Wind Energy

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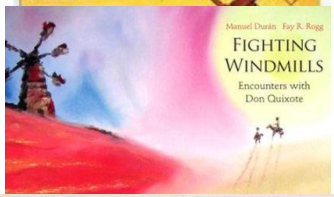
11/4/19

References

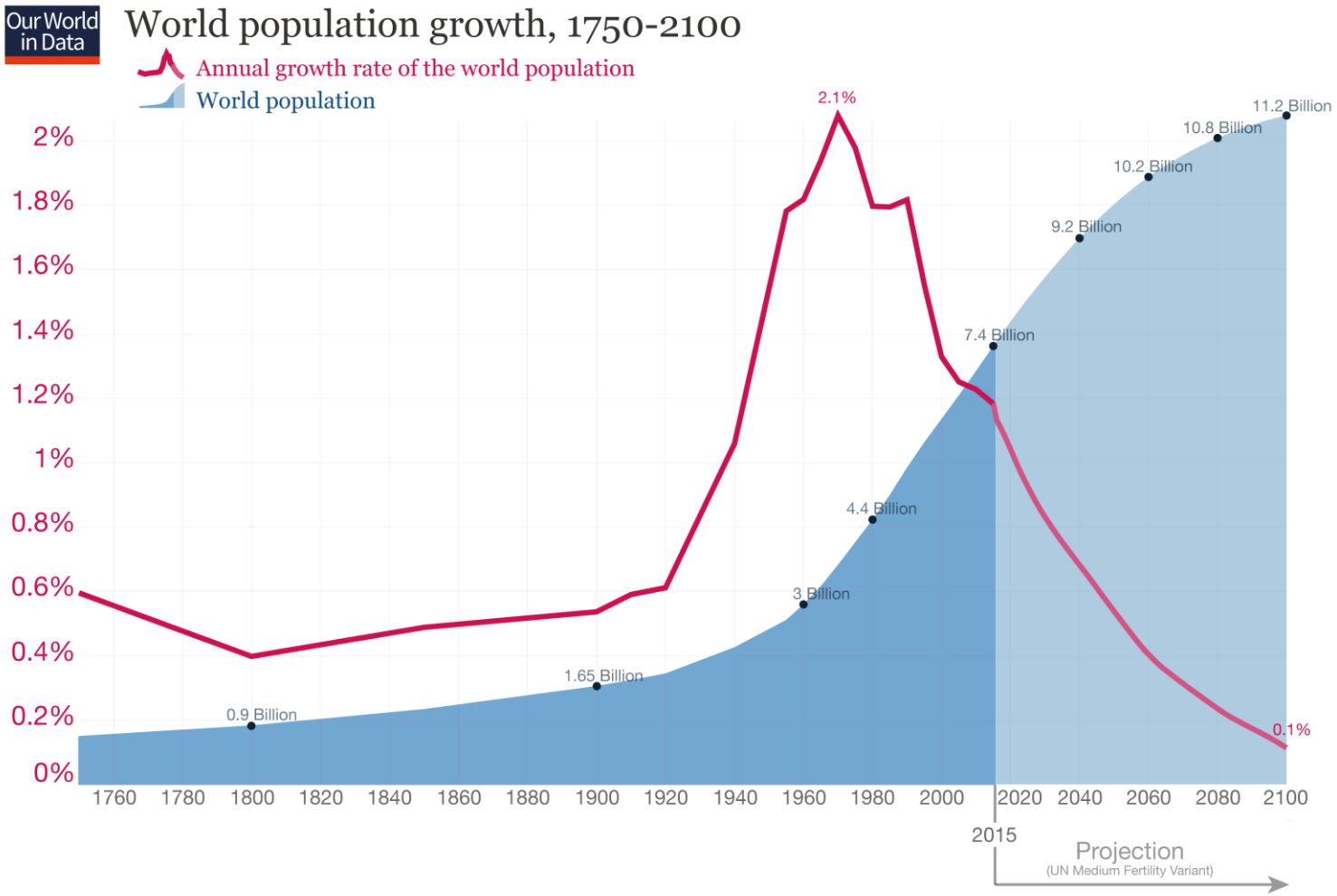
1. 20% Wind Energy by 2030 Increasing Wind Energy's Contribution to U.S. Electricity Supply
www.nrel.gov/docs/.../41869.pdf
National Renewable Energy Laboratory

2. Wikipedia



Don Quixote thought wind mills were
Monsters, Giants and Devils
Civic duty to kill them

Don Quixote and his loyal servant Sancho Panza



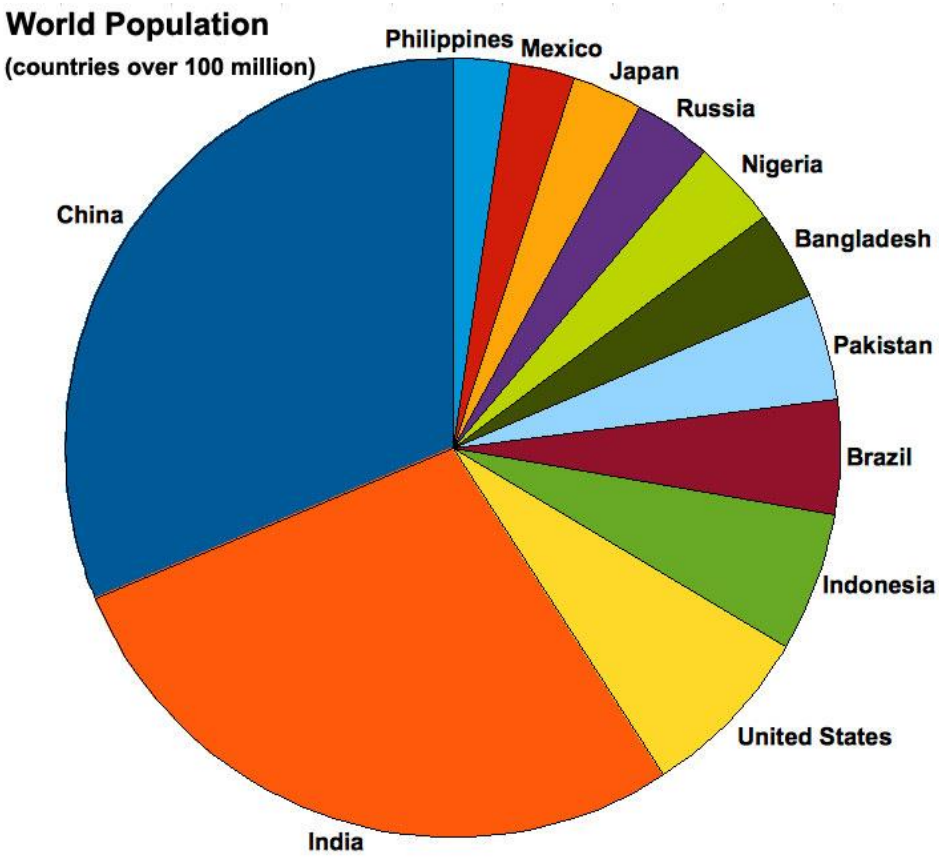
Data sources: Up to 2015 OurWorldInData series based on UN and HYDE. Projections for 2015 to 2100: UN Population Division (2015) – Medium Variant.
The data visualization is taken from OurWorldinData.org. There you find the raw data and more visualizations on this topic.

Population Growth Rate

Table 1-1 Acceleration of world population growth [2]

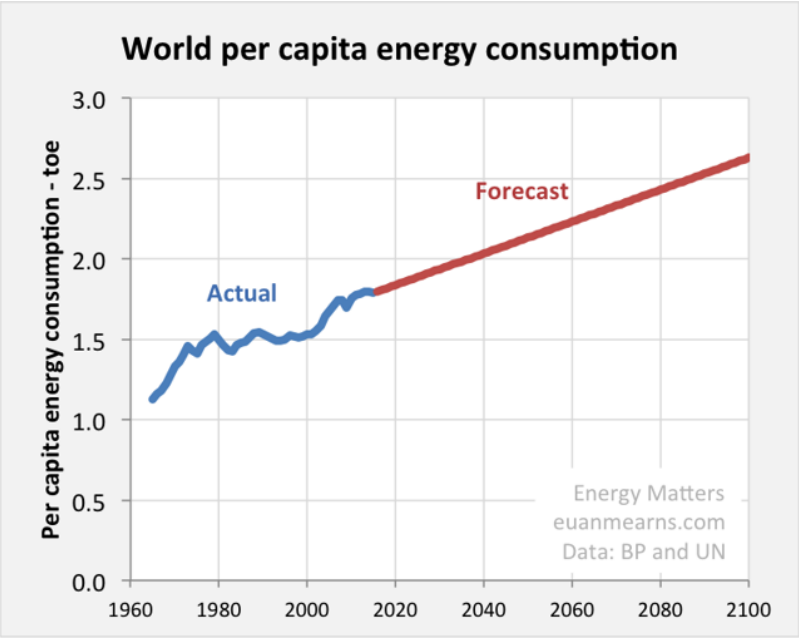
World Population (Billions)	Year Achieved (A.D.)	Time to Add Last Billion (Years)
1	1804	—
2	1927	123
3	1960	33
4	1974	14
5	1987	13
6	1999	12
7	2013	14
8	2028	15
9	2054	26

Education
Affluence
Farming to industrial age
Gov. control
Social pressure


World Population
(countries over 100 million)
Philippines
Mexico
Japan
Russia
Nigeria
Bangladesh
Pakistan
Brazil
Indonesia
United States
India
China

Growth in energy consumption

Population (Billions)	Energy Consumption (kWh/cap-day)
	2.9
	5.0
~0.1	9.4
0.3	
1.3	12.0
4.4	51.0
6.0	230

