity demand at all times, plus an additional reserve margin. For New Jersey the ISO is PJM. In PJM that additional reserve capacity is 15 percent above the peak demand. All things being equal, PJM will generally prefer plants that can generate power as needed when called on to deliver power. This would be a typical or conventional nuclear or fossil fuel power plant.

Some of these plants like nuclear or coal plants, because of their relative low cost to operate, are generating power which is called on and delivered into the grid at all the times. These plants are called a baseloaded plants. Others are operating be not adding energy to the grid until called on by PJM based on needed demand. They are "spinning" waiting to be called on by PJM as the load increases during the day. They are backed off as the load decreases at the end of the day. Most natural gas combined cycle plants operate in this manner because they have higher costs and can deliver energy quicker when called on by PJM. This is called delivering energy on the margin. Other plants are dispatched as needed based on demand and their cost to generate electricity.

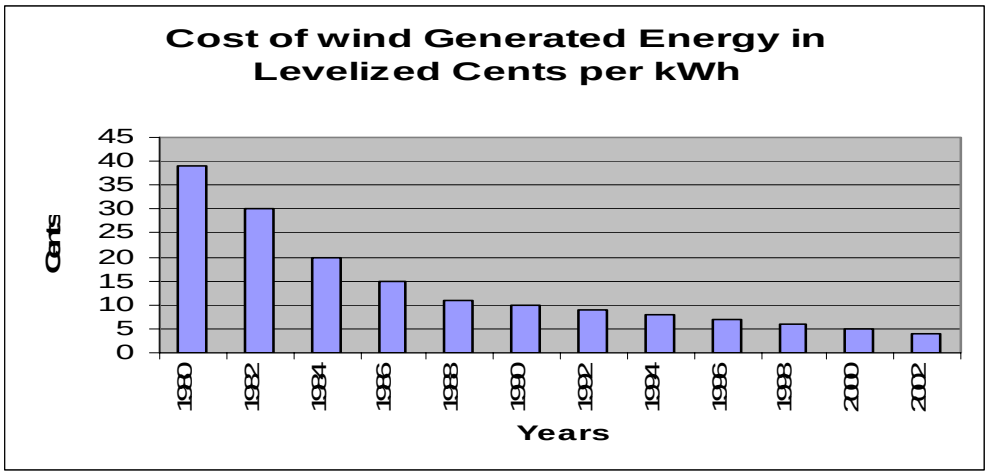
Wind energy systems are intermittent and can not just be switched on to deliver energy. In addition, their cost to operate is higher than other conventional power plants. In an economic energy dispatch system, as managed by PJM, wind energy systems would not be called on to deliver energy. However, because of State legislation that requires a certain amount of energy to be generated by renewable sources wind energy systems are dispatched by PJM in order to meet this requirement.

Researchers have found that despite its intermittent nature, wind can provide capacity value for utilities. A study by the Tellus Institute of Boston, MA. concluded that when wind turbines are added to a utility system, they increase the overall statistical probability that the system will be able to meet demand requirements. They noted that while wind is an intermittent resource, conventional generating systems also experience periodic outages for maintenance and repair.

The exact amount of capacity value that a given wind project provides depends on a number of factors, including average wind speeds at the site and the match between wind patterns and utility load (demand) requirements. Offshore wind would more closely match the daily load factors than onshore wind. The seasonal average energy production for offshore wind peaks in fall and winter but it also delivers energy during the late afternoon summer peak.

9. What are the average cost for a wind energy system?

Over the last 20 years, the cost of electricity from utility-scale wind systems has dropped by more than 80%. In the early 1980s, when the first utility-scale turbines were installed, wind-generated electricity cost as much as 30 cents per kilowatt-hour. Now, state-of-the-art wind power plants can generate electricity for less than 5 cents per kilowatt-hour (Class 5 and 6 areas) in many parts of the U.S., a price that is in a competitive range with many conventional energy technologies. The PJM grid baseload power plants generate electricity for 2 to 3 cents per kilowatt-hour.



