CHAPTER 1

INTRODUCTION TO SMALL-SCALE WIND ENERGY

Humans have harvested energy from the wind for centuries. Prior to the advent of steam-powered ships, for example, Phoenicians, Europeans and others relied on the wind to propel magnificent sailing vessels across a largely uncharted planet. Soon ships became an important mode of transport for raw materials and finished products to and from Europe.

Our predecessors also used wind to assist in food production and to manufacture goods. The windmills of Europe, for example, which were in place 800 to 900 years ago, were used to grind grain into flour to feed Europe's masses. The Dutch used wind to pump water from coastal wetlands, so they could be converted to farmland to grow food.

Wind energy has a long history in North America, too, stretching into the late 1800s. During this period, windmills on tens of thousands of farms in the Great Plains of North America pumped water for livestock, garden sand humans. Without them, many farmers would not have been able to provide sufficient water for their cattle and sheep — or themselves.

Although history books make little mention of it, in the 1920s through the early 1950s many Plains farmers also installed small wind turbines to generate electricity. These electric-generating wind turbines made life on the Great Plains more bearable. Home-grown electricity was used to power lights and a handful of modern conveniences, among them electric

Windmill vs. Wind Turbine

A windmill is a device that drives a mechanical load such as a water pump. A wind turbine or wind generator drives an electrical generator.

toasters, washing machines and radios, all ordered from the Sears catalog. The radio was highly coveted as a way of keeping in touch with the world. Purchasers of a radio were given a discount on their wind generator.

Both wind-electric generators and water-pumping windmills were extremely popular among farmers and ranchers.

In the 1890s, more than 100 manufacturers produced water-pumping windmills in the United States, notes small wind expert Jim Green of the National Renewable Energy Laboratory. According to the US Department of Energy's National Renewable Energy Laboratory, over 8 million mechanical windmills (water pumpers) were installed in rural America, beginning in the 1860s (Figure 1.1). Many of these water-pumping windmills have been restored and are still operating today, providing many years of reliable service with minimal maintenance.

Fig. 1.1: *Water pumping windmills like this one, photographed by Dan on a commercial wind farm in southeastern Colorado, were once common through the West and Midwest. The technology is so good that it hasn't changed in 100 years.*

Wind energy was not only vital to farmers, it was extremely important to railroads in the wild West — a fact largely ignored by historians. Windmills were often used to fill water tanks along tracks to supply the steam engines of early locomotives.

Unfortunately, the use of water-pumping windmills and wind-powered electric generators began to decline in the United States in the late 1930s. The demise of these technologies was due in large part to America's ambitious Rural Electrification Program.

This program, which began in 1937, was designed to provide electricity to rural America. As electric service became available, wind electric generators were mothballed. In fact, local power companies required farmers to dismantle their wind generators as a condition for providing service via the ever-growing electrical grid. The electrical grid, typically referred to as the grid, is the extensive network of electrical transmission lines that criss-cross our nation, delivering electricity generated by centralized power plants to cities, towns and rural customers. A key advantage of the grid was its ability to provide virtually unlimited amounts of electricity to those who had the wherewithal to pay for it. The grid also made it possible to power large motor loads, something that wind/battery systems were unable to do.

Although farmers' lives improved as a result of rural electrification, once-profitable manufacturers of wind-electric generators were driven out of business by the early 1950s. In the mid 1970s, however, wind energy made a resurgence as a result of intense interest in energy self-sufficiency in the United States and elsewhere. This new-found interest in self-reliance was stimulated principally by back-to-back oil crises in the 1970s that resulted in skyrocketing oil prices and a period of crippling inflation in the United States. Extremely generous federal incentives for small wind turbines (a 40 percent US federal tax credit), equally charitable incentives from state governments, and changes in US law that required utilities to buy excess electricity from small renewable energy generators helped spark the comeback. From 1978 to 1985, 4,500 small utility-connected residential wind machines were installed, according to Mike Bergey, whose company Bergey Windpower manufacturers small wind turbines. In addition, approximately 1,000 wind machines were installed in remote locations not connected to the electrical grid.

In short order, however, wind energy's resurgence died, falling victim to economic forces beyond its control. Energy efficiency measures in the United States and new, more reliable sources of oil from Great Britain, Russia and other countries, drove the price of energy downward. These factors, combined with the end of federal and state renewable energy tax incentives and a dramatic shift in the political climate away from renewable energy in the early 1980s, resulted in a precipitous decline in America's concern for energy independence. As a result of these changes, most of the fledgling wind manufacturers went out of business. In fact, six years after the end of the tax credits, virtually all of the 80 or so wind generator companies doing business in the United States disappeared, according to Mick Sagrillo, the small wind energy expert who served as a technical advisor for my writing of this book.

In the 1990s, after nearly two decades of quiescence, commercial and residential wind

Fig. 1.2: *Mick Sagrillo, perched on a tower in this photo, has been in the small-scale wind industry since 1981.*

Rated Power in Watts or Kilowatts

Wind turbines are commonly described in terms of rated power, also known as rated output or rated capacity. Rated power is the instantaneous output of the turbine (measured in watts) at a certain (rated) wind speed and at a standard temperature and altitude. Small wind turbines, the subject of this book, have a rated power of 1,000 to 100,000 watts. One thousand watts is one kilowatt (kW). Small wind falls in the range of one kilowatt to 100 kilowatts. Large wind turbines include all of those turbines over 100 kilowatts. Most larger turbines, however, are one megawatt and larger machines. A megawatt is a million watts or 1,000 kilowatts.

While rated power is commonly used when describing wind turbines, it is one of the least useful and most misleading of all parameters by which to judge a wind generator's performance, for reasons we'll make clear in Chapter 5.

As you study wind energy and other energy systems, you'll commonly hear experts talk about the "capacity" of a wind farm or a wind turbine. They'll talk about a 20-megawatt wind farm. The capacity of a wind turbine is its rated output. If you installed ten 20-kilowatt wind turbines, you would have installed 200 kilowatts of wind generation capacity — that is, 200 kilowatts of electric- producing *potential.* However, these wind machines do not produce this amount of electricity all of the time, only when they're running at their rated wind speed. At their rated wind speed, ten 20-kilowatt wind turbines should produce 200,000 watts of electricity.

energy made another comeback. This most recent rise in the popularity of wind and other renewable energy resources was spurred by deep concern over rising energy prices. However, several other factors have played a significant role in wind's latest resurgence: (1) profound concern for the decline in world oil production, (2) the sharp increase in price of natural gas and declining supplies in the United States and Canada, and (3) concern for global climate change and its costly impacts.