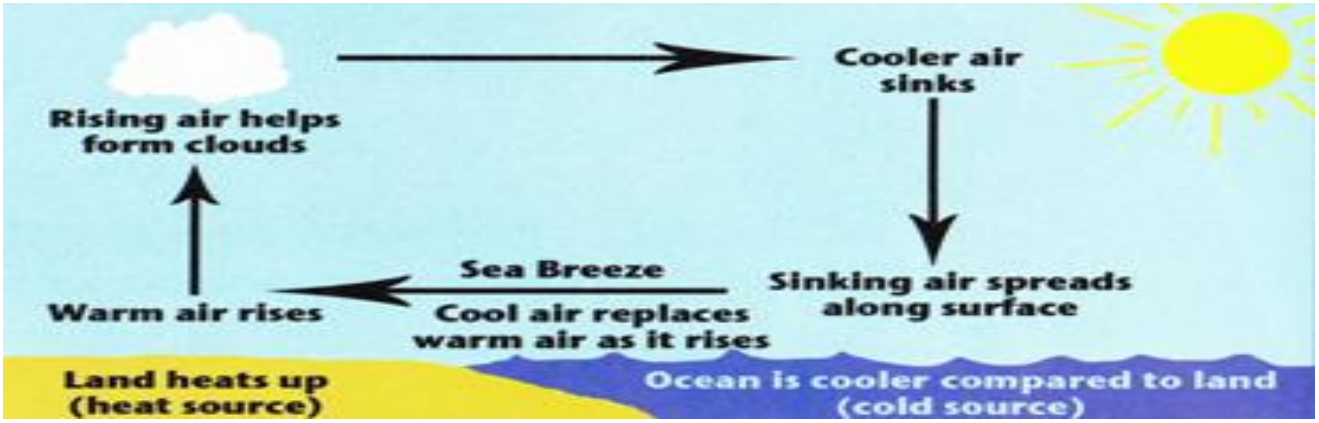


New Delhi, November 2, 2019

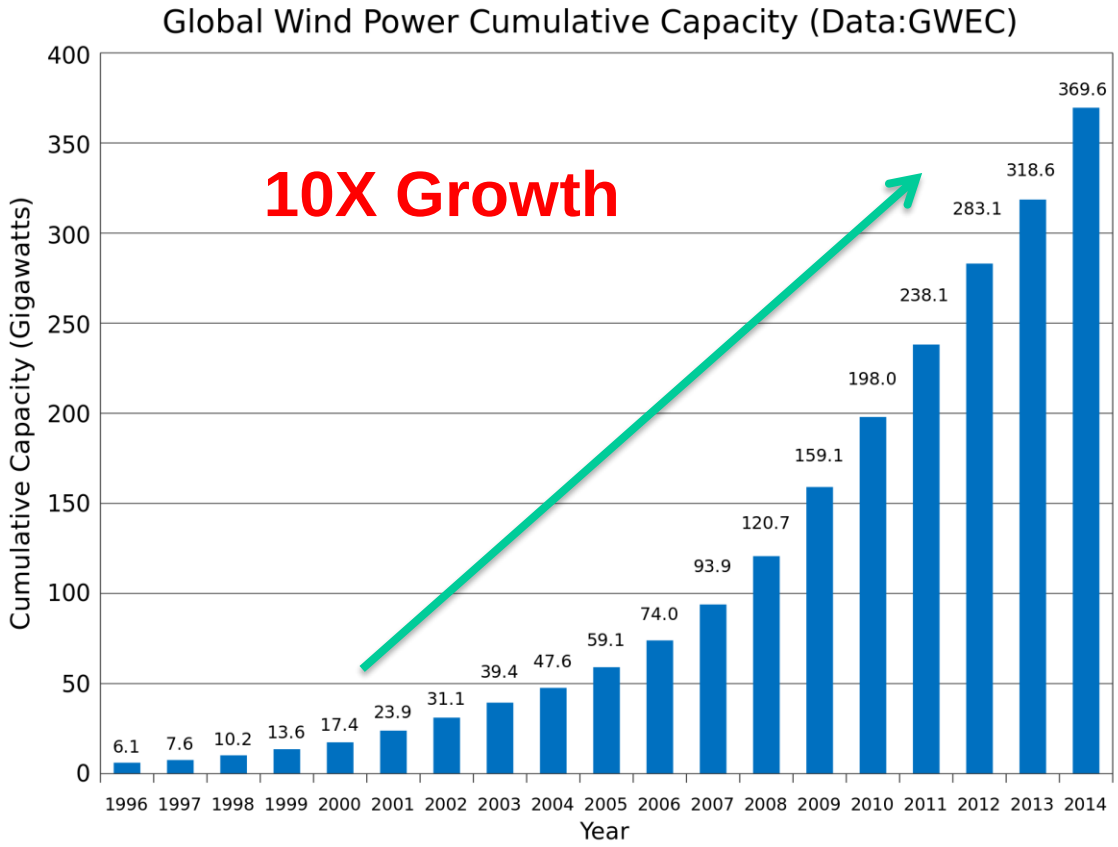
- **Wind energy** is to **supplement** other modes of power generation
- **Clean and renewable/sustainable**
- Never run out of wind
  Production of wind energy does not result in any form of solid, liquid, or gaseous emissions or residues: no CO_2 or toxic fumes are emitted
- It does not deplete any form of fuel
- Once installed, it is easy and inexpensive to maintain
- Offshore installations becoming popular

Wind is a form of solar energy. Winds are caused by the uneven heating of the atmosphere by the sun, the irregularities of the earth's surface, and rotation of the earth. Wind flow patterns are modified by the earth's terrain, bodies of water, and vegetation

Wind is formed when hot surface heat the air making it to rise. The cooler air moves into empty space creating wind

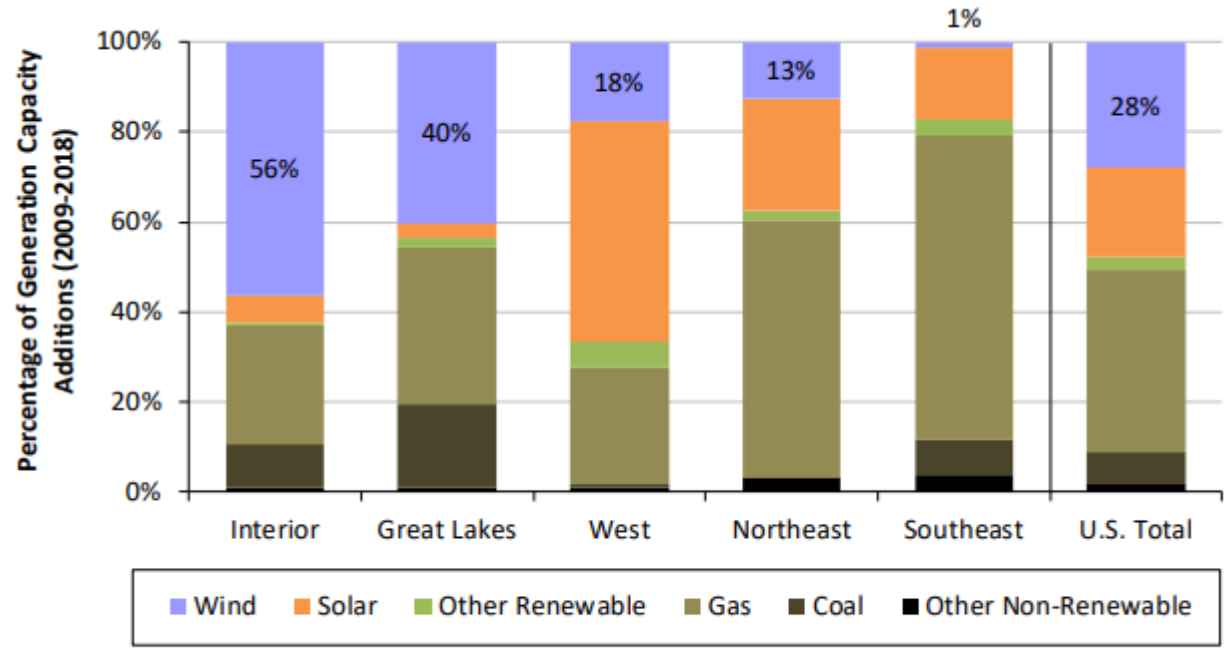


Land heats up faster than water



Estimate

22 percent of world's electricity generation by wind power in two decades (Global Wind Energy Council)



Sources: ABB, AWEA WindIQ, GTM Research, Berkeley Lab

Figure 4. Generation capacity additions by region (2009–2018)

Twenty eight percent of all new power generation built in the United States since 2009 has come from wind

How many have seen/driven by a wind turbine?

How can you get electricity from slow rotating blades?

How can you get electricity from slow rotating blades?

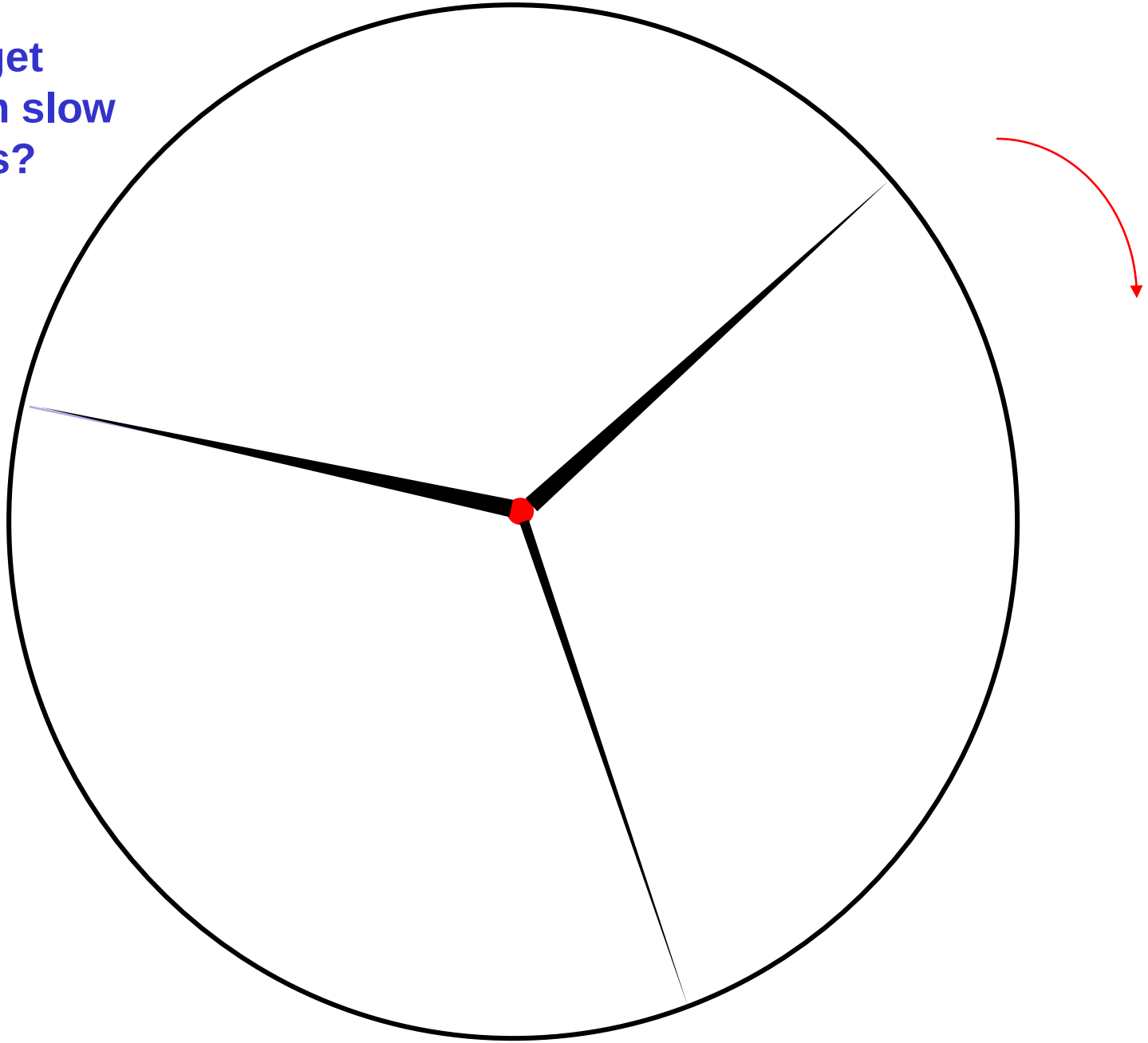
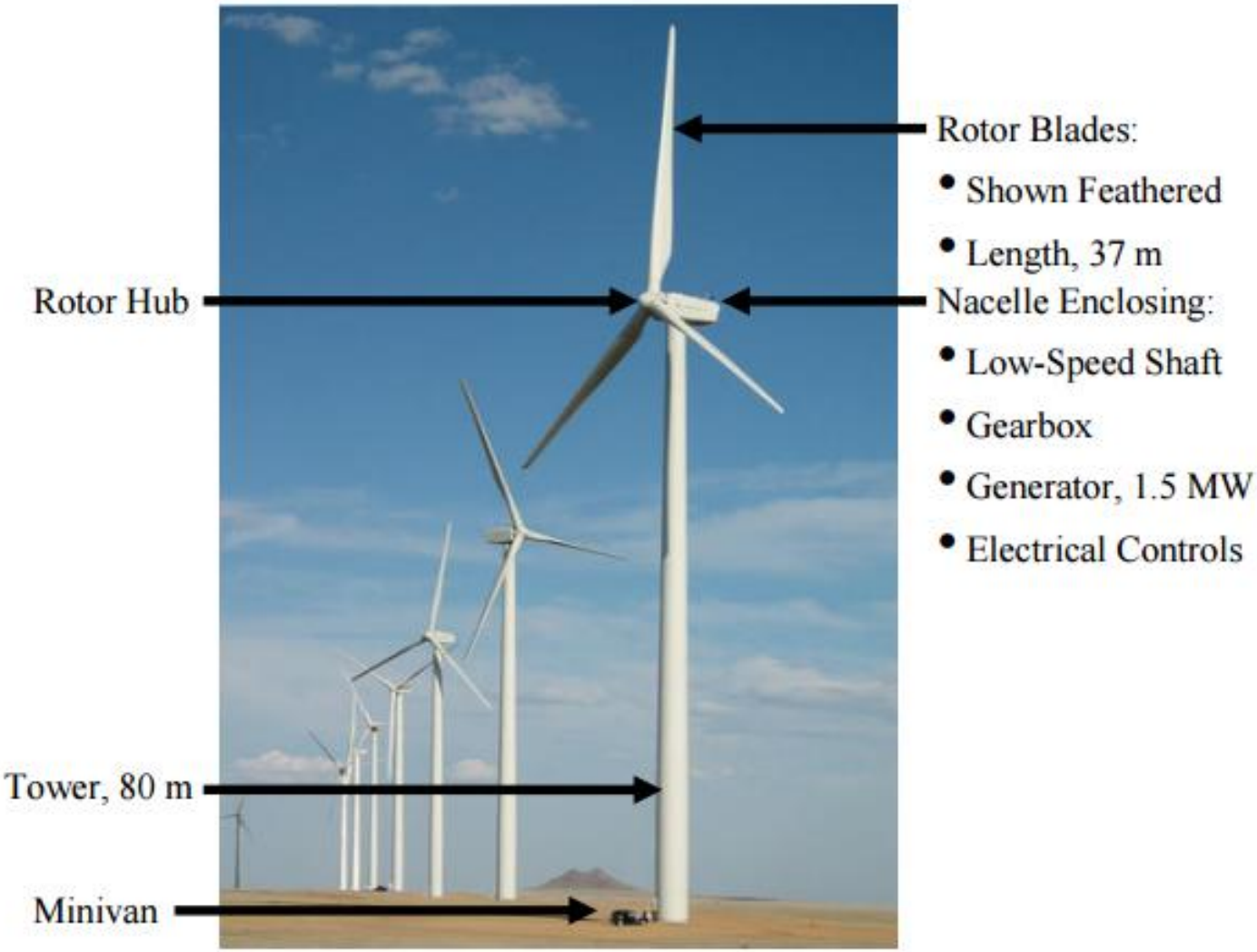
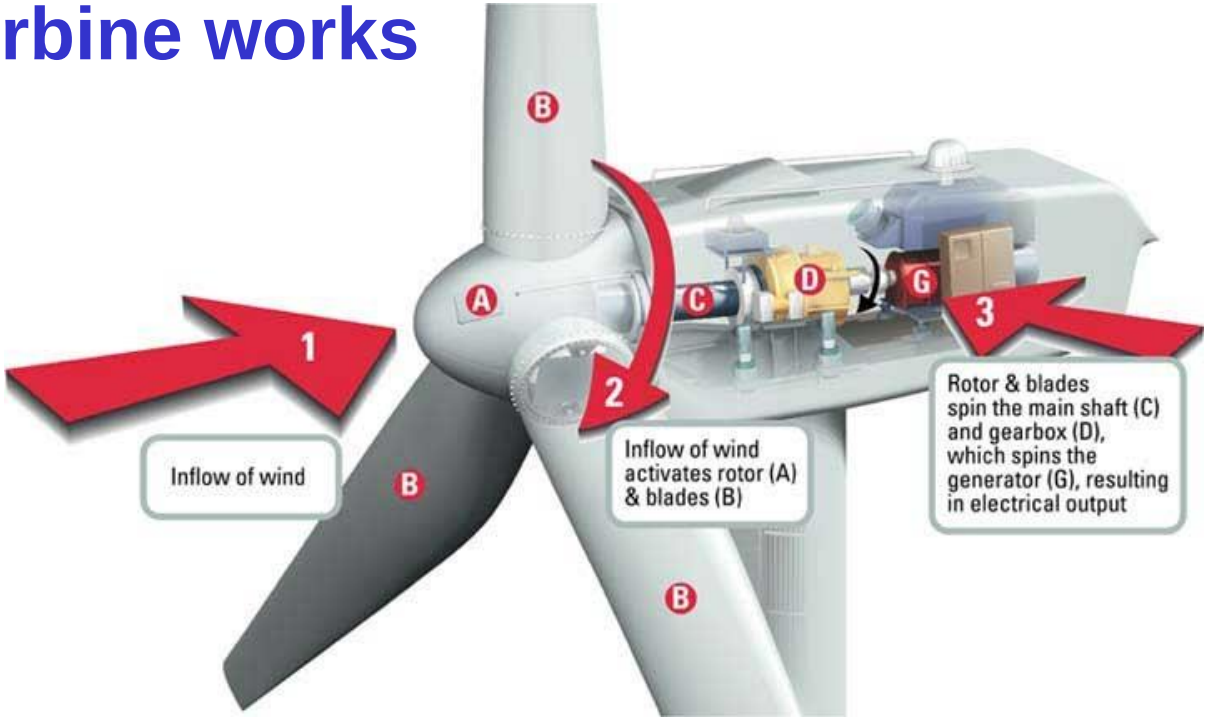