Assumptions: Levelized cost at excellent wind sites, mi-ge project size, not including FTC

Wind is the low-cost emerging renewable energy resource. Solar electric or photovoltaic (PV) can cost as high as 21 cents per kilowatt-hour to generate. Geothermal (not available in New Jersey) and sustianably grown and harvest biomass can generate electricity for approximately 6 to 7 cents per kilowatt-hour. Landfill gas to electricity project can generate electricity for less than 5 cents per kilowatt-hour.

Offshore wind is higher in cost than onshore wind because of additional costs which include:

1. Additional construction cost to install the foundation for the offshore wind turbine which could be in 50 plus feet of water.
2. Additional operating costs, with its corrosive salt environment and more severe weather increases this cost.
3. Additional power collection and transmission costs which could be 3 plus miles off shore.

A 100 MW offshore wind energy facility in an area with a wind speed of 8 to 8.5 meters per second and a capacity factor between 32 to 35 would result in a levelized electricity cost of between 8.5 to 8.9 cents per kilowatt-hour. This is more expensive than most Class 1 renewable energy systems including land based wind systems, sustainable biomass and landfill gas to electricity.

10. How is the total cost for a wind system calculated?

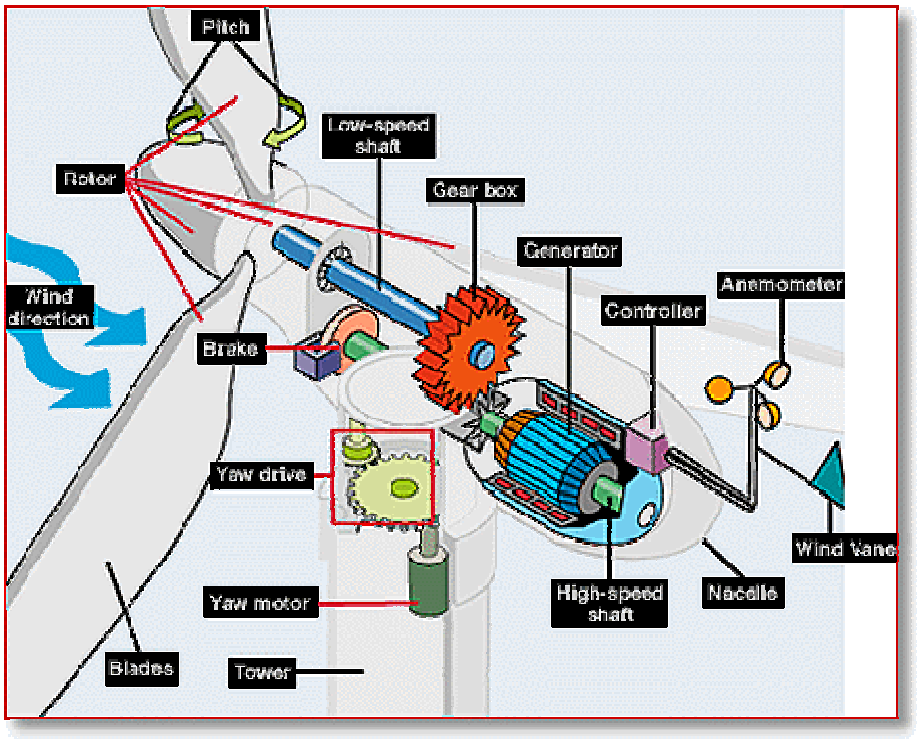
Cost of wind energy projects can be calculated using three basic measures: the installed capital cost, the specific capital cost and the lifecycle cost. The installed capital cost includes all planning, permitting, equipment, construction and installation costs. The installation costs include all supporting infrastructure costs that gather the electricity from each wind turbine and routes it to a substation and could include the cost of the substation or the lease or usage fee for use of this facility. Typical installed capital costs are $1,000 to $1,200 per kW for on-shore utility-sized wind energy systems. The typical installed capital costs are $1700 to $2,500 per kW for offshore wind energy systems. Offshore wind is 50 to 100 percent more than land based wind energy systems.

