MSCE in Energy Infrastructure

Brief on Wind Energy and Power Production

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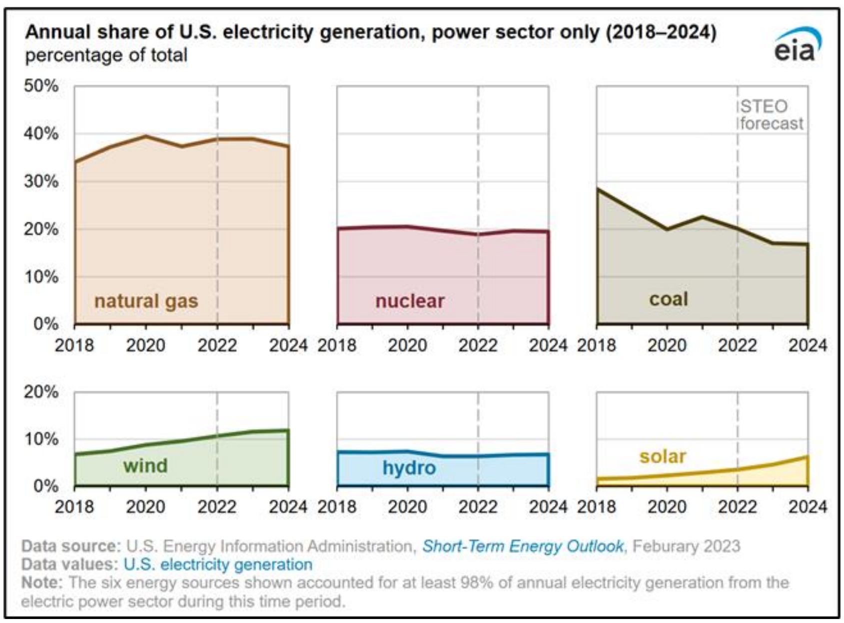
Topics

- Introduction and Definitions
- Wind Resource Information
- Turbine Performance Factors
- Sizes of Wind Turbines
- Wind Turbine Siting
- Wind Project Construction
- Useful Websites

Introduction and Definitions

This brief will cover some of the basics associated with wind energy projects. First, a bit of perspective.



This data shows the relative US electricity generation by fuel type over the last 6 years. Wind energy production is about 12% of the US total and slowly increasing as of 2024. The percentages are based on the MWh of total generation. Total US annual generation by all fuel types was about 4.2 billion MWh in 2023.

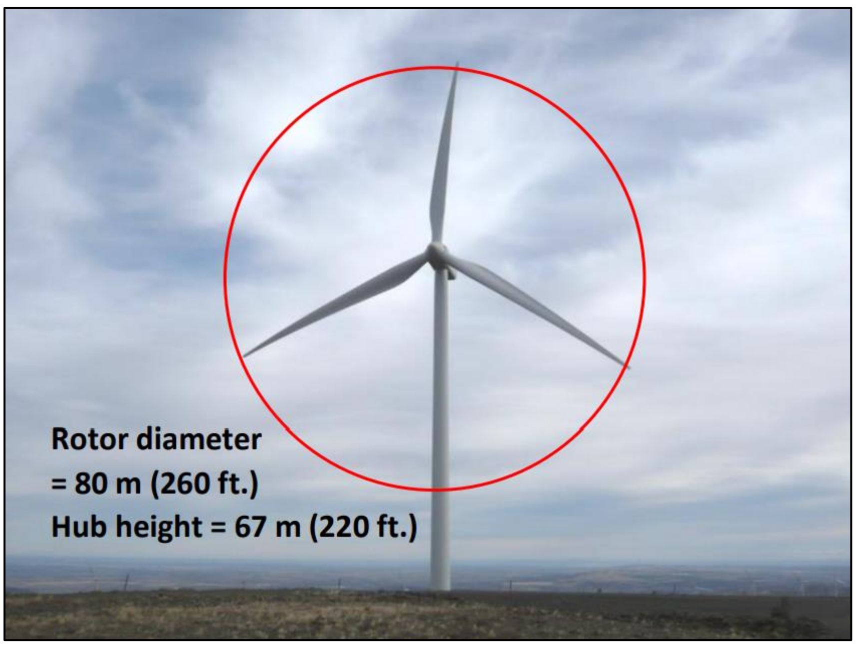
Source : EIA, https://www.eia.gov/outlooks/steo/report/BTL/2023/02genmix/article.php#:~:text=In%20our%20February%20ShortTerm%20Energy%20Outlook%2C%20we%20forecast,and%20to%2017%25%20in%20both%202023%20and%202024.