Figure 2-3. A modern 1.5-MW wind turbine installed in a wind power plant



How a wind turbine works



Basic parts:

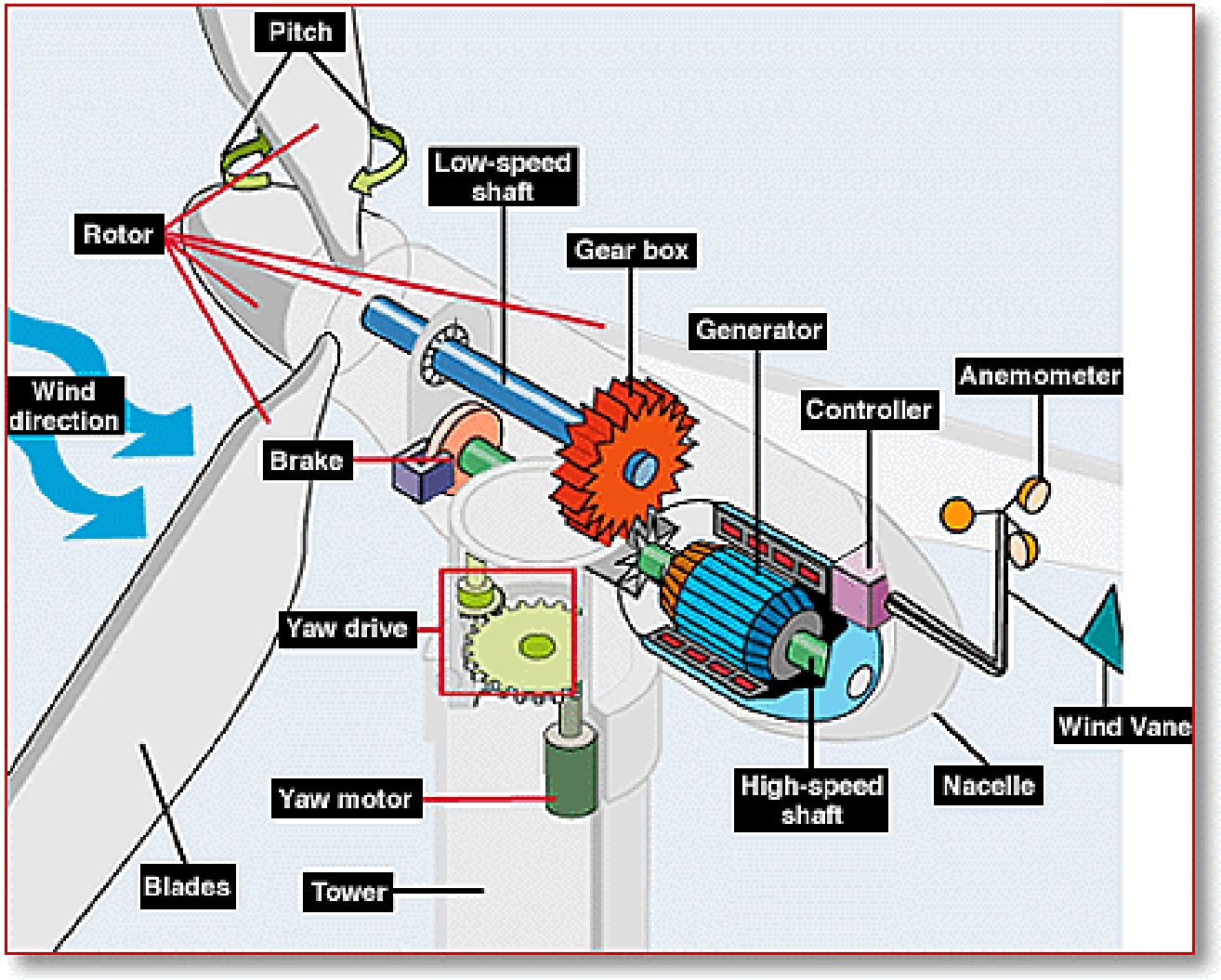
Blades (B) and **Rotor** (A) which rotate when the wind blows

Shaft (C)

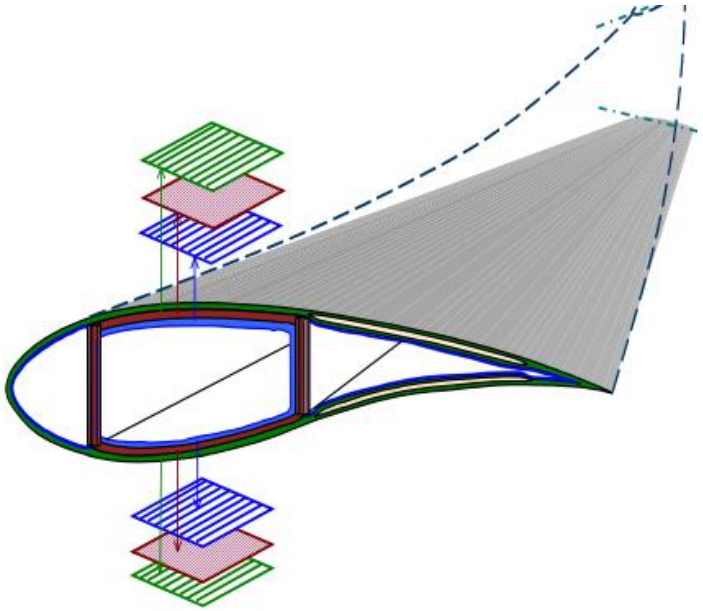
Gearbox (D) to adjust for the speed of the wind

Generator (G), which generates the electricity

The dynamo works by rotating a permanent magnet inside a coil of copper wire. The magnet causes the electrons inside the wire move in a particular direction. At the end of the coil are wires which carry electrons to provide electrical energy



An automatic yaw mechanism is provided to ensure that the rotor always faces the wind direction



Requirements

Stiffness

Bending stresses (wind load and gravity)

Fatigue life: vibration and wind variation

Lightweight (fiberglass composites)

Blades are made of fiber-reinforced plastics

GRP = glass-fiber-reinforced plastic, CRP = carbon fiber reinforced plastic

Blades must be stiff, and placed far enough ahead of the tower, to prevent collision with the tower under maximum wind conditions

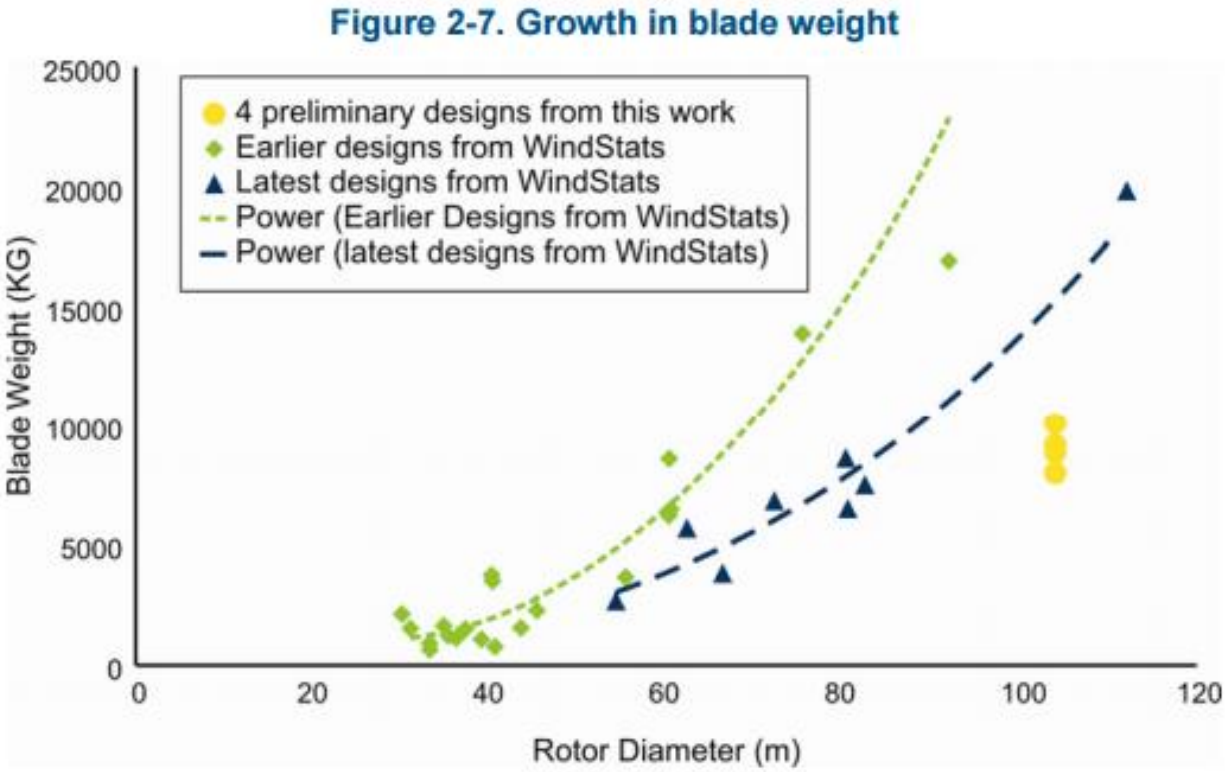
Three-blade designs are by far the most common

