



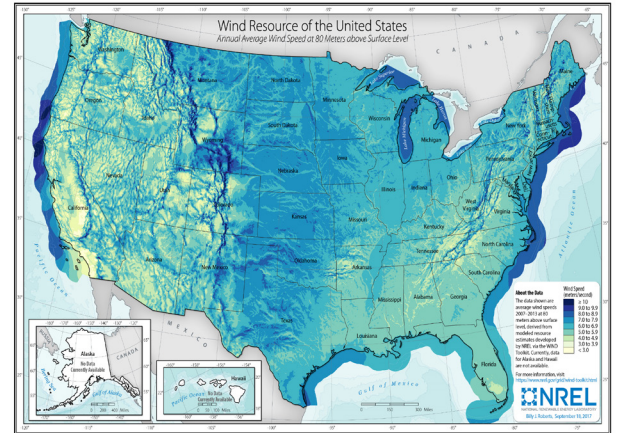
Wind Energy

Wind Resource and Potential

Approximately 2% of the solar energy striking the Earth’s surface is converted into kinetic energy in wind. Wind turbines convert the wind’s kinetic energy to electricity without emissions.¹ The distribution of wind energy is heterogeneous, both across the surface of the Earth and vertically through the atmosphere. Average annual wind speeds of 6.5m/s or greater at 80m are generally considered commercially viable. New technologies, however, are expanding the wind resources available for commercial projects.³ In 2021, 9.2% of U.S. electricity was generated from wind energy, but wind capacity is increasing rapidly.⁴

- High wind speeds yield more power because wind power is proportional to the cube of wind speed.⁵
- Wind speeds are slower close to the Earth’s surface and faster at higher altitudes. The average hub height of modern wind turbines is 90 meters.⁶
- Global onshore and offshore wind power potential at commercial turbine hub heights could provide 840,000 TWh of electricity annually.⁷ Total global electricity consumption from all sources in 2019 was about 23,788 TWh.⁸
- Similarly, the annual continental U.S. wind potential of 68,000 TWh greatly exceeds 2021 U.S. electricity consumption of 3,930 TWh.^{4,7}
- A 2015 study by the U.S. Department of Energy found wind could provide 20% of U.S. electricity by 2030 and 35% by 2050.⁹

U.S. Wind Resources, Onshore and Offshore²
(80 meter height)

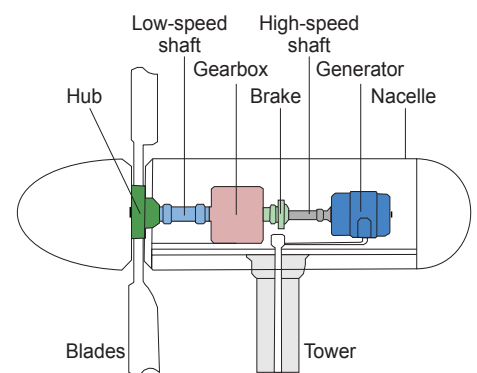


Wind Technology and Impact

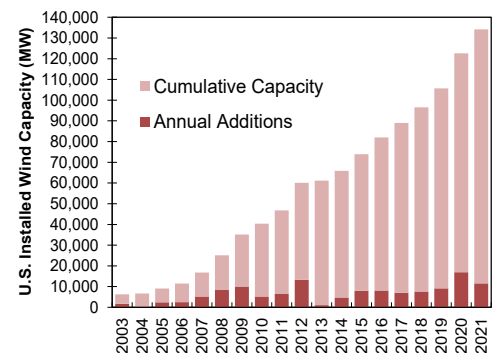
Horizontal Axis Wind Turbines

- 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 generator. The nacelle houses these components atop a tower that sits on a concrete foundation.¹⁰
- HAWT come in a variety of sizes, ranging from 2.5 meters in diameter and 1 kW for residential applications to 100+ meters in diameter and 10+ MW for offshore applications.
- The theoretical maximum efficiency of a turbine is ~59%, also known as the Betz Limit. Most turbines extract ~50% of the energy from the wind that passes through the rotor area.⁹
- The capacity factor of a wind turbine is its average power output divided by its maximum power capability.⁹ Capacity factor of land based wind in the U.S. ranges from 24% to 56% and averages of 36%.⁶
- Offshore winds are generally stronger than on land, and capacity factors are higher on average (expected to reach 51% by 2022 for new projects), but offshore wind farms are more expensive to build and maintain.^{11,12,13} Offshore turbines are currently placed in depths up to 40-50m (about 131-164ft), but floating offshore wind technologies could greatly expand generation potential as 58% of the total technical wind resource in the U.S. lies in depths greater than 60m.^{12,14}

