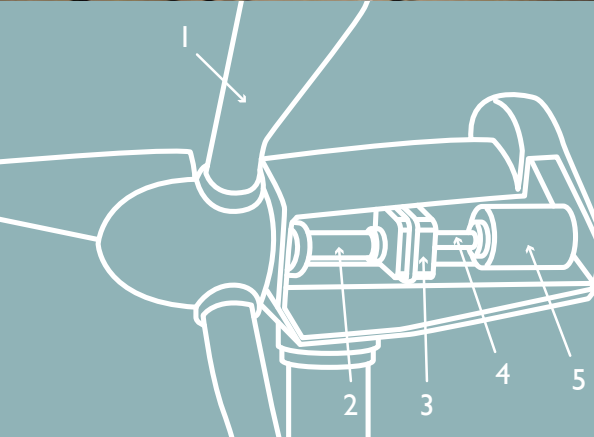


WindWise Education

Wind Energy Activities for Students

Grades 6–12



www.KidWind.org

3rd Edition

Introduction

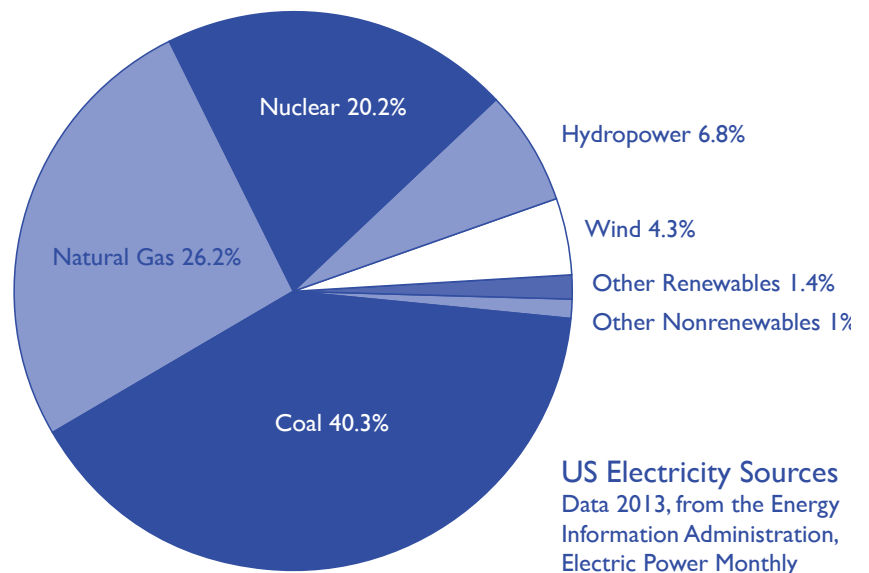
WHY WIND?

We tend to take for granted where our electricity comes from. We expect that when we flick the switch, the lights will come on. Behind that switch are billions of dollars of investment and thousands of people making sure that it is just as simple as that—flicking the switch.

Between 2009 and 2013, wind power comprised 31 percent of all new energy installations in the US (AWEA). As investors and power producers look to build new power infrastructure, they are looking to build wind farms at an increasing rate.

Of our current generation mix, over 4 percent of our energy is generated by the wind.

The US wind industry now totals 62,300 megawatts (MW = 1,000,000 watts) of cumulative wind capacity through the end of the third quarter of 2014. Some industry leaders believe that by the year 2030 we will get 15–20 percent of our energy from the wind. Reaching this goal will take great effort and lots of scientists, engineers, and technicians.