Because of these factors, many proponents of renewable energy believe that this time around, wind energy is here to stay. It's hard to argue with them. Evidence is everywhere. Much to the delight of renewable energy advocates, large commercially operated wind farms are popping up on land and in the sea in numerous countries, most notably the United States, Germany, Spain and Denmark. Commercial wind farms crank out huge amounts of electricity and promise to significantly change the way modern society meets its energy needs.

Today, wind-generated electricity is the fastest growing source of energy in the world (Figure 1.3). In 2006, over 15,000 megawatts of wind capacity were added (capacity indicates the full production of a power source under optimal conditions). In 2007, 20,000 megawatts of capacity was added, according to the Global Wind Energy Council. These additions are more than three times the wind capacity added in 2000 and twelve times the capacity added in 1995.

Although commercial wind farms are responsible for most of the growth in the wind industry, smaller residential-scale wind machines are also emerging in rural parts of America and other countries, supplying electricity to homes, small businesses, farms, ranches and schools (Figure 1.4). Even a few large businesses have installed small wind machines (under 100 kilowatts) to power their facilities. Most of the small-scale wind turbines "feed" the excess electricity they produce back onto the electrical grid.

A handful of wind pioneers have also explored ways to capture the energy of the wind to heat homes, although they have met with very limited success in the marketplace. In addition, many sailboats are equipped with very small wind machines under 1,000 watts — typically referred to as microturbines — to power lights, fans and refrigerators (Figure 1.5). Ranchers and farmers sometimes use wind turbines to supply power to electric fences, stock watering tanks and remote lighting — that is, small dedicated loads to which it is not cost effective to run a power line. I've seen small wind turbines used to power park facilities in remote locations in Alaska.

Wind energy is being tapped to power remote villages in less developed countries, where the cost of stringing power lines from centralized power plants is prohibitive. Wind energy has even found a home in remote sites in some developed countries. In France, for instance, the government paid to install wind

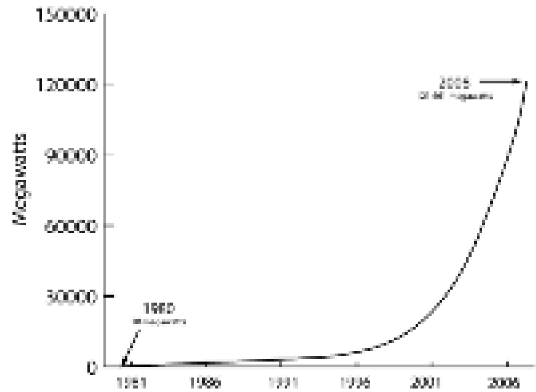

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Fig. 1.3 (above): *Global Wind Energy Capacity. This graph shows the installed global capacity (in megawatts) of commercial wind turbines. In 2007, the global capacity was the equivalent of 188 500-megawatt coal-fired power plants.*

Fig. 1.4 (left): *Small Wind Turbine on Tower. This ARE442 wind turbine installed at Mick's house during a workshop is mounted on a guyed lattice tower. Maintenance is performed by climbing the tower.*

MARLEC

a

DAN CHIRAS

b

Fig. 1.5: *Wind Turbine on Sailboat. (a) Microturbines, such as the one shown here by Marlec, are frequently used on sailboats to charge batteries that supply electricity for loads such as radios, lights, televisions and refrigerators. (b) Microturbines for marine use are designed to withstand the harsh environment. This one is made by Aerogen.*

turbines and solar electric systems on farms at the base of the Pyrenees, rather than running electric lines to these remote operations. Even nomads in Mongolia tote tiny wind machines to provide electricity to their yurts. When they move on every few weeks in search of new pasture for their livestock, their wind machines are packed up and transported on the backs of pack animals.

Wind clearly has a long history of service to humankind, and is on the rise. Proponents say it could become a major source of electricity in years to come.

World Wind Energy Resources

Although wind energy's popularity is at an all-time high, and continues to grow yearly, what is its potential? Can wind become a major source of energy in the future?

Wind is a ubiquitous resource. Although not evenly distributed throughout the world, significant resources are found on every continent. Globally, wind resources are phenomenal. Tapping into the world's windiest locations could theoretically provide 13 times more electricity than is currently produced worldwide, according to the Worldwatch Institute, a Washington, DC-based nonprofit organization that's played a huge role in creating a sustainable future.

In North America, wind is abundant much of the year in the Great Plains and in many northern states. It is also a year-round source of energy along the Pacific and Atlantic Oceans and the shores of the Great Lakes. Tapping into the windiest locations in the United States, for example, in North and South Dakota — or North Dakota and Texas — could produce enough electricity to supply *all* of the nation's electrical needs. Proponents of wind energy, like the Worldwatch Institute, estimate that wind energy could provide 20 to 30 percent of the electricity consumed in many countries. Others believe that wind could provide an even larger percentage.

Could wind provide 100 percent of the world's electrical energy needs?

Yes, it could, theoretically … if we are creative in storing electricity and also transferring it throughout countries via the grid.

Will it?

Probably not.

Other sources of renewable and nonrenewable energy will also play a role in meeting our energy needs.

In the future, however, wind will very likely play a huge role in many parts of the world. Commercial and, to a lesser extent, residential wind turbines will produce enormous amounts of electricity for homes, businesses, farms and ranches. Commercial solar electric facilities and solar-electric systems on homes and businesses could also produce a significant amount of electricity. Solar thermal electric systems, typically referred to as concentrated solar power, operated by large utilities could add to the mix.

The potential of the sun, like that of the wind, is nothing short of phenomenal. It's estimated, for instance, that the sunlight striking an area the size of the state of Connecticut could meet all of the United States' (inefficient and wasteful) electrical demand. Although no one is proposing the construction of such large solar-electric arrays, solar-electric modules on homes, office buildings, schools and commercial solar-electric facilities in the best locations could provide an enormous amount of electricity, supplementing wind energy production (Figure 1.6).