Because the wind speed increases and the wind flow stabilizes and becomes less turbulent with height from the ground, towers as high as possible

Offshore sites offer very high winds and large areas for utilization, often having more limited local environmental impacts

Corrosive marine environment impose additional requirements

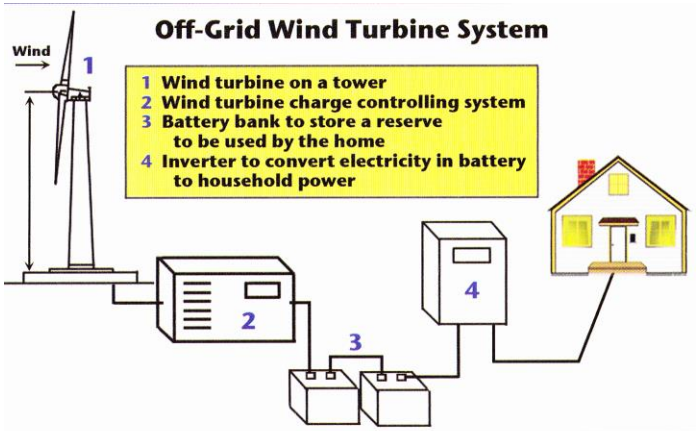
Rotor blade weight versus length



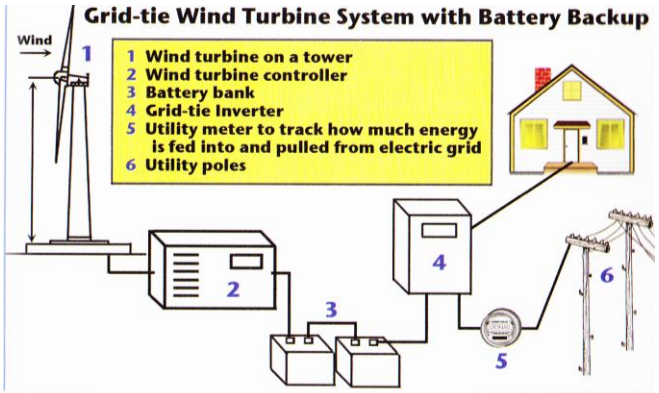
Wind turbines convert the kinetic energy in the wind into mechanical power. A generator converts the mechanical power into electricity

- **Long blades**
- **Can be two football field long**
- **High Tower to capture more wind**

Towers made of steel



There are two major types of "small wind" systems for your home—off-grid and grid-tie. An off-grid system relies on the turbine (1) for all electricity, because no other power lines are connected to the house. The wind turbine outputs electricity to a battery (3), where it is stored until it is needed.



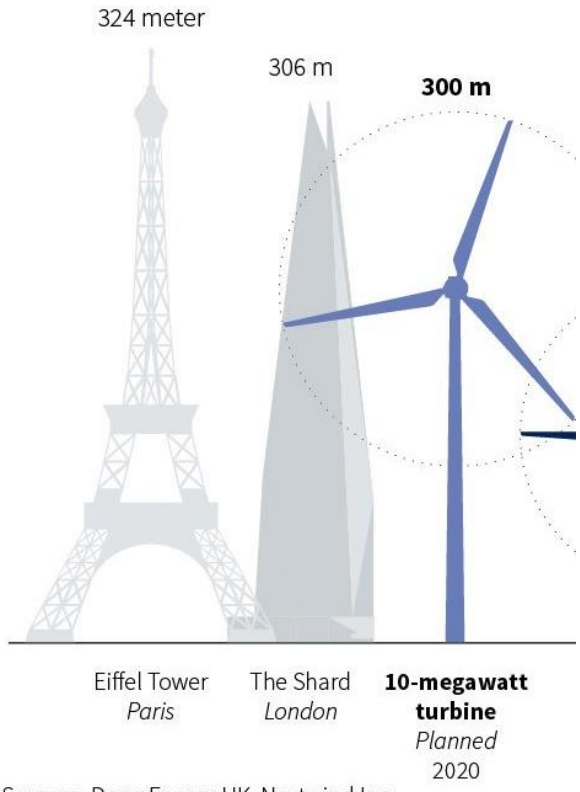
In a grid-tie system, the turbine's electricity taps into the same wires as the power company. The turbine (1) provides electricity to the house or to the power grid whenever the wind is blowing. Though you can have a battery backup (3), most people don't, so on less windy days the house uses electricity from the power grid (6).

Size of large wind turbines

Enercon, Germany E-126
Can generate up to 7 MW of electricity
500 homes
Rotor diameter of **413 feet**
Height 650 feet
Total weight 6000 ton
It only turns at 12 rpm. That means it takes five seconds to complete one revolution
10 to100 turbines in a wind farm

Vestas, Denmark V164,
8 MW, rotor diameter, 538 ft

Football field is 360 feet long


324 meter
306 m
300 m
Eiffel Tower
Paris
The Shard
London
10-megawatt
turbine
Planned
2020
Sources: Dong Energy UK; Nextwind Inc.
G. Cabrera, 20/06/2017


JCCS Limited
COLLETT
CAUTION
REAR STEER

Worlds largest turbines

1. MHI Vestas V164-9.5MW
Power rating: 9.5MW
Rotor diameter: 164m 540 feet
Blade weight 35 ton, Tower height 613 feet

2. Siemens Gamesa SG 8.0-167 DD
Power rating 8MW
Rotor diameter 167m 548 feet

Length of a football field 360 feet

ONSHORE & OFFSHORE WIND RESOURCE MAP

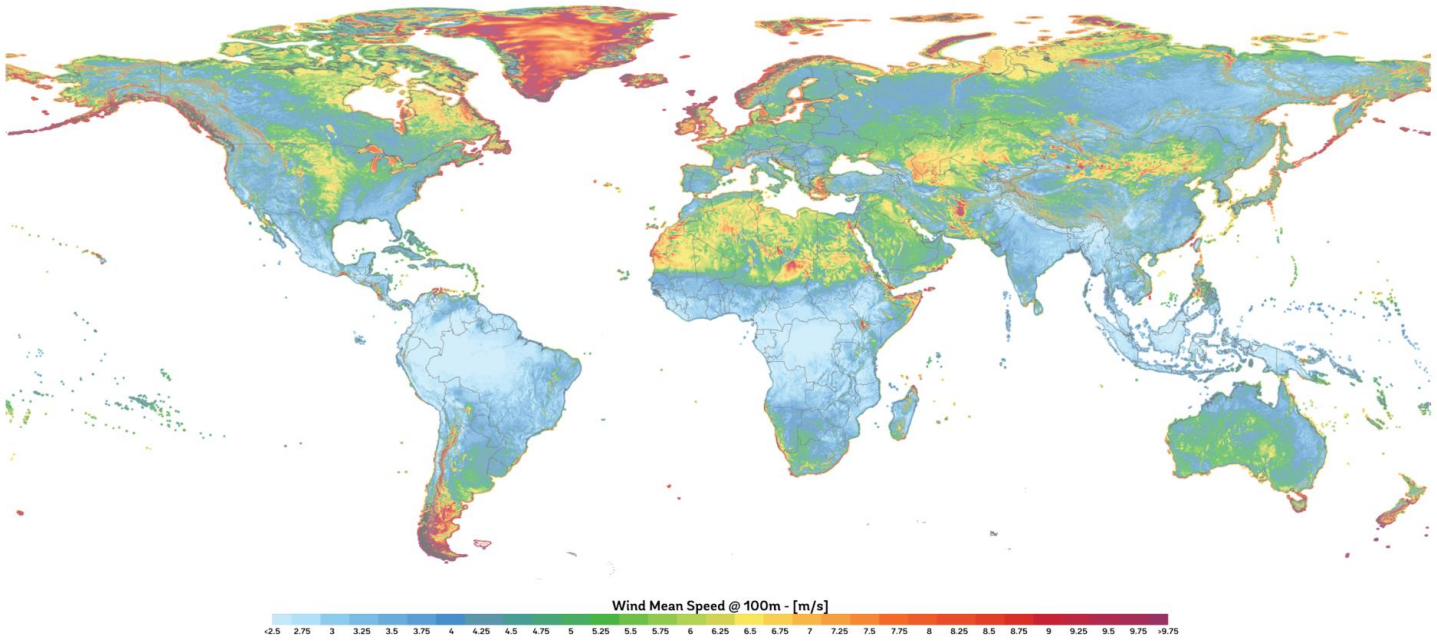
WIND SPEED

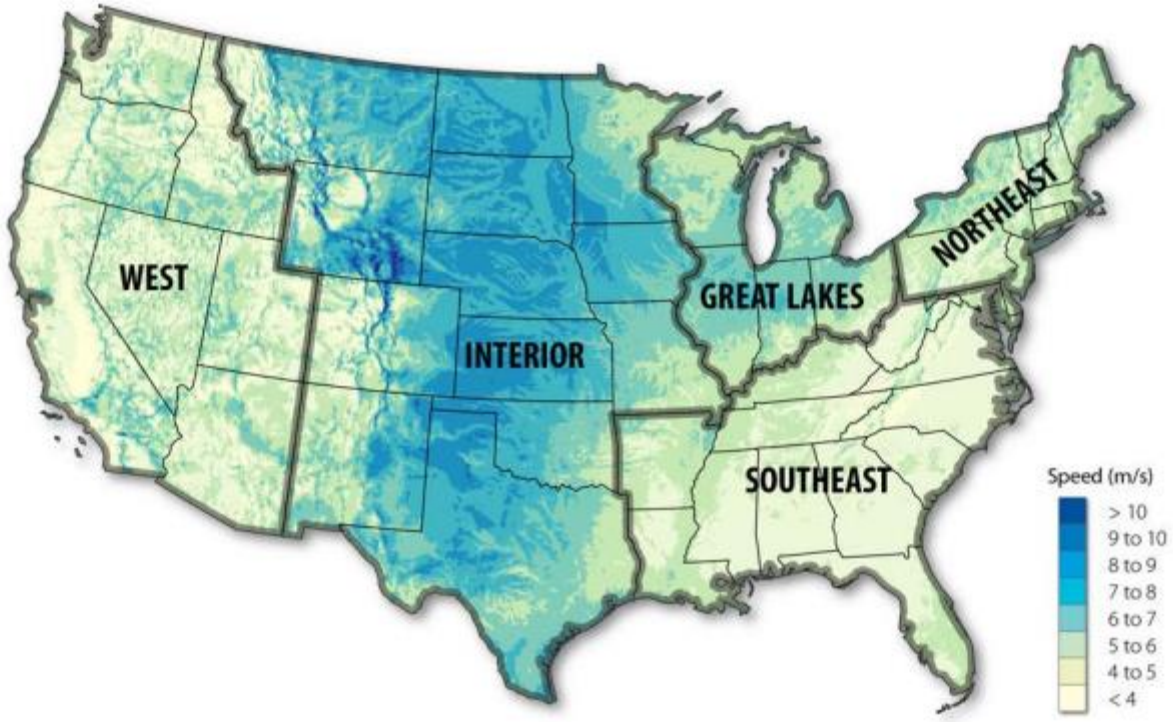
WORLD BANK GROUP

DTU Wind Energy
Department of Wind Energy

ESMAP
Energy Sector Management Assistance Program

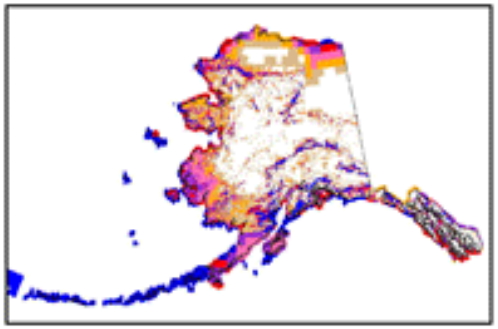
VORTEX





Sources: AWS Truepower, National Renewable Energy Laboratory (NREL)

