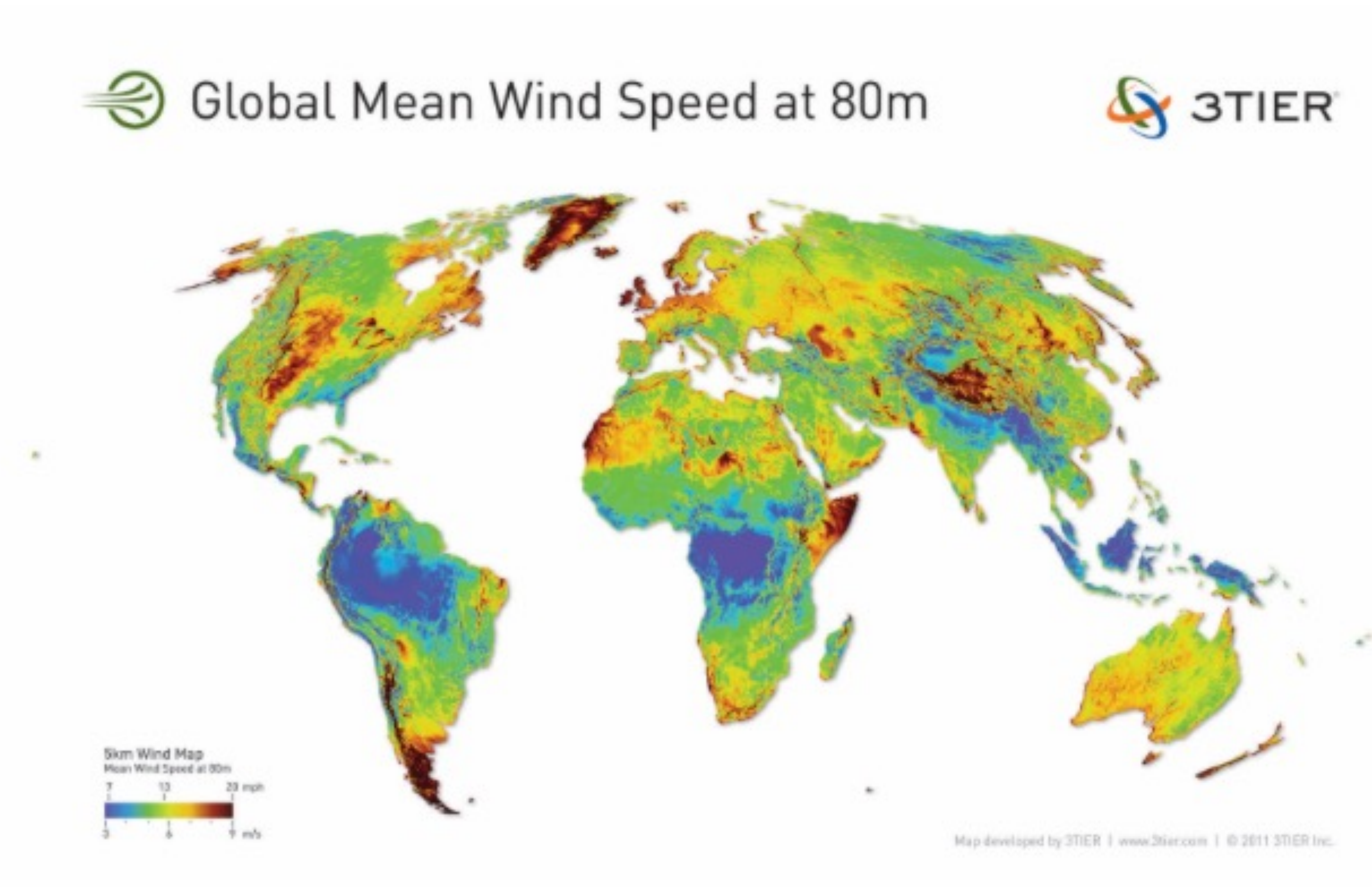
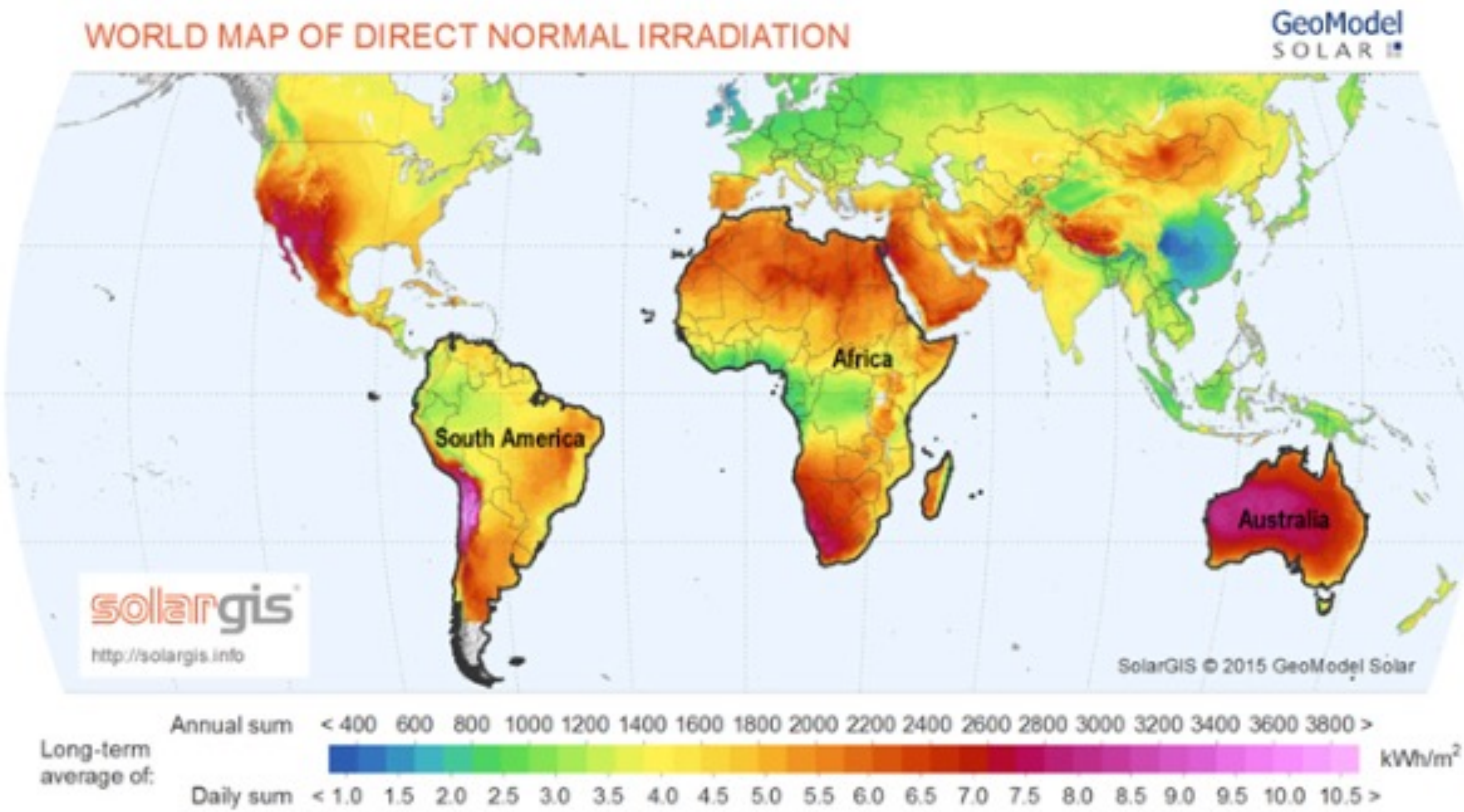
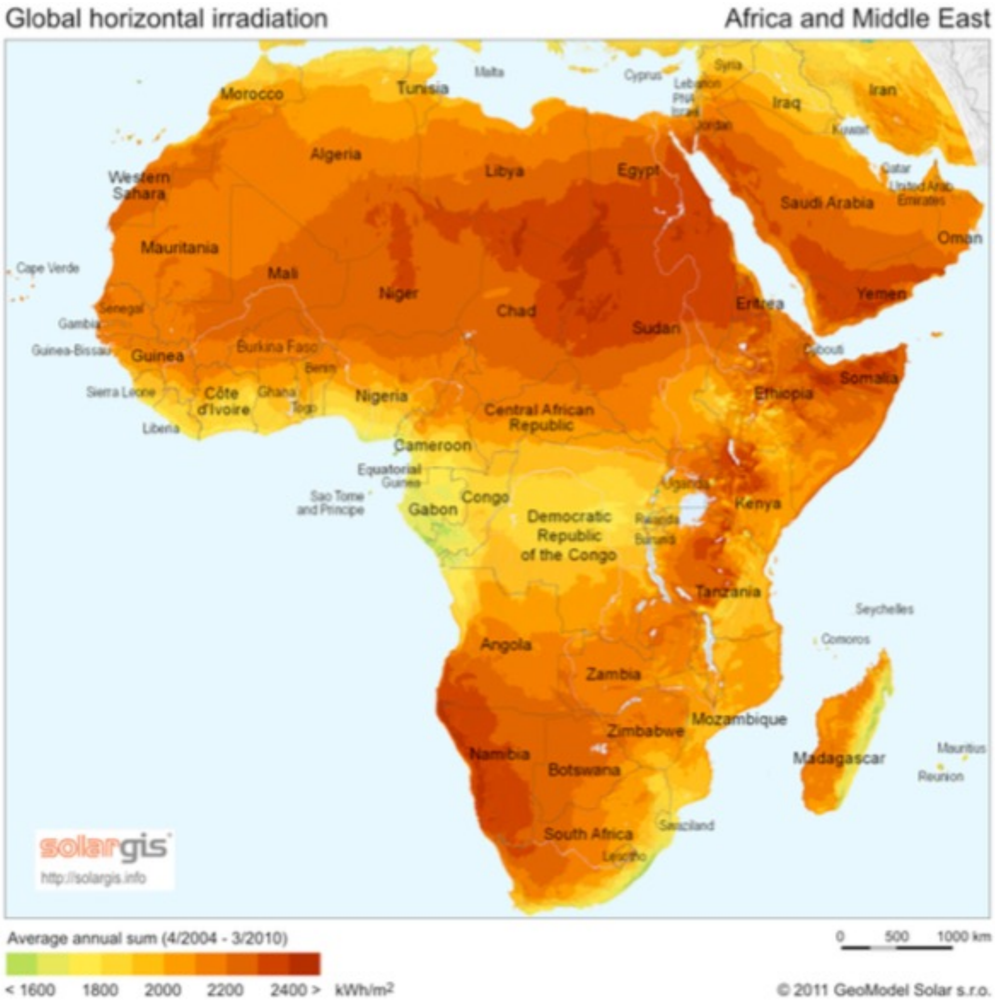
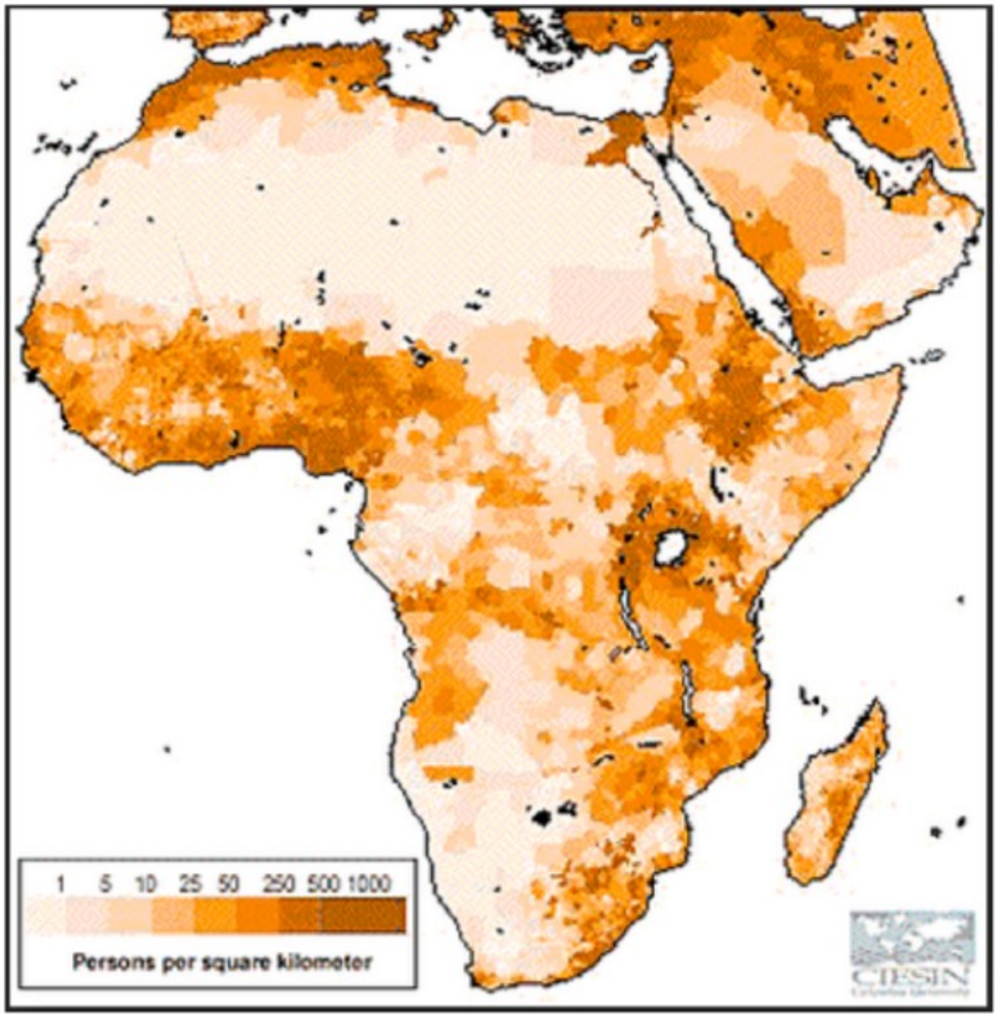

Global Mean Wind Speed at 80m
3TIER
5km Wind Map
Mean Wind Speed at 80m
7 13 20 mph
3 6 9 m/s
Map developed by 3TIER | www.3tier.com | © 2011 3TIER Inc.

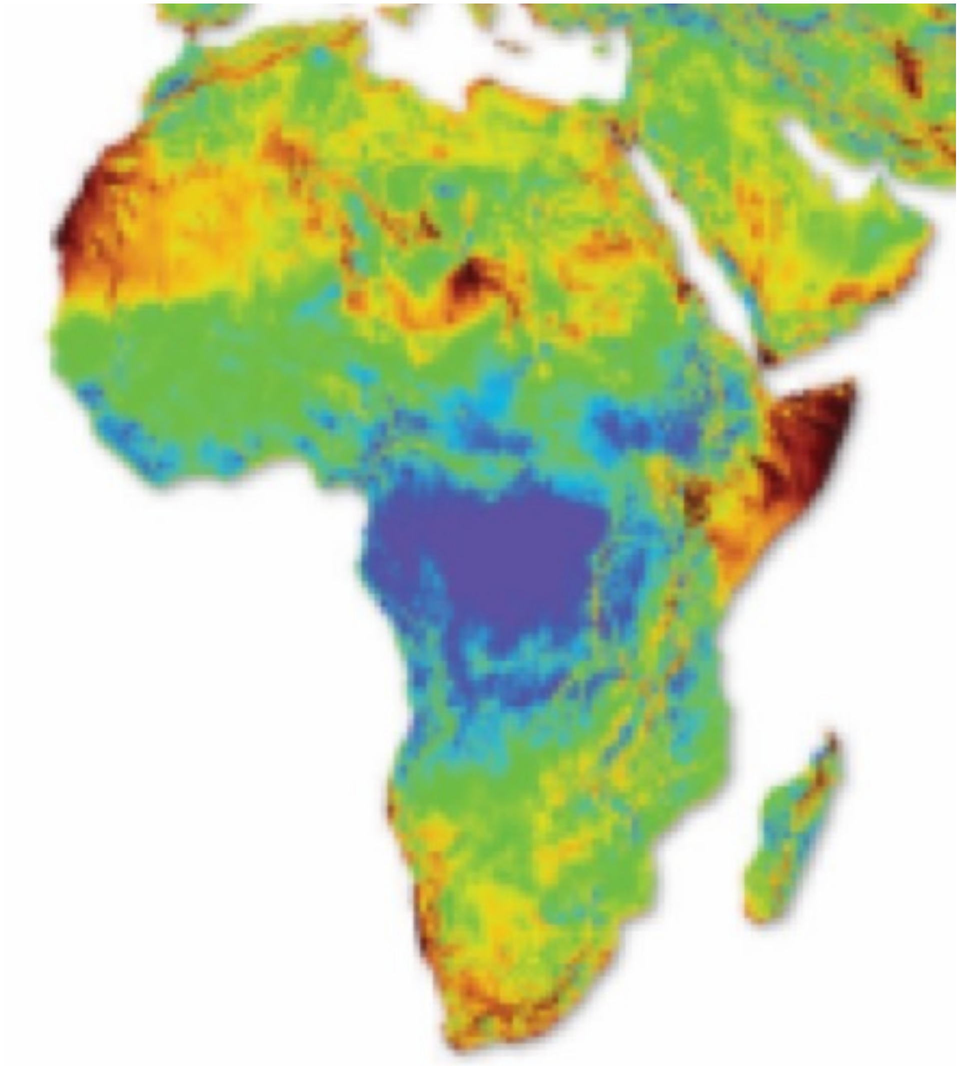
OFFSHORE WIND TECHNICAL POTENTIAL ANALYSIS AND MAPS