The specific capital cost combines the installed costs and the potential to efficiently capture wind power. The specific capital cost includes the annual energy production in order to calculate the cost of generating one kilowatt-hour per year.

The lifecycle cost incorporates all the capital costs, the cost of capital O&M costs and major overhauls. The O&M includes all maintenance, preventive maintenance, unscheduled maintenance, and overhaul costs. Within this cost includes the transmission/wheeling costs and the substation fees.

The total cost for energy from a wind turbine energy system is currently less than 5 cents per kilowatt-hour and is 70% capital cost, 16% unscheduled maintenance, 9% other operating costs, 4% preventive maintenance and less than 1% major overhaul costs.

Inside the Wind Turbine



Anemometer: Measures the wind speed and transmits wind speed data to the controller.

Blades: Most turbines have either two or three blades. Wind blowing over the blades causes the blades to "lift" and rotate.

Brake: A disc brake, which can be applied mechanically, electrically, or hydraulically to stop the rotor in emergencies.

Controller: The controller starts up the machine at wind speeds of about 8 to 16 miles per hour (mph) and shuts off the machine at about 65 mph. Turbines cannot operate at wind speeds above about 65 mph because their generators could overheat.

Gear box: Gears connect the low-speed shaft to the high-speed shaft and increase the rotational speeds from about 30 to 60 rotations per minute (rpm) to about 1200 to 1500 rpm, the rotational speed required by most generators to produce electricity. The gear box is a costly (and heavy) part of the wind turbine and engineers are exploring "direct-drive" generators that operate at lower rotational speeds and don't need gear boxes.

Generator: Usually an off-the-shelf induction generator that produces 60-cycle AC electricity.

High-speed shaft: Drives the generator.

Low-speed shaft: The rotor turns the low-speed shaft at about 30 to 60 rotations per minute.

Nacelle: The rotor attaches to the nacelle, which sits atop the tower and includes the gear box, low- and high-speed shafts, generator, controller, and brake. A cover protects the components inside the nacelle. Some nacelles are large enough for a technician to stand inside while working.

Pitch: Blades are turned, or pitched, out of the wind to keep the rotor from turning in winds that are too high or too low to produce electricity.

Rotor: The blades and the hub together are called the rotor.

Tower: Towers are made from tubular steel (shown here) or steel lattice. Because wind speed increases with height, taller towers enable turbines to capture more energy and generate more electricity.

Wind direction: This is an "upwind" turbine, so-called because it operates facing into the wind. Other turbines are designed to run "downwind", facing away from the wind.

Wind vane: Measures wind direction and communicates with the yaw drive to orient the turbine properly with respect to the wind.