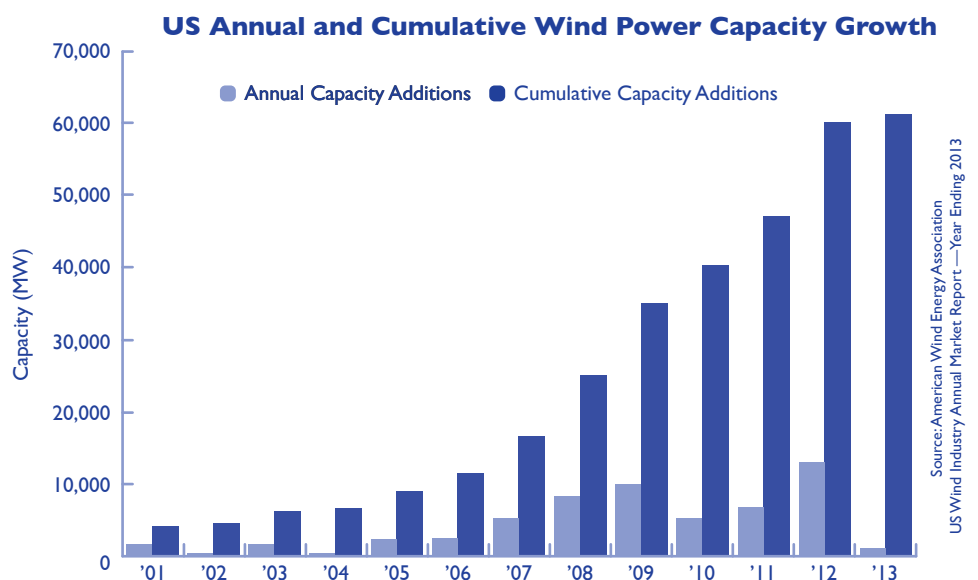


Why are we seeing more wind?

Per capita average consumption of electricity in 2013 was approximately 12,000 kWh. This is seven times higher than in 1949. Predictions are that US consumption will increase 1–2% a year for the next 20 years due to population and consumption changes (Department of Energy).

In many states, there is a drive to meet this increasing consumption by reducing overall demand (efficiency and conservation) and by generating electricity using cleaner technologies like wind, solar, and biomass.

Why this push for renewable sources of electricity? States and local governments are reacting to public pressure to reduce negative environmental impacts to air, water, and wildlife from coal, nuclear, and large hydropower generation. Based on data from the Intergovernmental Panel on Climate Change (IPCC), many state and regional governments are convinced that they need to significantly reduce the amount of carbon that is being pumped into the atmosphere. If they do not make radical changes, they



feel that their constituents will be adversely impacted by climatic change.

To convince power producers to build renewable energy facilities, over 30 states have enacted Renewable Portfolio Standard (RPS) legislation. These laws mandate that a specific percentage of electricity must come from renewable resources by a specific date. For example, in New York, the RPS mandates that 29 percent must come from renewable sources by 2015. These mandates are creating a huge market for renewable clean energy in the states where they have been enacted. Currently there is no national level RPS legislation, but there is a push to make that a reality.

Decreasing wind energy costs

As investors seek to build new renewable energy infrastructure, they look for the cheapest option. As of right now the cheapest, most mature utility scale option is wind energy. As you can see from the graph, in 2014 wind energy is one of the most affordable renewable energy options with a low carbon footprint.

The reduction in the cost of wind energy production is significant and has been realized through investment advances in wind energy technology. Investment returns in large wind farms have also been helped by significant government financial incentives to help offset the high initial capital cost of a wind farms.

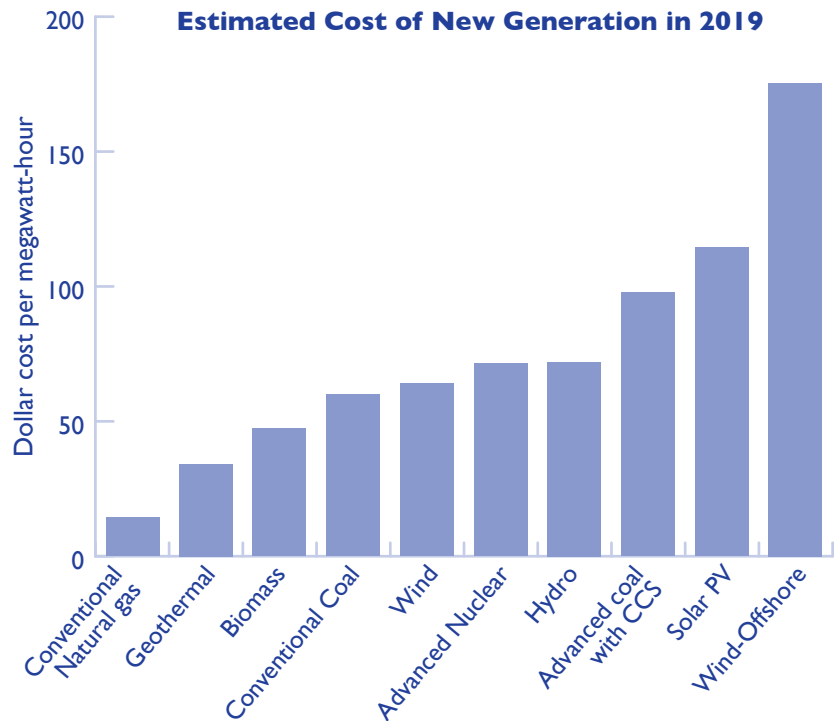
Wind energy is not free; a large wind farm may cost \$200 million to build, but the fuel is free. In a world where fuel prices have only one direction to go, wind is pretty interesting to investors and consumers.