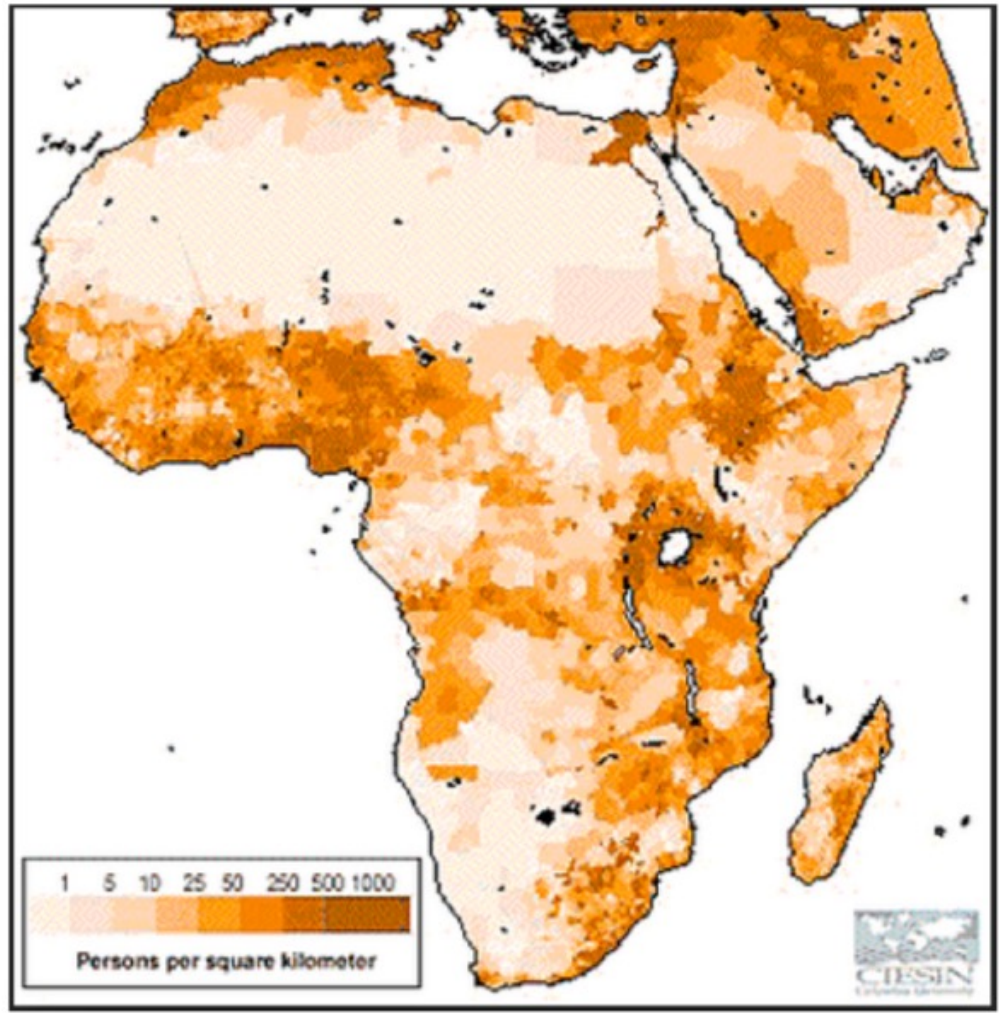
This wind resource map provides an estimate of mean annual wind speeds (m/s) extending 200 kilometers from shore at a hub height of 100 meters. It is provided under a World Bank Group (WBG) initiative on offshore wind that is funded and led by the Energy Sector Management Assistance Program (ESMAP). For more information visit: **https://esmap.org/offshore-wind**. The wind resource data is from the Global Wind Atlas (version 3.3), a free, web-based application that provides data with a 250m resolution based on the latest input datasets and modeling methodologies. For more information please visit: **https://globalwindatlas.info**.


WORLD MAP OF DIRECT NORMAL IRRADIATION
GeoModel SOLAR
South America
Africa
Australia
solargis
http://solargis.info
SolarGIS © 2015 GeoModel Solar
Long-term average of:
Annual sum < 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800 3000 3200 3400 3600 3800 >
kWh/m2
Daily sum < 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 8.0 8.5 9.0 9.5 10.0 10.5 >

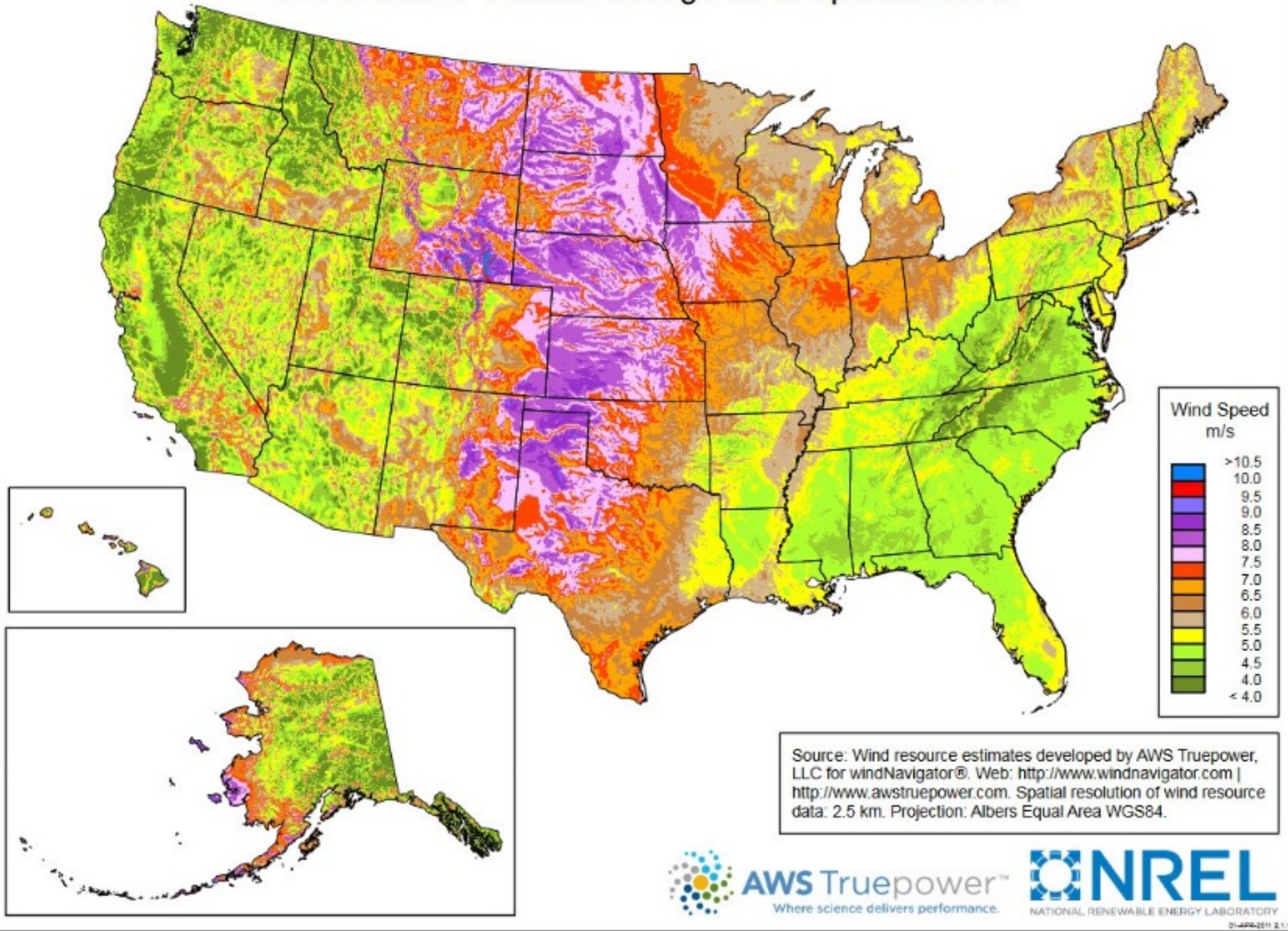

Global horizontal irradiation
Africa and Middle East
Morocco
Tunisia
Algeria
Libya
Egypt
Western Sahara
Mauritania
Mali
Niger
Chad
Sudan
Eritrea
Saudi Arabia
Oman
Yemen
Iraq
Iran
Syria
Cyprus
Malta
Cape Verde
Senegal
Gambia
Guinea-Bissau
Guinea
Burkina Faso
Benin
Sierra Leone
Côte d'Ivoire
Ghana
Togo
Liberia
Nigeria
Central African Republic
Ethiopia
Somalia
Djibouti
Cameroon
Equatorial Guinea
Sao Tome and Principe
Gabon
Congo
Democratic Republic of the Congo
Uganda
Kenya
Rwanda
Burundi
Tanzania
Seychelles
Comoros
Angola
Zambia
Mozambique
Zimbabwe
Namibia
Botswana
Madagascar
Mauritius
Reunion
South Africa
Swaziland
Lesotho
solargis
http://solargis.info
Average annual sum (4/2004 - 3/2010)
< 1600 1800 2000 2200 2400 > kWh/m2
0 500 1000 km
© 2011 GeoModel Solar s.r.o.