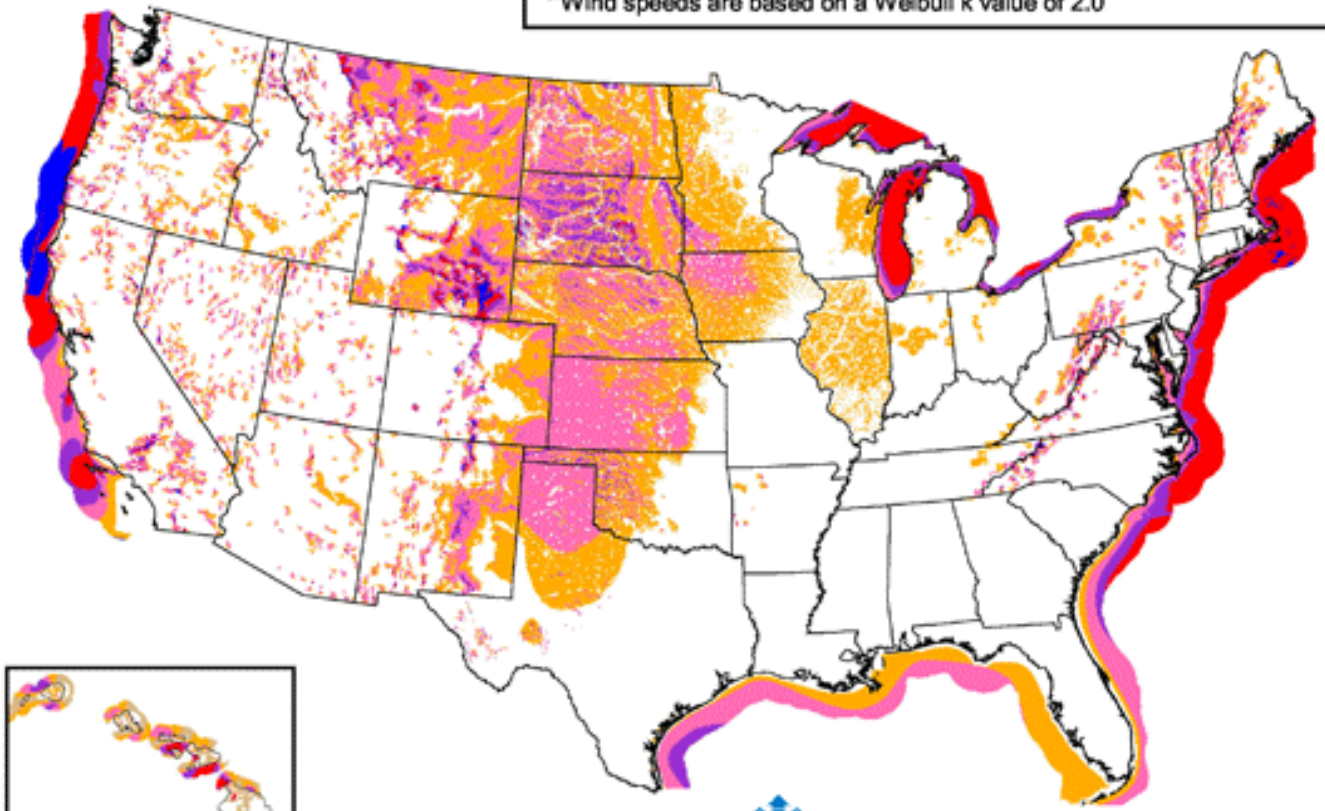
Wind power potential in USA



Wind Power Classification

Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m^2	Wind Speed[a] at 50 m m/s	Wind Speed[a] at 50 m mph
3	Fair	300 - 400	6.4 - 7.0	14.3 - 15.7
4	Good	400 - 500	7.0 - 7.5	15.7 - 16.8
5	Excellent	500 - 600	7.5 - 8.0	16.8 - 17.9
6	Outstanding	600 - 800	8.0 - 8.8	17.9 - 19.7
7	Superb	800 - 1600	8.8 - 11.1	19.7 - 24.8

[a] Wind speeds are based on a Weibull k value of 2.0



NREL National Renewable Energy Laboratory
Innovation for Our Energy Future

$$E = \frac{1}{2}mv^2 = \frac{1}{2}(Avt\rho)v^2 = \frac{1}{2}At\rho v^3 .$$

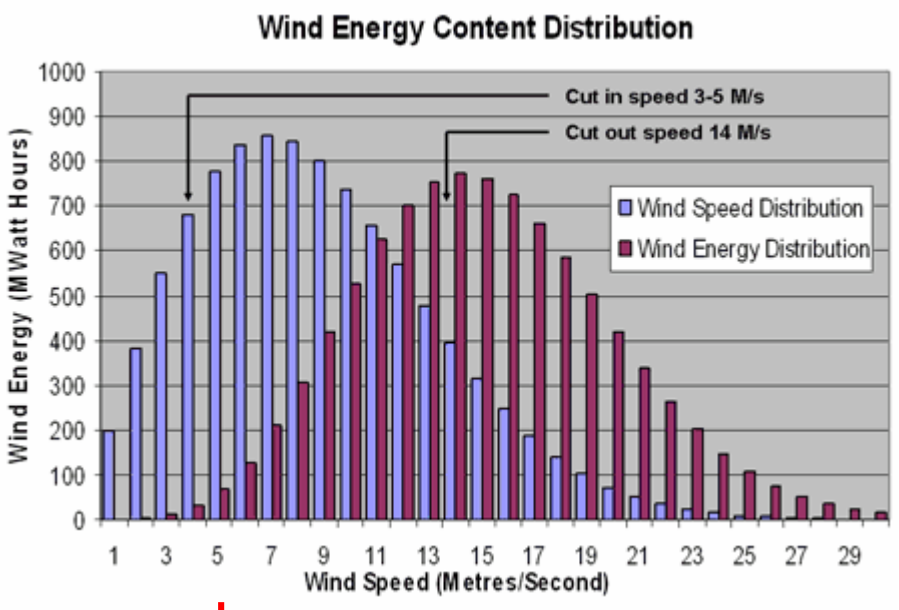
$$P = \frac{E}{t} = \frac{1}{2}A\rho v^3 .$$

Wind energy is the kinetic energy of air in motion, also called wind. Total wind energy flowing through an imaginary surface with area *A* during the time *t* is:

[32]

where *ρ* is the density of air; *v* is the wind speed; *Avt* is the volume of air passing through *A* (which is considered perpendicular to the direction of the wind); *Avtρ* is therefore the mass *m* passing through "A". ½ *ρv*² is the kinetic energy of the moving air per unit volume.
Power is energy per unit time, so the wind power incident on *A* (e.g. equal to the rotor area of a wind turbine) is:

[32]



11 miles/hour

31 miles/hour

Gentle breeze: 6-10 miles/hour

Leaves and small twigs in constant motion, wind extends light flag.

Moderate breeze: 10 to 16 miles/hour

Wind raises dust and paper, moves small branches.

The Betz Limit

59% of the energy

Wind energy content is proportional to the cube of its speed.

Energy generation typically does not cut in until wind is blowing at speeds of at least 3 m/s to 5 m/s.

High wind speeds cause high rotation speeds and high stresses in the wind turbine which can result in serious damage to the installation. Wind turbines are usually designed to cut out at wind speeds of around 14 m/s either by braking or feathering the rotor blades allowing the wind to spill over the blades.

Because of the upper speed limit at which the wind turbine can safely be used, it may capture only half or less of the available wind energy.

What is the minimum wind speed to turn the blades of a wind turbine?

Latest models can start at about 5 miles per hour wind speed, but most start at around 8 miles per hour,

Turbines also need a electrical 'kick-start' from the National Grid to get them into action, and a large amount of power is also required to brake them when the wind speed hits around 50-55 miles per hour, which is their upper safety limit.

Wind energy council estimate (1994):
27% of land surface has wind speed greater than 11miles/hour
Only 4% might be suitable due to unsuitable terrain, urban areas, crop cultivation, and other land uses