A table which contains a set of wind energy related definitions is shown on the next page.

Onshore wind projects are the focus of this Brief. Although, the first significant US offshore wind projects are now operational on the east coast of the US with more to come...although there remains uncertainty as to how many offshore projects will be built along US coasts in the near future.

Term	Description	Information Source
Capacity (MW)	Total nameplate capacity rating of assembly of turbines.	Information as received from project developer at end of each quarter.
Completion Date	Date on which wind project is considered to be operational. Usually "Commercial Operation Date."	Specific criteria for "Completion" is at the discretion of the project owner.
Merchant or Market	Wind power plants that are built without a traditional long-term power purchase agreement, instead selling power into a spot market, sometimes with a hedge contract, or an option to sell the power at a certain price in the future.	Project developer or owner
Owner/Equity Partner	Company or companies that will have a managing interest in project when it is complete, though they may not have 100% ownership.	Project developer or owner
Power Purchaser	Utility contracted to purchase power under long-term Power Purchase Agreement (PPA) contract or use the power in case of utility ownership.	Project developer or power purchaser
Project Developer	Company or companies managing most aspects of project development process. Is often a joint effort among several companies.	Project developer
Project Name	Name supplied by project developer	Project developer
Turbine Manufacturer	Turbine vendor or supplier	Project developer or turbine manufacturer
Turbine Rating (MW)	Nameplate capacity rating of each turbine—typically the maximum potential power output of the turbine generator	Project developer

The American Wind Energy Association provided a set of definitions that are relevant. An example is "Capacity (MW). Given the intermittent electricity generation by wind turbines, this term describes the maximum generation of a complete wind project in terms of MW producing power 24/7. On average, the actual capacity of the wind project averages about 35 to 40% of the maximum … which is termed the "capacity factor" … a definition not shown in the list.



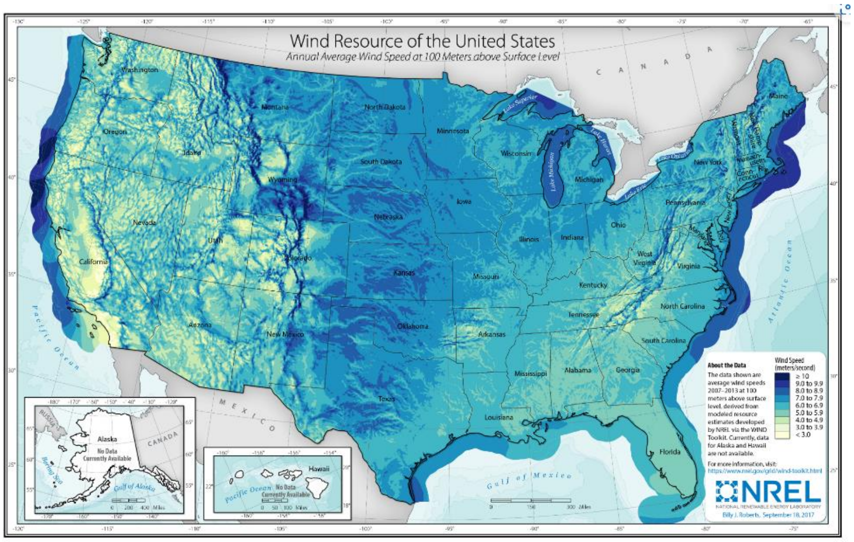
This photo is a wind turbine with a hub height of 67 m (220 ft) and a three-blade rotor with a diameter of 80 m (260 ft). The maximum capacity is 1.8 MW for this specific turbine. Installed in 2007, more recent **onshore wind turbines** have hub heights of 100 m or more, substantially larger rotors, and capacities up to 5 MW or more per turbine.