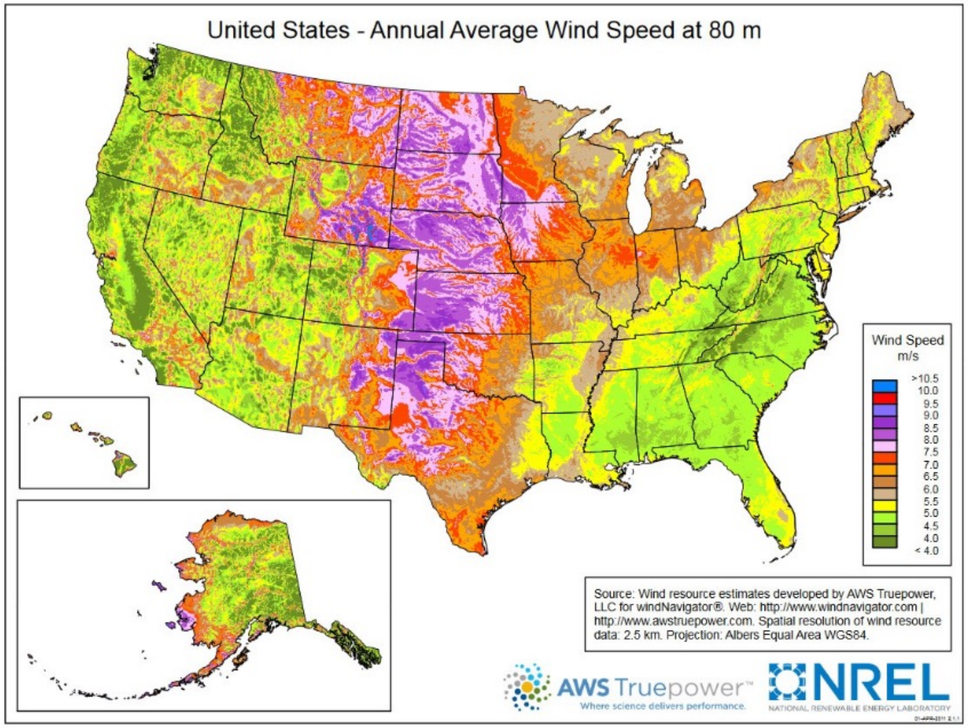

1 5 10 25 50 250 500 1000
Persons per square kilometer
CIESIN

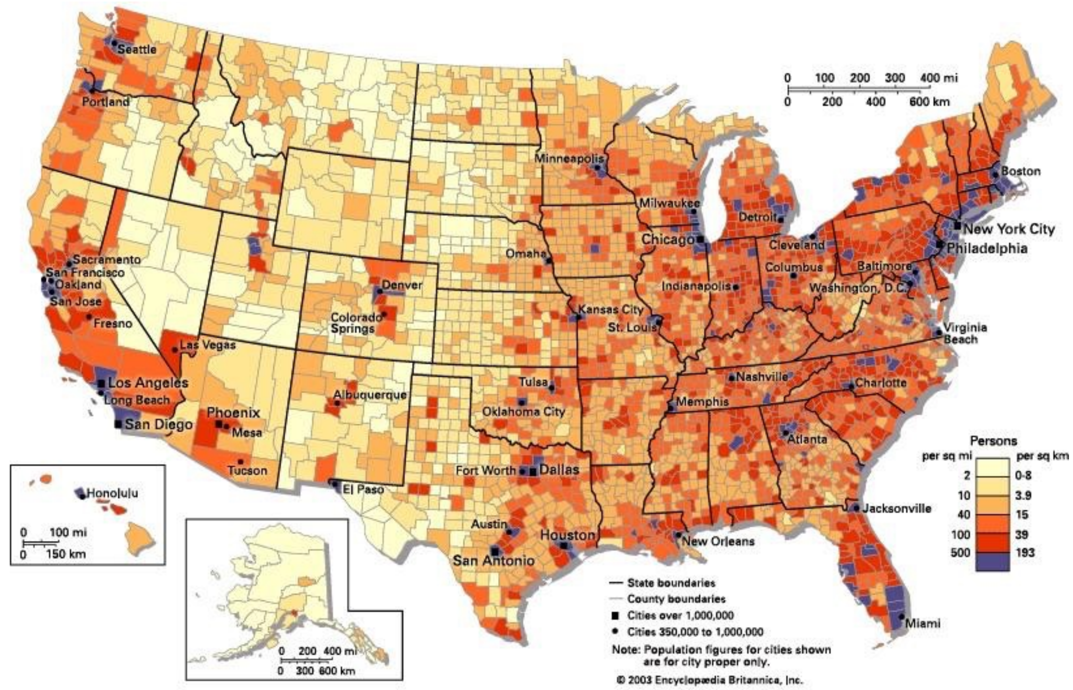


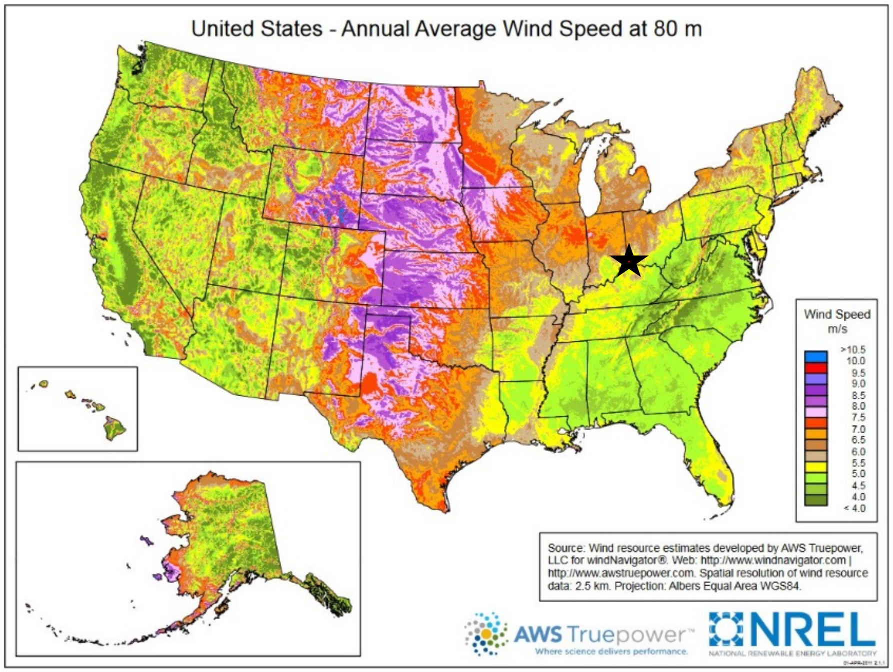

1 5 10 25 50 250 500 1000
Persons per square kilometer
CIESIN

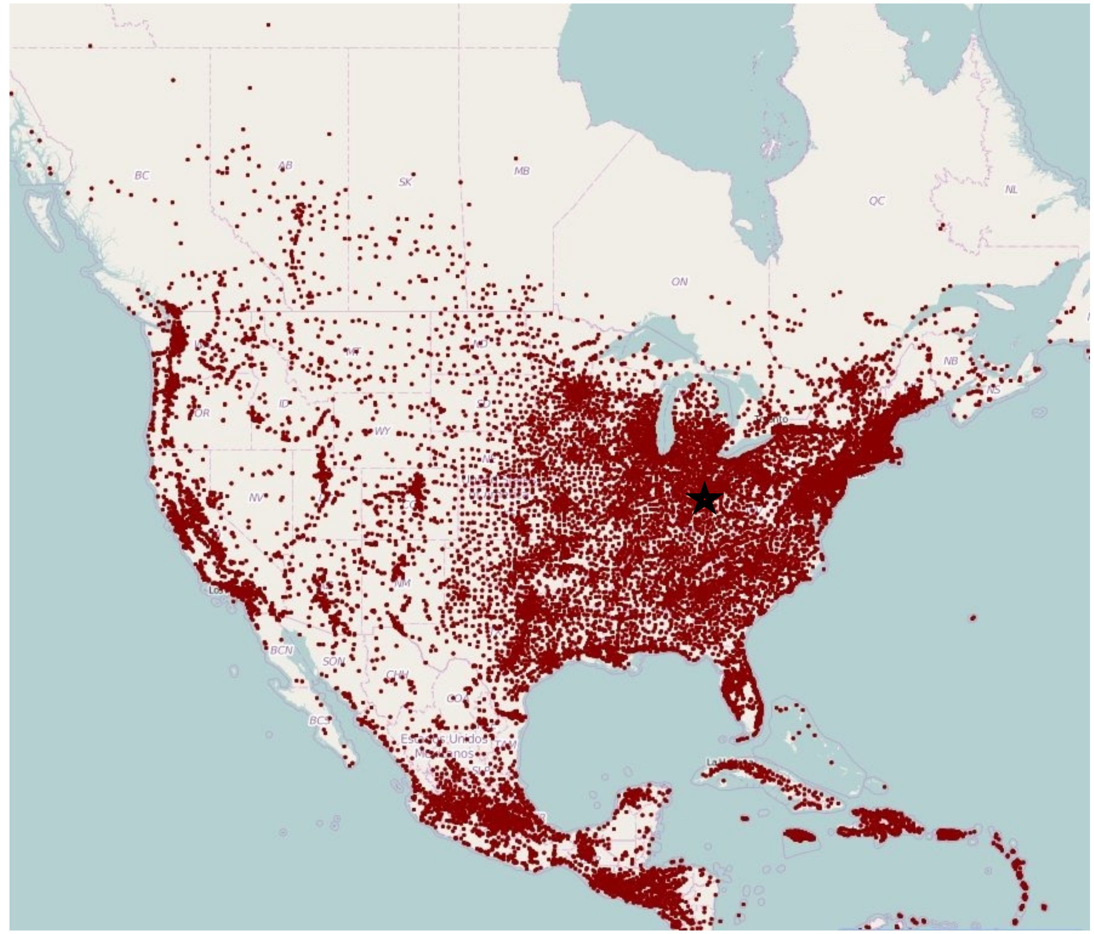
United States - Annual Average Wind Speed at 80 m



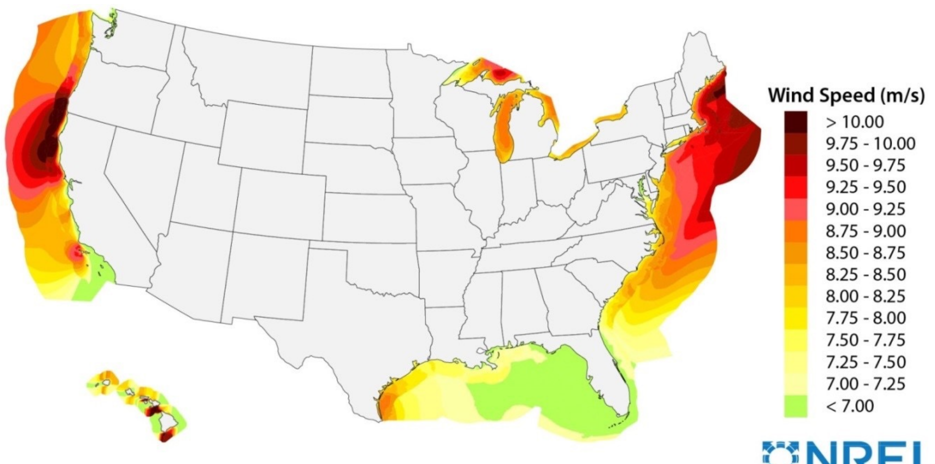

United States - Annual Average Wind Speed at 80 m
Wind Speed
m/s
>10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
< 4.0
Source: Wind resource estimates developed by AWS Truepower, LLC for windNavigator®. Web: http://www.windnavigator.com | http://www.awstruepower.com. Spatial resolution of wind resource data: 2.5 km. Projection: Albers Equal Area WGS84.
AWS Truepower
Where science delivers performance.
NREL
NATIONAL RENEWABLE ENERGY LABORATORY


Seattle
Portland
Sacramento
San Francisco
Oakland
San Jose
Fresno
Las Vegas
Los Angeles
Long Beach
San Diego
Phoenix
Mesa
Tucson
Denver
Colorado Springs
Albuquerque
El Paso
Minneapolis
Milwaukee
Chicago
Omaha
Kansas City
St. Louis
Tulsa
Oklahoma City
Fort Worth
Dallas
Austin
San Antonio
Houston
New Orleans
Memphis
Nashville
Atlanta
Jacksonville
Miami
Charlotte
Indianapolis
Detroit
Cleveland
Columbus
Baltimore
Washington, D.C.
Virginia Beach
Philadelphia
New York City
Boston
Honolulu
0 100 200 300 400 mi
0 200 400 600 km
0 100 mi
0 150 km
0 200 400 mi
0 300 600 km
Persons
per sq mi
per sq km
2
10
40
100
500
0-8
3.9
15
39
193
State boundaries
County boundaries
Cities over 1,000,000
Cities 350,000 to 1,000,000
Note: Population figures for cities shown are for city proper only.
© 2003 Encyclopædia Britannica, Inc.

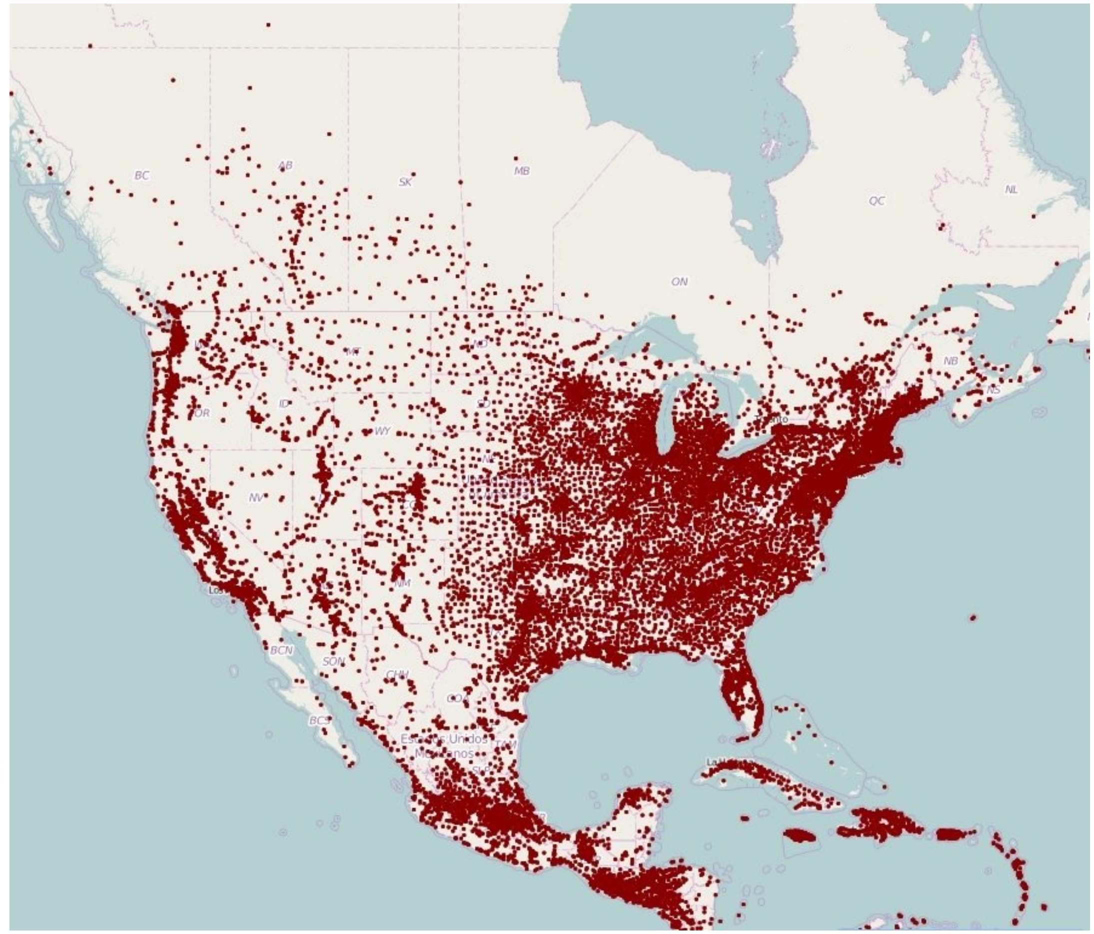




Population Density

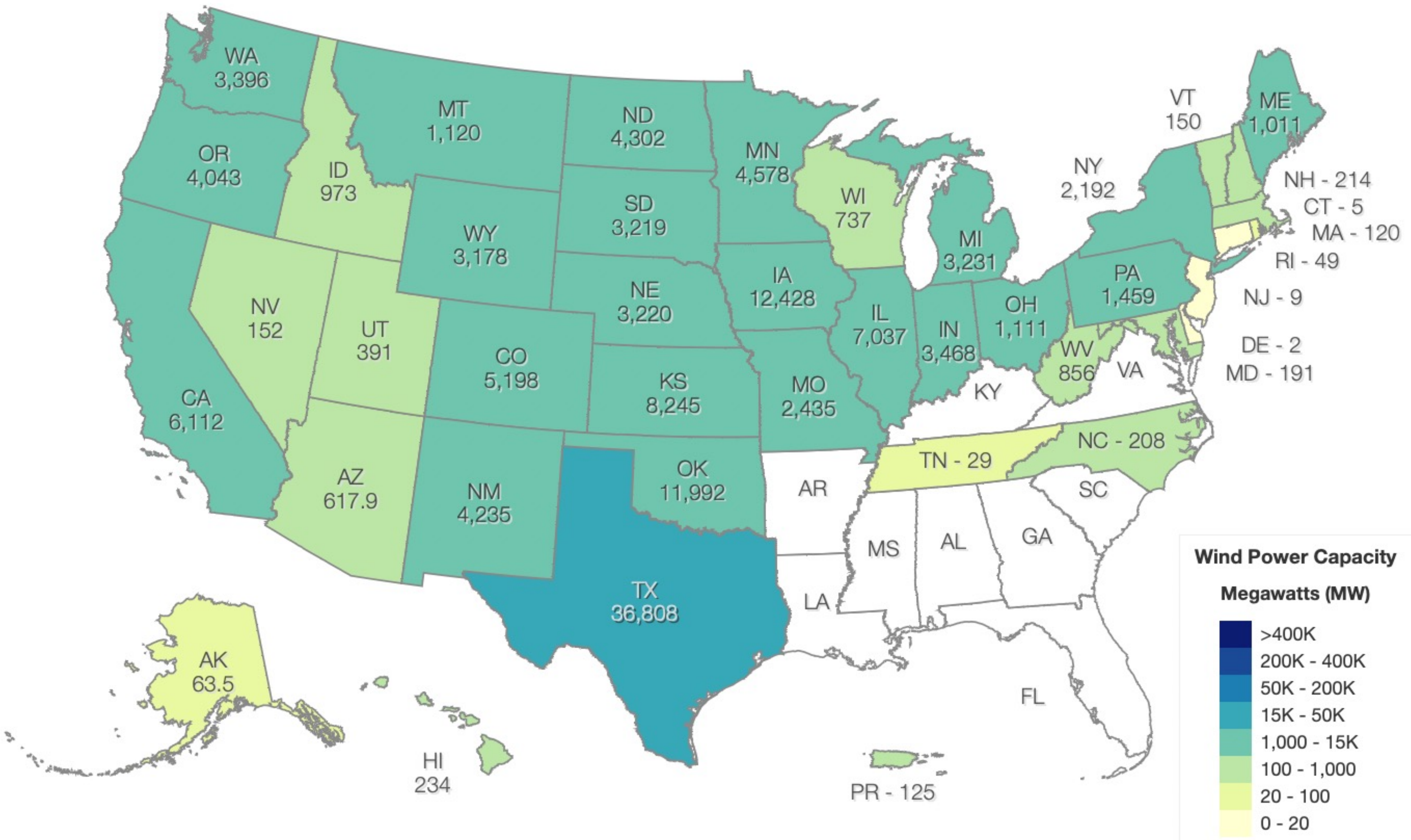


Data Source: AWS Truepower 0-50nm; NREL WIND Toolkit beyond 50nm.



Population
Density

Q2 2022 Installed Wind Power Capacity (MW)

