

Wind Power: The Ultimate Renewable Energy Source

BY JAN NULL AND CRISTINA ARCHER

As the debate over the need for renewable energy heats up in meeting rooms, legislatures, and boardrooms across the globe, the ultimate renewable energy source is blowing all around us. On average, there is enough power from the wind to meet the world's electricity needs 35 times over. Today, as the cost of a barrel of oil soars and global warming has us searching for clean, renewable sources of energy, policymakers and scientists around the world are working to make the idea of gleaning electrical power from the wind on a larger scale a new reality. The goal of drawing 20 percent of all generated electricity from the wind once seemed pie-in-the-sky, but it has been realized in Denmark and is a realistic goal in other parts of the world, such as Spain and Germany. In the United States, wind currently provides less than 2 percent of the electricity demand. But in several states, such as California, plans exist to reach the target of generating 20 percent of energy from renewable sources, including wind, by 2010 and 33 percent by 2020.

The Wild Horse Wind Power Project in Kittitas County, Washington, has a generating capacity of 228 megawatts, which can power 50,000 households annually.



AMERICAN WIND ENERGY ASSOCIATION



Wind farms like this one in Tehachapi, California, proliferated in the 1980s as the oil crisis helped kindle an interest in alternative power sources.

Wind Power Through the Ages

Using the wind for power is certainly nothing new. As far back as 5,000 years ago, there were wind-powered ships on the Nile River in Egypt. In ancient Persia around the year 1,000 B.C.E., some of the earliest windmills were used to grind grains. These very early windmills resembled large paddlewheels and were not terribly efficient at harnessing the wind. It wasn't until the end of the twelfth century that windmills with horizontal axes and vertical blades were developed along the Mediterranean.

Windmills subsequently spread rapidly north across Europe. They became a dominant power source and remained so into the nineteenth century, when there were an estimated 50,000 operational windmills across the continent for both grinding grain and pumping water. The Dutch were innovators throughout this period, developing Holland's ubiquitous four-blade rotors and a yaw mechanism to change the pitch of the blades. At one point in

the nineteenth century, some 700 windmills supplied power for factories in Amsterdam before they were replaced by steam power.

Windmills evolved in the New World with the "wind pump" as an integral part of the taming of the West in the United States. Used as a means of pumping water, they dotted the landscape around farms and along the expanding railroads to supply water to locomotives. Even today, it is estimated there are still 60,000 wind pumps in the United States and a million worldwide.

The first windmill used to generate electricity, a wind turbine, was built by the Danes in 1892 to run a generator that in turn charged batteries for direct current (DC) power. Wind as a source of electrical power didn't evolve until the 1930s in the United States, when cities became more and more electrified, while rural areas remained "off the grid." To take advantage of the latest electric appliances, such as radios, wind turbines were used to charge batteries that in turn were used for power.

These "wind chargers" took advantage of the new propeller aerodynamics from the aircraft industry to generate electricity efficiently on a small scale.

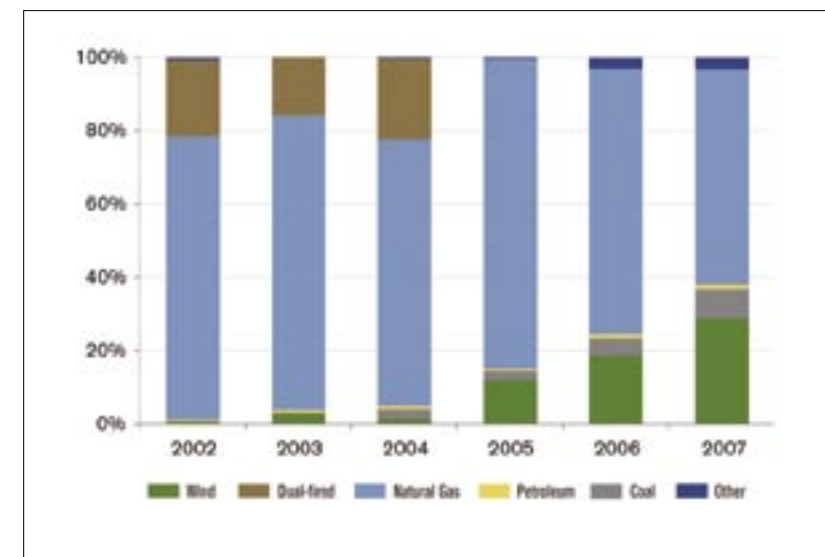
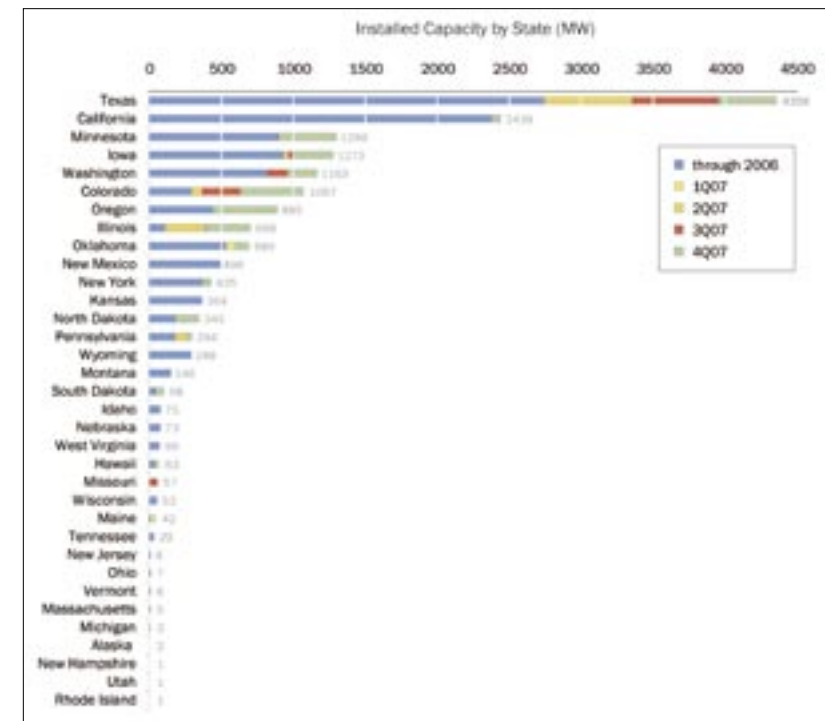
Large-scale wind turbines, with capacities to generate thousands of kilowatts (kW) and connect to existing power grids, were experimented with in the 1950s but did not really become a viable resource for generating electricity until the 1970s. The oil crisis in that decade helped rekindle an interest in alternative power sources in general and wind power in particular. Over the next 10 years, thousands of 55-kW turbines sprang up on wind farms in California, primarily along the ridges east of the San Francisco Bay area and east of the Los Angeles basin. However, this number remained fairly static through the end of the twentieth century as subsidies for wind power waned and other energy sources dominated.