Over the next 5–10 years, we are going to see many more wind turbines on the landscape. How dramatically this impacts the reliability and cost of electricity will depend on a variety of factors. The next few sections will help you understand the promise and challenges that face wind energy today.

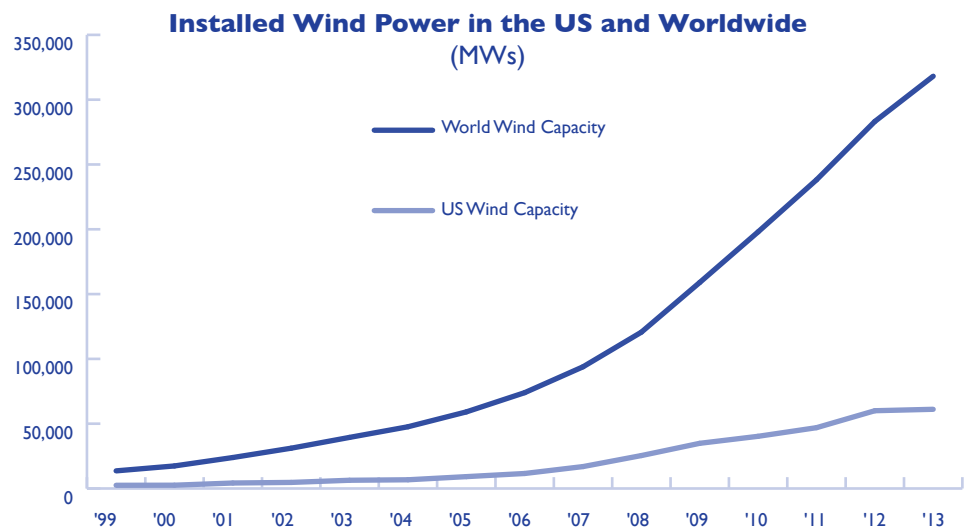
Wind in the US and worldwide

Wind power has seen rapid growth over the past 20 years. In 1990, wind energy had the capacity to produce 1,930 MW worldwide. About 76% of this installed capacity was located in the United States (1,484 MW). The vast majority of these wind turbines were located in California. By the beginning of 2014, installed wind capacity world wide had increased to 318,105 MW or 318 GigaWatts. (A gigawatt is 1,000,000,000 watts.)

In addition to the US, other countries at the forefront of wind energy installations include: China, Germany, UK, Brazil and India. At certain times of the day, Denmark can get more than 50% of its electrical energy from wind power.



Data: US EIA, Levelized Cost of New Generation Resources in the Annual Energy Outlook 2014



Data: GWEC, US DOE WindExchange

For many years, Europe led the development of wind farms and manufacturing of wind turbine components. More recently, the wind industry has spread globally, especially to China. Many of the top 10 wind turbine manufacturers are still based in Europe: Vestas (Denmark), Enercon (Germany), Gamesa (Spain), GE Energy (United States), Siemens (Denmark/Germany), Suzlon (India), Nordex (Germany), Acciona (Spain), Repower (Germany), and Goldwind (China). Of these ten manufacturers, seven have now opened manufacturing facilities in the US.

Today there are hundreds of companies producing components for wind turbines: gearboxes, turbine blades, braking systems, bearings, towers, and more. These companies are based all over the world. It has been estimated that the global wind industry employs approximately 834,000 workers today.

Turbines are also getting much larger and more efficient. The average turbine in 1990 stood only 54 meters tall and produced a maximum of 500 kilowatt (kW, 1000 watts). In 2014 most new turbines stand 100 meters tall and produce 2 MW of power at rated speed. The largest turbines produced in 2014 can produce 8MW. These turbines are designed for offshore applications.

HARNESSING WIND POWER

Basic concepts of wind power

Windmills have been used for centuries to pump water or to move heavy rocks to grind seeds into grain. A wind turbine is the modern advancement of the windmill, instead using the wind to turn an electrical generator.

The force of the wind on the blades causes them to move. As the rotor turns, it spins a driveshaft which is connected to a generator. The spinning generator converts mechanical (rotational) energy into the electrical energy we use every day. Large wind turbines often have a gearbox between the rotor and the generator so that the generator can spin much faster than the blades are spinning. (See the large wind turbine image on page 16).