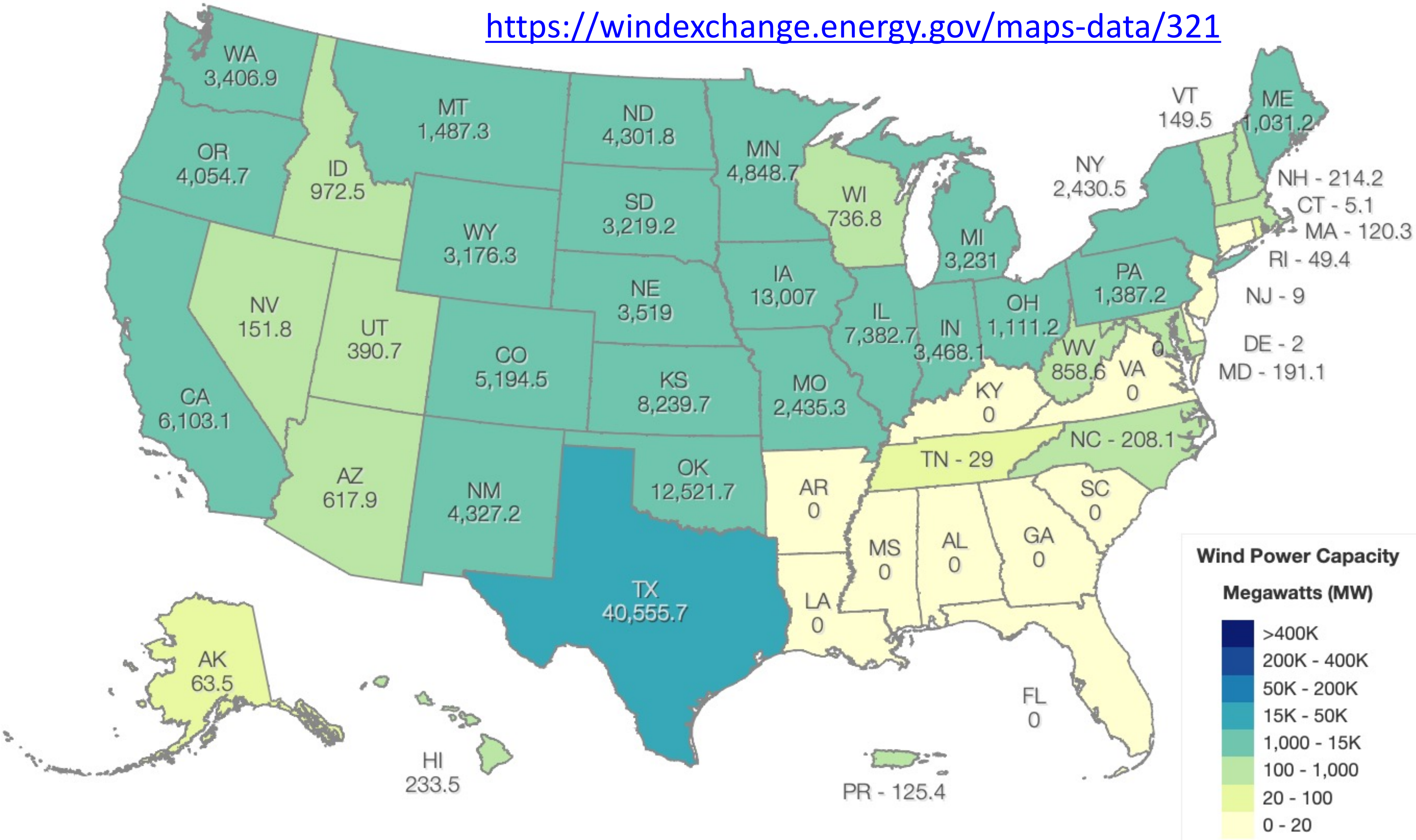


Total Installed Wind Capacity: 139,145 MW

Source: American Clean Power Association

Q1 2023 Installed Capacity by State

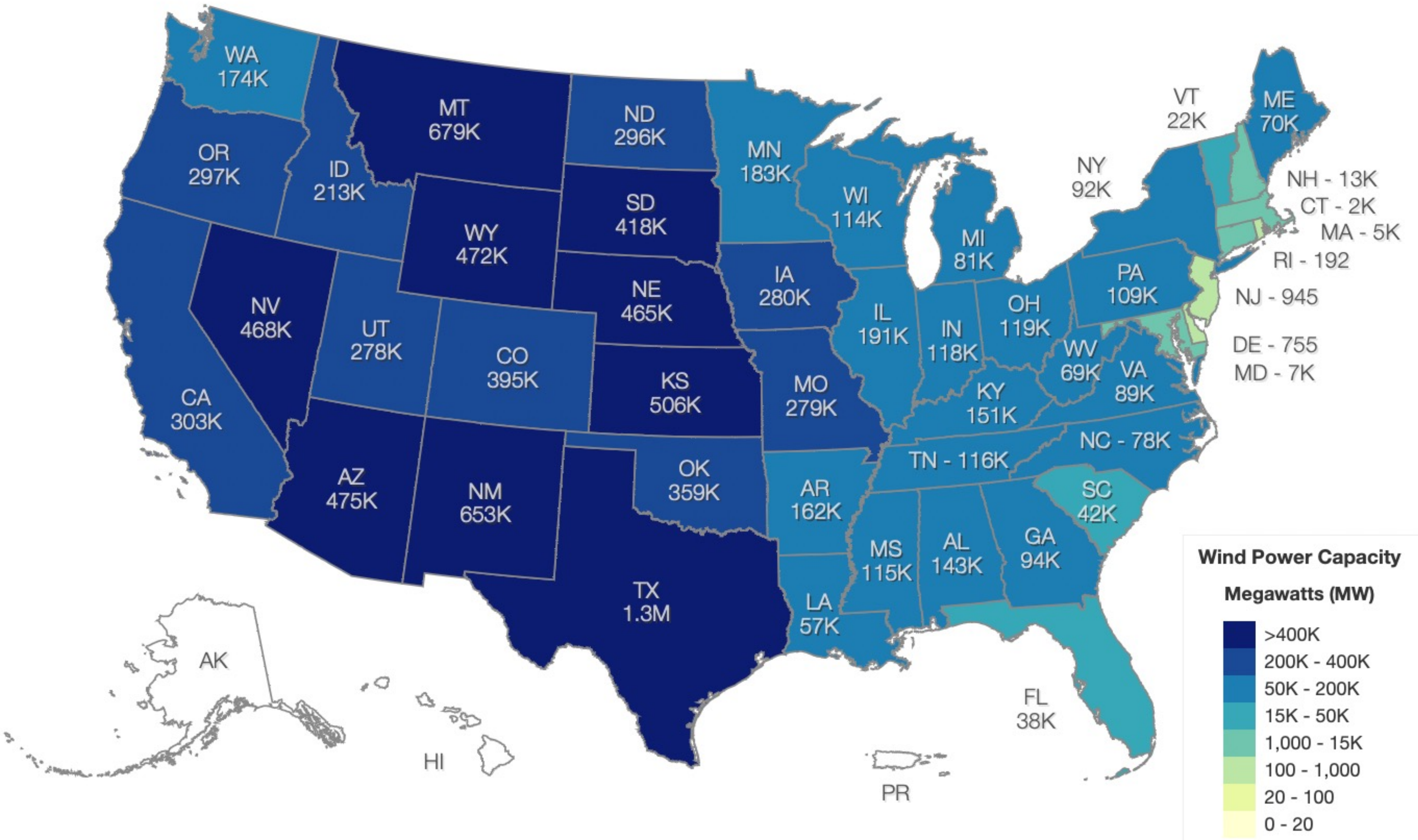
https://windexchange.energy.gov/maps-data/321



Total Installed Wind Capacity: 145,569 MW

Source: American Clean Power Association

U.S Potential Wind Capacity in Megawatts (MW) at 80 Meters



Total Potential Wind Capacity: 10,640,080 MW

Source: AWS Truepower, NREL

Wind power in Iowa

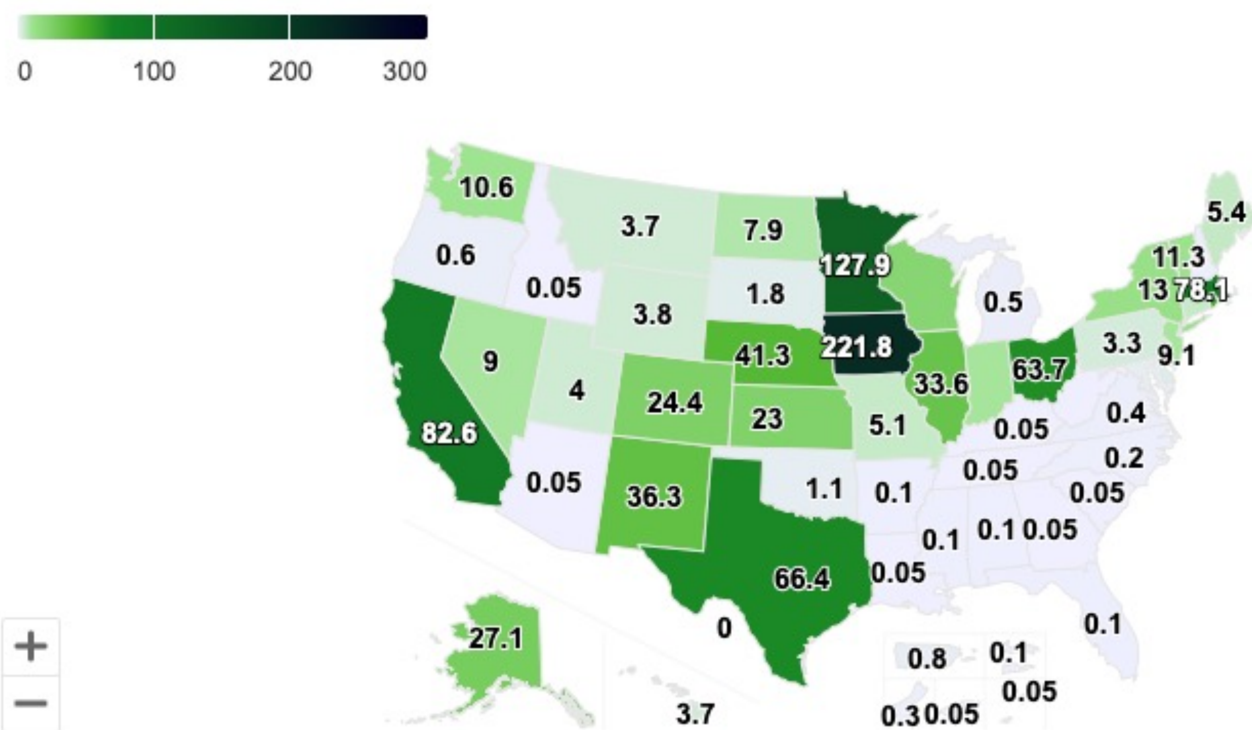
Article Talk

From Wikipedia, the free encyclopedia

Making up over 62% of the state's generated electricity in 2022, wind power is the largest source of electricity generation in Iowa.[1][2] In 2020, over 34 billion kWh of electrical energy was generated by wind power. As of 2022, Iowa has over 12,200 megawatts (MW) of installed capacity with over 6,000 wind turbines, ranking 2nd and 3rd in the nation below Texas respectively.[3]

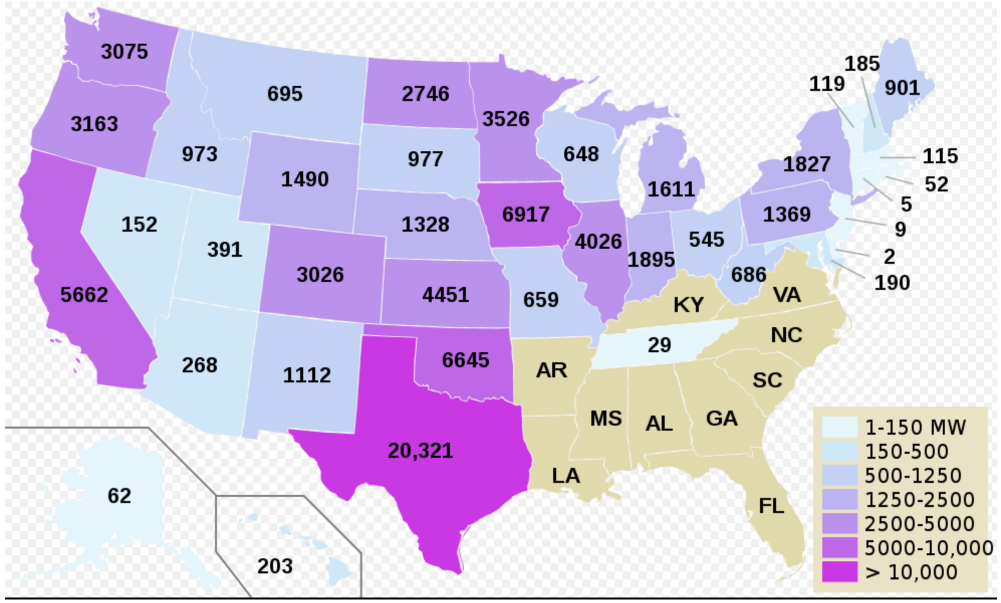
2022 U.S. Distributed Wind Energy Capacity

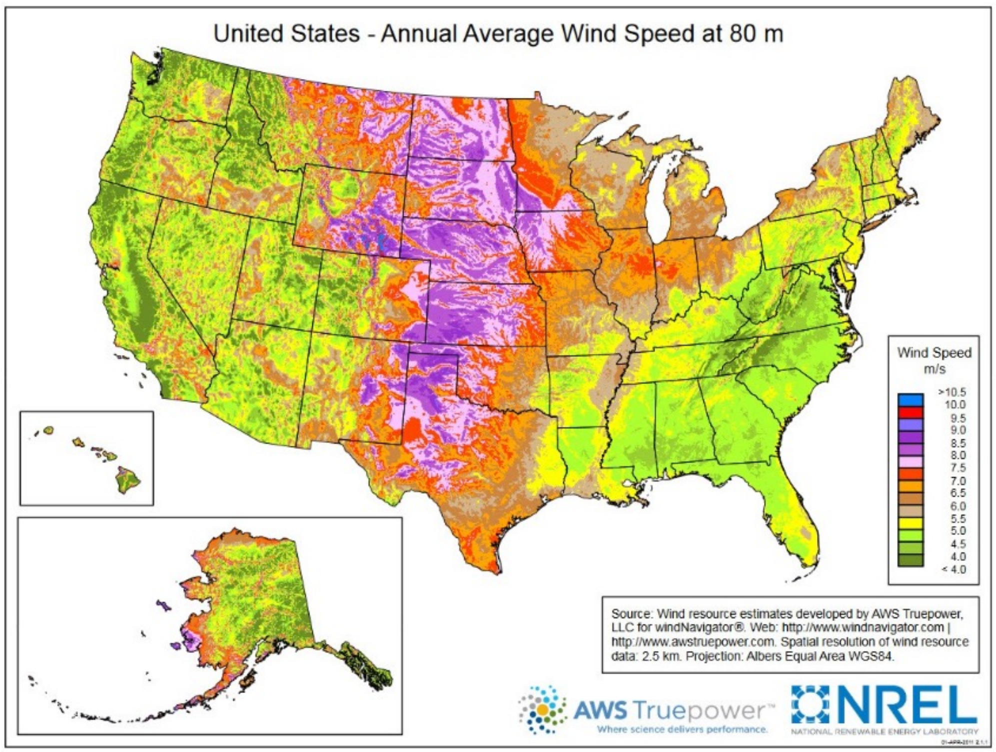
This map shows distributed wind energy capacity at the end of 2022 (and amount added in 2022) in megawatts in the Untied States by state or territory.



Values listed as 0.05 represent any installation < 0.1 megawatts. Values listed on island territories represent the cumulative of the U.S. Virgin Islands and Northern Mariana Islands rather than individual capacities for each island.

Source: *Distributed Wind Market Report: 2023 Edition*, U.S. Department of Energy Wind Energy Technologies Office © Natural Earth


3075
3163
5662
695
973
152
391
268
2746
1490
977
1328
3026
1112
3526
6917
4451
6645
20,321
648
4026
659
1611
1895
545
1827
1369
686
185
119
901
115
52
5
9
2
190
KY
VA
NC
SC
29
AR
MS
AL
GA
LA
FL
62
203
1-150 MW
150-500
500-1250
1250-2500
2500-5000
5000-10,000
> 10,000


United States - Annual Average Wind Speed at 80 m
Wind Speed
m/s
>10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
< 4.0
Source: Wind resource estimates developed by AWS Truepower, LLC for windNavigator®. Web: http://www.windnavigator.com | http://www.awstruepower.com. Spatial resolution of wind resource data: 2.5 km. Projection: Albers Equal Area WGS84.
AWS Truepower
Where science delivers performance.
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Iowa a leader in wind energy

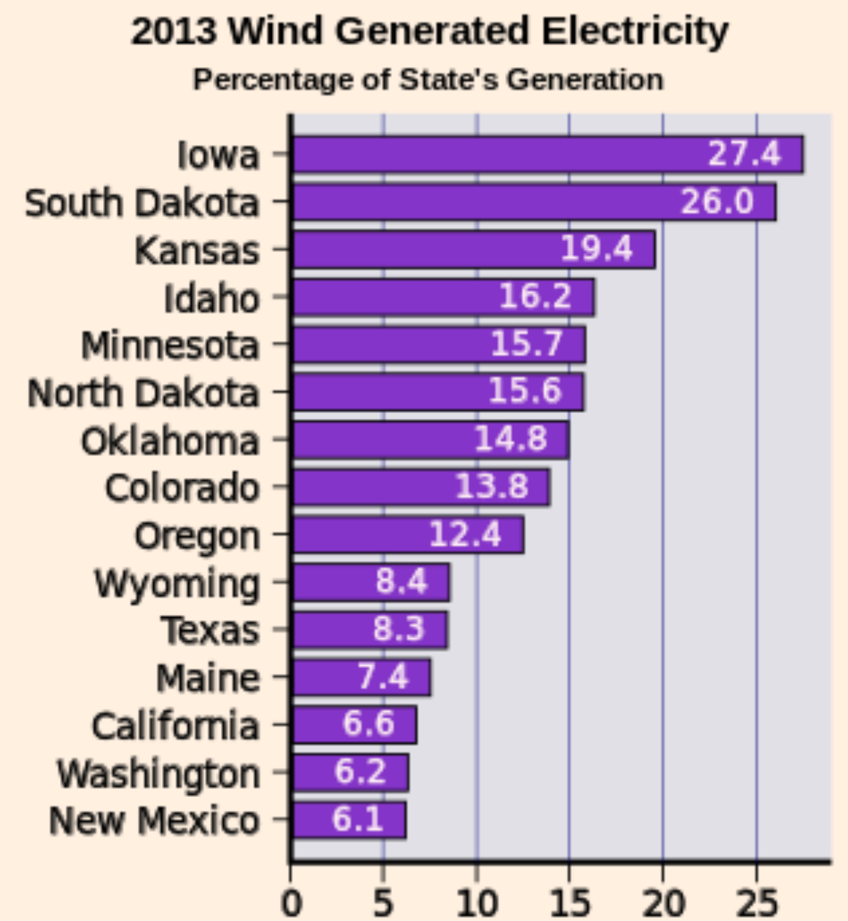
Iowa generates more than 36 percent of its electricity from wind power, ranking first in the nation for wind energy as a share of total electricity generation. It generates enough electricity to power more than 1.85 million U.S. households.

