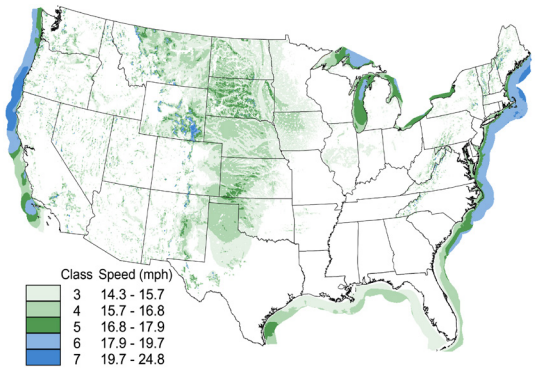
Wind Energy

Wind Resource and Potential

U.S. Wind Resources, Onshore and Offshore[2]
(50 meter height)



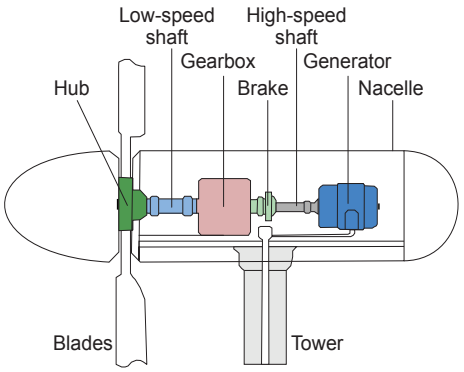
Approximately 2% of the solar energy striking the Earth's surface is converted to kinetic energy in wind.[1] Wind turbines convert the wind's kinetic energy to electricity without emissions. The distribution of wind energy is heterogeneous, both across the surface of the Earth and vertically through the atmosphere. Class 3 winds (average annual speed of 14.3 to 15.7 mph at 50m) are the minimum needed for a commercially viable project.[3] Only 3% of U.S. electricity was derived from wind energy in 2016, but wind capacity is increasing rapidly.[4]

- High wind speeds yield more power because wind power is proportional to the cube of wind speed.
- Wind speeds are lower close to the Earth's surface and more wind power is available at higher altitudes. The average hub height of most modern wind turbines is 82.0 meters off the ground.[5]
- Potentially, global onshore and offshore wind power at commercial turbine hub heights could provide 840,000 TWh of electricity each year, while total global electricity consumption from all sources in 2014 was about 20,715 TWh.[6,7] Similarly, the U.S. annual wind potential of 68,000 TWh (lower 48 states) exceeds annual U.S. electricity consumption by about 64,289 TWh.[4,6]
- A 2015 study by the U.S. Department of Energy found wind could provide 20% of U.S. electricity by 2030 and 35% by 2050.[8]
- Wind's variability increases the cost to operate the grid by less than 0.7¢/kWh of electricity (at 40% electricity from wind).[5]

Wind Technology and Impacts

Horizontal Axis Wind Turbines

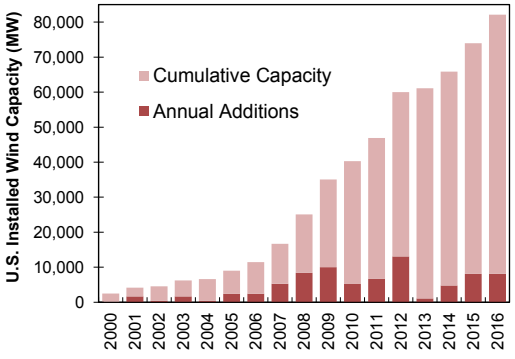
Horizontal Axis Wind Turbine Diagram[9,12]



- Horizontal axis wind turbines (HAWT) are the predominant turbine design in use today. The HAWT rotor comprises blades (usually three) symmetrically mounted to a hub. The rotor is connected via a shaft to a gearbox, and the generator is housed within the nacelle. The nacelle is mounted atop a tower connected to a concrete foundation.[9]
- HAWT come in a variety of sizes, ranging from 2.5 meters in diameter and 1 kW for residential applications up to 100+ meters in diameter and over 3.5 MW for offshore applications.
- The theoretical maximum efficiency of a HAWT is ~59%, also known as the Betz Limit. Most HAWT extract about 50% of the energy from the wind that passes through the rotor area.[8]
- The capacity factor of a wind turbine is its average power output divided by its maximum power capability.[8] On land, capacity factors range from 0.26 to 0.52.[10] Offshore winds are generally stronger than on land, and capacity factors are higher on average, but offshore wind farms are more expensive to build and maintain.[10] Offshore turbines are currently placed in depths up to 40-50m (about 131-164ft).[11]

Installation, Manufacturing, and Cost

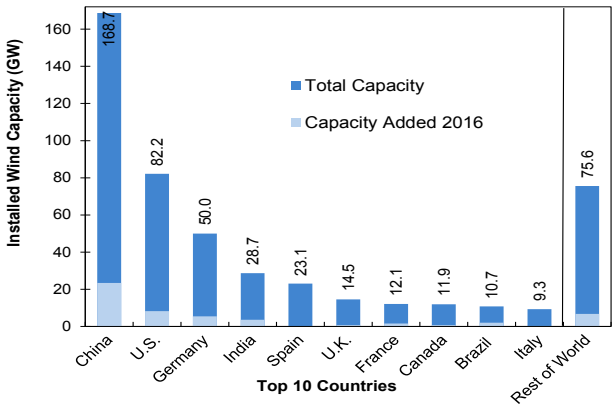
U.S. Wind Capacity[13,14]



