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Case history

Wind of change

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Energy: Wind power has established itself as an important source of renewable energy in the past three decades. The basic idea is ancient, but its modern incarnation adds many new high-tech twists

Corbis

OLD-FASHIONED windmills, no longer used to grind flour, have become tourist destinations in much of the developed world. Most people would agree that wooden windmills fit pleasingly into the landscape, and are charming reminders of a simpler, agrarian past. But opinion is divided about their high-tech descendants, wind turbines, which are springing up across the world as a source of renewable electricity. To some they are a blight on the landscape; to others they are graceful, majestic structures that signal the shift towards new sources of energy.

The first wind farms sprouted in California in the early 1980s, beneficiaries of generous tax credits. Among the rolling hills of Altamont Pass, near San Francisco Bay, some early turbines can still be seen spinning, turning a portion of the wind's kinetic energy into electricity. With capacity of mere tens of kilowatts and a rotor diameter of 15 metres or so, these windmills are no giants, at least by today's standards. New machines typically have a capacity of 1.5-2.5 megawatts (MW), or 30 to 50 times that of the early Altamont Pass turbines, with rotor diameters as great as 100 metres, so that their blades sweep an area about the size of a football field.

The wind-power industry has come a long way since the first Altamont Pass turbines started to spin. Although wind generates only about 1% of all electricity globally, it provides a respectable portion in several European countries: 20% in Denmark, 10% in Spain and about 7% in Germany. Wind power is also on the rise in America, where capacity jumped by 45% last year to reach nearly 17 gigawatts (GW) at the end of 2007. In China the pace has been faster still. Since the end of 2004, the country has nearly doubled its capacity every year. Globally, wind power installations are expected to triple from 94GW at the end of 2007 to nearly 290GW in 2012, according to BTM Consult, a Danish market-research firm. They will then account for 2.7% of world electricity generation, the company predicts, and by 2017 their share could be nearly 6%.

Wind power is attractive because it is a widely available and renewable source of energy that produces neither pollution nor climate-changing greenhouse gases. Once the turbines have been installed, the only “fuel” they need is the wind. And global wind resources are so vast that they could easily meet the world’s current energy needs, at least in theory. According to a study by researchers at Stanford University, global wind-energy potential in 2000 was about 72,000GW—nearly five times the world’s total energy demand.

What is more, the technology needed to tap into this source of energy is getting cheaper: the cost of generating electricity from wind power has fallen from as much as 30 cents per kilowatt hour in the early 1980s to around ten cents in 2007. Various incentives, in the form of tax credits and feed-in tariffs, mean that wind power is already cost-competitive with electricity derived from natural gas and even coal in many markets. With a tax of $30 per tonne of carbon dioxide, says Maria Sicilia of the International Energy Agency (IEA), electricity produced from wind could compete with fossil fuels in most markets even without subsidies.

Even without a price on carbon emissions, the growth of wind power is likely to continue. To combat climate change, the European Union has set itself the goal of deriving 20% of its energy from renewable sources by 2020, with a large portion coming from wind power. In America, a recent report by the Department of Energy laid out a plan to reach 20% wind power by 2030. And these ambitions may be dwarfed by Asia, which seems likely to become the biggest market for new wind installations within five years.

The rush to erect wind turbines has filled manufacturers’ order-books for the next year or two. But there are difficulties ahead. The wind does not blow all the time, and when it does, it often blows far away from cities that need electricity. For wind to continue its remarkable expansion, the industry will need to build new transmission lines and improve the integration of wind power into the grid. And because it is still dependent on subsidies, the industry remains vulnerable to the risk that incentives might suddenly be cut off (at least until a price is imposed on carbon emissions). In addition, some people remain to be convinced that wind farms make good neighbours.