Largest wind farms

20 GW Jiuquan Wind Power Base. **Goal 200GW of installed wind capacity in the country**

1,600MW Jaisalmer Wind Park, India

1,548MW Alta Wind Energy Centre (AWEC) in Tehachapi, Kern County, California

1,500MW Muppandal Wind Farm, India

845MW Shepherds Flat Wind Farm near Arlington in Eastern Oregon

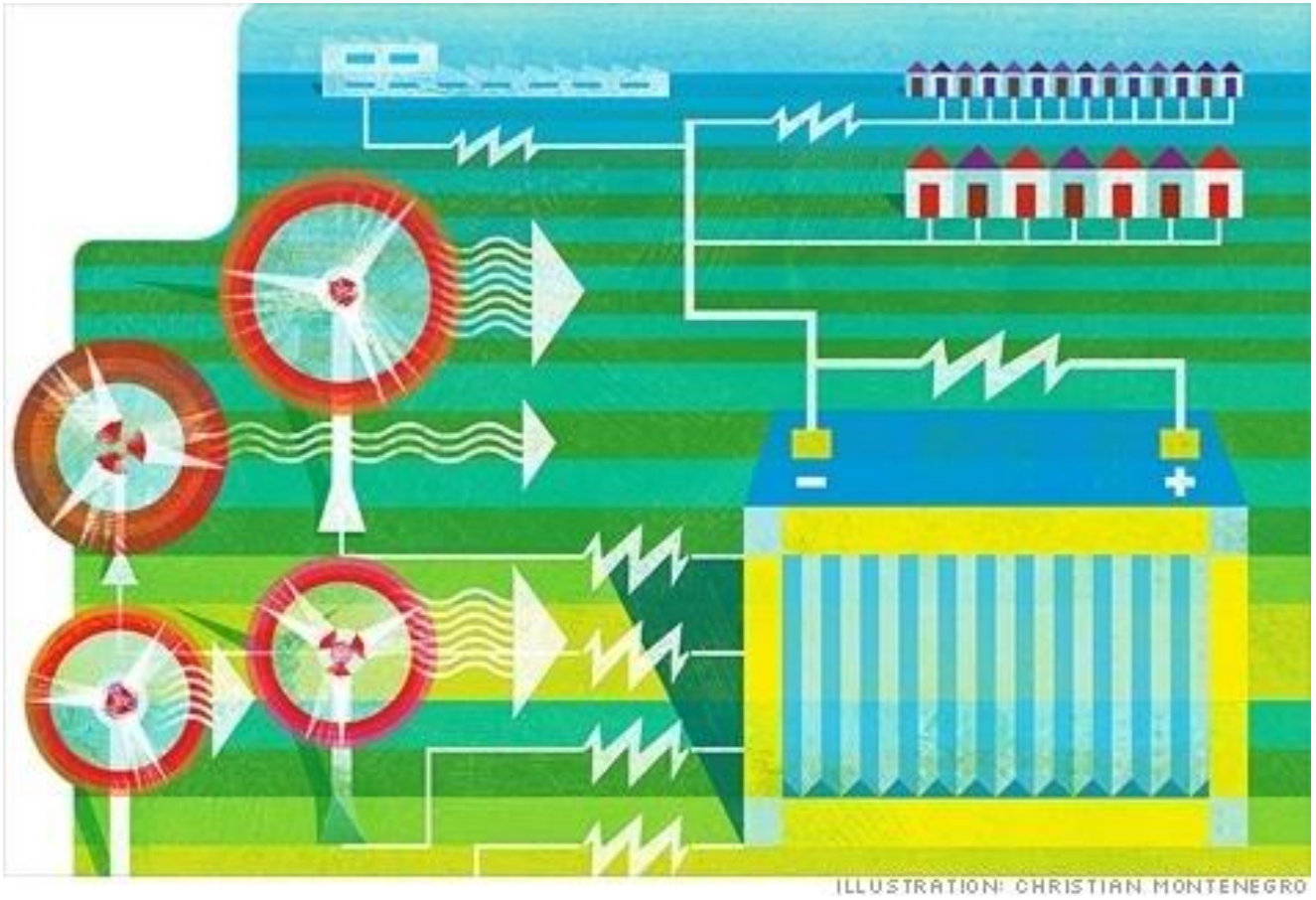
London Array Offshore Wind Farm, UK

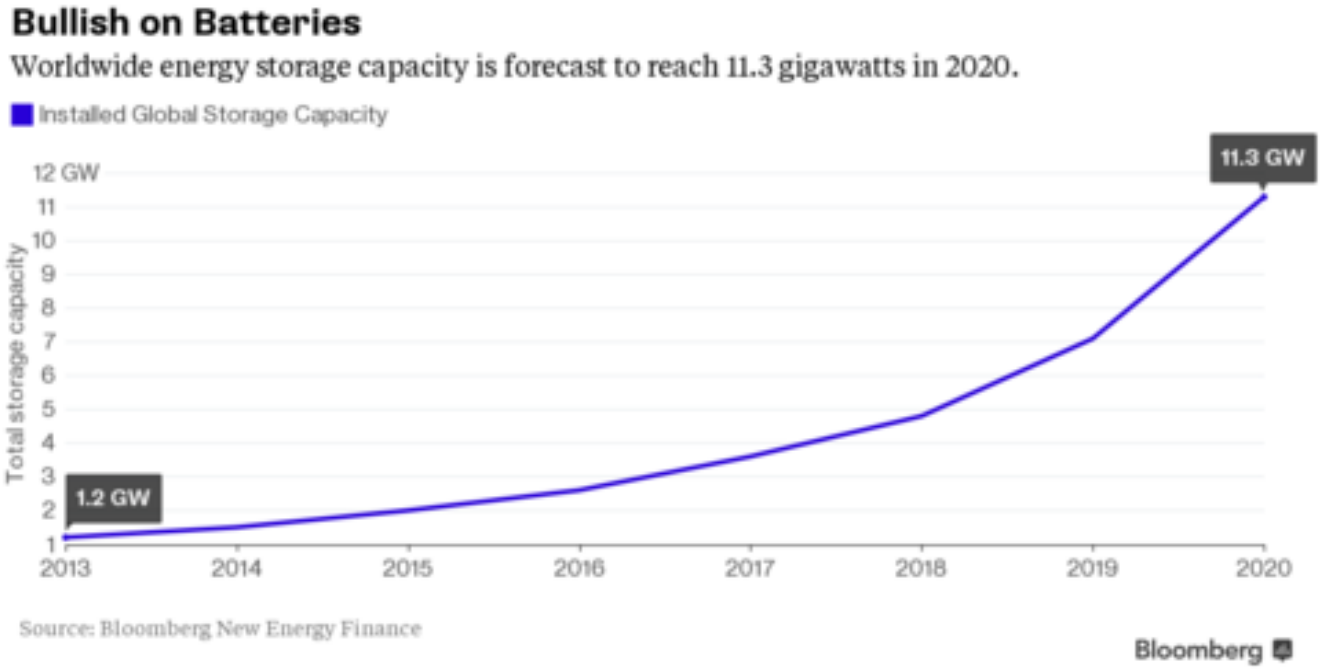
The London Array Offshore Wind Farm, the largest offshore wind farm in the world with an installed capacity of 630MW, ranks as the world's sixth largest wind farm. It is located in the outer Thames Estuary more than 20km off the coasts of Kent and Essex.

d Power Capacity: Land-based and Offshore

	Cumulative Capacity (end of 2018, MW)	
55	China	210,247
38	United States	96,433
71	Germany	59,312
91	India	35,129
39	Spain	23,531
01	United Kingdom	20,964
65	France	15,309
29	Brazil	14,707
20	Canada	12,816
56	Italy	9,959
93	*Rest of World*	91,466
18	TOTAL	589,872

Energy Storage with a Battery

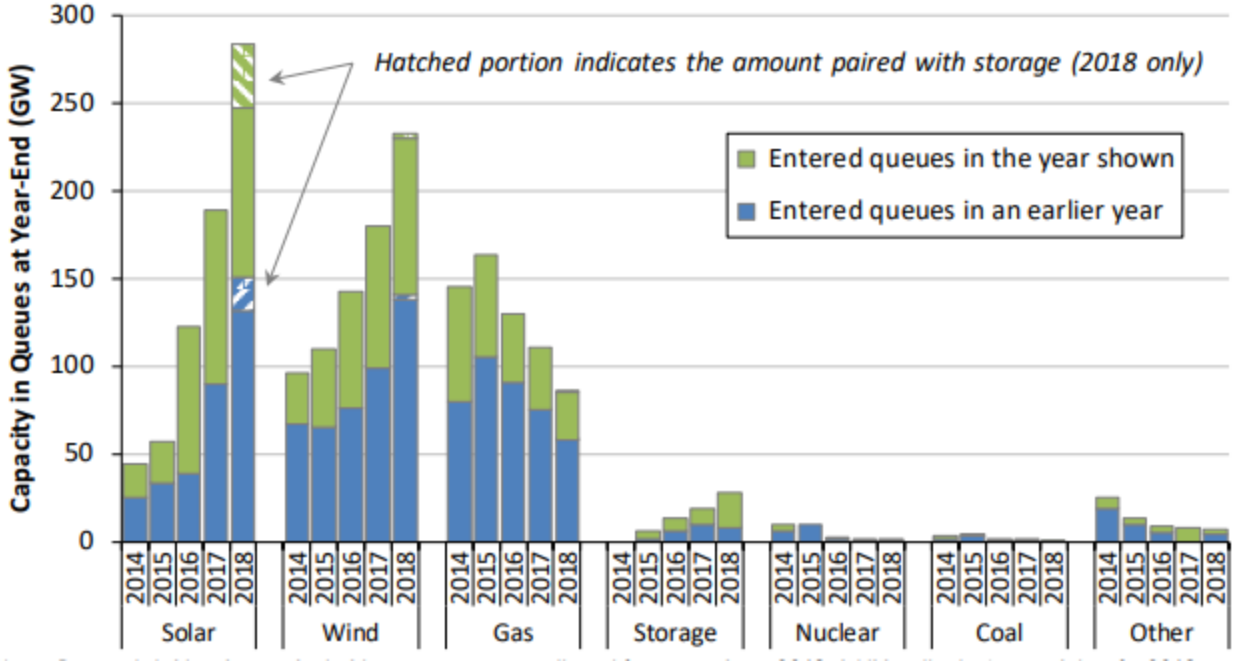




A gigawatt can power about 800,000 households

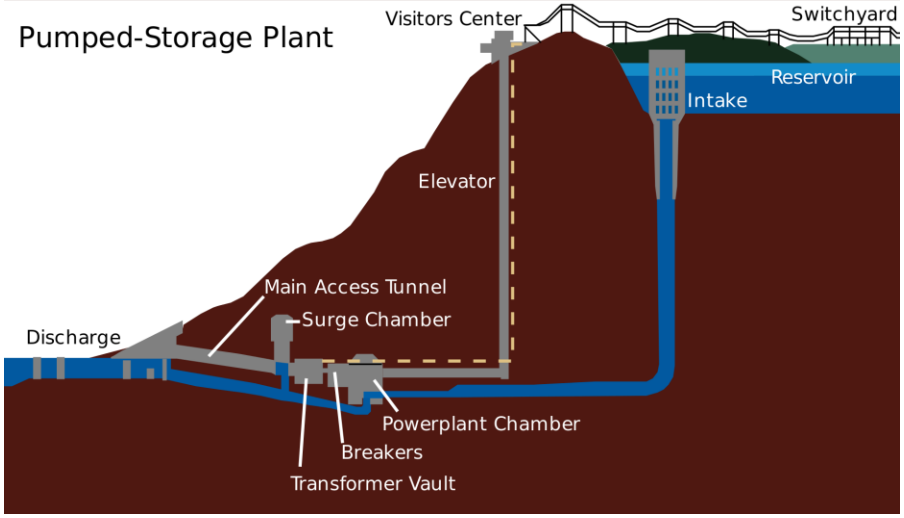
Southern California Edison and San Diego Gas & Electric claims supply from batteries now competes against natural-gas fired plants

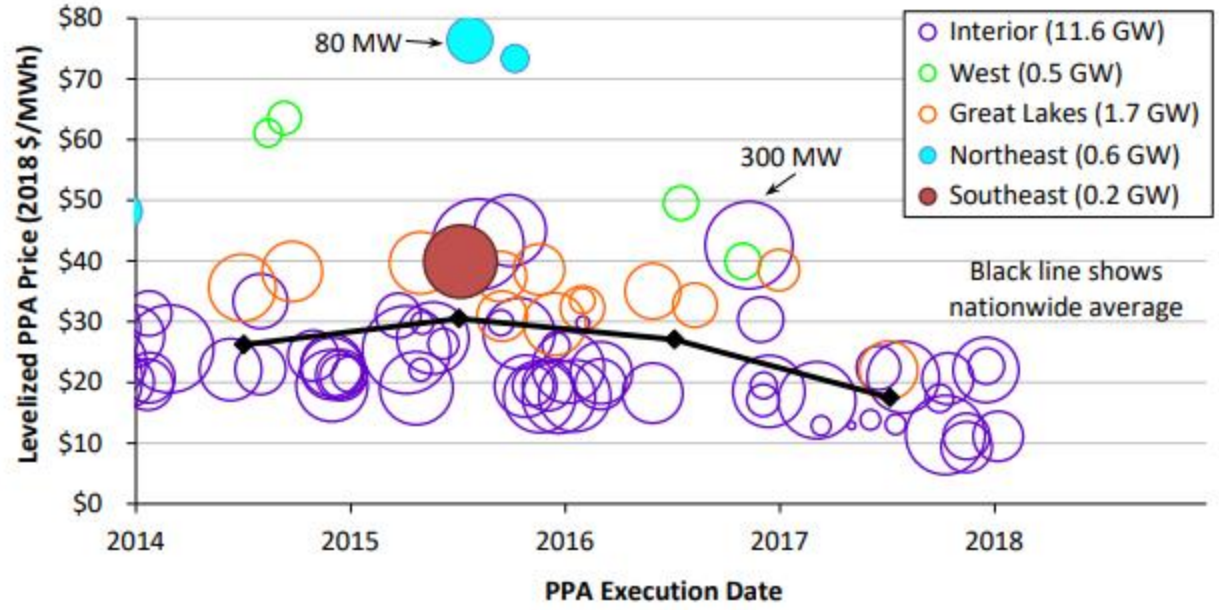
BloombergBusiness, October 19, 2015


Capacity in Queues at Year-End (GW)
300
250
200
150
100
50
0
Hatched portion indicates the amount paired with storage (2018 only)
Entered queues in the year shown
Entered queues in an earlier year
2014
2015
2016
2017
2018
Solar
Wind
Gas
Storage
Nuclear
Coal
Other

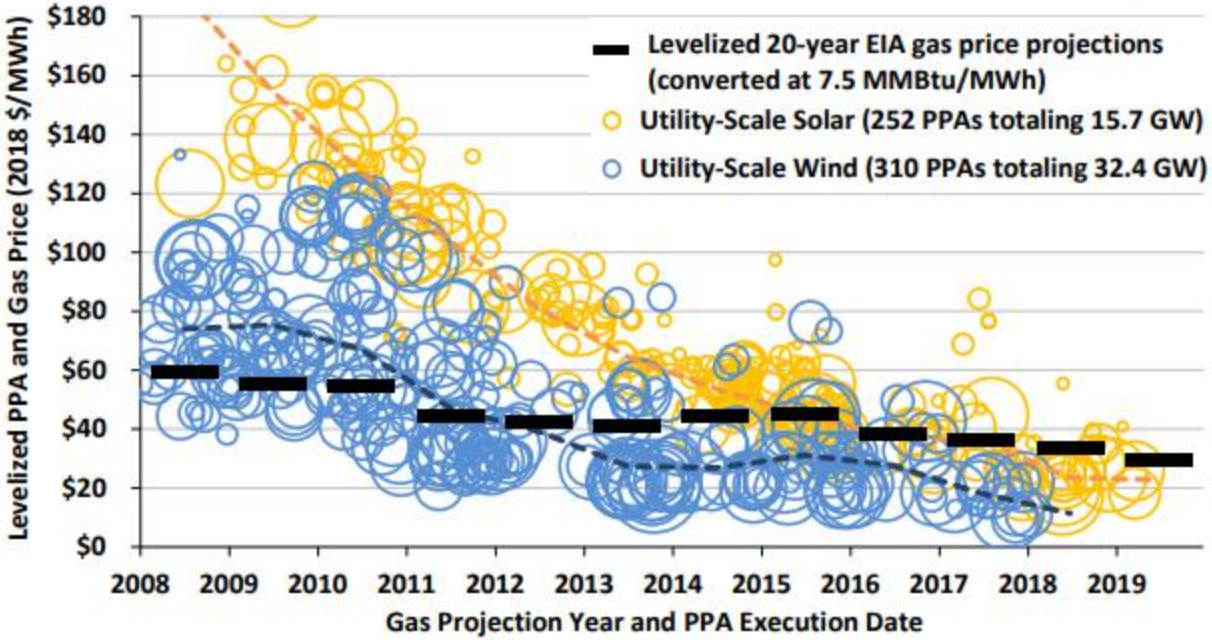
- Molten salt is circulated through highly specialized piping in the receiver (heat exchanger) during the day, and held in storage tanks at night – requiring no fossil fuels
- The tanks store the salt at atmospheric pressure
- Use of molten salt for both heat transfer and thermal energy storage minimizes number of storage tanks and salt volumes needed
- Molten salt is stored at 1050ºF (566ºC) until electricity is needed – day or night, whether or not the sun is shining
- As electricity is needed, molten salt is dispatched from the hot tank through a heat exchanger to create super-heated steam which then powers a conventional steam turbine
- The molten salt never needs replacing or topping up for the entire 30+ year life of the plant
- Heat loss is only 1ºF per day
- The salt, an environmentally friendly mixture of sodium nitrate and potassium nitrate, is able to be utilized as high grade fertilizer when the plant is eventually decommissioned