Geothermal and biomass resources could contribute their share as well. Biomass resources refer to plant matter such as wood chips that can be burned directly to produce heat to generate steam to make electricity. Plant matter such as corn can also be converted into gaseous or liquid fuels that can be burned to create electricity. Animal wastes can also be used to generate methane, the main component of natural gas.

Hydropower will continue to do its part in the future, and lest we forget, conventional fuels such as oil, natural gas, coal (burned as cleanly as possible), and nuclear energy will also be part of the mix for many years to come.

Can Wind Do it All?

As Ian Woofenden, wind energy expert, author, and technical advisor to this book points out, "The 'Can wind do it all?' question is a bit of a red herring. "Wind is one piece in the puzzle; nothing is the whole answer. What we need is movement in the right direction. If we don't get all of our energy from renewable sources, the world will not collapse. If we don't start moving in that direction, it might."

Despite what some critics contend, renewable energy, including wind, is here to stay and will likely contribute significantly to our energy future. It has to for the simple reason that fossil fuels are limited. Oil could be economically depleted within 30 to 50 years. Production rates worldwide are on the decline now. Natural gas production could also peak in the not-too-distant future. The sun, however, which powers solar energy systems and creates winds that can be tapped by wind turbines, is going to be around for at least 5,000,000,000 years.

The Pros and Cons of Wind Energy

Wind is a seemingly ideal fuel source that could ease many of the world's most pressing problems. Like all energy sources, wind power has its advantages and disadvantages. Let's look at its downsides first.

Disadvantages of Wind Energy

As you read the downsides of wind energy, you'll discover that many of them pertain to large commercial wind projects. These concerns, in turn, trickle down unfairly to small

DAVID AMSTER

Fig. 1.6: *Solar Array. In a renewable energy economy, large-scale solar electric installations, like this one, will supplement electricity produced by other renewable resources, including wind, hydropower and biomass, as well as conventional fuel sources.*

wind. You'll also see that, while there are valid problems with wind energy, some are perception problems — "problems" that result from misconceptions and deception on the part of opponents. We'll be sure to point these out as we proceed. We'll also counter unfair criticism so you receive a balanced view.

Variability and Reliability of the Wind

Perhaps the most significant "problem" with wind is that the wind does not blow 100 percent of the time in most locations. Like solar energy, wind is a variable resource. A wind turbine may operate for four days in a row, then sit idle for the next two days. In most locations, winds are typically strongest in the fall, winter and early spring, but die down during the summer months.

Wind even varies during the course of a day. Winds may blow in the morning, then die down for a few hours, only to pick up later in the afternoon and blow throughout the night.

Even though wind is a variable resource, it is not unreliable. Just like solar energy, you can count on a certain amount of wind each year. With smart planning and careful design, you can design a wind system to meet some or all of your electrical needs.

Wind's variable nature can be managed to our benefit by installing batteries to store surplus electricity in off-grid systems. The stored electricity can power a home or office when the winds fail to blow — or when demand exceeds the output of the turbine.

Surplus electricity can also be stored on the electrical grid in many systems. That is, when a wind-electric system is producing more power than a home or business is using, the excess can be fed onto the grid. In times of shortfall, electricity is drawn from the grid. (The grid serves as an unlimited battery bank to store excess electricity.) A grid-connected wind system can be designed to meet a small percentage of your electrical needs or all of them. (We'll discuss off-grid and grid-connected systems in more detail in Chapter 3.)

Wind's variable nature can also be offset by coupling small-wind systems with other renewable energy sources, for example, solar-electric systems or micro hydro systems. These are referred to as hybrid systems. Solar-electric systems or photovoltaic (PV) systems generate electricity when sunlight strikes solar cells in solar modules. Micro hydro systems tap the energy of flowing water in streams or rivers near homes and businesses. They convert this energy into electricity. Hybrid systems can be sized to provide a year-round supply of electricity. As you shall see in Chapter 3, residential wind-generated electricity can also be supplemented by small gas or diesel generators.

> "As a power source, wind energy is less predictable than solar energy on a day to day basis, but it is also typically available for more hours in a given day."
>
> — Mike Bergey, Bergey Windpower

Wind's presumed unreliability even comes into question when renewable energy experts compare their systems — for example, when wind is compared to solar electricity. Some experts mistakenly view solar electricity as a more reliable resource than wind. However, the wind is much more predictable than you'd think. To understand what we mean by this, let's look at the capacity factor, a measurement used to compare different electrical generating technologies.

Capacity factor is the ratio of the actual output of a power plant over some period to what its output would have been had it operated at its rated power for the same period. For example, let's suppose you live in an area with four peak hours of sunlight for PV production per day. In this location, the capacity factor for PV would be 4 hours per day divided by 24 hours per day or about 17 percent.

In the lower 48 states, the capacity factor from most fixed PV systems ranges from 8 to 25 percent, depending on the location. According to Mick, the capacity factor of small wind systems ranges from 10 to 28 percent. So, PV and wind systems are fairly similar.

The capacity factor of wind is so high because wind turbines can work day or night — in sunny weather and cloudy weather. What is more, because wind and sunlight are often available at different times, the two technologies can complement each other extremely well. Hybrid systems increase the electrical energy produced at a site; they also reduce the hourly, daily and seasonal variation in output.

Bird and Bat Mortality

Another perceived problem that frequently arises in debates over wind energy is bird and bat mortality. Unfortunately, this issue has been blown way out of proportion for both small and large wind turbines. Although a bird may occasionally perish in the spinning blades of a residential wind machine, this is an extremely rare occurrence. Ian is aware of only one instance of a bird kill, when a hawk flew into a small wind turbine. "Because of their relatively smaller blades and short tower heights, home-sized wind machines are considered too small and too dispersed to present a threat to birds," notes Mick in his article, "Wind Turbines and Birds" published by Focus on Energy, Wisconsin's Renewable Energy Program.

The only documented bird mortality of any significance occurs at large commercial-scale wind turbines — but even then, the number of deaths is extremely small. In our view, the argument that wind energy development should be halted because of bird kills is ill-informed, or sometimes a dishonest ploy by individuals and organizations that oppose wind energy development. If citizens and governments were serious about bird kills, we'd ban the truly lethal forces discussed in the accompanying box: domestic cats, utility transmission towers, cars, pesticides and windows. We'd even prohibit farming, which destroys bird habitat and poisons birds with pesticides.