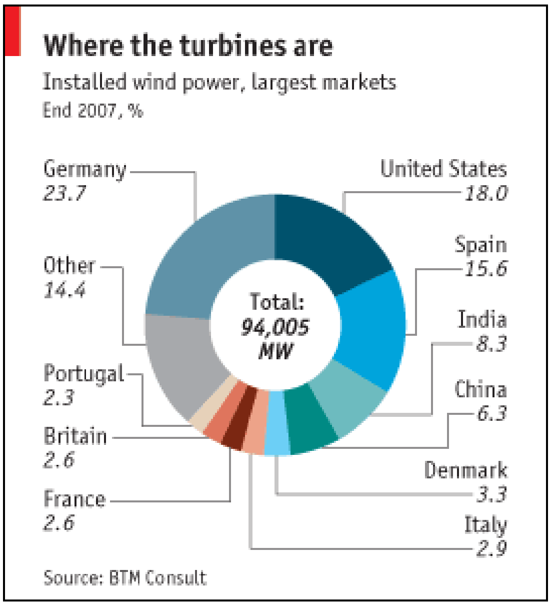
Why the wind blows

When sunlight heats the Earth, it also heats the atmosphere. As hot air rises, cooler, heavier air rushes in to fill its place—thus creating wind. For more than 2,000 years people have captured this energy with windmills and used it to do useful things, such as grind grain or pump water. By the late 19th century, windmills were also being used to produce electricity, mostly in rural areas.

Compared with traditional windmills, however, modern wind turbines are far more efficient. Their rotors are pointed into the wind under computer control, and their blades exploit the phenomenon of aerodynamic “lift” that keeps aeroplanes in the air. Turbine blades are shaped like aerofoils, with one side curved and the other almost flat. This shape causes the air to flow more quickly over the curved side than the flat side, and the fast-moving air results in an area of low pressure on the curved side of the blade, which causes the blade to move and the rotor to turn. The blades are attached to a rotor hub, which is in turn connected to a drive shaft. But this shaft spins quite slowly, so a gearbox is used to get the drive shaft to turn a second shaft at a much higher speed, suitable for spinning a generator to produce electricity. In a wind farm, the electricity from multiple turbines is collected and fed into the grid.

Modern wind power got started after the first oil crisis in 1973, when countries began to look for ways to generate energy from sources other than fossil fuels. Denmark, which was almost entirely dependent on foreign oil for its electricity, was hit particularly hard. But it had one abundant potential energy resource: wind. So, in the mid-1970s, the country embarked upon an ambitious research project to develop the technology.

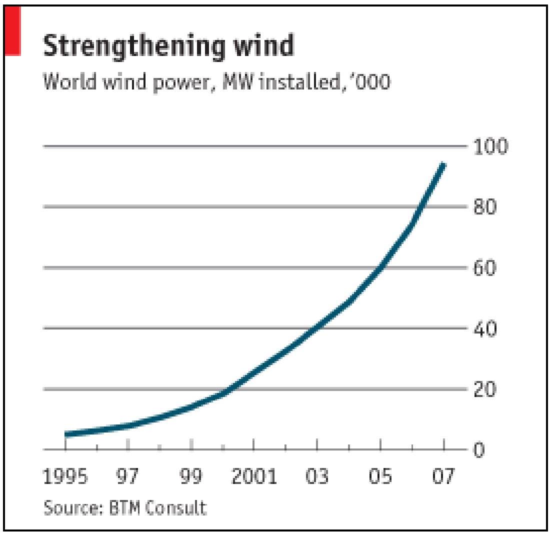
America also began research on wind turbines. With funding from the government, large organisations such as Boeing, an aerospace giant, and NASA, America’s space agency, began designing large, multi-megawatt machines. Because bigger machines with larger rotors sweep a larger area, they can collect more energy from the wind. But many of these big turbines were expensive to operate and maintain.



Entrepreneurs and start-ups also began tinkering with designs that appeared on the American market in the late 1970s and early 1980s. Those machines were much smaller, and there was a wide variety of them, including models with two-bladed rotors spinning about a horizontal axis, and vertical-axis machines. The Danes also experimented with different designs, but by the early 1980s a standard Danish architecture had emerged: the three-bladed, horizontal-axis, upwind machine.