Wind Power Today

The world has seen a renewed interest in renewable energy at the turn of the twenty-first century. This, combined with a new generation of megawatt-size wind turbines, has given new life to wind power as a viable alternative not only in the United States but around the world. By 1996, 550-kW wind turbines were commonly being installed worldwide. These turbines were about 10 times more productive than the turbines of the 1970s. Today, the latest turbines being installed average 1.5 megawatts (MW), with some wind farms putting in 3.0-MW machines. Projections show that over the next 10 years, turbines in excess of 5.0 MW will be common. Already, a prototype 7.0-MW wind turbine is spinning in Germany.

These trends have translated into a dramatic increase in the power generated from wind both in the United States and around the world. At the end of 2007, there were 94 gigawatts (GW) of installed capacity globally, nearly double the capacity of 2004, when there were 48 GW, and more than 5 times the 2000 figure of 18 GW. Germany leads the pack with nearly 22 GW installed, followed by the United States and Spain with 17 GW and 15 GW, respectively. Projected growth worldwide is expected to continue at these dramatic rates, with an electrical capacity from wind of 160 GW by 2010. Areas with great potential worldwide include northern Europe along the North Sea, the southern tip of the South American continent, and the island of Tasmania in Australia.

However, for the past three years, the United States has been leading the world in new installed capacity, with a spurt of 45 percent in 2007 alone. The latest "wind rush" has been in Texas, whose wind power capacity has doubled in the past two years. Other states leading the growth spurt include California, Iowa, Minnesota, and Washington.



Top: Rankings of wind capacity in all states with "utility-sized" turbines (those with generators of 100 watts or higher). Bottom: New, electricity-generating installed capacity by energy source; in 2007, wind power made up 30% of the total.

The growth in these states has been in large part due to a two-cent per kilowatt-hour federal tax credit that was part of the 2005 energy bill. This incentive has made wind energy competitive with coal-fired power plants, producing electricity at approximately 3.6 cents per kilowatt hour, compared with 2.4 cents per kilowatt hour, including fuel cost and without CO₂ sequestration, for coal-fired electricity.

Only about 13 percent of land worldwide is windy enough for wind power installations to be economical. Assuming that we can cover that fraction of the land with 1.5-MW, 80-meter-tall turbines, the

Germany's Enercon E-112 wind turbine, which is 394 feet tall (120 meters) and can produce 4.5 megawatts, was the largest wind turbine in the world until December 2004. At the end of 2004, it was upgraded to 6 megawatts.



wind power potential turns out to be 72 Terawatt (TW). One TW is 1,000 GW, and 1 GW is the size of a modern coal-fired power plant. Consequently, the world's wind potential is equivalent to 72,000 new coal plants, which corresponds to 35 times the global electricity demand and 6 times the Earth's total energy demand (which also includes heating, transportation, and other energy).