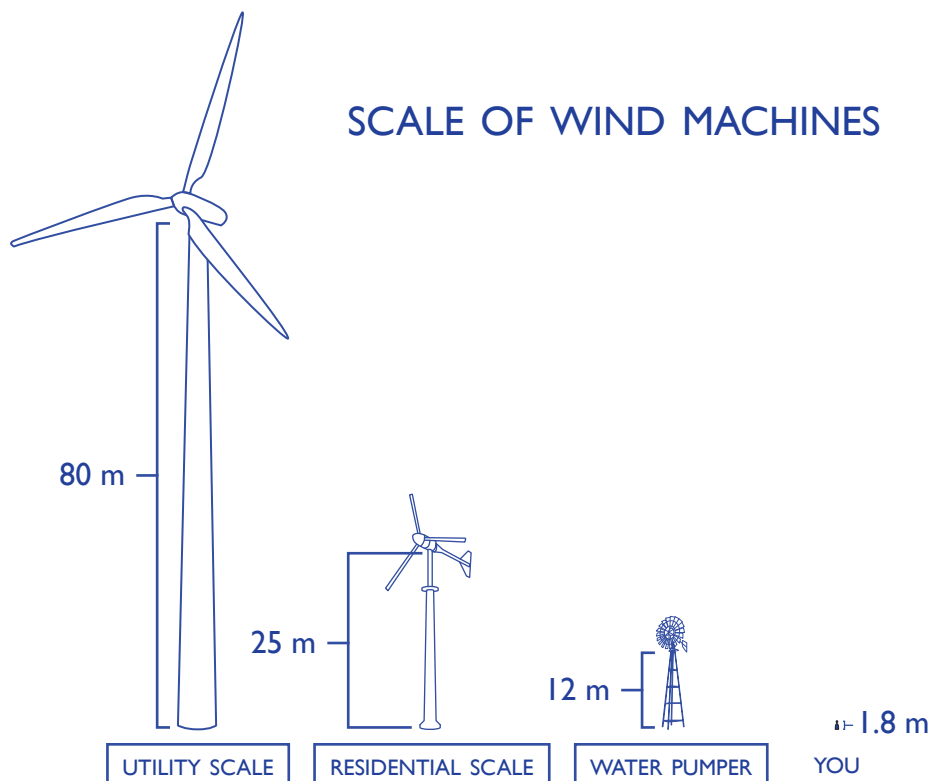
The amount of electricity a wind turbine is able to produce depends on several variables: wind speed, the diameter (size) of the rotor, the density of the air, and the efficiency of the turbine. Wind speed, or velocity, dramatically affects how much power is available in the wind. As wind speed doubles, the power available in that wind is multiplied eight times!

Large wind turbines are often built in clusters called wind farms. A wind farm may have just a few turbines or several hundred. Wind farms act just like other power plants—feeding electricity directly into the power grid.