Studies also show that while bats are killed by large commercial wind turbines in certain locations, such occurrences are rare. According to researchers, large wind turbines in certain locations kill, on average, 2.45 to 3.21 bats per year.[1]

While bat deaths, like bird deaths, are regrettable, there's no indication that bat populations in the vicinity of large or small wind turbines are in any way threatened by them. Other factors play a much larger role in bat mortality, including pesticides, habitat destruction,

Bird Kills from Commercial Wind Farms: Fact or Fiction?

While commercial wind machines do kill a small number of birds, scientific studies show that the problem has been grossly exaggerated. These studies indicate that bird kills from large commercial wind turbines pale in comparison to deaths from several common sources, among them domestic cats, electric transmission lines, windows, pesticides, motor vehicles and communication towers (Table 1-1). Worldwide, hundreds of millions of birds — perhaps even billions — are killed each year by these sources. Commercial wind turbines, on the other hand, kill a miniscule number of the birds. So why has wind gotten such a bad reputation?

Table 1.1
Estimated Annual Bird Death in the United States by Source

Activity/Source of Bird Mortality	Estimated Annual Mortality
Killed by cats	270 million or more
Collisions with and electrocution by electrical transmission wires	130 to 170 million
Collisions with windows	100 to 900 million
Poisoning by pesticides	67 million
Collisions with motor vehicles	60 million
Collisions with communications towers	40 to 50 million

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lighthouses, communication towers, power lines, fences and human disturbance during hibernation. For more on this topic, check out Mick's article "Bats and Wind Turbines" published in the February 2003 issue of AWEA's *Windletter*.

Wind machines got a bad rap from one of America's oldest and largest wind farms: the Altamont Pass Wind Resource area in California. Located just east of San Francisco, Altamont Pass is home to a mind-boggling 7,000 wind turbines. It is also the habitat of numerous raptors. Soon after the wind turbines were erected, the birds began to perch on the wind towers in search of abundant prey (ground squirrels and other rodents) that live year-round in the grasses at the base of the towers. Some raptors died as they flew into the blades of the turbines toward prey on the ground.

A two-year study of bird kills in the region revealed only 182 dead birds in that time. While any raptor death is of concern to those of us who cherish wildlife, the death rates at Altamont from wind machines are insignificant compared to those from other factors.

Cats are probably the most lethal force that birds encounter. According to one study, a feral cat kills as many birds in one week as a large commercial wind turbine does in one to two years. Declawing a cat doesn't seem to help much. According to one researcher, the majority of cats (83 percent) kill birds, even declawed and well-fed cats prey on wild birds. Neutering or spaying a cat does not seem to cut down on hunting, either. With more than 64 million cats in America alone, what's the total loss?

No one knows for sure, but if the situation in Wisconsin is indicative of the national toll, America's bird population is being decimated by our furry feline companions. In Wisconsin alone, researchers estimate that cats kill approximately 39 million birds per year. Nationwide, the number is estimated to be around 270 million, and is very likely much higher. "Even if wind were used to generate 100 percent of US electricity needs, at the current rate of bird kills, wind would account for only one of every 250 human-related bird deaths," notes the AWEA.

Another 130 to 174 million birds die each year as a result of collisions with or electrocution by electrical transmission lines that crisscross the nation. Many victims are raptors, waterfowl and other large birds, electrocuted when their wings bridge two hot wires.

Another 100 million to 900 million birds perish after flying into windows, mostly in rural areas, according to another report.

Pesticides kill an estimated 67 million birds each year. Scientists estimate that about 60 million birds die each year in the United States after being struck by motorized vehicles, according to the American Wind Energy Association's report "Facts about Wind Energy and Birds."

Yet another 40 to 50 million birds perish after flying into communications towers and the guy wires that support them. Studies of one television transmitter tower in Eau Claire, Wisconsin, showed that it killed over 1,000 birds a night on 24 consecutive nights. This same tower killed a record 30,000 birds one evening! A similar tower in Kansas killed 10,000 birds in a single evening.

Another 1.25 million die as a result of collisions with tall structures such as buildings, smokestacks and towers.

Clearly, the Altamont Pass wind farm is benign compared to a host of other lethal factors. Altamont is also an isolated case. No other wind farm in the United States experiences mortality rates remotely close to Altamont Pass. Why?

Contemporary wind developers have been selecting sites for new wind farms that are out of migratory pathways. Improvements in the design of commercial wind turbines have also helped to minimize bird kills at commercial wind farms. Over the years, wind machines have gotten taller, blades have gotten longer, and the speed at which the blades rotate has declined substantially. These large, slow-moving blades are more easily avoided by birds. Ever-larger commercial wind machines currently under development could reduce the risk even more.

As shown by the graph below, large commercial wind turbines are an extremely minor source of bird mortality.

"Double the number of turbines," Mick adds, "and we're up to 0.02 to 0.04 percent. Increase the number by 1,000 percent and we're up to 0.1 percent! How many birds does habitat destruction such as mountain top removal to mine for coal kill — forever?!?"

To learn more about efforts to further reduce bird deaths, check out "Facts about Wind Energy and Birds" at the American Wind Energy Association's website, awea.org. Mick has written several articles on the topic, which you can check out at renewwisconsin.org. On the lower left, click on "Small Wind Toolboxes."

Aesthetics

Another downside of wind turbines is that some people don't like the look of them or believe that wind turbines detract from natural beauty. While some individuals object to the sight of a residential wind turbine or a commercial wind farm, others find them to be things of great beauty. Ironically, those who find wind turbines to be unsightly often ignore the great many forms of visual blight that litter our landscape, among them cellphone towers, water towers, electric transmission lines, radio towers and billboards. To be fair, there are differences between a wind tower and common sources of visual pollution. For one, wind turbines with their spinning blades call attention to themselves. Another is that we've grown used to the ubiquitous electric lines and radio towers. As a result, many often fail to see them anymore. Yet another difference is that the structures we ignore are often ones that were erected without public consent. That is, they were exempt from public hearings. People had no choice in their placement and have eventually grown used to them.