Molten salt is stored at 1050ºF until electricity is needed – day or night, whether or not the sun is shining


Pumped-Storage Plant
Visitors Center
Switchyard
Reservoir
Intake
Elevator
Main Access Tunnel
Surge Chamber
Discharge
Powerplant Chamber
Breakers
Transformer Vault

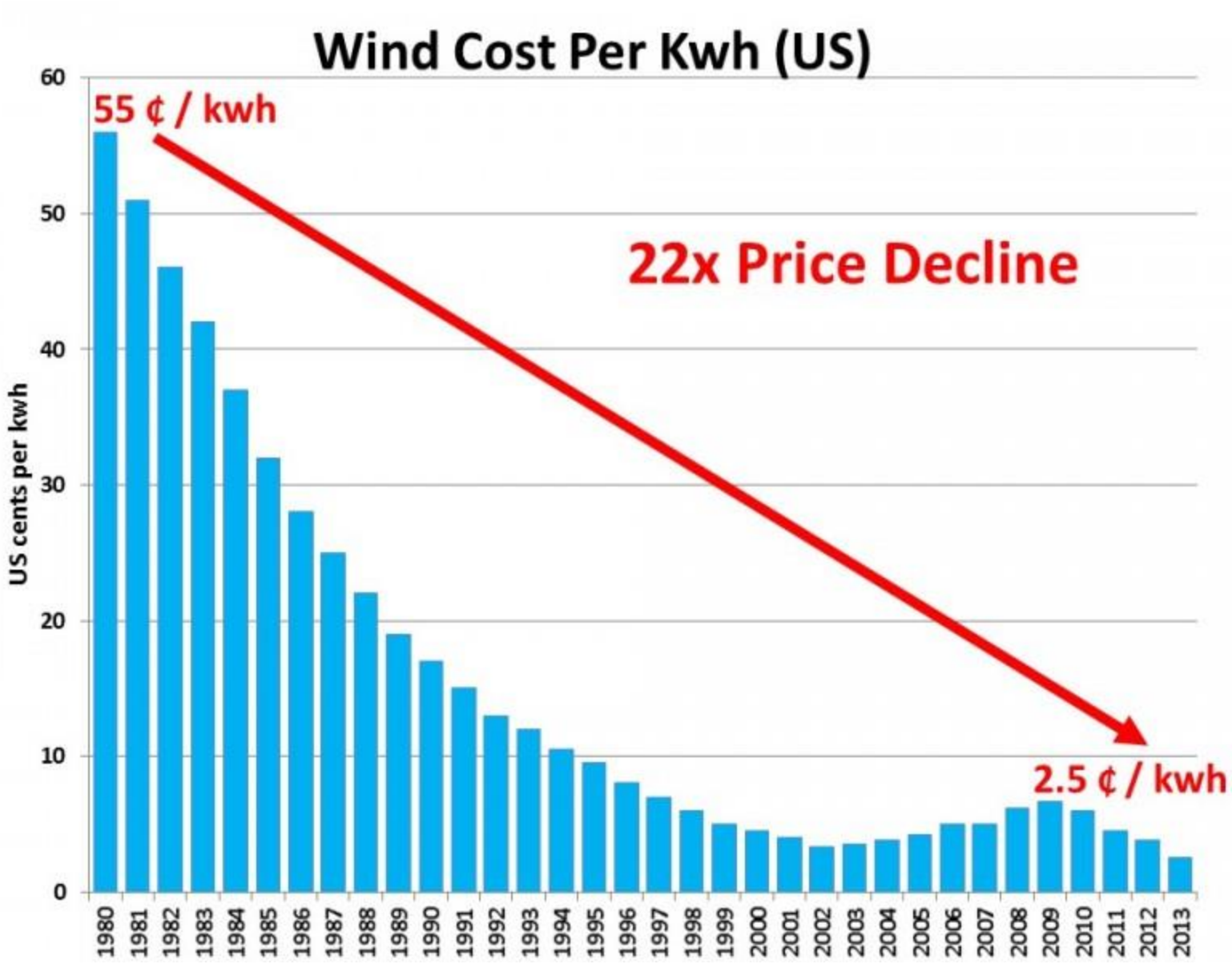


Source: Berkeley Lab



Sources: Berkeley Lab, Energy Information Administration

Figure 56. Levelized wind and solar PPA prices and levelized gas price projections


Wind Cost Per Kwh (US)
55 ¢ / kwh
22x Price Decline
2.5 ¢ / kwh
US cents per kwh
60
50
40
30
20
10
0
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
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2009
2010
2011
2012
2013

World's Largest Offshore Wind Farms

World's largest offshore wind farms

Wind farm	Capacity (MW)	Country	Turbines and model	Commissioned
Walney Extension	659	United Kingdom	47 x Vestas 8MW 40 x Siemens Gamesa 7MW	2018
London Array	630	United Kingdom	175 × Siemens SWT-3.6	2012
Gemini Wind Farm	600	The Netherlands	150 × Siemens SWT-4.0	2017
Gwynt y Môr	576	United Kingdom	160 × Siemens SWT-3.6 107	2015
Greater Gabbard	504	United Kingdom	140 × Siemens SWT-3.6	2012
Anholt	400	Denmark	111 × Siemens SWT-3.6–120	2013
BARD Offshore 1	400	Germany	80 BARD 5.0 turbines	2013

GE to provide world's most powerful turbines for British wind project: capacity of 12 megawatts (MW)
October 1, 2019

Status unknown: numerous challenges and barriers

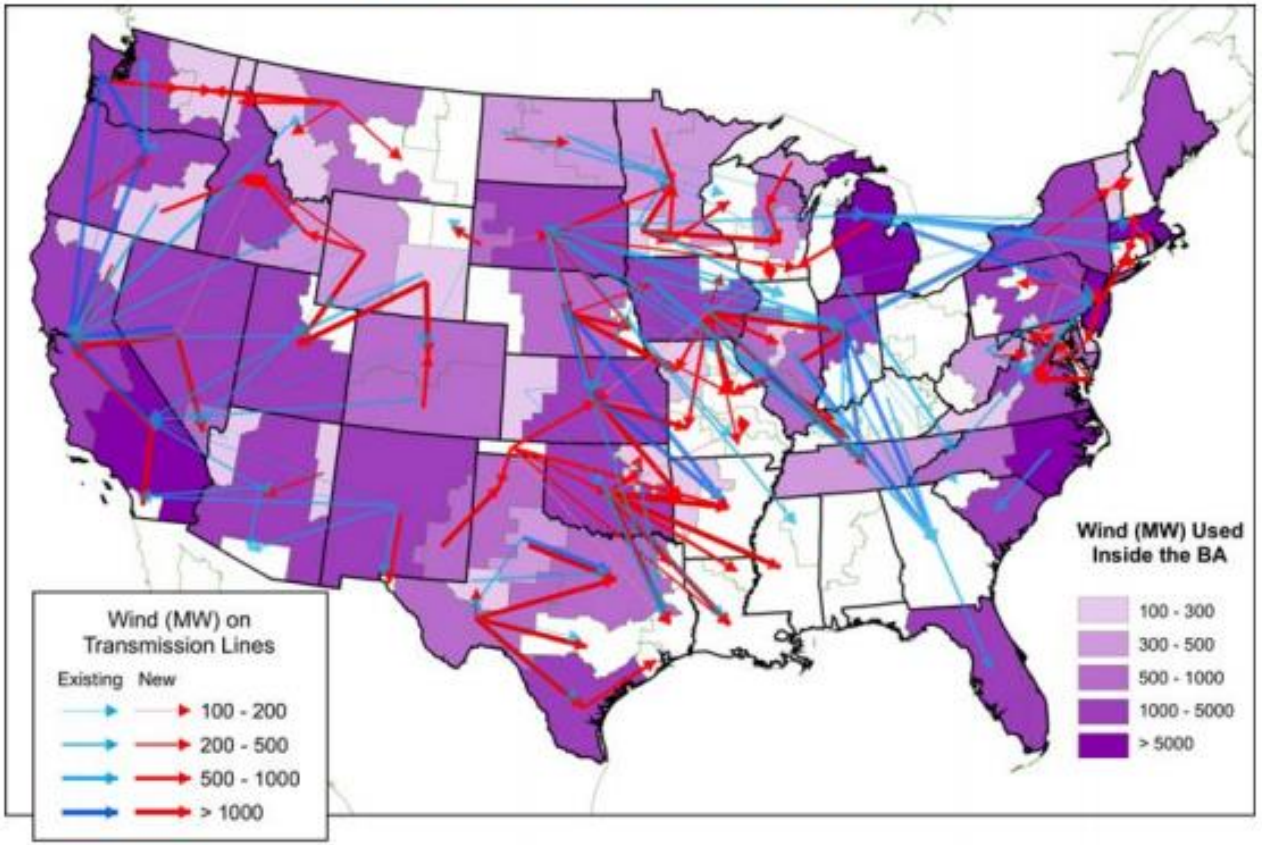
Built by Trans-Elect and sponsored by Good Energies, Google, Marubeni Corporation and Elia System Operator

The Mid-Atlantic region offers more than 60,000 MW of offshore wind potential in the relatively shallow waters of the outer continental shelf. These shallow waters, which extend miles out to sea, allow for the development of large, distant wind farms, mitigating visibility issues and allowing for greater energy capture from stronger winds.

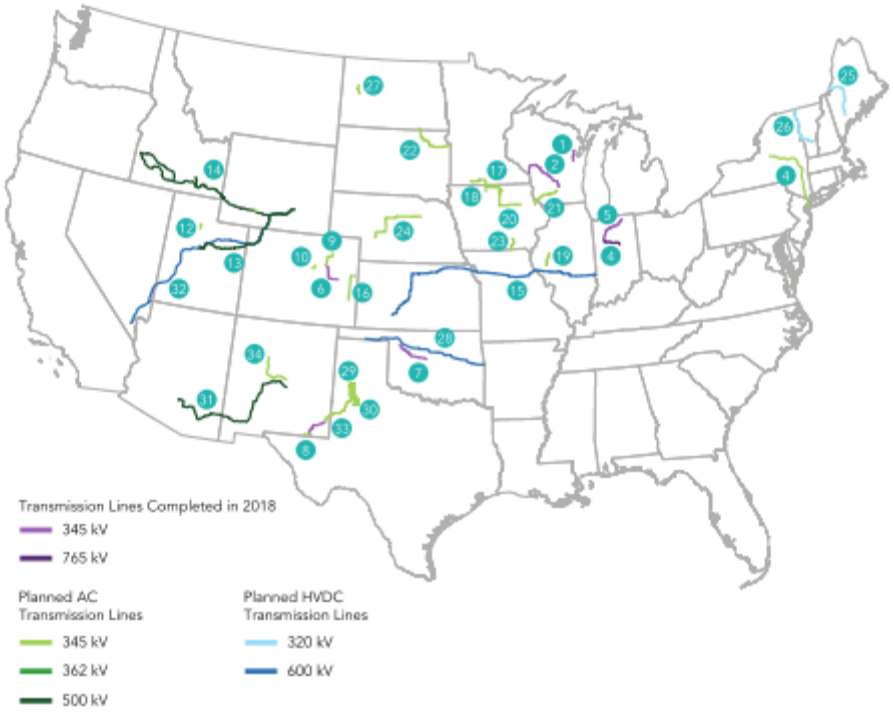
7,000 MW of offshore wind, enough power to serve approximately 1.9 million households.
Initial cost; $1.3 billion
Google commitment: $5 B

133,000 and 212,000 U.S. Jobs during construction
43,000 permanent operations and maintenance jobs would be created if 54,000 MW of offshore wind turbines were installed by 2030.