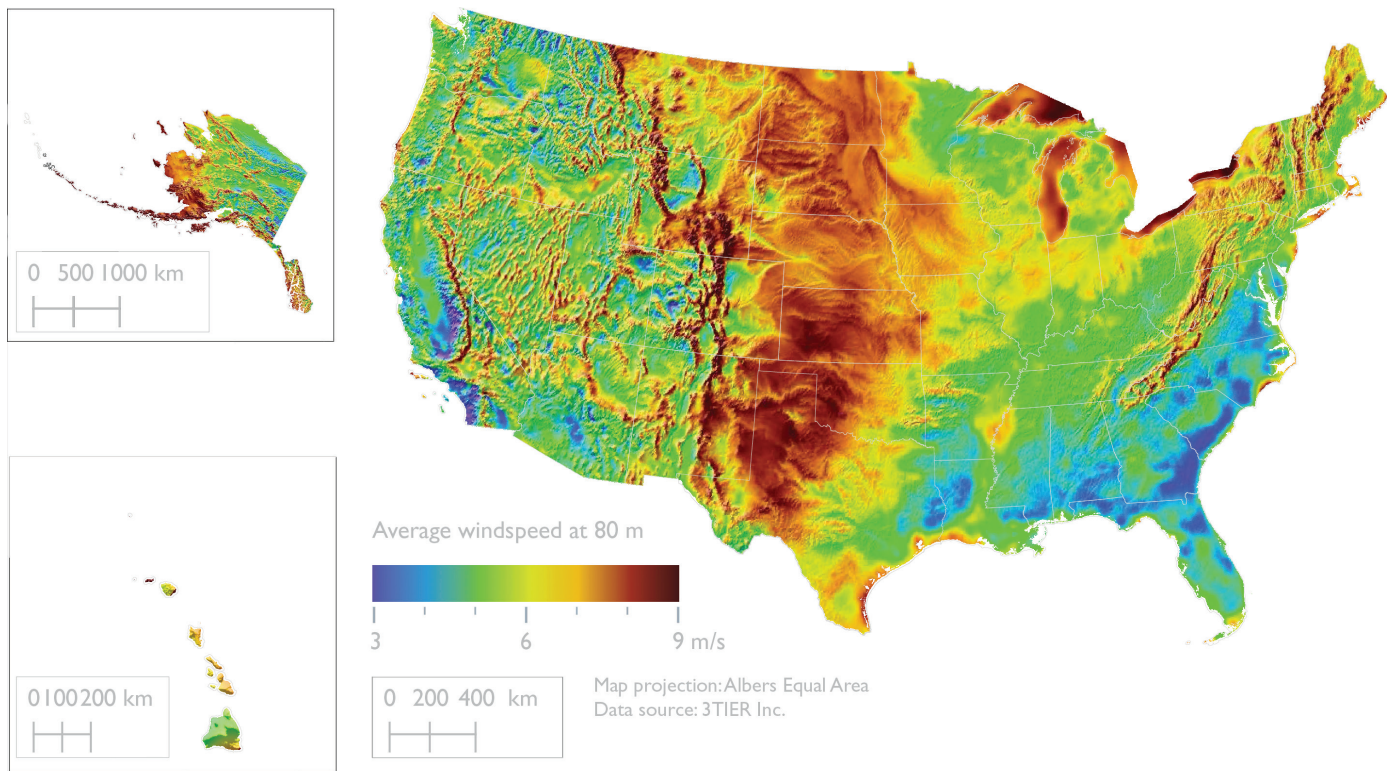
Small vs. large wind turbines

Wind turbines come in all shapes and sizes. The smallest wind turbines produced have a rotor diameter of 1 meter and only produce enough power to charge a few 12 volt batteries—or about 100 watts. A wind turbine that could power your whole house is still considered “small.” This wind turbine might have a rotor diameter of 7 meters and could produce 10 kW (10,000 watts).

A typical “large” or utility scale wind turbine has a rotor diameter of 100 meters and stands on a tower 100 meters tall. This wind turbine could produce 2 MW (2,000,000 watts)—enough electricity for about 400 American homes. Utility-scale turbines are getting bigger and bigger. The largest turbine produced in 2014 can produce 8MW of power and has a rotor diameter of 160 meters.



US WIND RESOURCE



Where Are Wind Farms?

Since wind velocity greatly affects the power in the wind, it makes sense to build wind farms in places that are very windy. Look at the wind speed map of the United States. Where would you put a wind farm? The windiest places in the US are the Great Plains (the “wind belt”), mountainous areas, and coastal areas. Currently, the majority of wind turbines installed in the US are in the Great Plains, from Texas to North Dakota.

In Europe, many wind farms have been built out in the sea—miles from land. Consistent, fast, and smooth offshore wind means that these wind farms can make a lot of power. It is safe to assume that there will be many offshore wind farms built around the US in coming years.

WIND ENERGY CHALLENGES

Humans have harnessed wind power for thousands of years using windmills, sailboats, and other mechanisms. The current versions of residential—and utility—sized turbines are young, with designs less than 20 years old. How long have we been burning coal or other fuels—thousands of years? Will there be problems? Yes, but with continued investment wind turbine technology is going to become more efficient, longer lasting, and more economical. The question is will we make those investments and have some patience?