Given the opportunity to oppose a structure in their viewshed — for example, at a public hearing required for permission to install a residential wind system — Mick points out that many neighbors are quite willing to speak up in opposition. As he notes in an article on aesthetics in AWEA's *Windletter*, "anyone who has tried to deal with aesthetics in a public

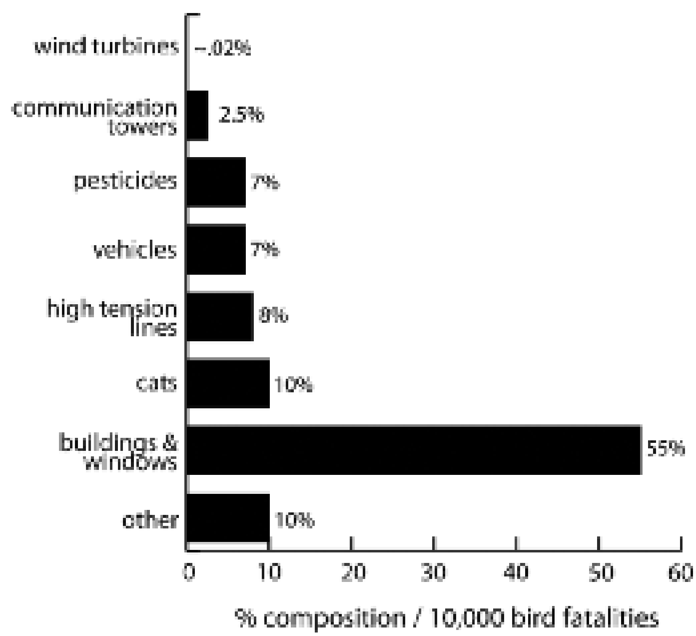


Fig. 1-7: *This graph shows the relative number of bird deaths from various sources. Note that wind turbines are responsible for only a tiny portion of total annual bird deaths.*

Wallace P. Erickson; Western EcoSystems Technology, Inc.

hearing knows only too well why art has never been created by committee."

While the battle continues over commercial wind development and individual battles arise as homeowners or business owners attempt to install small-scale wind to meet their needs, it may be comforting to those who support wind to learn that when windmills were first introduced into Holland, they were looked upon by some with distaste. Another case in point: a large commercial-sized wind machine recently built at the Portsmouth Abbey School in Rhode Island drew criticism at first, but is now widely loved by residents of the community. In Chapter 10, we'll discuss ways individuals can help prevent and overcome opposition from neighbors based on aesthetics.

An Opposing View

"I think that the goal should be to site wind turbines near homes without fear," Ian argues. "It's better to build relationships with your neighbors, and get them excited about renewable energy. Then the question will be 'Will I be able to see the blades spin?' not 'Must I look at it?' Some wind energy users," he adds, "share electricity with neighbors during utility outages, which builds interest and appreciation." Working out an arrangement like this in advance may help overcome barriers with reluctant or skeptical neighbors and win their support. When dealing with neighbors, remember that many of them share your excitement for renewable energy. Many people would love to reduce their electric bill or achieve greater energy independence, or just enjoy the coolness factor that owning a wind turbine brings, but not all can. "Your neighbors can be cool by association," Ian notes, "if you do the PR in advance."

Proximity to Homes and Property Values

Critics do raise legitimate concerns when it comes to the placement of wind machines near their property. Although most of the issues over proximity have been raised by individuals and groups that oppose large commercial wind farms, residential systems can also cause a stir among neighbors. Some may be concerned about aesthetics. Others may worry about safety.

To avoid problems, we recommend installing machines, whenever possible, in locations out of sight and hearing of sensitive neighbors. Although tower collapse is an extremely rare event and always the result of bad design and improper installation and homeowner's insurance should cover damage to individuals and property, it is best to place a wind turbine and tower away from your neighbors' property lines. This could help overcome objections.

Unwanted Sound

Opponents of wind energy and apprehensive neighbors sometimes voice concerns about unwanted sound, aka noise, from residential wind machines. Small wind turbines do produce sound and as the wind speed increases, sound output increases.

Sound is produced primarily by the spinning blades and alternators. The faster a turbine spins, the more sound it produces.

Individuals can reduce unwanted sound by selecting quieter low-rpm wind turbines. As we point out in Chapter 5, high-rpm wind turbines tend to be louder than low-rpm units. If you are concerned about sound, make this a high priority as you shop for a turbine and let your neighbors know this is an issue to which you are sensitive.

Wind turbines also come with governing mechanisms, systems that slow down or even turn off the machines, when winds get too strong, to protect them from damage. Different governing systems result in different sound levels. (We'll discuss this topic in Chapter 5.) When researching your options, we recommend that you listen to the turbines you're considering buying in a variety of wind conditions, including those that require governing.

Besides buying a quieter wind turbine to reduce sound, it's also important to mount your turbine on a tall tower. Suitable tower heights, which we'll discuss later, are usually at least 80 to 120 feet. A residential wind turbine mounted high on a tower catches the smoother and stronger — and hence most productive — winds. This strategy also helps reduce sound levels on the ground. Part of the reason for this is that sound dissipates quickly over distance. (For mathematically inclined readers, sound decreases by the square of distance.)

Residential (and commercial) wind machines are also much quieter than many people suspect because the sounds they make are partially drowned out by ambient sounds on windy days. Rustling leaves and wind blowing around one's ears often drown out some of the sound produced by a residential wind turbine.

Sound is measured in two ways — by loudness and frequency. Loudness is measured in decibels (dB). Frequency is the pitch. A low note sounded on a guitar has a low frequency or pitch. A high note has a high frequency. Interestingly, the average background noise in a house is about 50 dB. Nearby trees on a breezy day measure about 55 to 60 dB. According to Mick, "Most of today's residential wind turbines perform very near ambient levels over most of their effective operating range." However, even though the intensity of a sound produced by a wind generator may be the same as ambient sound, the frequency may differ. As a result, wind turbine sounds may be distinguishable from ambient noises, even though they are not louder.