Figure 1-9. All new electricity generation including wind energy would require expansion of U.S. transmission by 2030



Total Between Balancing Areas Transfer >= 100 MW (all power classes, land-based and offshore) in 2030.
Wind power can be used locally within a Balancing Area (BA), represented by purple shading, or transferred out of the area on new or existing transmission lines, represented by red or blue arrows. Arrows originate and terminate at the centroid of the BA for visualization purposes; they do not represent physical locations of transmission lines.



Source: AWEA (2019a)

Figure 64. Transmission line activity: completed in 2018, and planned

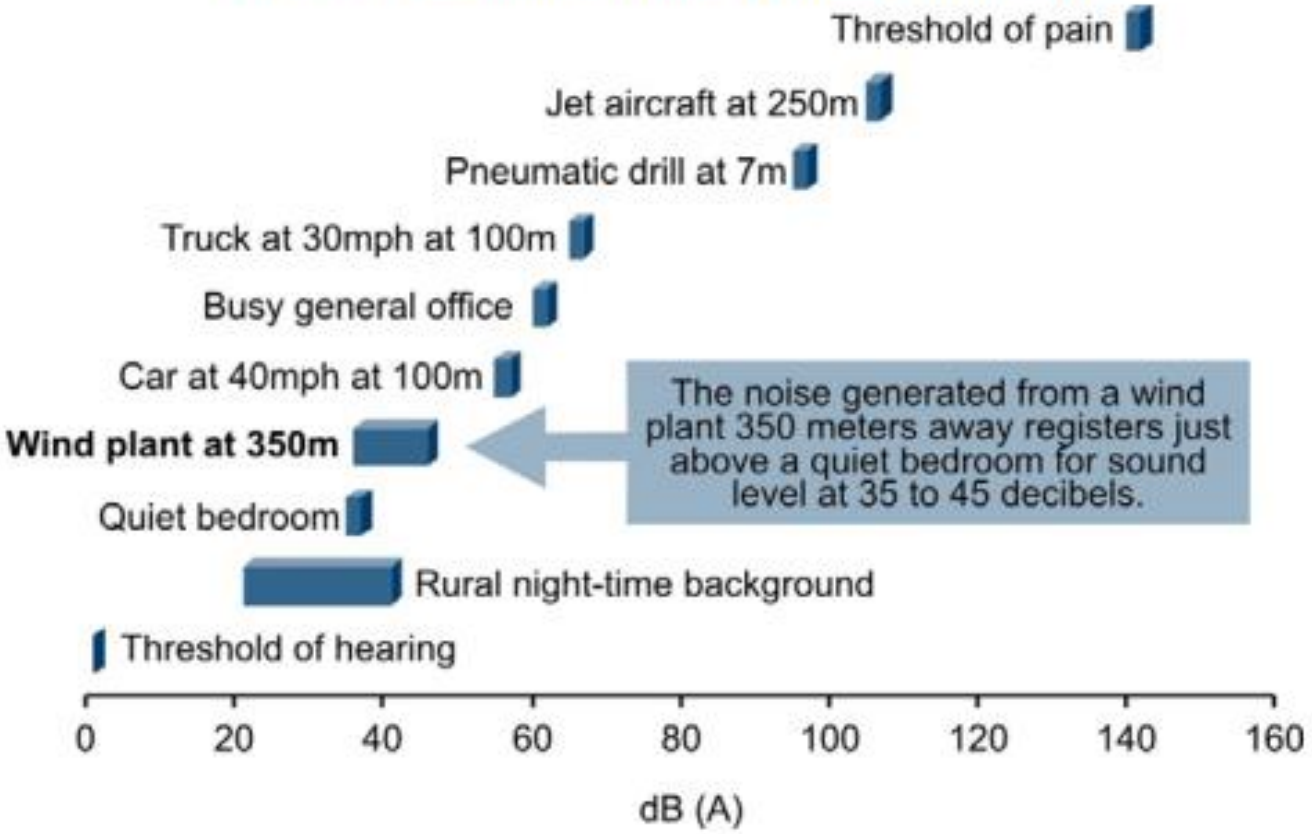
Countries Depending on Wind Power

Country	Penetration[a]
Denmark (2015)[98][22]	42%
Portugal (2013)[99][100]	23%
Ireland (2015)[101][102]	23%
Spain (2014)[103]	20.2%
Germany (2017)[104]	18.7%
United Kingdom (2018)[105]	18%
United States (2016)[106]	6%

[a]Percentage of wind power generation over total electricity consumption

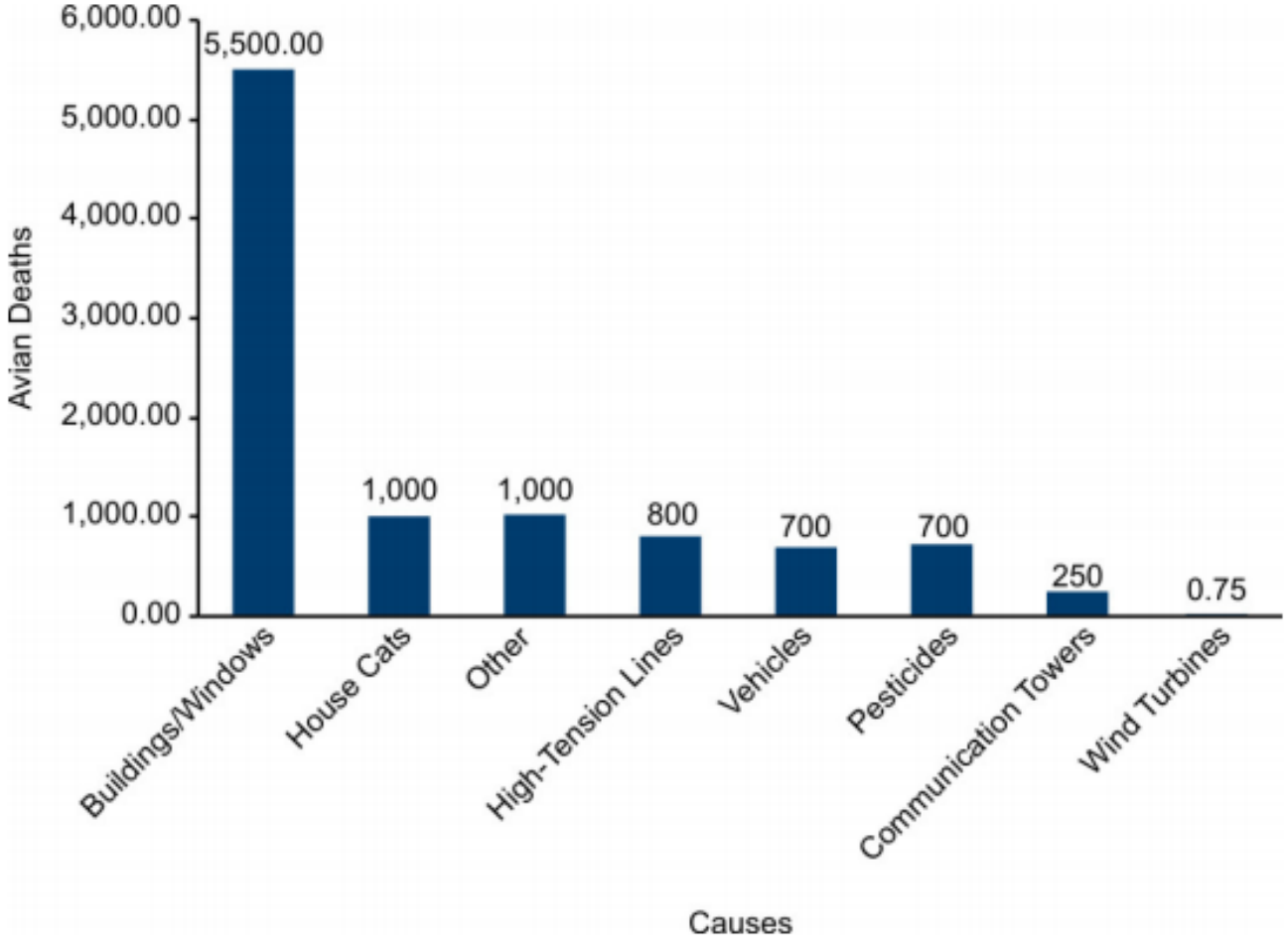
Wind can provide 40 times current worldwide consumption of electricity, 5 times total global use of energy in all forms

Figure 5-4. Decibel levels of various situations



Source: BWEA (2007)

Figure 5-2. Anthropogenic causes of bird mortality
(per 10,000 avian deaths)



Source: Erickson et al. (2002)

New industry guidelines, aim to save tens of thousands of bats each year by idling turbines at low wind speeds during peak bat migration season. They could reduce by a third the number of bats killed at wind farms
Migratory bats, for some reason, have a lethal attraction to wind turbines. Now, they may get help via "feathering.“

By **Andrew Curry**, for National Geographic

PUBLISHED SEPTEMBER 02, 2015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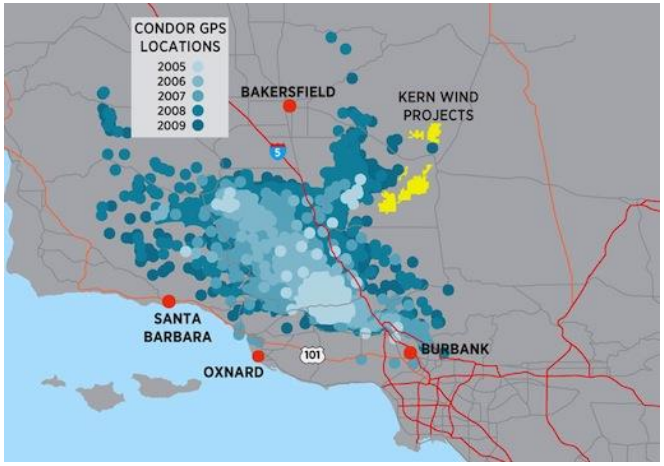
North America's largest bird, **Candor**: nine-and-a-half-foot wingspan bird of uncommon intelligence and longevity. manipulates hot winds to soar hundreds of miles without flapping its wings.

With the investment of tens of millions of dollars and extraordinary effort by scientists, the condor, is staging a spectacular comeback after verging on extinction 25 years ago. The 200 birds in the wild today (out of 400 total) are rapidly expanding their historic range

It's a flight path that is taking the condor perilously closer to the spinning blades of Tehachapi wind turbines that depend on those same thermal currents to generate power; biologists fear it's only a matter of time before the condor begins hitting the 500-foot-high machines.

A single death could be catastrophic for the wind industry, the regional economy and, not least, the condor. "We cannot envision a situation where we would permit the lethal take of California condors. The day a condor is killed by a wind turbine in California changes the course of future development."



Deploying avian radar units that could shut down turbines when a condor approaches appears to be getting the most attention

Revival Of Iconic California Condor Threatens State's Wind Farm Boom

Forbes, 1/16/2012

In the past 36 months the wind industry has attracted $3.2 billion in investment to the Kern County, region, California (Tehachapi Mountains)

A multibillion-dollar transmission line under construction in the Tehachapi will carry as much as 4,500 megawatts of renewable energy, most of it from wind farms, to coastal cities.

At peak output that's the equivalent of four or five big nuclear power plants and a linchpin of California's mandate to obtain a third of its electricity from renewable sources by 2020.

Power Capacity: Land-based and Offshore

	Cumulative Capacity (end of 2018, MW)	
	China	210,247
	United States	96,433
	Germany	59,312
	India	35,129
	Spain	23,531
	United Kingdom	20,964
	France	15,309
	Brazil	14,707
	Canada	12,816
	Italy	9,959
	Rest of World	91,466
	TOTAL	589,872