Many of the early turbines had drawbacks. "The vertical-axis machines were not as aerodynamically efficient as the horizontal-axis machines, so they had to sweep out more area to capture the same amount of power and energy," notes Sandy Butterfield, chief engineer at the National Wind Technology Center in Colorado. (Vertical-axis designs are better at coping with variations in wind direction, but their blades are moving against the wind half the time.) Two-bladed rotors also had some disadvantages. Because they are not as dynamically balanced as three-bladed rotors, they are harder to design. They also typically spin faster to extract a similar amount of energy as three-bladed designs, which makes them noisier. And people prefer the look of three-bladed rotors.

The main difference between the American and the Danish designs was that the American machines were structurally softer. "American designs were typically intended to bend with the wind," explains Robert Poore of DNV Global Energy Concepts, a consultancy based in Seattle. Danish machines, by contrast, tended to be rigid and weighed about twice as much. In the early days engineers knew little about the impact of fluctuating winds on turbine structures, and the softer American designs tended to come apart under heavy loads.



Even though the technology was in its early stages, California installed more than 1.2GW of wind power, then almost 90% of global capacity, in the first half of the 1980s—an era that has come to be known as the great "wind rush". The rush was driven by a combination of federal tax credits and generous state incentives for wind power. Previously, wind turbines had been installed as single machines or in small clusters. But during the boom, turbines began to be installed in large arrays, or "wind farms". When the tax credits expired in the mid-1980s, however, America's wind-power industry came to a grinding halt. Many companies went bankrupt, and even some of the Danish firms, such as Vestas, fell on hard times, because they had come to rely on exports to

California. But the Danish three-bladed design had emerged as the industry standard—though much work remained to be done to optimise the machines.

In the early days, wind turbines operated only at fixed speeds. If the wind became too strong, a simple mechanism prevented the blades and rotor from turning any faster. A limitation of this design was that the rotor had to be able to cope with wind fluctuations without being able to adjust its speed, putting enormous stresses on the blades and drivetrain. And to start with, knowledge about the impact of gusts on turbines was limited. To cope with the uncertainty, Danish engineers designed turbines conservatively, making them very heavy for their size.

Spin doctoring

Over the years, however, scientists at Denmark's Risø National Laboratory and other research institutions conducted tests which helped them develop mathematical models that could predict how the components would be affected by stretching, bending and vibration. This enabled engineers to optimise the machines and reduce their weight. By the late 1980s components started to become much lighter, allowing companies to scale up their turbines while keeping weight gain to a minimum.

Around the same time, researchers also started developing ways to manage and reduce the effect of gusts. Turbines equipped with variable "pitch" could adjust the angle of their blades and limit the force with which the wind was able to act on the rotor and the drivetrain, reducing wear and tear. This system worked even better in conjunction with variable-speed turbines, which were developed in the early 1990s. Such machines operate at high efficiency over a wider range of wind speeds, converting more of the wind's kinetic energy into electricity and allowing the rotor to adjust its speed to that of the wind, thus further reducing the impact of gusts on turbine structures.

All these advances have allowed manufacturers to produce ever-larger machines and to build turbines with longer blades for a given output rating. This has several benefits. Since longer blades sweep a larger area and capture more energy from the wind, the turbine produces its rated amount of power at lower wind speeds, and will therefore run at its rated power a higher percentage of the time. And because the drivetrain does not have to be scaled up, the turbine generates more energy for a given cost.

Global wind resources are so vast that they could easily meet the world's current energy needs.