> "Remember that sound is very subjective — what to some might be irritating is the pleasant sound of renewable energy at work to others."
>
> —Ian Woofenden

"Today's home-sized wind turbines typically operate from just below to just above ambient environmental sound levels at their loudest when governing," he adds. "This means that while the sound of a wind turbine can be picked out of surrounding noise if a conscious effort is made to hear it, home-sized wind turbines are by no means the noisy contraptions that some people make them out to be."

For more on sound, you may want to read Mick's article, "Residential Wind Turbines and Noise" in the April 2004 issue of AWEA's *Windletter*. We'll also spend more time on this topic in Chapter 5 on wind turbines and will discuss strategies for addressing sound issues at zoning hearings in Chapter 10.

SHAWN SCHREINER

Fig. 1.8: *Perched on top of this 168-foot tower is wind energy expert, author, and workshop teacher Ian Woofenden who served as a primary technical advisor on this book. This extremely tall tower raises the turbine well above the trees that carpet the island where Ian lives, allowing access to the wind and permitting excellent performance.*

Site Specific

Yet another criticism of wind that's of great importance to small wind systems is that it is more site specific — or restricted — than solar energy.

To understand what this means, we begin by pointing out that there are good solar areas and good wind areas. In a good solar region, most people with a good southern exposure can access the same amount of sun. In a windy area, however, hills and valleys or stands of trees can dramatically reduce the amount of wind that blows across a piece of property. Therefore, even if you live in an area with sufficient winds, you may be unable to tap into the wind's generous supply of energy because of topography or vegetation like tall stands of trees. That's what critics mean when they say that wind energy is more site specific.

That said, we'd be remiss if we did not point out that solar resources also vary. If you live in a forest, you'll have less solar energy than a nearby neighbor whose home is in an open field. In addition, we should point out that homeowners can access the wind at less-than-optimum sites by installing turbines on tall towers. Ian, for example, recently installed an ARE110 turbine, made by Abundant Renewable Energy in Oregon, in a densely forested island in the Pacific Northwest. He made it work by installing the turbine on a 168-foot tower well above the tops of the trees. Tall towers help us overcome topographical and other barriers.

We'd also be remiss not to mention that wind can be augmented or "magnified" at a site. That is, an individual can harvest more wind energy at a site by increasing tower height. As Mick points out in his wind energy workshops, you can't make a location sunnier, but by increasing tower height you can move a turbine into higher velocity winds and achieve much greater output.

Ice Throw

Like trees and powerlines, wind turbines can ice up under certain conditions. Ice buildup and possible ice throw and the dangers they pose are issues that may arise during hearings on residential wind turbines.

While ice builds up on blades in ice storms, it is typically deposited on turbines and towers in very thin sheets. When the blades are warmed by sunlight, however, the ice tends to break up into small pieces, not huge and potentially dangerous chunks.

Ice buildup on the blades of a wind turbine also dramatically reduces the speed at which a turbine can spin.[2] It's a little like trying to drive a car with four flat tires. As a result, ice is not thrown great distances; it tends to fall around the base of the tower — just as it does from trees and power lines.

Any prudent person would be advised to stay away from the tower base when ice is shed from the blades, as they would from ice falling from trees or power lines. Ice-laden trees are also considerably more dangerous, as ice-coated branches can and often do break and fall to the ground, damaging power lines and cars or houses. Entire trees can topple as a result of ice buildup.

On the rare occasion that ice builds up on a wind turbine, experienced wind turbine operators shut down their machines until the sun or warmer temperatures melt the ice since they cannot generate electricity spinning at such low rpms anyway.

Interference with Telecommunications

Some opponents of wind energy also raise the issue of interference with telecommunications signals.

While there are a few reports of large-scale wind turbines causing interference with television reception, these problems arose because the turbines were installed directly in the line of sight between the TV transmitter and a residential antenna. The spinning blades chopped up the signal, causing flickering on televisions. Interference represented isolated cases and was easily corrected by installing larger antennas or signal boosters.

With small wind turbines, interference is extremely unlikely. Turbines for homes and small businesses have small blades that do not interfere with such signals. The blades of modern wind turbines are also made out of materials that are unlikely to cause problems. Unlike the metal blades of years past which can reflect TV signals, the fiberglass and plastic blades in use today are "transparent" to telecommunications signals.

As a case in point, we should note that small wind turbines are often installed to power remote telecommunications sites. The US-based company, Abundant Renewable Energy, which manufactures two wind turbines, mounted their Internet receiver/transmitter on their wind turbine tower. Telecommunication equipment wouldn't be installed in such locations if there was a problem with interference.

Photoepilepsy and Strobing

Yet another issue that may be raised from time to time by concerned neighbors or opponents of wind energy is the possibility of shadow flicker from wind turbines stimulating epileptic seizures in individuals who suffer from photosensitive epilepsy. This is an extremely rare type of epilepsy in which seizures are triggered by flickering or flashing light.

This concern, most often raised by opponents of large commercial wind turbines, but occasionally raised at zoning hearings for small wind turbines, is not just overblown, it's not even true. According to researchers, there's never been a case of epileptic seizure triggered by a wind turbine in human history.

While blades of small turbines may form small and rather vague shadows, it is difficult to see the shadow of individual blades due to the speed with which the blades spin. As Jim Green notes, "The rotors of residential-scale wind turbines, 10 kilowatts and smaller, essentially become transparent at typical operating speeds because the blades spin faster than the eye can detect."

The true test of this issue's serious may come from installers and dealers. Mike Bergey of Bergey Windpower, for example, has never received a complaint about shadow flicker from customers or neighbors of the more than 3,000 turbines his company has sold over more than two decades.

Property Values

Opponents of wind farms often raise the specter of declining property values, despite the lack of any evidence to support their assertions. Nonetheless, concerns over property values often arise in zoning hearings over small wind turbines. As Mick puts it, the rationale is that the neighborhood viewshed will be compromised as a result of the installation of a home-sized wind turbine. Neighbors worry that they will not be able to sell their property for its true value.

While wind turbines on tall towers are visible, lots of other tall structures like silos, barns, high-power transmission lines, water towers and cell phone towers are present in rural environments where residential and small business wind systems are typically installed. Small wind systems are often much less visible than these structures.

Moreover, we've never heard of an instance in which a residential wind turbine adversely affected the value of a neighbor's property. For the system owner, a wind turbine could increase property values, in part as a result of reduced utility bills.