The use of three-bladed rotors is considered the most efficient for large wind turbines (currently). This is also true for offshore wind turbines which now have capacities of up to 14 MW per turbine and continue to increase.

Wind projects are located in a wide range of terrain from mountainous to flat as illustrated by a project in Central Washington State and another in South Texas.

Wind Resource Information

A wind resource map developed by NREL follows. The wind speed, as you would expect, is critical for electricity generation. This map data assumed a wind turbine hub height of 100 m (the significance of hub height will be covered shortly).



The map shows color coded **average wind speeds** from less than 3.0 m/s (7 mph) to over 10.0 m/s (22 mph). The wind speeds are estimated based on a wind turbine hub height of 100 m. The map also estimates wind speed for up to 50 miles offshore. Onshore, the Midwestern US + Texas have the highest wind speeds. Offshore … the west and upper east coasts.

Source: NREL, https://www.nrel.gov/gis/assets/images/wtk-100m-2017-01.jpg

Turbine Performance Factors

Initial wind speed criteria. Since wind speed varies with height above terrain, always check what height was used for measurements. Typically, wind speeds measured for wind farm planning will use 80 to 100 m heights.

General **wind speeds must exceed** these two criteria to be viable:
< 5.0 m/s (11 mph) annual average wind speed @ 10 m height not likely a good location for a wind project (10 m is a standard height for a weather station).
< 6.5 m/s (15 mph) annual average wind speed @ 80 m height (80 m is more typical of wind turbine hub heights) also not likely to be a good location for a wind project.

Wind turbine power. The power captured by a wind turbine varies as the **cube of the wind velocity:**

$$P = \frac{1}{2}\rho\left(v_1\right)^3 A C_P$$

where
P = power in watts

v_1 = speed of the oncoming air in m/s
ρ = density of the air = 1.225 kg/m^3 at 15.55°C and 101.325 Pa
A = swept area of blades (m^2)
C_p = power coefficient

The coefficient of power of a wind turbine is a measurement of how efficiently the wind turbine converts the energy in the wind into electricity.

C_p = (electricity produced by a wind turbine)/(total energy available in the wind)

Wind turbines extract energy by slowing down the wind. For a wind turbine to be 100% efficient it would need to stop 100% of the wind which is not possible. If you had a wind turbine with just one rotor blade, most of the wind passing through the area swept by the turbine blade would miss the blade completely and so most of the kinetic energy would be kept by the wind.

Hub height wind speed. As noted earlier, the hub height of the rotor has a strong influence on wind speed … hence the amount of power generated by a wind turbine. The following equation is used to estimate wind speed at the hub based on wind speed measured at a standard 10 m height:

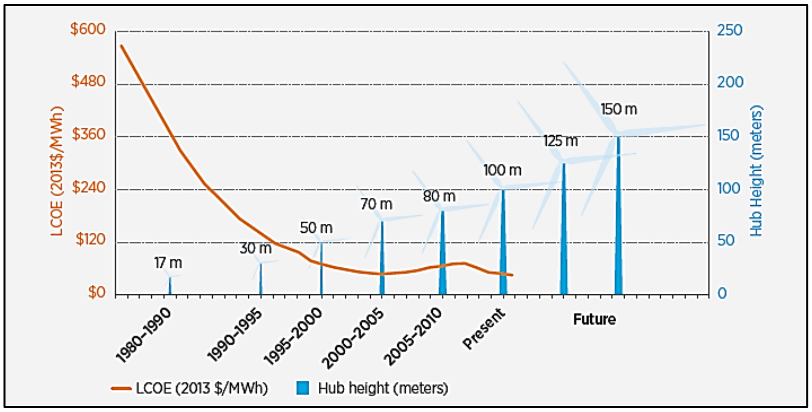
$$v/v_o = (h/h_o)^{\alpha}$$

where
v = velocity at height h (m/s)
v_o = velocity at height h_o (m/s) [typically at a height of 10 m]
α = wind shear exponent which varies from 0.1 over open water up to 0.25 for hilly, mountainous terrain.