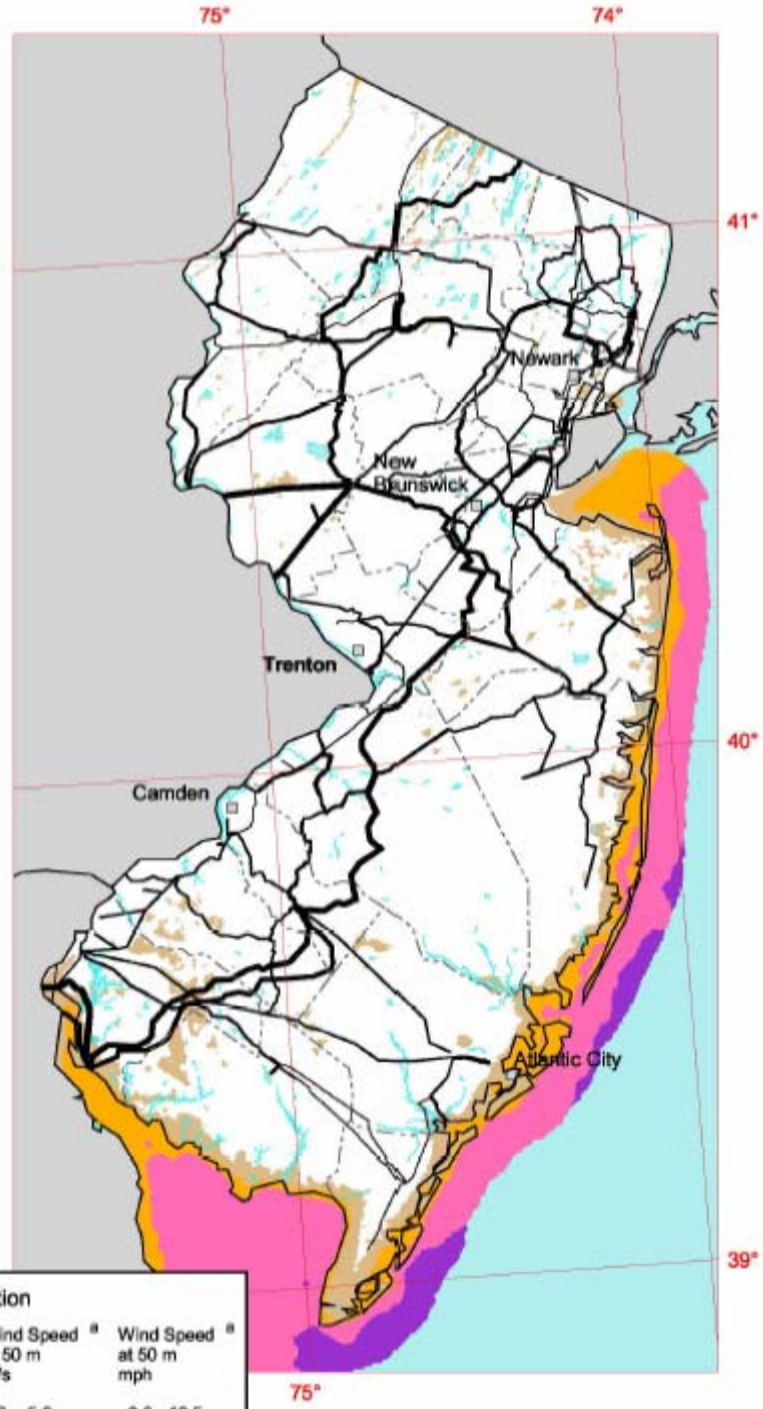
Yaw drive: Upwind turbines face into the wind; the yaw drive is used to keep the rotor facing into the wind as the wind direction changes. Downwind turbines don't require a yaw drive, the wind blows the rotor downwind.

Yaw motor: Powers the yaw drive.

New Jersey

50 m Wind Resource Map

The annual wind power estimates for this map were produced by TrueWind Solutions using their Mesomap system and historical weather data. It has been validated with available surface data by NREL and wind energy meteorological consultants.



15 0 15 30 45 Kilometers

10 0 10 20 30 Miles

Transmission Line*

Voltage (kV)

- 115 - 138
- 230
- 345
- 500

* Source: POWERmap, c ©02 Platts, a Division of the McGraw-Hill Companies

Wind Power Classification

Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m²	Wind Speed [a] at 50 m m/s	Wind Speed [a] at 50 m mph
1	Poor	0 - 200	0.0 - 5.6	0.0 - 12.5
2	Marginal	200 - 300	5.6 - 6.4	12.5 - 14.3
3	Fair	300 - 400	6.4 - 7.0	14.3 - 15.7
4	Good	400 - 500	7.0 - 7.5	15.7 - 16.8
5	Excellent	500 - 600	7.5 - 8.0	16.8 - 17.9
6	Outstanding	600 - 800	8.0 - 8.8	17.9 - 19.7
7	Superb	> 800	> 8.8	> 19.7

[a] Wind speeds are based on a Weibull k value of 2.0

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