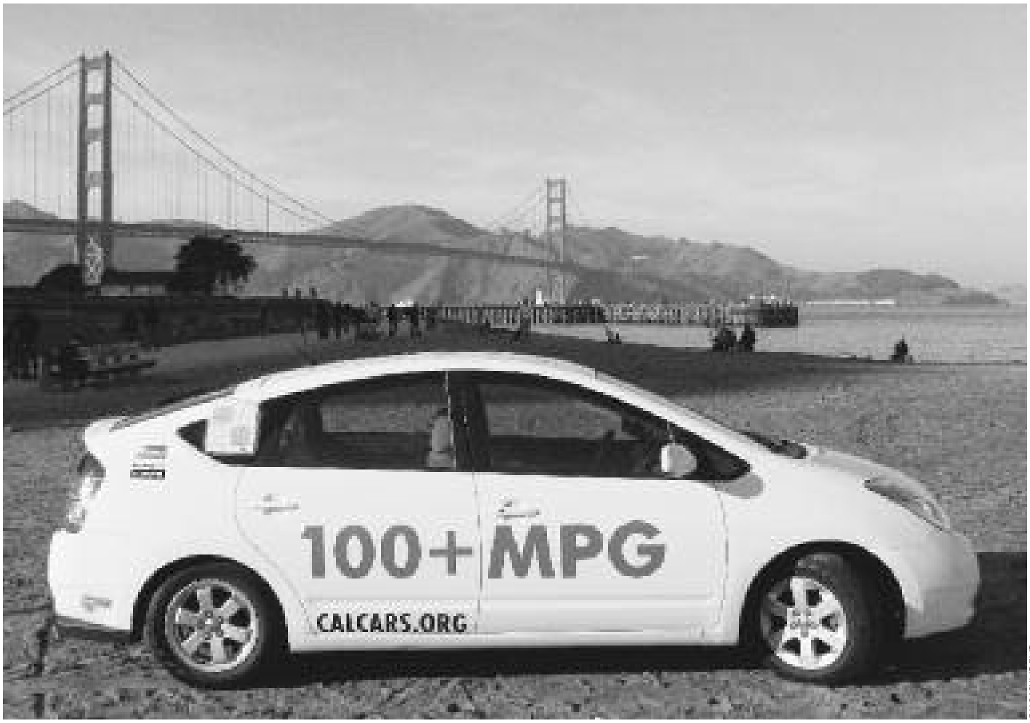
The Advantages of Wind Energy

Although residential wind turbines and their energy source, the wind, have their downsides, many features make them well worth considering. To begin with, wind energy is an abundant and renewable resource. We won't run out of wind for the foreseeable future, which stands in stark contrast to the future of oil and natural gas.

Small-scale and large-scale wind energy could help decrease our reliance on declining and costly supplies of oil. Electricity generated by wind, for instance, could be used to power electric or plug-in hybrid cars and trucks in areas with abundant wind resources, displacing gasoline, which is refined from oil.

Wind energy — both large and small — can also play a meaningful role in offsetting declining US natural gas supplies. In the United States, approximately 18 percent of all electricity is currently generated by natural gas, according to the US Department of Energy. As supplies continue to decline, wind could help ease the crunch, supplying a growing percentage of our nation's electrical demand long into the future.

Wind could even replace nuclear power plants the world over. Nuclear power plants generate about 20 percent of America's electricity, and substantially higher percentages in countries such as France. Although wind energy does have its impacts, it is a relatively benign



CalCars.org

Fig. 1.9: *Electric cars and plug-in hybrids like the one shown here are the most promising automobile technologies on the horizon.*

technology compared to fossil fuel and nuclear power plants. Because of this, it could help all countries create a cleaner and safer energy future at a fraction of the cost and impact of conventional electrical energy production.

Another benefit of wind energy is that, unlike oil, coal and nuclear energy, the wind is not owned by major energy companies. The cost of wind is not subject to price increases, protecting us from price gouging by commodity traders and multinational corporations. Price hikes caused by rising fuel costs are not probable in a wind-powered future. However, this is not to say that wind energy is immune to the rising price of fossil fuels. As Ian notes, while the fuel itself (the wind) will not increase in price, the price of wind generators is likely to increase as traditional fuel prices rise. That's because it takes energy to extract and process minerals to make the steel and copper needed for wind turbines and towers. It also takes energy to make turbines and towers and ship and install them.

Another huge benefit to consider is that wind could also be used to power electric and plug-in hybrid vehicles, helping nations wean themselves from their costly oil addiction, clean up their air, and halt global warming.

An increasing reliance on wind energy could also ease political tensions worldwide. If we free ourselves from Middle Eastern oil we won't need costly military operations aimed, in part, at stabilizing a region where the largest oil reserves reside. We'll likely never fight a war over wind energy resources. Not a drop of human blood need be shed to ensure a steady supply of wind energy to fuel the economy.

Yet another advantage of wind-generated electricity is that it uses existing infrastructure, the electrical grid, and existing technologies like electric toasters, microwaves and so on. A transition to wind energy could occur fairly seamlessly.

Individuals can also meet all or part of their energy needs in rural areas with good wind resources at rates that are competitive with conventional electricity. In remote locations, wind or wind and solar electric hybrid systems may be cheaper than conventional power delivered through newly installed and costly electric lines from the utility grid.

Finally, lest we forget, wind is a clean resource. Wind energy will help homeowners and businesses do their part in solving costly environmental issues such as acid rain and global climate change. As Mick points out in his workshops, the average home in the United States consumes 900 kilowatt-hours of electricity per month. Replacing the electricity generated by a coal-fired power plant with wind-generated electricity will reduce a family's consumption of coal by approximately 5.5 tons per year. This,

Dan Chiras

Fig. 1-10: *Wind turbines like these in central Kansas are typically sited to reduce mortality and, as explained in the text, are responsible for only a tiny portion of total annual bird kills. The real culprits are cats, buildings, cell phone towers, cars and trucks, and pesticides.*

in turn, will reduce the emission of carbon dioxide by about 11 tons per year. It will also reduce mercury emissions. You couldn't ask for more reasons to justify a switch to wind energy.