- More than 53,000 utility-scale wind turbines are installed in the U.S., with a cumulative capacity of 84.1 GW.[13] U.S. wind capacity increased by 492% between 2007 and 2016, a 19% average annual increase.[13] Global wind capacity increased by 20% annually, on average, from 2007 to 2016, reaching 487 GW in 2016.[15]
- U.S. average turbine size was 2.0 MW in 2015, up from 1.11 MW in 1999.[5]
- Average capacity factor has increased from 0.30 for projects installed through 2005 to around 0.33 for recent projects. Higher capacity factors tend to lower cost of energy.[5]
- On a capacity-weighted average basis, installed wind project costs declined by roughly $3,500/kW between the early 1980's and 2015. In 2015, costs were $1,690/kW.[5]
- The installed cost of a small (<100 kW) turbine is approximately $5,760 per kW, on average.[16]
- Currently, commercial wind energy costs average 3.8¢/kWh wholesale.[5] The 2016 average U.S. residential electricity price was 12.6¢/kWh.[4]
- Texas (21,044 MW), Iowa (6,952 MW), and California (5,656 MW) are the leading states in total installed wind capacity.[13] Iowa generated over 36% of its electricity from wind, the highest percent in the U.S.[17]

- Wind turbines and components are manufactured at more than 500 U.S. facilities.[18]
- In 2016, an estimated 100,000 full-time workers were employed in the U.S. wind industry.[19]
- Large (>20 MW) wind projects require roughly 85 acres of land area per MW of installed capacity, but 1% or less of this total area is occupied by roads, turbine foundations, or other equipment; the remainder is available for other uses.[8]
- For farmers, annual lease payments provide a stable income of around $3,000/MW of turbine capacity, depending on the number of turbines on the property, the value of the energy generated, and lease terms.[8] For a 250-acre farm, with income from wind at about $55 an acre, the annual income from a wind lease could be $14,000.[20]

Global Wind Capacity, 2016[15]



Energy Performance and Environmental Impacts

- Wind turbines can reduce the impacts associated with electricity generation. The 2015 U.S. wind capacity of 74 GW annually avoids an estimated 132 million metric tons of CO_2 emissions and reduces water use by about 73 billion gallons compared with conventional power plants.[18]
- According to a 2015 study, if 20% of U.S. electricity was wind-generated by 2030, electric sector GHG emissions would be reduced 16%, eliminating 380 billion kg of CO_2 emissions annually, or 3.3 trillion kg cumulatively, and decreasing water use by 4%.[8]
- A 2005 study of two U.S. wind farms found life cycle net energy ratios (energy generated/energy invested) of 47 and 65.[21]
- Annual avian mortality from collisions with turbines is 200,000, with 130 million mortalities due to power lines and 300-1,000 million from buildings. The best way to minimize mortality is careful siting.[8] Bat mortality due to wind turbines is less well studied, but research shows that a large percentage of bat collisions occur in summer and fall months when bats are most active.[22] The wind industry has been testing methods that potentially reduce bat mortality by more than 50%.[8]
- Noise 350m from a typical wind farm is 35-45 dB(A). For comparison, a quiet bedroom is 35 dB(A) and a 40 mph car 100m away is 55 dB(A).[23]
- As of 2013, several studies have conclusively determined that sound generated by wind turbines has no impact on human health.[8]

Solutions and Sustainable Actions

Policies Promoting Renewables

Policies that support wind and other renewables can address externalities associated with conventional electricity, such as health effects from pollution, environmental damage from resource extraction, and long-term nuclear waste storage.

- A Renewable Portfolio Standard (RPS) requires electricity providers to obtain a minimum fraction of their energy from renewable resources.[24]
- Feed-in tariffs set a minimum price per kWh paid to renewable electricity generators by retail electricity distributors.[24]
- Net metering - offered in 39 states, D.C., and three U.S. territories - allows customers to sell excess electricity back to the grid.[25]
- Capacity rebates are one-time, up-front payments for building renewable energy projects, based on the capacity (in watts) installed.
- The federal production tax credit (PTC) provides a 2.3¢/kWh benefit for the first ten years of a wind energy facility's operation, for projects started by the end of 2014. In 2015, the Consolidated Appropriations Act retroactively reinstated the tax credit for projects started by December 31, 2019. [26] Small (<100 kW) wind installations can receive tax credits for up to 30% of the capital and installation cost.[27]
- Qualified Energy Conservation Bonds (QECBs) are interest-free financing options for state and local government renewable energy projects.[28]
- Section 9006 of the Farm Bill is the Rural Energy for America Program (REAP) that funds grants and loan guarantees for agricultural producers and rural small businesses to purchase and install renewable energy systems.[29]
- System benefits charges are paid by all utility customers to create a fund for low-income support, renewables, efficiency, and R&D projects that are unlikely to be provided by a competitive market.[30]

What You Can Do

- Make your lifestyle more efficient to reduce the amount of energy you use.
- Invest in non-fossil electricity generation infrastructure by purchasing "green power" from your utility.
- Buy Renewable Energy Certificates (RECs), also known as green tags or green energy certificates. RECs are sold by renewable energy producers in addition to the electricity they produce; for a few cents per kilowatt hour, customers can purchase RECs to "offset" their electricity usage and help renewable energy become more competitive.[31]
- Consider installing your own wind system, especially if you live in a state that provides financial incentives or has a net metering policy.

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