The midwestern United States is known for its untapped, massive wind potential, and the north-eastern and northwestern coasts of the United States likewise offer large potential for offshore wind power development. Several proposals are pending approval for offshore farms in the Gulf of Mexico as well. Due to its relatively shallow continental shelf, the East Coast of the United States has an offshore wind power potential of 330 GW. This is out to a depth of 100 meters and takes into account exclusion areas for bird migrations, competing uses, beach rehabilitation, military exclusion, and shipping lanes. This is more than enough capacity to supply the adjacent region, whose demand is "just" 212 GW. Along the Pacific Coast, because of the steeper coastal shelf, the offshore potential is one order of magnitude less.

Overcoming the Barriers

Given the controversial nature of the topic, wind power is not without its proponents and detractors. Those touting wind energy point to its vast potential, its image as the poster child for clean, renewable power, and the fact that it is not impacted by world stock markets or political instability. It is also the most competitive renewable power source and by its very nature will maintain those credentials. The bottom line is that it is a "free" fuel, one that can never be charged for by the barrel.

Opponents to wind power most often point to avian fatalities from the rotors, noise, concerns about aesthetics, wind intermittency, and the occasional mismatch between wind availability and electricity demand, especially during heat waves.

Modern turbines have already mitigated many of the issues associated with both birds and noise. The new, larger high-capacity turbines turn at a slower rate, which ameliorates the noise and makes it possible for birds to avoid the turning blades. But even before the newer turbines, the number of bird killed was fewer than 2 deaths per turbine per year, and the total amount was about 0.1 percent of those killed by cats and 0.02 percent of those caused by birds flying into windows and buildings.

Meanwhile, the aesthetics of a wind farm is in the eye of the beholder. Put into historical context, before the Eiffel Tower and Golden Gate Bridge were built, they were widely mocked because it was thought they would ruin the surroundings. Today,

views of these edifices are highly sought after and bring premium dollar on the real estate market. It should also be noted that many of the current and planned wind farms are not even visible to the vast populations of the world, making their impression upon the scenery irrelevant.

“The world’s wind potential is equivalent to 72,000 new coal plants...[or] 35 times the global electricity demand.”

A more serious barrier to large-scale implementation of wind power than concerns about aesthetics or bird kills is the intermittency of winds. It is possible to experience sudden, unexpected changes in wind speed, such as gusts or lulls. This means that wind power as a reliable source of electricity has some problems. One way to reduce wind power swings is interconnected power. By linking multiple wind farms together, it is possible to improve the overall performance of the interconnected system—or array—substantially compared with that of any individual wind farm. The idea is that, while wind speed could be calm at a given location, it will be active somewhere else in the aggregate array, so there can be a constant flow of power outward from the entire system if the farms are all interconnected. Spain, one of the world's leaders in wind power production, has created a system in which sudden wind power swings are eliminated. During a particularly windy period in the spring of 2007, wind power in Spain contributed 27 percent of the nation's electricity—more than coal, nuclear energy, or hydropower.

Another problem of wind power is its temporal mismatch with the electricity demand. The winds are often weakest when the electricity demand is highest, such as during a heat wave. One solution to this is pumped hydroelectric storage. During periods when there is high production from the wind and low demand (for example, at night), the excess electricity is used to pump water from a reservoir located at low altitude to a second, higher reservoir. Subsequently, during times of high demand (for example, in the afternoon), water from the higher reservoir is released to generate electricity and complement the wind's reduced generation. Similarly, the wind's excess electricity can be used at night to compress air into a cavern below a wind farm. The com-

The turbines at the Sacramento Municipal Utility District in Solano County, California, are the largest currently operational in the United States at 3 megawatts and 415 feet tall, higher than the Statue of Liberty. They operate at as little as 8 mph and peak at 33 mph to 56 mph.



pressed air is then run through a traditional turbine to generate electricity during high-demand hours. On a small scale, a network of car batteries from electric or plug-in vehicles connected to the grid can provide emergency backup electricity.

New Technologies


New technologies are also emerging in the wind power sector. From kites tethered to a ground-based generator to four-armed rotorcrafts with electric generators on board, many new wind turbine designs have been patented in recent years. But regardless of the technology, the aim is universal: tapping the enormous resource of high-altitude wind power, possibly one day harnessing the jet streams.

The drive for clean, inexpensive power from the wind is not confined to megawatt turbines. Small and even microscale wind power is becoming an increasingly popular alternative. A small wind energy system that is capable of producing 10 kilowatts (enough power for a household) costs \$30,000 to \$50,000 to install and has a lifespan of 20 to 30 years. If sited in an area with moderate wind poten-

tial (for example, wind speeds of 10 mph) and with existing tax credits, it can pay for itself in about 15 years, a length of time that is comparable to similar-capacity solar energy systems. Or if you just need to power your iPod and want to "go green," there is a hand-sized mini-turbine called HyMini that will charge most five-volt gadgets.

As the demand for clean, renewable energy sources increases both in the United States and around the world, wind will become an increasingly important component; subjective aesthetic qualms are not enough to ground a largely eco-friendly energy source. If recent years are an indication, the future will be brightly lit by wind-generated electricity. **W**

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