Horizontal Axis Wind Turbine Diagram^{10,15}



U.S. Wind Capacity¹⁶



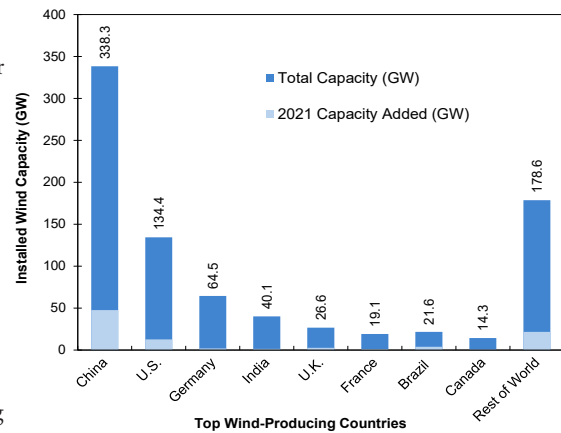
Installation, Manufacturing, and Cost

- More than 60,000 utility-scale wind turbines are installed in the U.S., with a cumulative capacity of 134.2 GW. U.S. wind capacity grew from 40 GW in 2010 to 134 GW in 2021, a 12% average annual increase.¹⁶ Global wind capacity increased by 13% annually, on average, from 2011 to 2021, reaching 837 GW in 2021.¹⁷
- U.S. average turbine size was 2.8 MW in 2020, up 10% from 2.55 MW in 2019.⁶
- Average capacity factor has increased from 25% for projects installed from 1998 to 2001 to 41% for projects built between 2014 and 2019.⁶
- On a capacity-weighted average basis, wind project costs declined by roughly \$3,147/kW between the early 1980’s and 2020. In 2020, costs were \$1,462/kW.⁶
- The average installed cost of a small (<100 kW) turbine was approximately \$9,500 per kW in 2020.¹⁸
- In 2019-20, new wind energy purchase contracts averaged 2.5¢/kWh, while the average residential electricity price was 13.7¢/kWh in 2021.^{4,6}
- Texas (35,049 MW), Iowa (12,006 MW), and Oklahoma (10,716 MW) are the leading states in total installed wind capacity.¹⁶ Iowa generated over 67% of its electricity from wind and had the second highest annual electricity generation from wind of any U.S. state in 2021.¹⁹

- In 2020, there were over 117,000 full-time workers in the U.S. wind industry and turbines and components were manufactured at over 500 facilities.²⁰
- Large (>20 MW) wind projects require ~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.⁹
- 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.⁹

Energy Performance and Environmental Impacts

- Wind turbines can reduce the impacts associated with conventional electricity generation. The 2020 U.S. wind capacity avoided an estimated 319 million metric tons of CO₂ emissions.²⁰
- According to a 2015 study, if 35% of U.S. electricity was wind-generated by 2050, electric sector GHG emissions would be reduced by 23%, eliminating 510 billion kg of CO₂ emissions annually, or 12.3 trillion kg cumulatively from 2013, and decreasing water use by 15%.⁹
- A 2013 study found energy return on investment (EROI) (energy delivered/energy invested) for wind power of between 18-20:1.²¹
- Annual avian mortality from collisions with turbines is 0.2 million, compared with 130 million mortalities due to power lines and 300-1,000 million from buildings. The best way to minimize mortality is careful siting.⁹ Bat mortality due to wind turbines is less well studied. Research shows that a large percentage of bat collisions occur in migratory species during summer and fall months when they are most active.^{9,22} The wind industry has been testing methods that potentially reduce bat mortality by more than 50%.⁹
- Noise 350m from a typical wind farm is 35-45 dB. For comparison, a quiet bedroom is 35 dB and a 40 mph car 100m away is 55 dB.²³
- As of 2013, several studies have conclusively determined that sound generated by wind turbines has no impact on human health.⁹
- Turbine foundations and transmission cables alter benthic habitats, but foundations can create pelagic habitats. Appropriate siting of offshore wind farms is the most effective way to avoid conflicts.²⁴



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.