Source: American Wind Energy Association

Iowa [edit]

Main article: Wind power in Iowa

More than 35 percent of the electric power generated in Iowa now comes from wind power.[5] Iowa had over 6900 megawatts (MW) of generation capacity at the end of 2016.[5] Electrical energy generated in Iowa by wind in 2014 amounted to over 16 million Megawatt-hours.[23] Since Iowa adopted a renewable energy standard in 1983, the wind power industry has generated over $10 billion in investment.[58] The second



2013 Wind power generation percentage.
Source: U.S. Energy Information Administration
Electric Power Montly, February 2014

Wind Energy Facilities
Installed Capacity
Ranked by State/Territory

(Largest to Smallest Capacity for the 4th Quarter of 2020)

Rank	State	Installed Capacity (Megawatts)
1	Texas	33,133
2	Iowa	11,660
3	Oklahoma	9,048
4	Kansas	7,016
5	Illinois	6,409
6	California	5,922
7	Colorado	4,692
8	Minnesota	4,299
9	North Dakota	3,989
10	Oregon	3,737
11	Washington	3,395
12	Indiana	2,968
13	Wyoming	2,738
14	New Mexico	2,723
15	Michigan	2,681
16	**Nebraska**	**2,531**
17	South Dakota	2,305
18	Missouri	1,987
18	New York	1,987
19	Pennsylvania	1,459
20	Maine	996
21	Idaho	973
22	Montana	880
23	Ohio	864
24	Wisconsin	746
25	West Virginia	742
26	Arizona	618
27	Utah	391
28	Hawaii	233
29	New Hampshire	214
30	North Carolina	208
31	Maryland	191
32	Nevada	152
33	Vermont	149
34	Puerto Rico	125
35	Massachusetts	120
36	Rhode Island	75
37	Alaska	64
38	Tennessee	29
39	New Jersey	9
40	Connecticutt	5
41	Delaware	2
	United States Total	**122,465**

#1

IN THE NATION IN WIND ENERGY AS A PERCENTAGE OF TOTAL POWER OUTPUT

EIA, 2017

18%

LOWER CONSTRUCTION COSTS THAN NATIONAL AVERAGE

NAI GLOBAL

#2

LOWEST COST OF DOING BUSINESS IN THE COUNTRY

BUSINESS FACILITIES, 2017

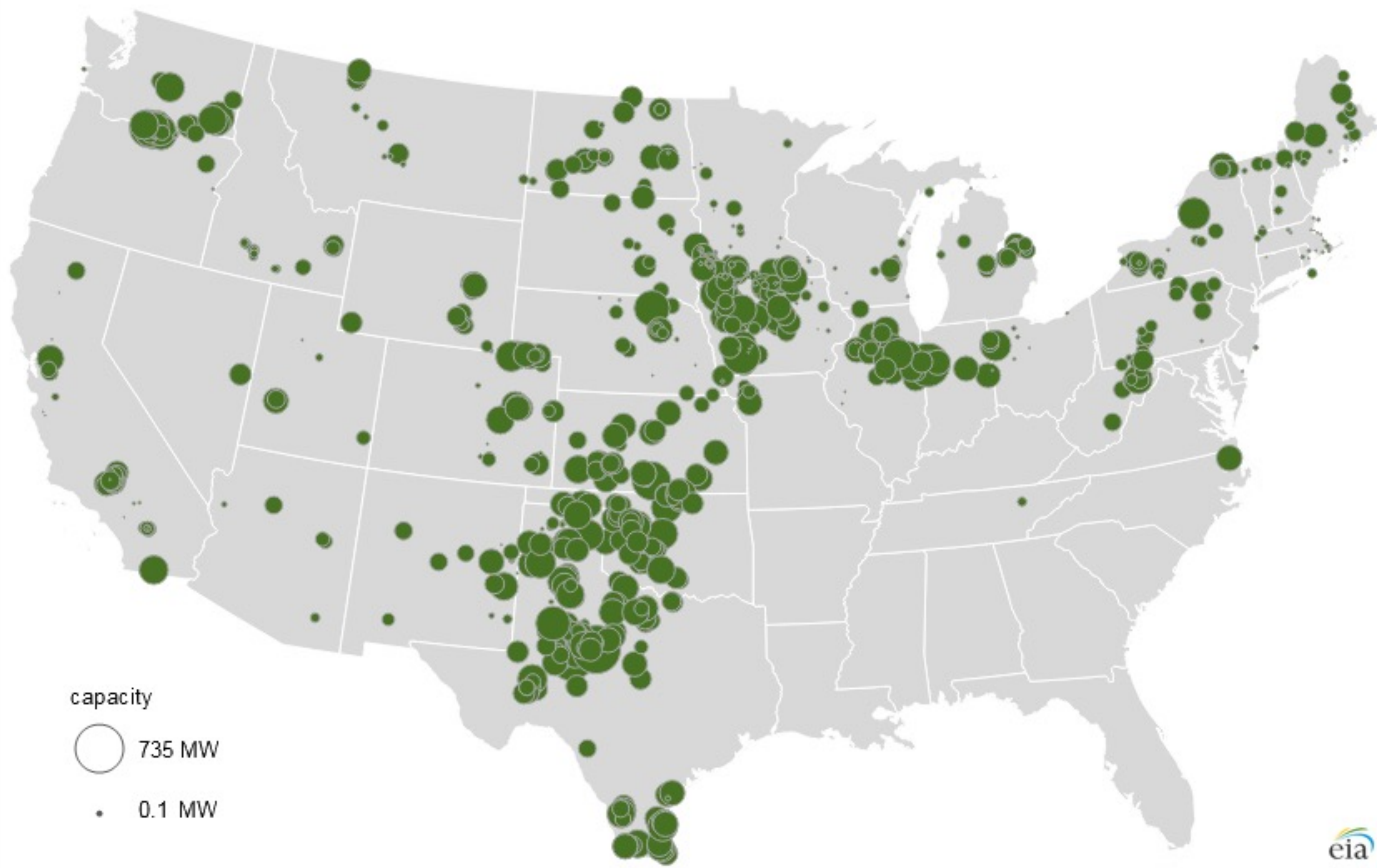
DATA CENTERS IN IOWA

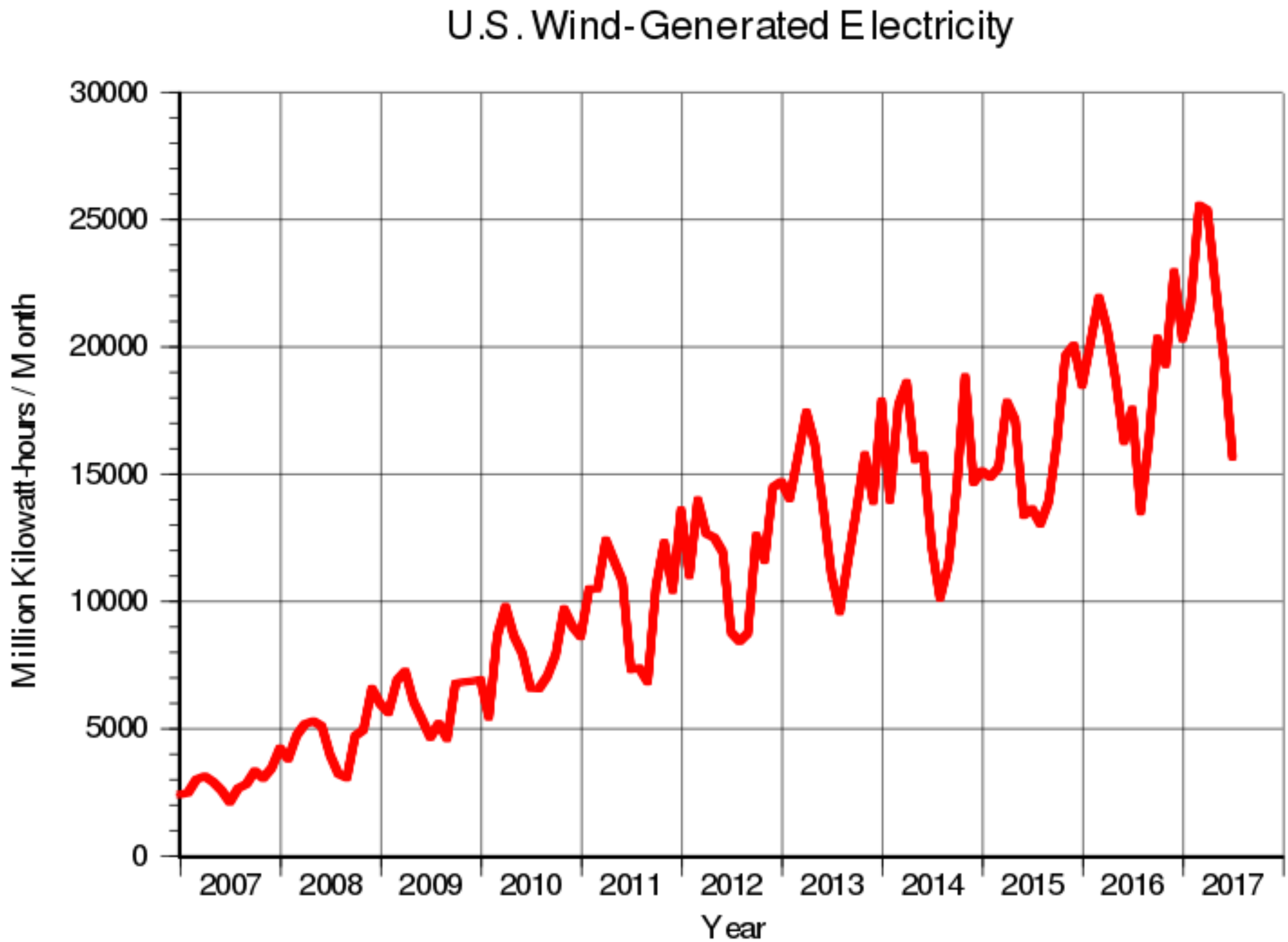
facebook.

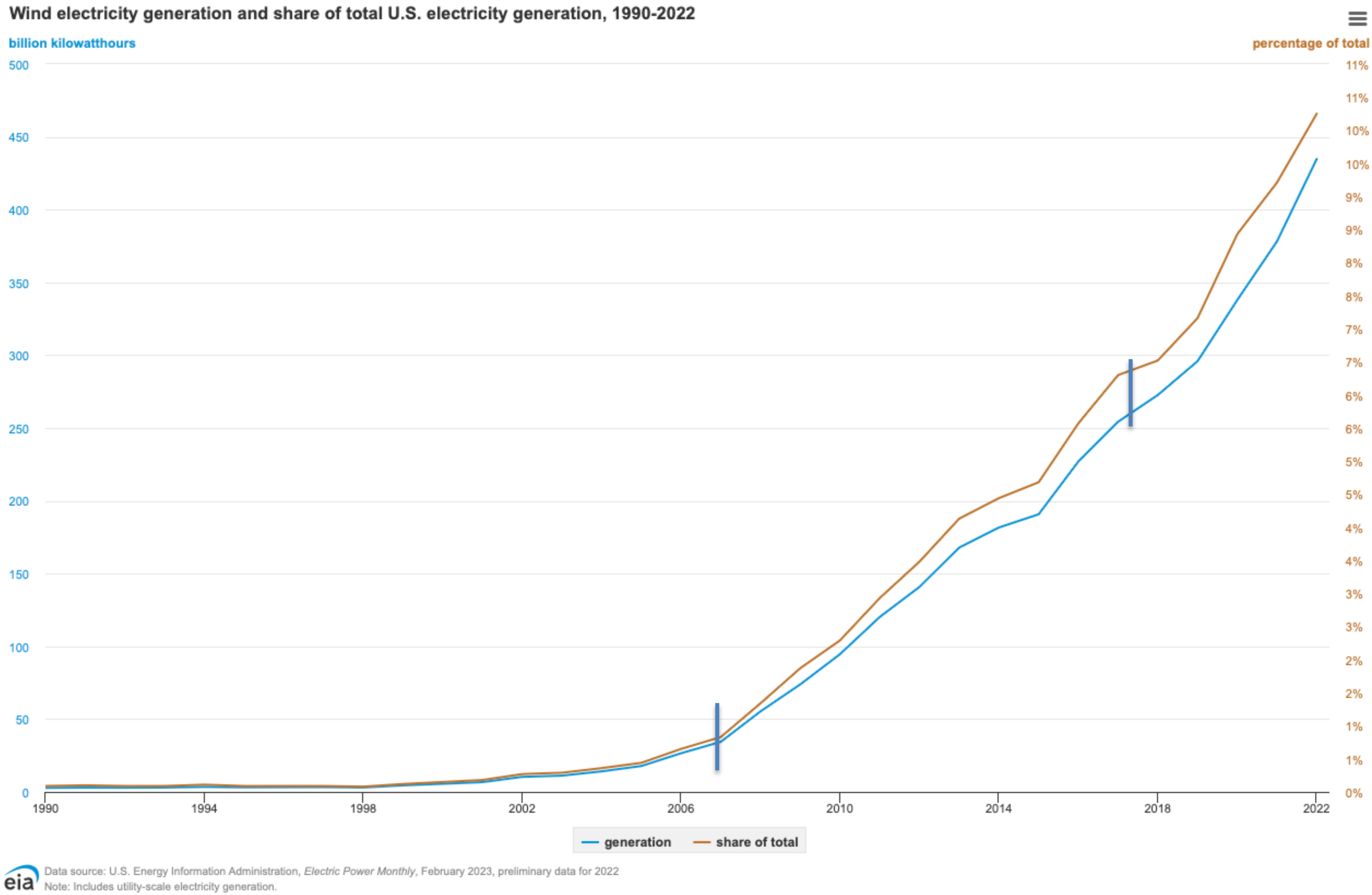
Google

Microsoft

Distribution of wind power plants in the Lower 48 states (as of December 2016)

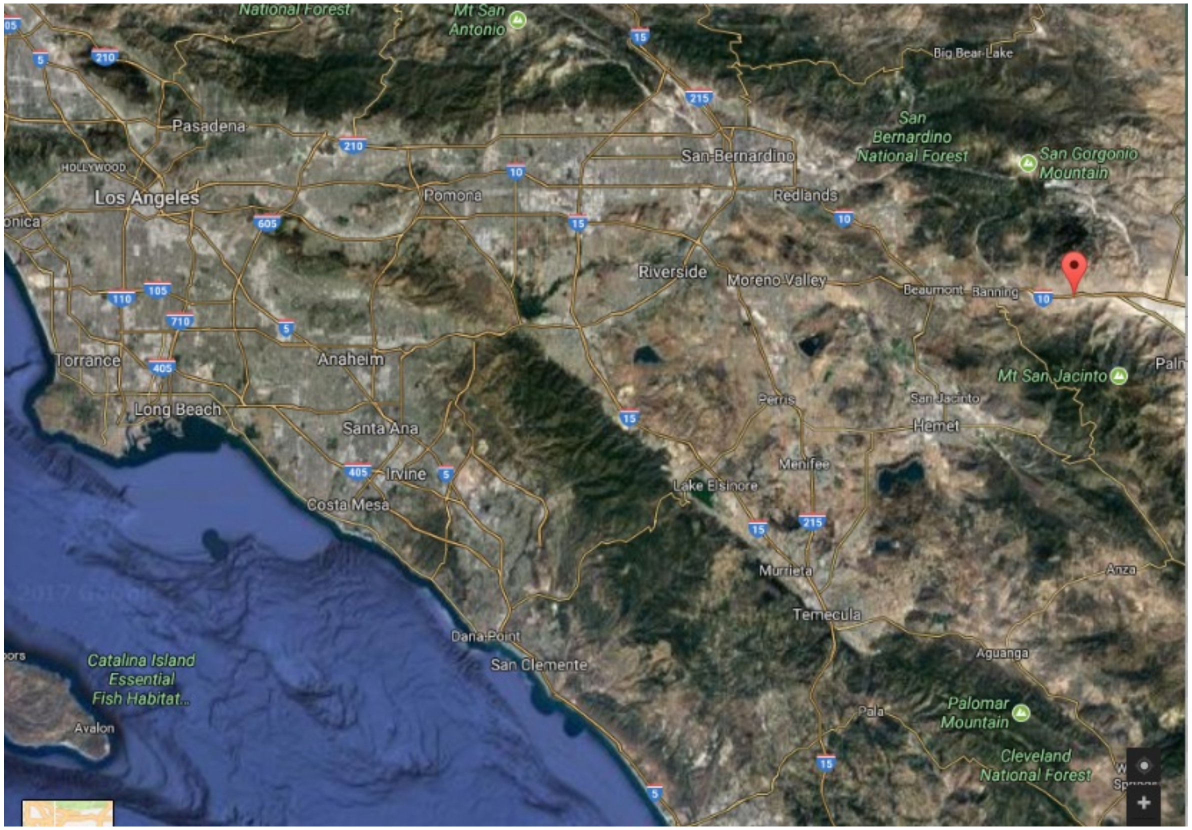


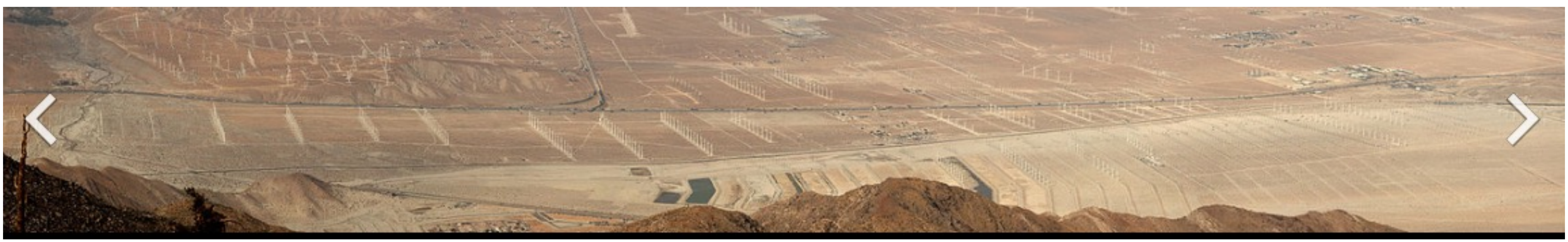

U.S. Wind-Generated Electricity
30000
25000
20000
15000
10000
5000
0
Million Kilowatt-hours / Month
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
Year



Wind electricity generation and share of total U.S. electricity generation, 1990-2022
billion kilowatthours
percentage of total
500
450
400
350
300
250
200
150
100
50
0
11%
11%
10%
10%
9%
9%
8%
8%
7%
7%
6%
6%
5%
5%
4%
4%
3%
3%
2%
2%
1%
1%
0%
1990
1994
1998
2002
2006
2010
2014
2018
2022
generation
share of total
Data source: U.S. Energy Information Administration, *Electric Power Monthly*, February 2023, preliminary data for 2022
Note: Includes utility-scale electricity generation.