Technological Hurdles

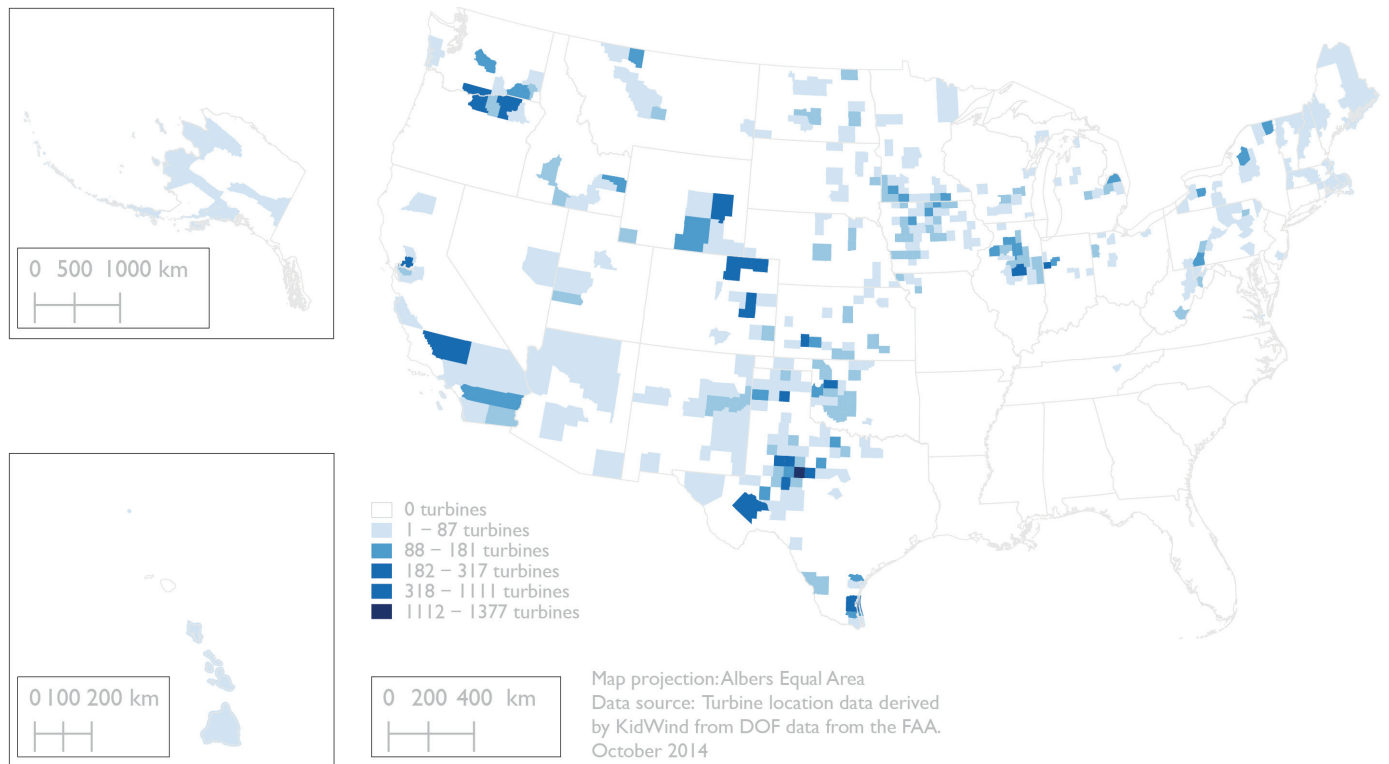
The industry continues to learn how to make wind turbines larger, cheaper, longer lasting, and more reliably connected to the grid. This process is accelerating as the market grows and more companies try to make money in a rapidly growing industry.

Major research is currently taking place on improving, or removing gearboxes from large turbines, squeezing more electricity from generators, enhancing blade performance, and programming control systems that automate wind turbine response and performance.

Variable Production

One major complaint is that wind energy is not reliable since we cannot predict when the wind will blow. This is not exactly true: there is a huge amount of research taking place to more accurately predict when the wind will blow, how fast it will blow, and for how long. The better the wind industry gets at predicting the wind resource, the more like

NUMBER OF TURBINES PER COUNTY



other power plants wind farms will become; it is all about prediction. As they say in the industry “the wind is always blowing somewhere.” We just need to quantify and predict.

Do we need resources when the wind does not blow? Yes. Do we need a 100 percent backup for wind farms? No! Some studies have shown that the amount of reserve power to cover variable wind production could be in the 8–10 percent range; others put it higher at 20–40 percent. The actual ratio depends heavily on proximity of wind generation to load, other generators on the system, overall system load (both forecasted and real time), planned outages of generators and transmission lines, and other reliability criteria.

Currently we do not store wind energy; as it is produced it goes right onto the grid. This may change in the future; storage options are being explored in compressed air, pumped water, and hydrogen technology systems.

Transmission

Some consider transmission to be the single biggest hurdle facing wind energy development. Moving wind-generated power from rural locations to urban centers is going to require a great deal of infrastructure. This will be costly and not without controversy; people do not like high voltage power lines in their neighborhood. Some claim we should distribute the turbines more evenly and generate power closer to the cities and urban locales. The problem with this is that often the wind resource is not as good in those locations and some of the economies of scale of having a large farm are lost.

Cost is a huge issue. Who pays the billions in upgrade costs to get the power where it needs to go? Is it a cost that is shared by everyone who uses the grid? Is it a cost that generators will pay? Is it a cost that companies that own transmission will pay? These questions are still being played out.

Offshore wind power is very promising as 48 percent of our population lives within 50 miles of the ocean. The concept would be to build large wind farms in the ocean or the Great Lakes and run cables many miles back to shore. In 2010, Cape Wind received approval to build the first offshore wind farm in the US.