Today's machines extract around 50% of the kinetic energy in the wind—close to the theoretical limit of 59%. However, the scaling up of machines and their components has also caused problems, in particular with gearboxes, which are exposed to lots of vibrations and movements inside the turbines, explains Flemming Rasmussen, head of aeroelastic design at Risø's Wind Energy Department. Enercon, a German firm, has developed a "direct-drive" system with a generator that can operate at low rotational speeds and does not require a gearbox. The problem with that approach is that such generators are very heavy, and tend to be more expensive. The jury is still out on whether this approach is superior, industry insiders say.

Size is everything

Despite some difficulties in transporting, deploying and maintaining large turbines, the industry still believes that bigger is better. Onshore machines are creeping up to about 3MW in capacity, and some offshore turbines on the drawing board are more than twice as powerful. Clipper Windpower, for example, is building a 7.5MW prototype that may turn into a 10MW machine once it reaches commercial production. "When you've spent the money to put in a very expensive foundation in the seabed, it pays to put the largest piece of equipment on top of it which you possibly can," notes Mr Butterfield.

Eyevine

Offshore installations cost around 40% more than onshore ones, which is one reason why only about 1% of wind power is generated offshore at the moment. But Robert Thresher, wind-research fellow at America's National Renewable Energy Laboratory, believes offshore wind has huge potential. Its capacity is expected to increase from 1.1GW in 2007 to 8.2GW in 2012.

If carefully chosen, offshore sites can offer higher wind speeds and less variation. Offshore farms can be positioned near densely populated areas where power is needed. They can also be positioned so that they can barely be seen from land and cannot be heard, which may spark less opposition. (In America many proposed offshore projects have run into resistance from locals who do not want turbines to clutter up the horizon, but in Europe about 20 offshore farms are already operating and many more are planned.) This could set the stage for a comeback by noisier two-bladed designs. According to studies at Risø, two-bladed designs could be about 15% cheaper than equivalent three-bladed turbines.

Wind power has made great progress, but the industry faces new growing pains. “Before it was a one-front war: we had to improve the technology,” explains Dr Thresher. Now that turbines have evolved into sophisticated machines with elaborate control systems, new problems have come into view beyond simply improving their performance. One of these is the need to win greater public acceptance for the technology. As well as complaining that wind turbines spoil the view or make too much noise, opponents of wind turbines also worry about the danger they pose to birds. (Proponents respond that many more birds are killed annually by cats, vehicles and buildings.)

But perhaps the greatest obstacle to the wider adoption of wind power is the need to overhaul the power grid to accommodate it. Transmitting wind power from rural areas with strong winds to populated areas with high demand will require expensive new transmission lines. In addition, the power grid must become more flexible, though some progress has already been made. “Although wind is variable, it is also very predictable,” explains Andrew Garrad, the boss of Garrad Hassan, a consultancy in Bristol, England. Wind availability can now be forecast over a 24-hour period with a reasonable degree of accuracy, making it possible to schedule wind power, much like conventional power sources.

Still, unlike electricity from traditional sources, wind power is not always available on demand. As a result, grid operators must ensure that reserve sources are available in case the wind refuses to blow. But because wind-power generation and electricity demand both vary, the extra power reserves needed for a 20% share of wind are actually fairly small—and would equal only a few percent of the installed wind capacity, says Edgar DeMeo, co-chair of the 20% wind advisory group for America’s Department of Energy. These reserves could come from existing power stations, and perhaps some extra gas-fired plants, which can quickly ramp up or down as needed, he says. A 20% share of wind power is expected to raise costs for America’s power industry by 2%, or 50 cents per household per month, from now until 2030.

Whether or not the 20% goal is reached in America, wind power is poised to make a significant contribution to curbing greenhouse gas emissions. In America alone, about 35% of new electricity-generating capacity in 2007 came from wind power. The IEA projects that by 2030 wind power will produce 14% of the electricity in the European Union, accounting for 60% of its growth in electricity generation (though additional policy measures could increase this share even further). From a zero-fuel-cost, zero-carbon perspective, notes Victor Abate, vice-president of renewables at GE Energy, wind power is currently the most cost-effective and scalable technology available to mankind.