This relationship illustrates the importance of hub height.

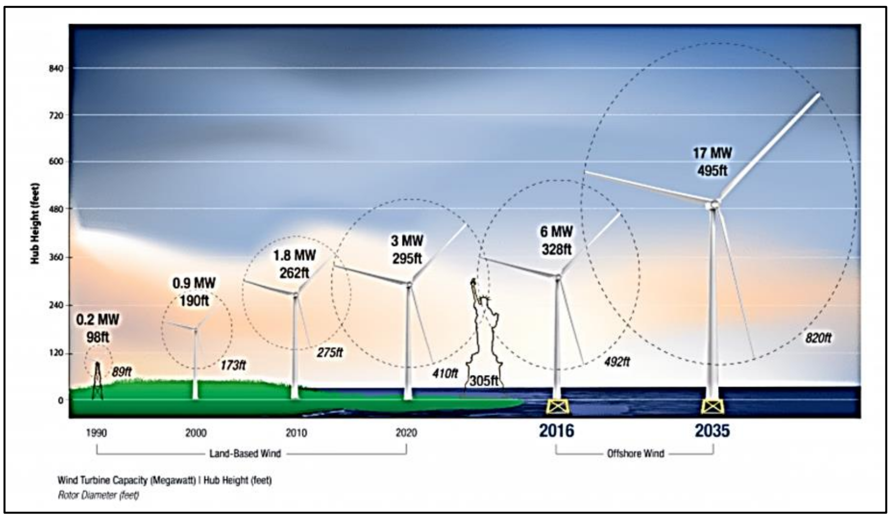
Sizes of Wind Turbines

This graphic shows how wind turbines have evolved over almost 50 years.



The figure illustrates the growth in **hub heights** over ti… Leveliz… price) … capacit… curren… onshor…

Source… Power… Market…



This figure shows how **wind turbine sizes** have changed over a 45-year period (projected through 2035) for both onshore and offshore applications. The Statute of Liberty provides additional scale. Shown are the MW capacities, the hub heights and the rotor diameters.

Source: "Wind Turbines: the Bigger, the Better," Department of Energy, August 23, 2023.

Wind Turbine Siting

How wind turbines are located is a critical portion of the design of a wind project. We will focus only on a few basic approximations.

This photo shows rows of wind turbines with moisture illustrating turbulence. The first row of turbines generates turbulence which affects subsequent rows.

A few “rules of thumb” (approximations) as to spacing turbines:

- 5 rotor diameters apart in the plane perpendicular to the prevailing wind direction,
- 8 to 10 rotor diameters apart in the plane parallel to the prevailing wind direction.

Also consider (permits typically require these actions):

- Setbacks from roads (100 m), buildings (500m), and property boundaries
- Visual impacts (avoid top of ridges)
- Noise impacts (avoid proximity to nearby residences)

Wind Project Construction

Construction of a major wind project involves several steps. To keep this brief, let’s focus on the time required to go from development to commissioning…and that is about 5 years. This timeline, as you might expect, overlaps for several activities.

- 6 months looking at potential site conditions
- 18 to 21 months to collect wind data
- 12 to 24 months to perform front end engineering, permitting, land acquisition, preliminary balance of plant engineering
- 36 months for major equipment acquisitions
- 8 to 10 months construction, and
- 2 to 3 months commissioning.

A major portion of the actual construction is constructing the turbine foundation followed by erection of the tower and placement of the nacelle. The photos illustrate these tasks.




Photo sources: Puget Sound Energy and Joe Mahoney

Useful Websites

- American Clean Power, https://cleanpower.org/facts/wind-power/
- List of wind farms in the United States, Wikipedia, https://en.wikipedia.org/wiki/List_of_wind_farms_in_the_United_States
- Database of State Incentives for Renewables & Efficiency (DESIRE) database, https://www.dsireusa.org/
- EIA Glossary, https://www.eia.gov/tools/glossary/index.php?id=A
- NREL System Advisor Model (SAM), https://sam.nrel.gov/
- UW MSCE Energy Infrastructure, https://www.energy-infrastructure.uw.edu/