Ecological Factors

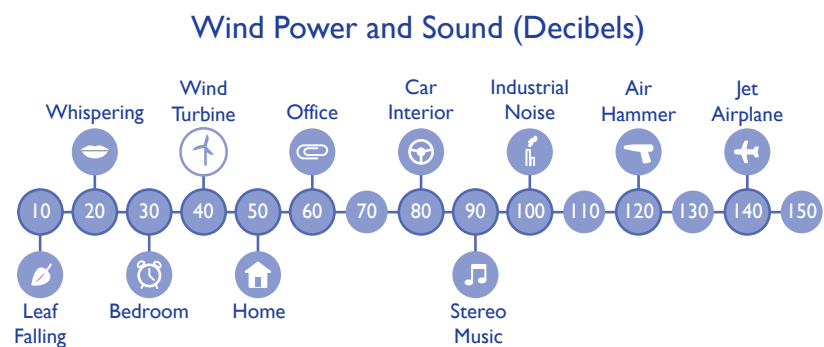
Compared to other energy-generation sources, wind energy has very low impacts on the environment and on wildlife. A wind farm requires many studies before construction begins to determine whether ecosystems or wildlife will be impacted during construction and operation. These studies look at the location and type of natural areas at the site, the wildlife species present, the potential placement of turbines, the placement of power lines, and the location of

maintenance roads and structures. Wind energy has a small physical “footprint,” meaning that the space the turbines, roads, and buildings take up is small. Wind farm infrastructure generally takes up only about 2–5 percent of a wind farm’s land. Wind farm developers must consider the potential impacts to wildlife, especially birds and bats, when they are deciding where to place their turbines.

Birds and bats can be impacted by wind turbines in three main ways: they can be killed by the blades when they are flying, they can be displaced from their normal habitat by the presence of the turbines, and their habitat can be impacted by the construction of turbines and wind farm infrastructure. Although birds do collide with turbines, turbine collisions are a very small risk to birds in general and are only a minor contributor (less than 1 percent) to human-caused bird fatalities nationwide. Nevertheless, bird impacts from turbines are continually monitored and studied by scientists and regulators. Bats have recently become a major concern for developers and scientists. Bats can be killed by collisions with turbines or by “barotrauma” when they suffer a sudden drop in pressure if they fly too close to a spinning turbine blade. There is uncertainty about the amount of impact turbines have on bat populations. Scientists, developers, and regulators are working together to learn more about and minimize the impact that wind farms have on bats.

Sound

There have been complaints about adverse impacts related to the sound that turbines produce. A number of individuals living near wind farms have made the claim that their health has been negatively impacted by the sound and infrasound produced by turbines. The industry has produced studies that declare this is not supported by medical fact. Nevertheless this problem will definitely be explored more deeply in the next few years to determine appropriate setbacks for wind turbines from peoples’ homes and businesses.

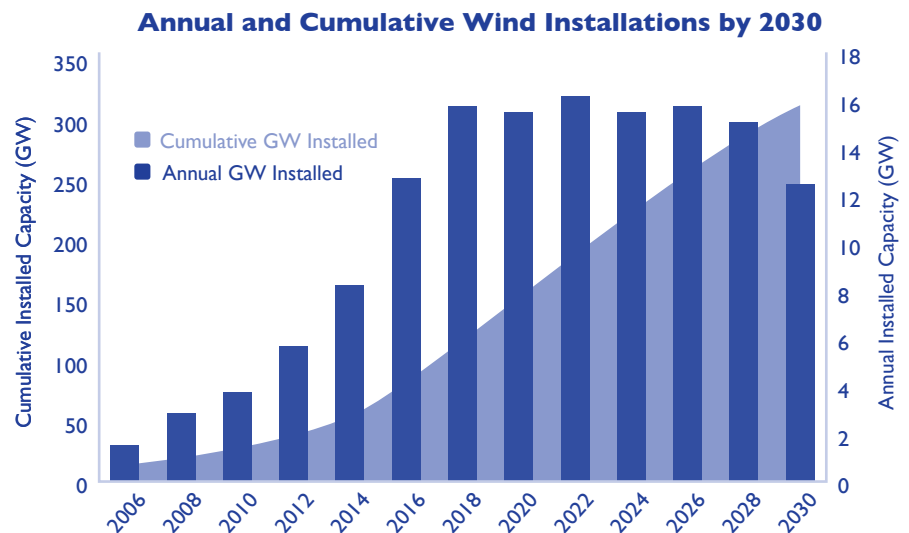


Landscape Impact and Public Perceptions of Wind Energy

While a large majority of Americans support the production of wind energy as a concept, there can be resistance to the siting of wind turbines in rural communities. While local concerns often relate to sound, health, and wildlife issues, residents are also very concerned about how these new technologies will impact landscape values and local economies.

In some locations around the US, wind projects are creating bitter local politics where neighbors are being pitted against one another. Active oppositional campaigns are politically challenging new projects. While some landowners are benefiting from lease payments, their neighbors often claim that viewshed impacts are significantly affecting entire communities and this may result in lower property values and erode the historic qualities of small towns. (A viewshed is an area of land, water, or other environmental elements that is visible to the human eye from a fixed vantage point). Local planners and elected officials often have to balance these concerns with the new jobs and tax base the wind farm may provide.