- Renewable Portfolio Standards (RPS) require electricity providers to obtain a minimum fraction of energy from renewable resources.²⁵
- Feed-in tariffs set a minimum price per kWh paid to renewable electricity generators by retail electricity distributors.²⁵
- Net metering — offered in 39 states, D.C., and four U.S. territories — allows customers to sell excess electricity back to the grid.²⁶
- 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 1-2¢/kWh benefit for the first ten years of a wind energy facility's operation for projects started by December 31, 2021.²⁷ Small (<100 kW) installations can receive tax credits for between 22-26% of the capital and installation cost based on the construction start date.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
- The first U.S. commercial offshore wind farm began delivering electricity in 2016. In 2020, a second offshore wind farm completed installation. As of May 2022, 9 states have offshore wind projects seeking leasing status.³¹

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). RECs are sold by renewable energy producers for a few cents per kilowatt hour, customers can purchase RECs to “offset” their electricity usage and help renewable energy become more competitive.²⁵
- Consider installing your own wind system, especially if you live in a state that provides financial incentives or has net metering.

- Gustavson, M. (1979) “Limits to Wind Power Utilization.” *Science*, 204(4388): 13-17.
- U.S. Department of Energy (DOE), National Renewable Energy Lab (NREL) (2017) U.S. Wind Resource Map.
- U.S. DOE, Energy Efficiency and Renewable Energy (EERE) (2020) “U.S. Average Annual Wind Speed at 80 Meters.”
- U.S. Energy Information Administration (EIA) (2022) Monthly Energy Review April 2022.
- Massachusetts Institute of Technology (2010) Wind Power Fundamentals.
- U.S. DOE, Lawrence Berkeley National Lab (LBNL) (2021) Land-Based 2021 Wind Technologies Market Report.
- Lu, X., et al. (2009) “Global potential for wind-generated electricity.” *Proceedings of National Academy of Sciences*, 106(27).
- U.S. EIA (2022) International Energy Statistics: Total Electricity Net Consumption.
- U.S. DOE (2015) Wind Vision Report.
- U.S. DOE, EERE (2021) “The Inside of a Wind Turbine.”
- U.S. DOE, NREL (2015) “Transparent Cost Database: Capacity Factor” Open Energy Information.
- International Renewable Energy Agency (2018) Offshore Innovation Widens Renewable Energy Options.
- NREL (2021) 2020 Cost of Wind Energy Review.
- U.S. DOE, NREL (2016) 2016 Offshore Wind Energy Resource Assessment for the United States.
- California Energy Commission (2012) “Energy Quest: Wind Energy.”
- U.S. EIA (2022) Preliminary Monthly Electric Generator Inventory February 2022.

- Global Wind Energy Council (GWEC) (2022) Global Wind Report 2022.
- U.S. DOE, Pacific Northwest National Lab (PNNL) (2021) 2021 Distributed Wind Data Summary.
- U.S. EIA (2022) Electric Power Monthly February 2022.
- ACP (2022) “Wind Power Facts.”
- Hall, C., et al. (2013) EROI of different fuels and the implications for society. *Energy Policy* (64), 141-152.
- U.S. Geological Survey, Fort Collins Science Center (2016) “Bat Fatalities at Wind Turbines: Investigating the Causes and Consequences.”
- U.S. DOE, EERE (2008) 20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply.
- European Commission (2020) Guidance Document on Wind Energy Developments and EU Nature Legislation.
- U.S. EPA (2021) “State Renewable Energy Resources.”
- DSIRE (2021) Net Metering Policies.
- U.S. DOE, EERE (2021) Production Tax Credit and Investment Tax Credit For Wind.
- U.S. DOE, EERE (2021) Advancing the Growth of the U.S. Wind Industry: Federal Incentives, Funding, and Partnership Opportunities.
- DSIRE (2018) “USDA - Rural Energy for America Program (REAP) Grants.”
- DSIRE (2016) “Glossary.”
- U.S. Bureau of Ocean Energy Management (2021) State Activities