San Gorgonio Pass, CA



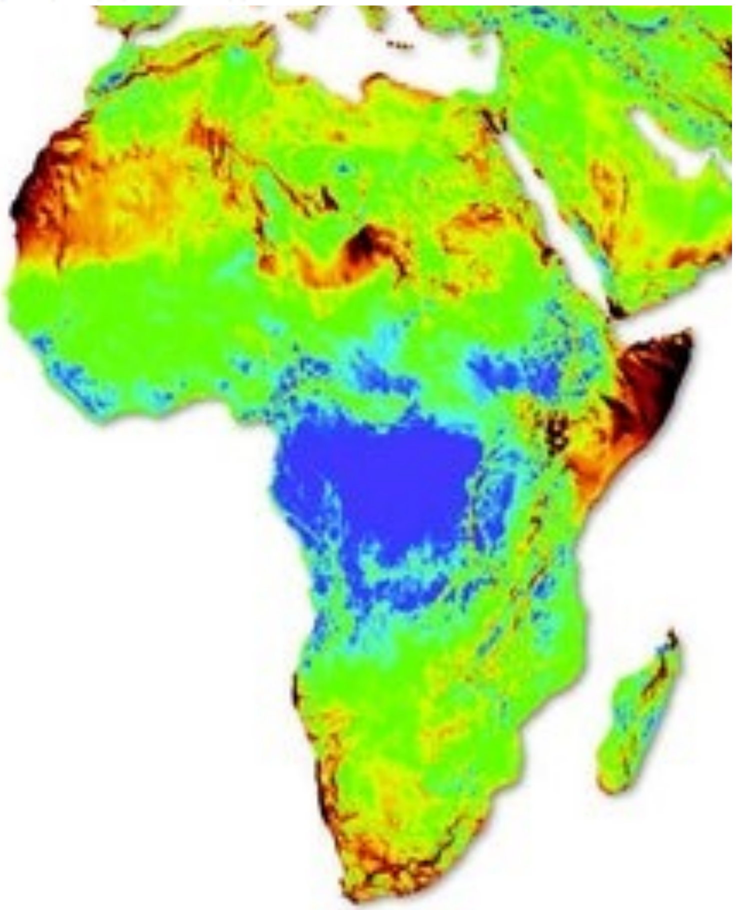


The majority of the San Gorgonio Pass Wind Farm as viewed from the San Jacinto Mountains to the south. (The farm continues over the hills to the north along California State Route 62 and is not visible from this vantagepoint). The layout includes a variety of large modern and older smaller turbine designs

In Africa there is Some Wind Power

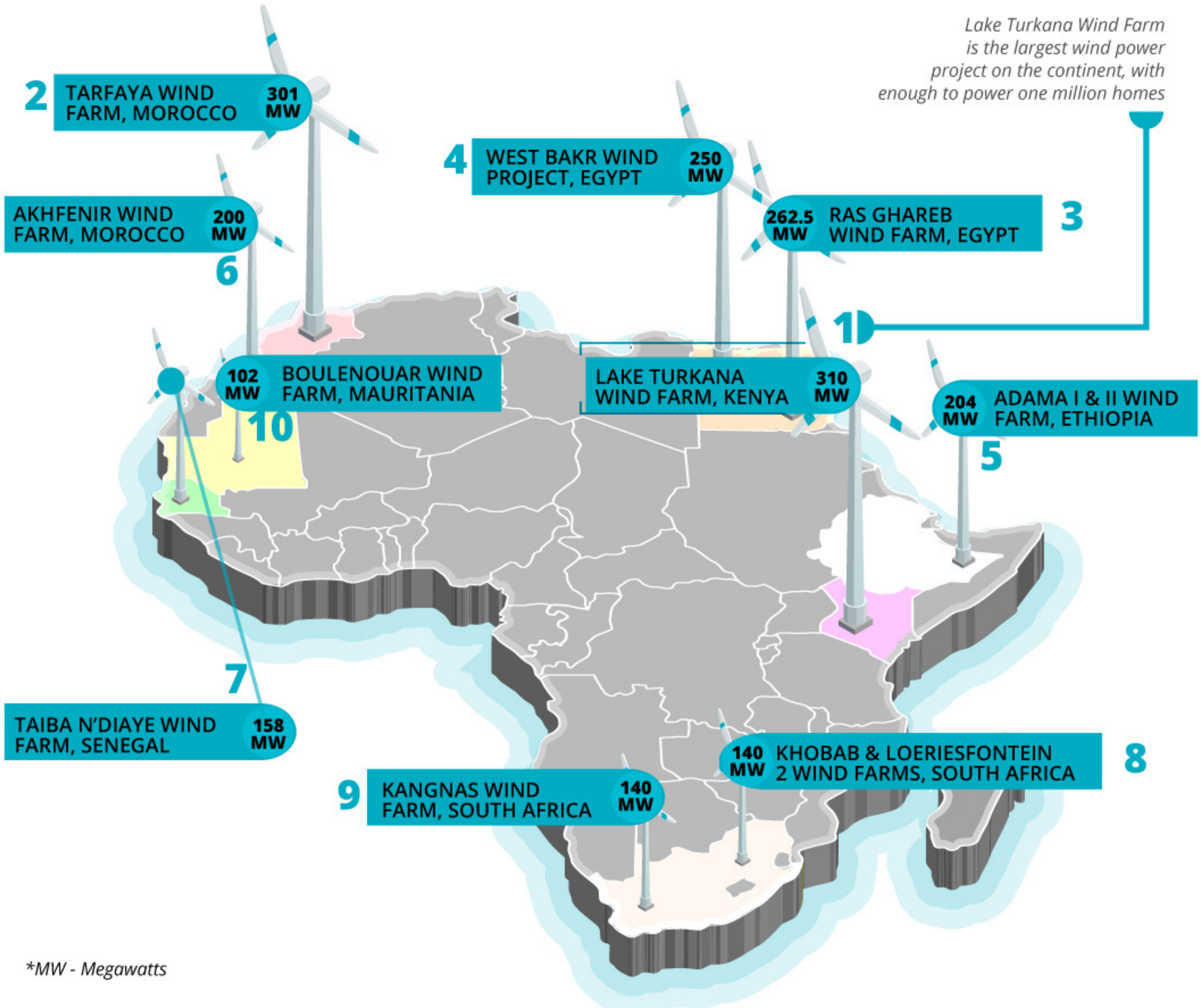
Countries	Operational (MW)	Under construction (MW)
1- South Africa	1,170	840
2- Morocco	870	50
3- Egypt	750	0
4- Ethiopia	320	0
5- Kenya	14	310
Total	**3,124**	**1,200**

Figure 1. The five biggest wind markets in Africa.

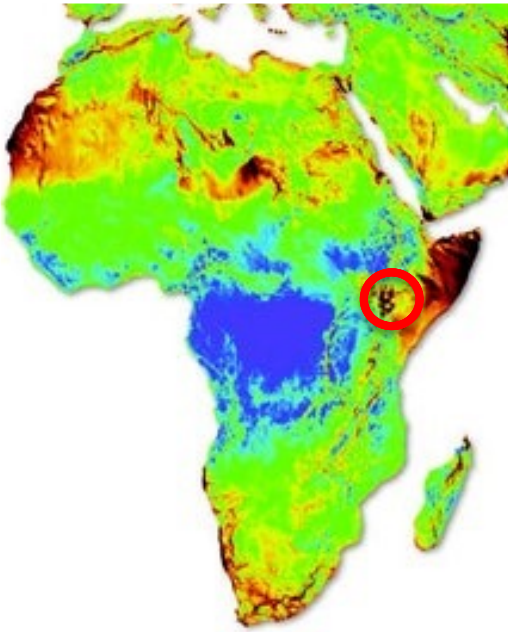


South Africa
Namibia
Somalia/Somaliland
And the Sahel
Have the greatest promise

TOP 10 WIND FARMS IN AFRICA



Source: Energy Capital & Power



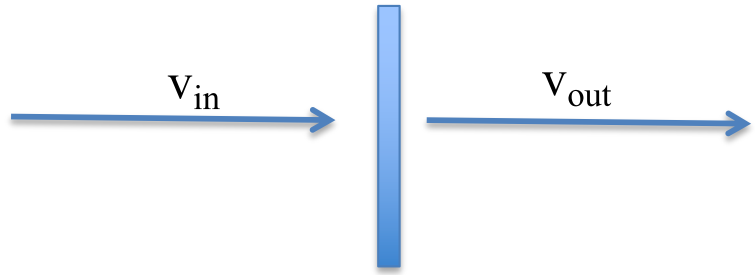
Kenya Wind Farm 300 MW

Lake Turkana

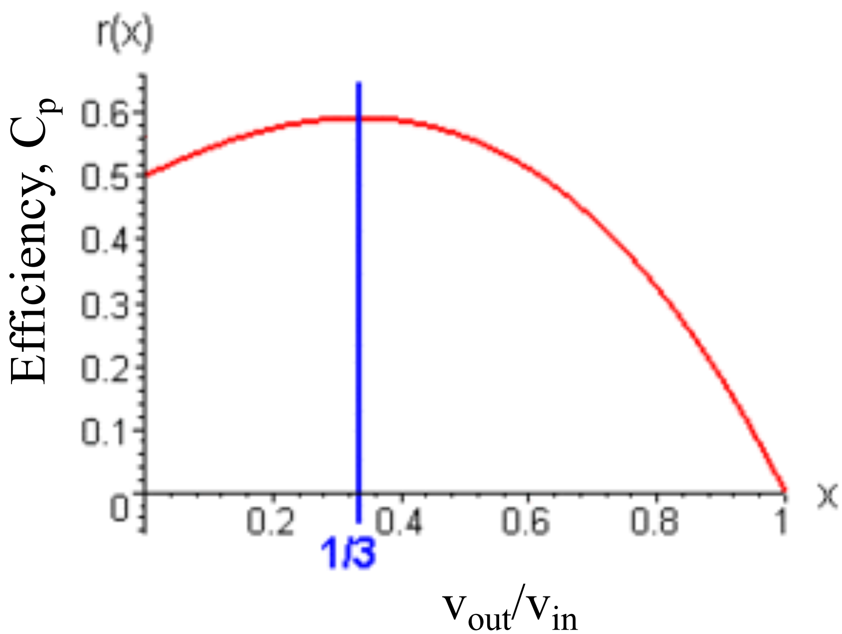
https://www.cnbc.com/2017/09/08/a-wind-farm-of-epic-proportions-is-taking-shape-in-africa.html

Betz Limit: 59.3% efficiency

A) Consider an ideal wind turbine that extracts 100% of the fluid energy, $v_{out} = 0$.
Power output is 0.



B) For an ideal wind turbine that extracts 0% of the fluid energy, $v_{out} = v_{in}$.
Power output is 0.



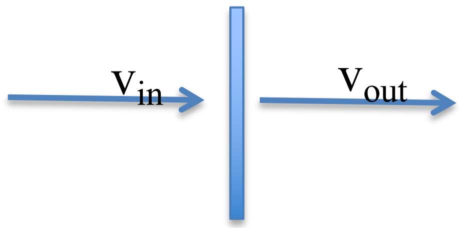
Power is proportional to v_{in}^3

$$P = C_p \cdot \tfrac{1}{2} \cdot \rho \cdot S \cdot v_1^3.$$

S is area of turbine
ρ density of fluid

Under optimum condition
$v_{out}/v_{in} = 1/3$

16/27 or 59.3% of energy is extracted



Betz Limit: 59.3% efficiency

Force

$F = ma$

$= m\, dv/dt$

$= dm/dt\, \Delta v$

$= \rho S v\, (v_{in} - v_{out})$

Energy

$dE = F\, dx$

Power

$P = dE/dt$

$= F\, dx/dt$

$= F\, v$

$P = \rho S v^2\, (v_{in} - v_{out})$

Kinetic Energy

$E = ½\, mv^2$

$P = dE/dt = ½\, (dm/dt)\, v^2$

$P = dE/dt = ½\, (dm/dt)\, v^2_{in} - ½\, (dm/dt)\, v^2_{out}$

$= ½\, (dm/dt)\, (v^2_{in} - v^2_{out})$

Continuity

$(dm/dt) = \rho S v$

Power

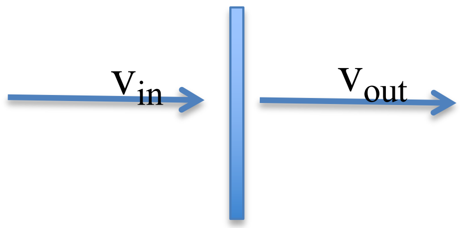
$P = ½\, \rho S v\, (v^2_{in} - v^2_{out})$

Power

$½\, \rho S v\, (v^2_{in} - v^2_{out}) = \rho S v^2\, (v_{in} - v_{out})$

$½\, (v^2_{in} - v^2_{out}) = ½\, (v_{in} - v_{out})\, (v_{in} + v_{out}) = v\, (v_{in} - v_{out})$

$v = ½\, (v_{in} + v_{out})$



Betz Limit: 59.3% efficiency

$v = \frac{1}{2} (v_{in} + v_{out})$

Power

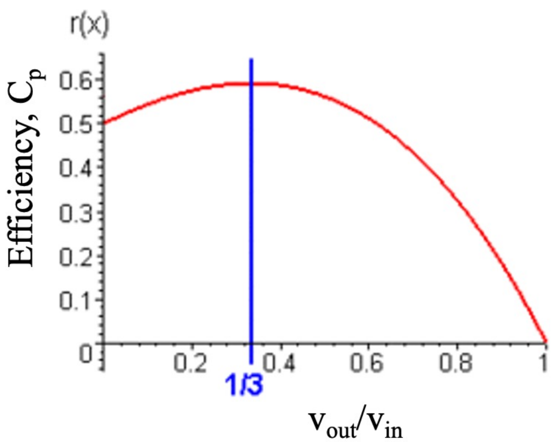
$P = \frac{1}{2} \rho S v (v^2_{in} - v^2_{out})$

$= \frac{1}{4} \rho S (v_{in} + v_{out}) (v^2_{in} - v^2_{out})$

$= \frac{1}{4} \rho S v^3_{in} (1 - (v_{out}/v_{in})^2 + (v_{out}/v_{in}) - (v_{out}/v_{in})^3)$

Find Maximum Power at $dP/d(v_{out}/v_{in}) = 0$

$(v_{out}/v_{in}) = 1/3$



Plug into Power

Max Power = $(16/27) (1/2) \rho S v^3_{in}$

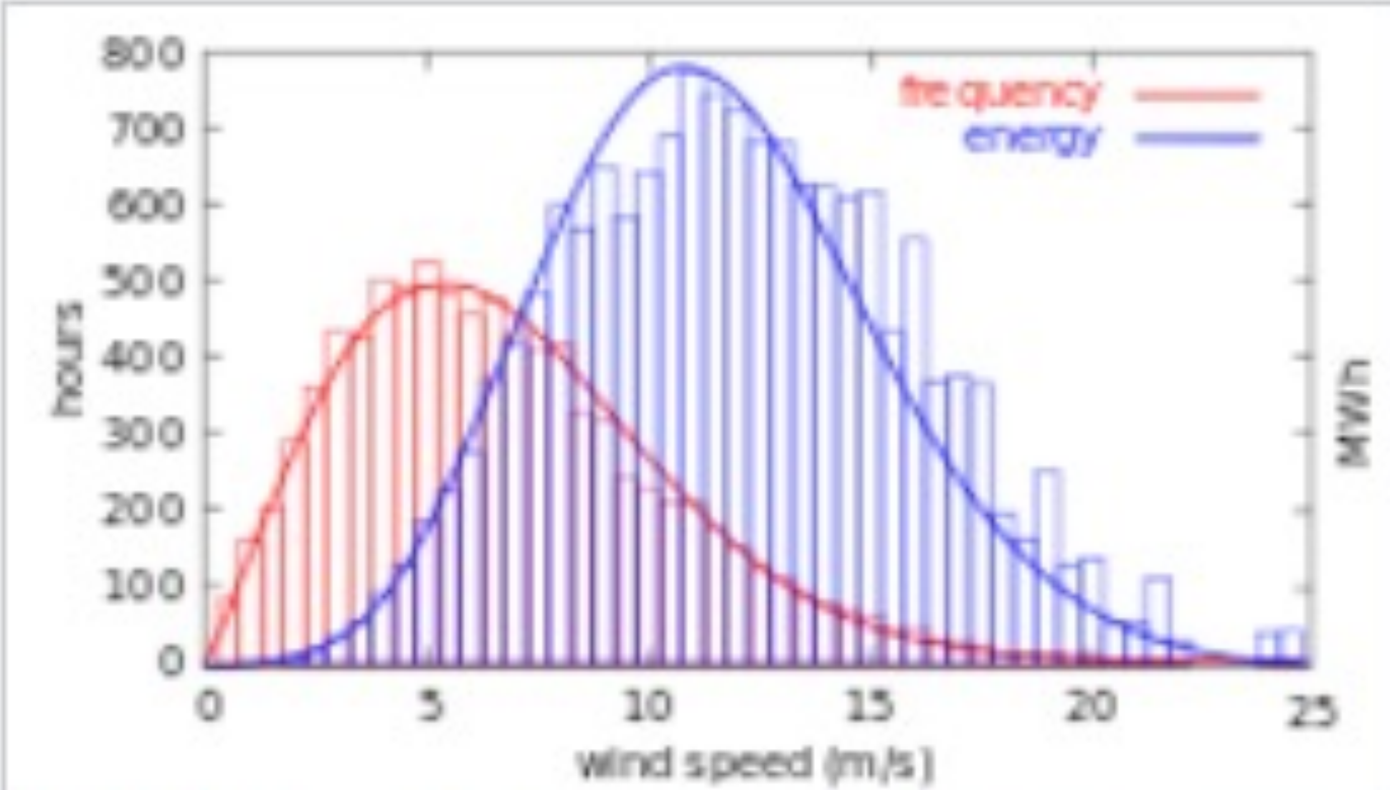
Incident Power = $(1/2) \rho S v^3_{in}$