Many communities feel the solution to these conflicts is more transparency and democracy in the process of building a wind farm. The industry counters that it has the most open process of any energy generation source currently being constructed.



20% Wind Energy by 2030 DOE Report (2007)

Cheap Fossil Fuel Prices

If natural gas and coal remain very cheap, that makes it harder for wind energy to compete for capital and makes the cost of wind energy more expensive compared to those sources. One thing that may change is that in the next 5–10 years, we could see a tax on carbon. This would add an additional cost to coal and natural gas generation and make wind a more attractive option. At this point a “carbon tax” is a very controversial proposition in US politics.

Future of Wind

It is clear that we are going to see more electricity from wind energy in the future. How much will depend on the variety of factors that we have discussed. A recent Department of Energy report predicts we will get about 5 percent of our electricity from wind in 2020.

Another report released in 2008 indicated that with aggressive public policy and private investment, the US could produce 20 percent of its electricity from wind by 2030. That would be a colossal program. There are currently 35 GW (1GW=1000 MW) of wind power capacity installed in the US. To get to 20 percent we need 305 GW! That's a lot of turbines.

Would this be challenging? Definitely! Is it possible? Based on this study, we have the technology, materials and skills to do this. What we need is the will.

The benefits of this kind of widespread clean energy development would be monumental. By 2030, in this scenario we would reduce the cumulative amount of CO₂ being put in the atmosphere by 7600 metric tons. Close to 200,000 jobs would be created to manufacture, install, and maintain these devices. Additionally, we would see huge reductions in water use for power and reductions in negative health impacts from pollutants from other energy sources. If wind energy is introduced properly, we would see little or no increase in the cost of electricity and no decrease in reliability.

One of the major findings of the “20% by 2030” report was that a major hurdle in reaching this goal was that in the US there is a predicted decrease in the number of trained engineers and scientists who could do the research required to improve the turbine technology. What this means is that we would be importing much of this new technology, not inventing or designing it ourselves. That is a problem that WindWise seeks to address.

There is a great deal of work to be done and this is a beginning. WindWise is designed to start students down a road towards where they understanding the limits and promise of wind energy and seeing it as a career choice in the future.

Off we go!

A QUICK HISTORY OF WIND ENERGY TECHNOLOGY

3,500 BC	Egyptians made the earliest known sailboats, using the wind to propel boats.
200 BC	Windmills were used to pump water in China.
600 AD	In Persia (present-day Iran), windmills were used to grind grain into flour.
1100 AD	Wind power appeared in Europe during the medieval period. Windmills were used to grind grain.
1300 AD	The first horizontal-axis windmills appeared in Western Europe and were used to drain fields in the Netherlands and to move water for irrigation in France.
1800s	American settlers used windmills to pump water along the western frontier. By the late 1880's, six million windmills had sprung up across America. Steel blades for windmills improved efficiency.
1887	The first windmill for electricity production was built by Professor James Blyth in Glasgow, Scotland.
Early 1900s	Electric wind turbines appeared all over Europe and were used to power rural homes and farms in America.
1920's	French inventor G.J.M. Darrieus developed a vertical axis turbine shaped like an eggbeater.
1931	A 100 kW wind turbine was built in the USSR (present-day Russia). This is a precursor to the modern wind turbine.
1941	A large wind turbine (1,250 kW) was constructed in Vermont in response to fuel shortages. This supplied power for several years during World War II.
1956	A 200 kW, three-bladed turbine was invented by Johannes Juul in Denmark. This turbine inspired many later turbine designs.
1973	The OPEC oil embargo caused oil prices to rise dramatically. High oil prices increased interest and research in alternative energy sources.
1977–1981	The US designed several two-bladed turbine prototypes. One prototype, called the MOD-1, had a 2 megawatt capacity.
1985	California wind capacity exceeded 1,000 megawatts, enough to power 250,000 homes. Wind turbines were still very inefficient at this time.
1990's	Growing public concerns about environmental issues such as air pollution and global warming encouraged interest in renewable energy.
1991	The world's first offshore wind farm began operating off the coast of Denmark.
1999	The US Department of Energy began the Wind Powering America (WPA) Program
2001	Wind energy capacity reached 24,800 megawatts. The global wind power industry generated about \$7 billion in business.
2004	The cost of electricity from wind generation became competitive with fossil fuel generation.
2014	Global wind power exceeded 318,105 megawatts installed, employing 834,000 people with an economic impact of over \$81 billion annually.

ENERGY TRANSFERS AND CONVERSIONS IN A TURBINE