Wind energy also provides some substantial economic benefits. In 2007, for instance, nine billion dollars was invested in US wind farms, according to the American Wind Energy Association. Wind also creates more jobs per kilowatt-hour generated than other type of power plant. It also concentrates economic benefits locally, within states or communities. And wind power does not require extensive use of water, an increasing problem for coal, nuclear and gas-fired power plants, particularly in the western US and other drought-stricken areas.

The Purpose of this Book

This book's principal focus is on small wind-electric systems. As noted earlier, the rated output of small wind turbines ranges from 1 kilowatt to 100 kilowatts. Most of the turbines we'll be discussing fall in a range from 1 kilowatt to 20 kilowatts. The blades of small turbines (1 to 100 kilowatts) run from 4 feet to 32 feet in length. Small-scale wind systems serve a variety of purposes. The smaller units are sufficient to power cabins and cottages and larger turbines power homes, small businesses, schools, farms, ranches, manufacturing plants and public facilities. Throughout this book, we'll refer to these applications as small wind systems or small-scale wind systems, sometimes even residential and business wind energy systems, to avoid having to repeat the long list of applications.

This book is written for individuals who want to learn about small-scale wind systems. It is also written for those who aren't particularly well versed in electricity and electronics. You won't need a degree in electrical engineering, renewable energy, or physics to make sense of the material covered in this book.

The overarching goal in writing this book was to create a user-friendly book that teaches readers the basics of wind energy and wind energy systems. We should point out emphatically that this book is *not* an installation manual. It will not turn you into a wind energy installer or equip you to install a wind turbine and tower on your own. It will, however, help you determine if wind energy is right for you. When you finish reading and studying the material in

"Envision a future in which distributed (small) wind power is *embraced* in the local landscape because it *expresses community support* for clean air, reduced carbon emissions and strong local economies through use of a sustainable, indigenous energy source."

— Jim Green, National Renewable Energy Laboratory

True North Power Systems.

Fig: 1-11: *Small wind turbines like this one from Canada's True North Power Systems are rarely, if ever, responsible for bird deaths.*

this book, you'll know an amazing amount about wind and wind energy systems. You will have the knowledge required to assess your electrical consumption as well as the wind resource at your site, to determine if wind will meet your needs.

When you are done with this book, you should have a good working knowledge of the key components of wind energy systems, especially wind turbines, towers, batteries and inverters. In keeping with our long-standing goal of creating knowledgeable buyers, this book will help you know what to look for when shopping for a wind energy system. You'll also know how wind machines are installed and their maintenance requirements.

If you choose to hire a professional wind energy expert to install a system, a route we highly recommend, you'll be thankful you've read and studied the material in this book. The more you know, the more input you will have into your system design, components, siting and installation — and the more likely that you'll be happy with your purchase.

In keeping with another long-standing goal of ours, this book should also help readers develop realistic expectations. We believe that those interested in installing renewable energy systems need to proceed with their eyes wide open. Knowing the shortcomings of wind energy — or any renewable energy technology, for that matter — helps avoid mistakes and prevents disappointment often fueled by unrealistic expectations. Wind energy systems, for instance, require annual inspection and maintenance — climbing or lowering a tower to access the wind turbine to check for loose fasteners and blade damage and, much less commonly, an occasional part replacement. If you are not up for it or don't want to pay someone to climb or lower your tower once or twice a year to check things out, you may want to invest in a solar-electric system instead.

Organization of this Book

Now that you know a little bit about the history of wind energy, the pros and cons of this clean, renewable energy source, and the purpose of this book, let's start our exploration. We'll begin in the next chapter by studying wind, the driving force in a wind energy system. You will learn how winds are generated and explore the factors that influence wind flows in your area.

In Chapter 2, we will also explore the factors that affect energy production by a residential wind turbine. We call this the mathematics of wind energy. The math isn't difficult, and this discussion will demonstrate how the proper design and placement of a wind machine can result in dramatic increases in electrical output. When you finish, you will understand why it is important to mount a wind machine as high as you can and out of the way of obstructions that reduce wind speed and create turbulence when the winds blow. This advice could make the difference between a successful wind venture and a costly failure.

In Chapter 3, we'll explore wind energy systems. You'll learn the three types of residential wind energy systems: (1) off-grid, (2) batteryless grid-tie, and (3) grid-connected with battery backup. You'll also learn about the basic components of each one. We'll also look at hybrid wind systems.

Chapter 4 explores the feasibility of tapping into wind at your site. We'll teach you how to assess your electrical energy needs and how to determine if your site has enough wind to meet them. You'll learn why cost-effective energy efficiency measures that reduce your electrical demands will save you heaps of money when buying a wind energy system. You'll also learn ways to evaluate the economics of a wind system.

Chapter 5 introduces you to wind turbines. You'll learn about the different types of wind turbines and how they work. We'll also give you shopping tips — what to look for when buying a wind turbine. We'll even spend a little time looking at ways to build your own wind generator.

Chapter 6 describes three basic tower options. You will learn how towers and guy wires (used to support certain types of towers) are anchored. We'll underscore the importance of mounting a wind machine high above the ground — out of turbulent ground-level air and dead air zones and into the much smoother and more powerful winds that blow higher up. We'll also look briefly at how towers are installed.

In Chapter 7, we'll tackle storage batteries, one of the key components of off-grid wind systems. You will learn whether you will need a battery bank and, if so, what kind of batteries you should install. You will learn about battery care and maintenance and ways to make your life with batteries much easier. You'll benefit from our combined decades of experience with battery systems as we point out common mistakes and ways to avoid them. You will also learn about battery safety and how to size a battery bank for a wind energy system.

Chapter 8 addresses another key component of wind energy systems, the inverter. You will learn how inverters work, what functions they perform, and what to look for when shopping for one.

In Chapter 9, we'll give a brief overview of wind energy system maintenance. Because each wind machine and tower is different, we won't go into specifics. We will, however, underscore the importance of regular inspection and maintenance and describe some of the most common things you'll have to do to keep your wind energy system performing optimally.

With this information in mind, in Chapter 10 we'll explore a range of issues such as homeowner's insurance, financing renewable energy systems, obtaining building permits and electrical permits, and zoning issues.

Finally, this books ends with a fairly comprehensive resource guide. It contains a list of books, articles, videos, associations, organizations, workshops and websites on residential wind energy.

What do you say — shall we get started?