-Power increases rapidly with wind speed

(this limits the wind range in which

a turbine can safely operate)

- (Max Power)/(Incident Power) = 16/27 = 0.593



Distribution of wind speed (red) and energy generated (blue). The histogram shows measured data, while the curve is the Rayleigh model distribution for the same average wind speed.

$$P = C_p \cdot \frac{1}{2} \cdot \rho \cdot S \cdot v_1^3$$

A small wind turbine can expect $C_p = 35\%$

Expected power output (in Watts) =
Cp * ½ * air density * swept area * wind velocity^3
where:
Cp = % efficiency loss of entire system
Air density = 1.23 kg per cubic meter at sea level (1.0 here in Colorado)
Swept area is in square meters
Wind velocity is in meters per second

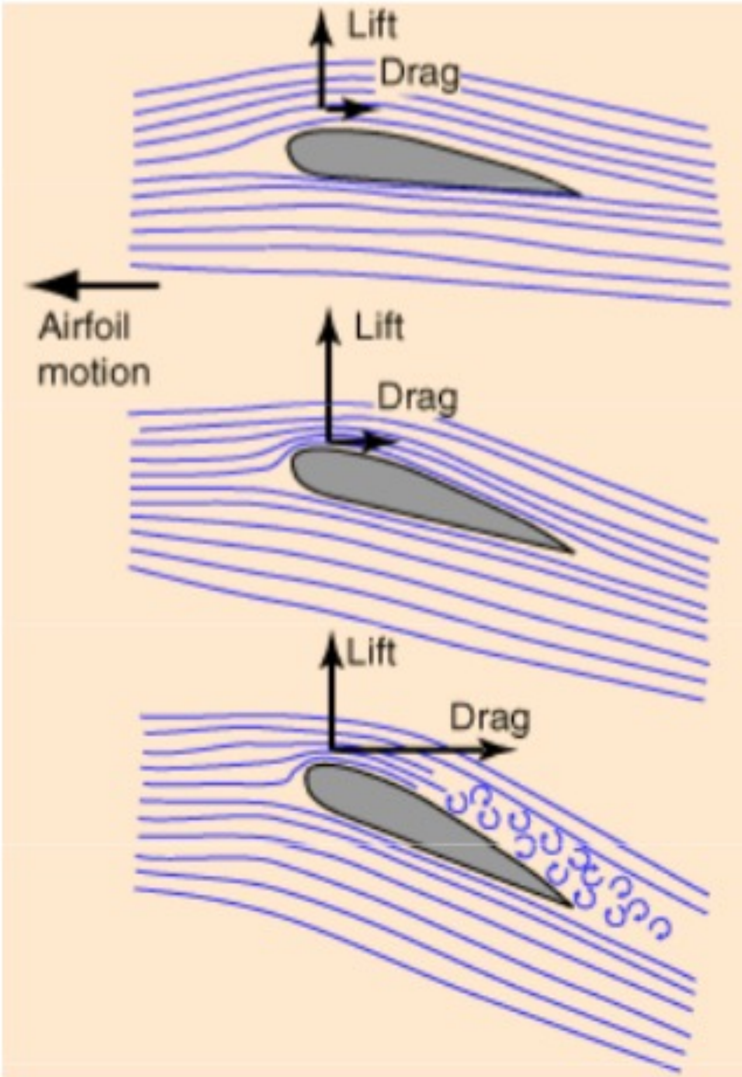
So, a 10-foot (3.048 m) diameter wind turbine rotor gives a 7.30 m^2 swept area, and in a 10 mph (4.4704 m/s) wind, we can expect no more than:
Power output (Watts) =
0.35 * ½ * 1.23 * 7.30 * 4.4704^3 = 140 Watts
and in a 20 mph wind:
Power output (Watts) =
0.35 * ½ * 1.23 * 7.30 * 8.9408^3 = 1123 Watts

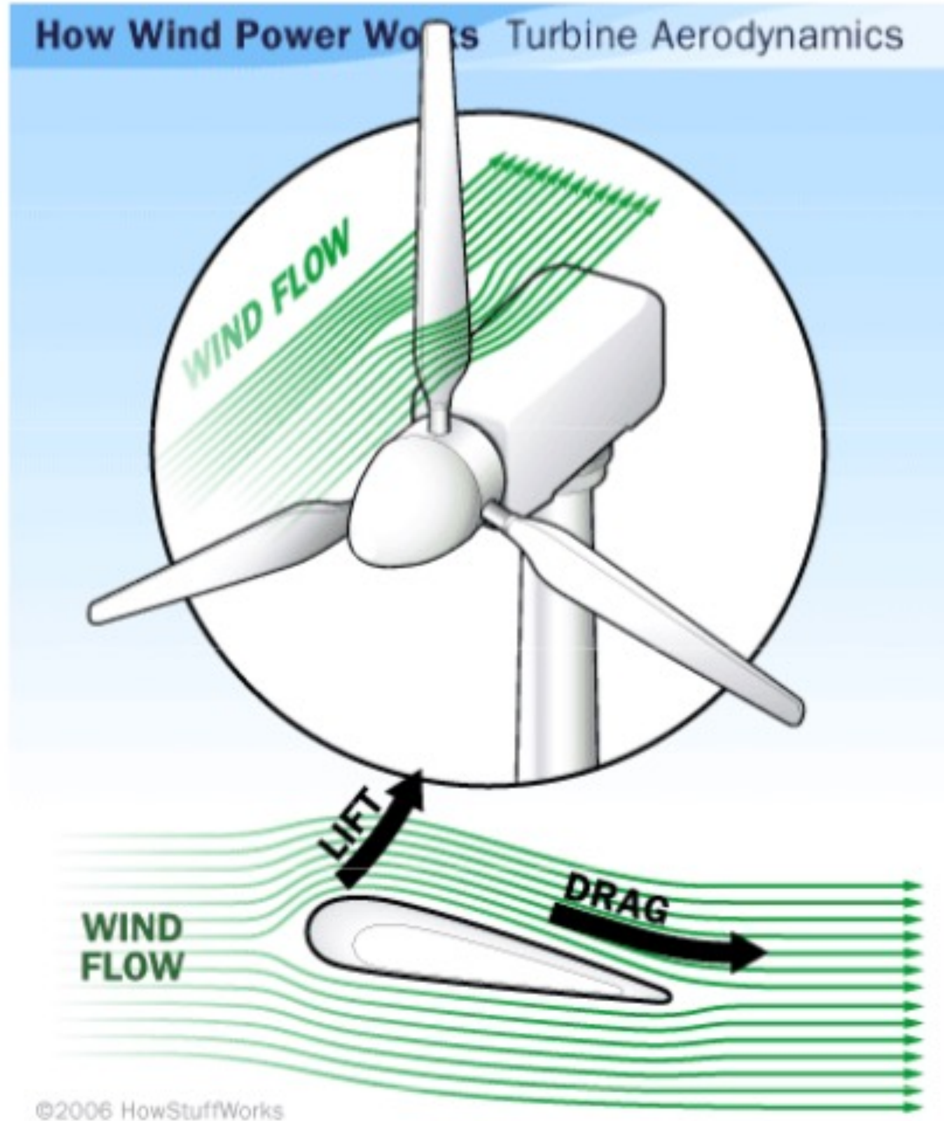
Key concept:
double the windspeed, and the available power increases by a factor of **EIGHT !**

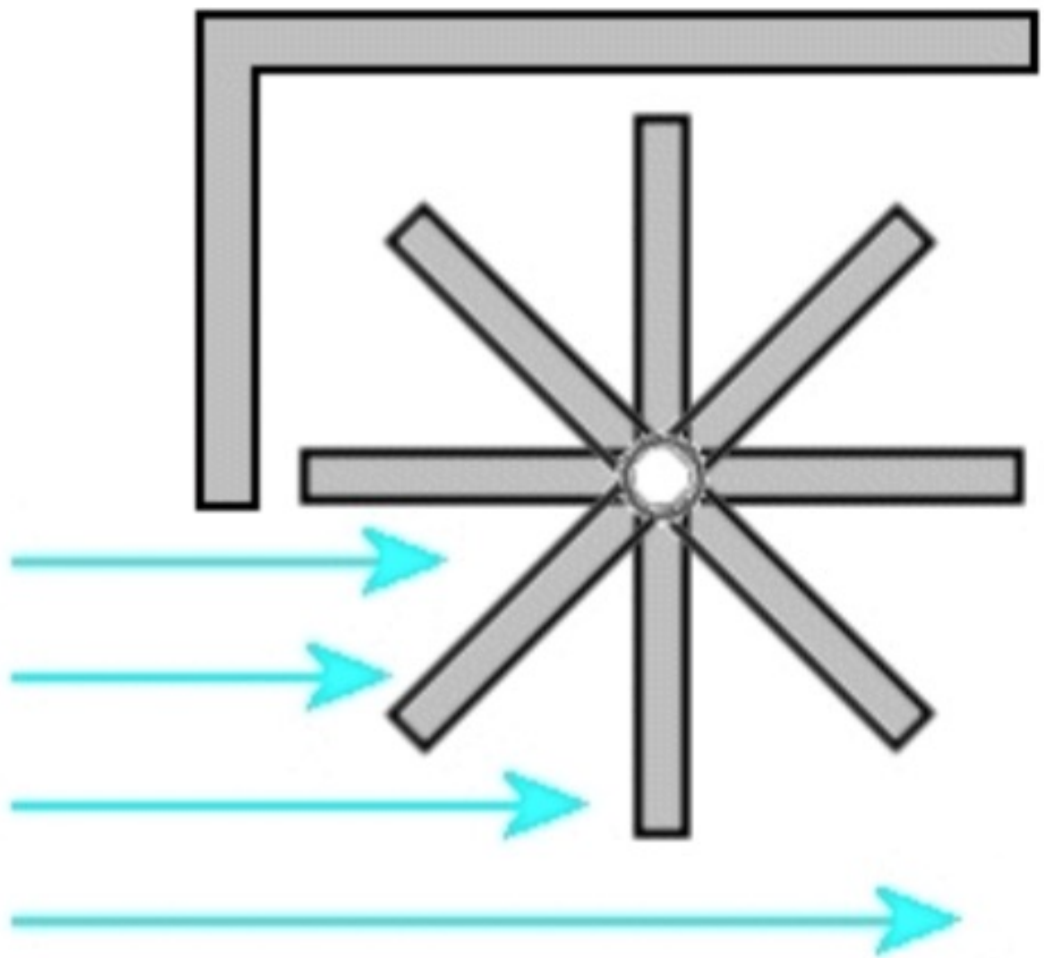
http://www.rebelwolf.com/essn/ESSN-Aug2005.pdf

600 kW utility-scale Advanced Research Turbine at NREL's National Wind Technology Center near Golden, CO, USA. Note how the variable-pitch blades are positioned so they can't make power—the turbine is shut down and can't spin. Photo by the author.

Lift and Drag Forces







Looking down on a 'Panemone'
an early design of a drag-based machine
(just like a steamboat paddle)

Note the wall that's erected around the half of the machine that is hurting performance by moving against the wind. **In any drag-based design, the blades can never move faster than the wind**. This turns out to be a critical concept for both efficiency and the ease of generating electrical power.

Wheel can't move faster than the wind

½ of the area is wasted

"Dutch" HAWTs

While not exclusively Dutch in origin, these machines were built all over Europe for grinding grain, and the earliest ones were drag-based.

The Maud Foster grain-grinding mill, Boston, England. Built in 1819, and still used for grinding grain commercially (and as a great tourist attraction) today. Photo by Ron Fey

Drag based horizontal wind turbine

Slow speed is good for grinding grain (not good for electrical power generation)

Mechanical furling

"Dutch" HAWTs

While not exclusively Dutch in origin, these machines were built all over Europe for grinding grain, and the earliest ones were drag-based.

The Maud Foster grain-grinding mill, Boston, England. Built in 1819, and still used for grinding grain commercially (and as a great tourist attraction) today. Photo by Ron Fey

Middletown RI

American Waterpumping HAWTs

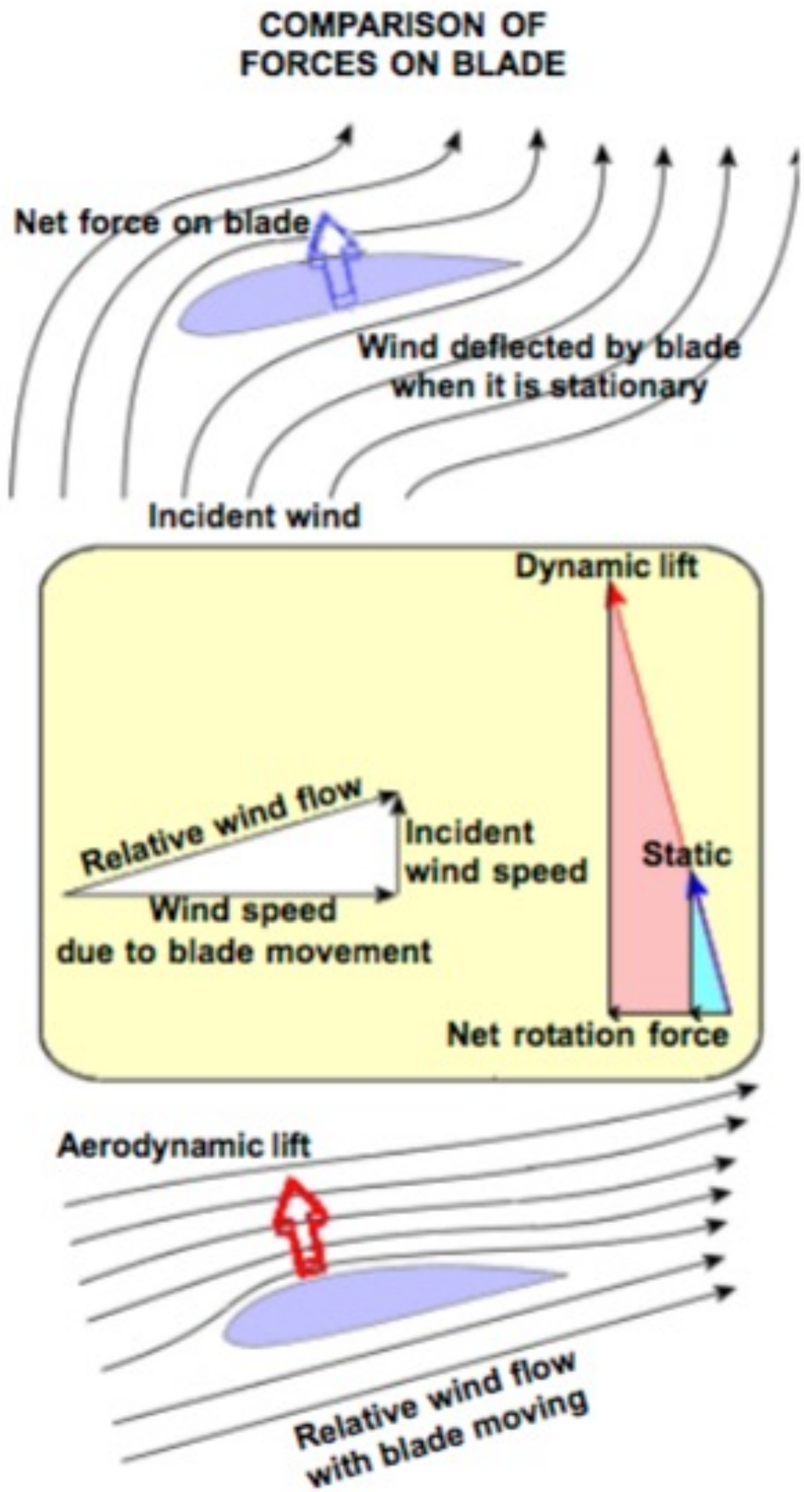
Over 6 million of these were installed on farms and ranches across America, starting in the mid 1800s.

A typical Aermotor water pumping windmill, still common and in operation all over the American West. Photo courtesy of DeanBennett.com, Denver, CO. This company sells all the replacement parts to keep these beautiful old machines running, and also sells new waterpumping windmills.

Drag based horizontal wind turbine

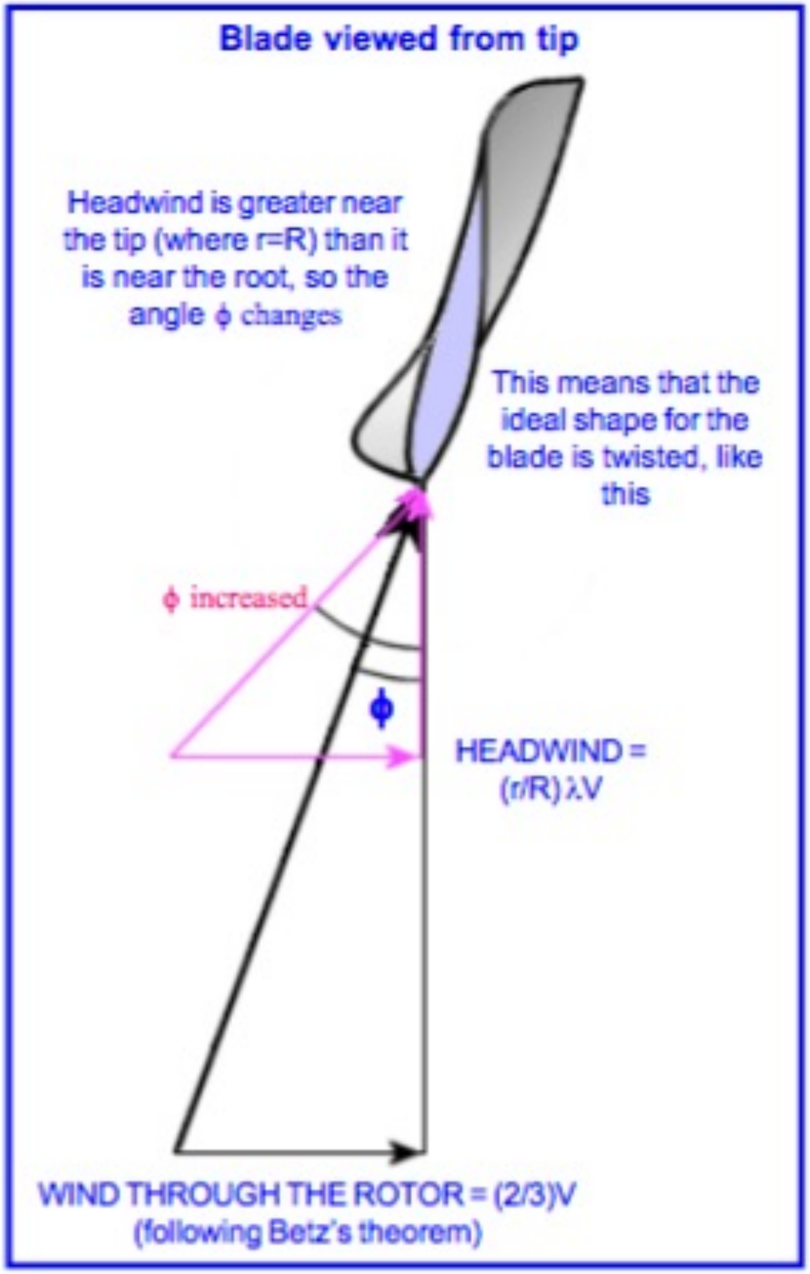
Slow speed is good for pumping water (not good for electrical power generation)

Tail allows furling of the turbine



COMPARISON OF
FORCES ON BLADE
Net force on blade
Wind deflected by blade
when it is stationary
Incident wind
Dynamic lift
Relative wind flow
Incident
wind speed
Static
Wind speed
due to blade movement
Net rotation force
Aerodynamic lift
Relative wind flow
with blade moving

BLADE TWIST



When the angle of attack is wrong for the apparent wind, the airfoil stalls and ceases to produce lift—the same thing that happens when an airplane tries to climb too steeply for its speed and begins to fall. When a wind turbine rotor begins to start spinning from a full stop, it is always stalling. As the wind increases and the blades pick up speed, the angle of attack gets better and better, and the turbine accelerates dramatically from the added lift force. It's fun to watch this happen! And a turbine can stall at higher windspeeds too—it will no longer pick up RPMs as the wind increases. This is not frequently observed, as the turbine has usually furled by that point to reduce wind input.

Horizontal Axis Wind Turbine (HWAT)

Up wind or down wind designs

Modern Electricity-Generating HAWTs: They come in sizes ranging from tiny (4 foot diameter, to mount on a sailboat or remote cabin) to huge (300 foot diameter, multi-megaWatt, utility-scale machines). These machines can be designed for either 'upwind' or 'downwind' operation. In upwind turbines, the blades are in front of the tower toward the oncoming wind, and point into the wind using a tail vane or (in giant turbines) electronic controls. Downwind turbines don't have a vane, and the blades are behind the tower relative to the wind. While upwind designs are the most common, there are excellent downwind machines commercially available.

All modern electricity-producing HAWTs are lift-based, so the blade tips can travel faster than the wind.

The resulting high RPMs are ideal for producing electricity, and these machines can be highly efficient. Small machines are approaching 35% efficiency (Cp=35%), while utility-scale machines are rapidly approaching the Betz Limit (Cp<59.26%, see Part 1 of this series, ESSN July 2005).

Upwind Turbines

The rotor on an upwind turbine is in the front of the unit, positioned similar to a propeller driven airplane. This is the most common type of small turbines operating in the U.S. To keep it oriented into the wind, a yaw mechanism such as a tail is needed.

Advantage The reduced tower shading. The air will start to bend around the tower before it passes it so there is some loss of power from the interference, just not the degree as in the downwind turbine.

Disadvantage The extended nacelle that is required to position the rotor far enough away from the tower to avoid any problems with a blade strike. The blades themselves must be somewhat stiff to avoid bending back into the tower. This will mean the point where the blade attaches to the rotor hub will be stressed during high, gusty wind conditions.

Downwind Turbines

The downwind turbine has its rotor on the back side of the turbine. The nacelle typically is designed to seek the wind, thus negating the need for a separate yaw mechanism.

Advantage

The rotor blades can be flexible since there is no danger of a tower strike. The flexing blade has two advantages.

1. They can be less expensive to make

2. They can relieve stress on the tower during high or gusty wind conditions since the

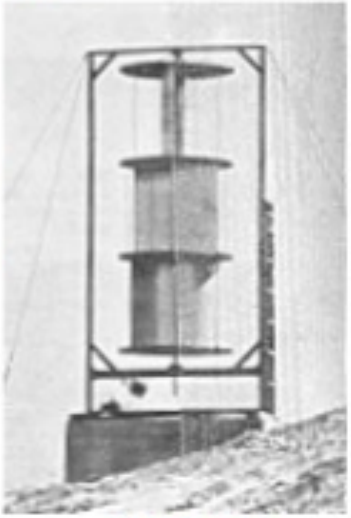
flexing allows some wind load to be transferred directly to the blades instead of the tower. The Proven has a hinged design that allows the blade to flex back to dissipate energy for speed control.

Disadvantage

The flexible blade advantage can also be a disadvantage as the flexing may fatigue the blades.Tower shadow is problem with a downwind machine since the rotor blade actually passed behind the tower. This can cause turbulence and increased fatigue on the unit.

Drag-based VAWTs

The ancient Persian design shown before, the Panemone, is one example. Other designs include the Savonious Rotor which can be easily built using coffee cans, plastic buckets, or metal barrels.



Savonius

Anemometer

Photos courtesy the American Wind Energy Association AWEA

A simple anemometer is another drag-based VAWT design. While fun for experimenters and students to build and test, these designs are extremely inefficient, and give only low torque since the blades or cups can never travel faster than the wind. Yes, I know ... anemometers often spin quite fast, but as they usually have a very small arm length, they have very little torque.

Lift-based VAWTs

Darrieus, Giromill, and H-rotor designs are big improvements over drag-based machines, since the blades have airfoils and utilize lift to move faster than the wind. However, there are inherent difficulties with any VAWT design, and these problems are why VAWTs have never been very successful in the commercial market, on either small or large scales.

Photos courtesy the American Wind Energy Association AWEA

Darrieus

Giromill

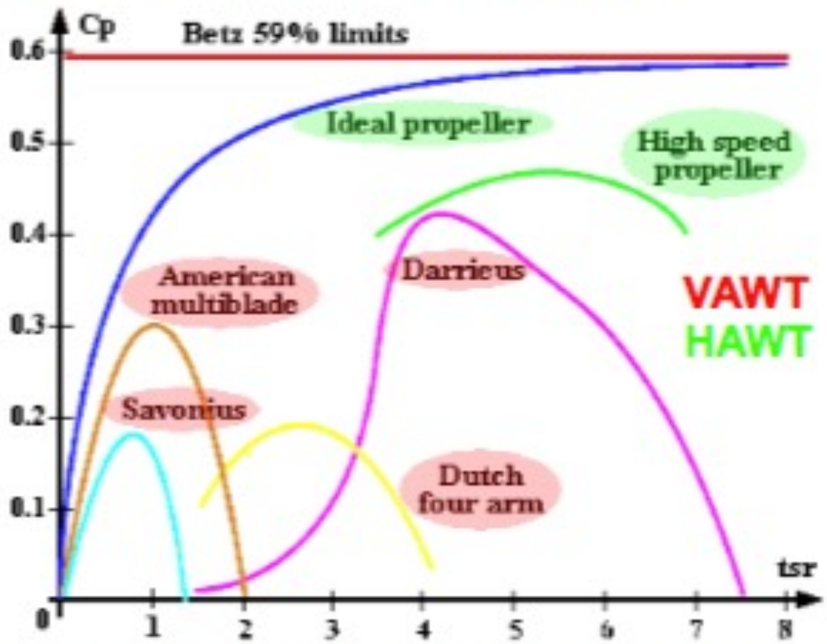
H-rotor

Should I choose a HAWT or a VAWT for my installation?

If you are looking for a fun wind power experiment or science fair project, a VAWT might suffice. You can find some good ideas here.

If you **really** need to make some serious electricity to power an on- or off-grid home, a lift-based HAWT is the best choice. Plus, you'll have a very hard time even finding a commercial VAWT from a reputable manufacturer for sale in any size.

In general, VAWTs are also lower in efficiency than HAWTs. Drag-based designs of any kind are the worst because maximum possible efficiency (Cp) is directly related to how much faster than the wind the blade tips are moving. This ratio of blade speed to wind speed is called the Tip Speed Ratio (TSR), and the best possible Cp is obtained around TSR = 5-6. Only lift-based VAWT designs can even approach this TSR, and are still limited by the other factors listed above.



This diagram shows the maximum Cp theoretically possible, versus Tip Speed Ratio, for different wind turbine designs. Courtesy of http://www.windturbine-analysis.com/ (Note: used without permission - email address on website no longer valid)

tsr

Ratio between the speed of the tip of the turbine blades and the wind speed

More blades = more torque but lower RPM

For power generation 2 or 3 blades are optimum

For moving air or pumping water/grinding grain 5 blades or more.

As the number of blades and the amount of the swept area that's taken up with their surface area increase (this ratio of blade surface area to swept area is called "solidity"), more torque and less RPM are produced, the tip speed ratio is lower, and the blades must be proportionally narrower. The typical 3-bladed rotor is the best compromise for physical strength and rotation speed.

Massive power increase with wind speed

Alternator can't handle this dynamic range

Design a turbine for optimum performance between 7 and 30 mph

Design to survive higher winds while still producing peak power

Options are:
Variable Pitch Blade: Tilt the blade (previous picture)
Tilt the entire turbine (old American west turbines)

Furling tail

This photo shows a home-built 17-foot diameter 3.5 kW turbine with the tail in fully furled position. The machine is still making near maximum power, but it facing at an angle into the wind to reduce wind input. Photo by Dan Bartmann.

Furling

This is where the front part of the nacelle containing the rotor and generator fold about a hinge and the tail continues to track the wind. The desired effect is to turn the blades at an angle to the wind so the rotor will slow down.

Furling happens without motors or special devices. It works because the rotor axis is offset from the furling axis. When the wind exceeds a determined force on the rotor, the rotor rotates around the furling hinge or pin, either vertically or horizontally. As the wind speed slows, the turbine rotor turns back into the wind.

http://www.power-talk.net/blade-pitch.html

Photo courtesy of NREL - Dean Davis.

Springs or a shock absorbing piston may be utilized to provide dampening. Furling is a fairly simple method that works but comes with it's disadvantages. When the rotor is turned out of the wind, power production is reduced. Also the wind hitting the blades at an angle can cause increased noise.

Blade Pitch

A more complex method is to use blades that pitch. As the rotor increases speed, the blade moves to a less efficient aerodynamic angle. The blade basically stalls, thus decreasing lift and limiting the rotor speed. This is accomplished with weights or springs that act on centrifugal force.

http://www.power-talk.net/blade-pitch.html

Photo Courtesy of Proven Energy.

This design has it's drawbacks also - complexity and increased cost. On the positive side, this method is said to be more reliable than furling in protecting the machine. It also allows the machine to continue producing maximum power in high wind where the furling machine will actually drop in production.

This design has it's drawbacks also - complexity and increased cost. On the positive side, this method is said to be more reliable than furling in protecting the machine. It also allows the machine to continue producing maximum power in high wind where the furling machine will actually drop in production.

http://www.power-talk.net/blade-pitch.html

Blade tip pitch is another variation that is used on one small turbine made in the U.S. It is the machine built by the Ventera Energy Corporation. The outer tip of the blade responds to centrifugal force instead of the whole blade.

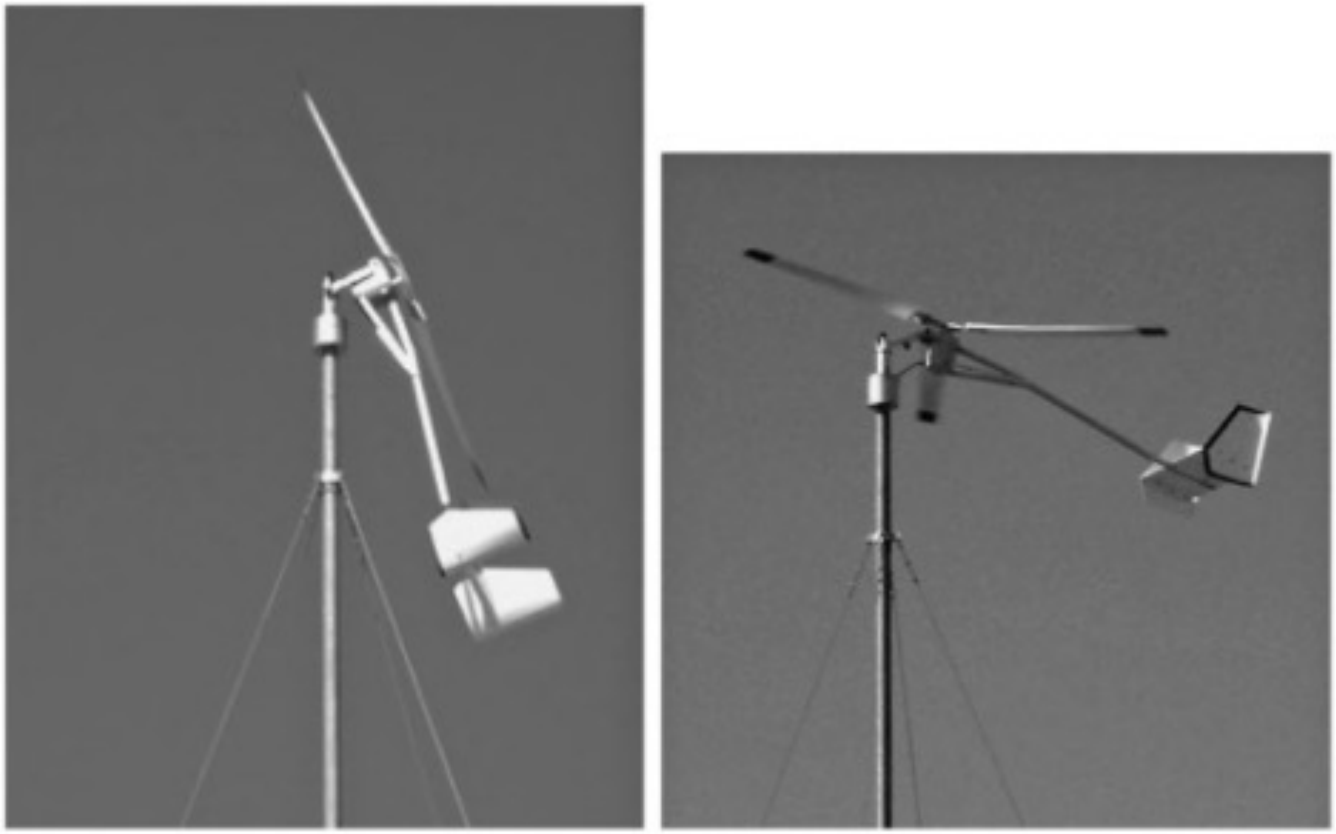


FIGURE 6.25 Rotor axis offset from horizontal pivot point for control. Left: run position at wind speeds below 13 m/sec. Right: furled position in high winds.

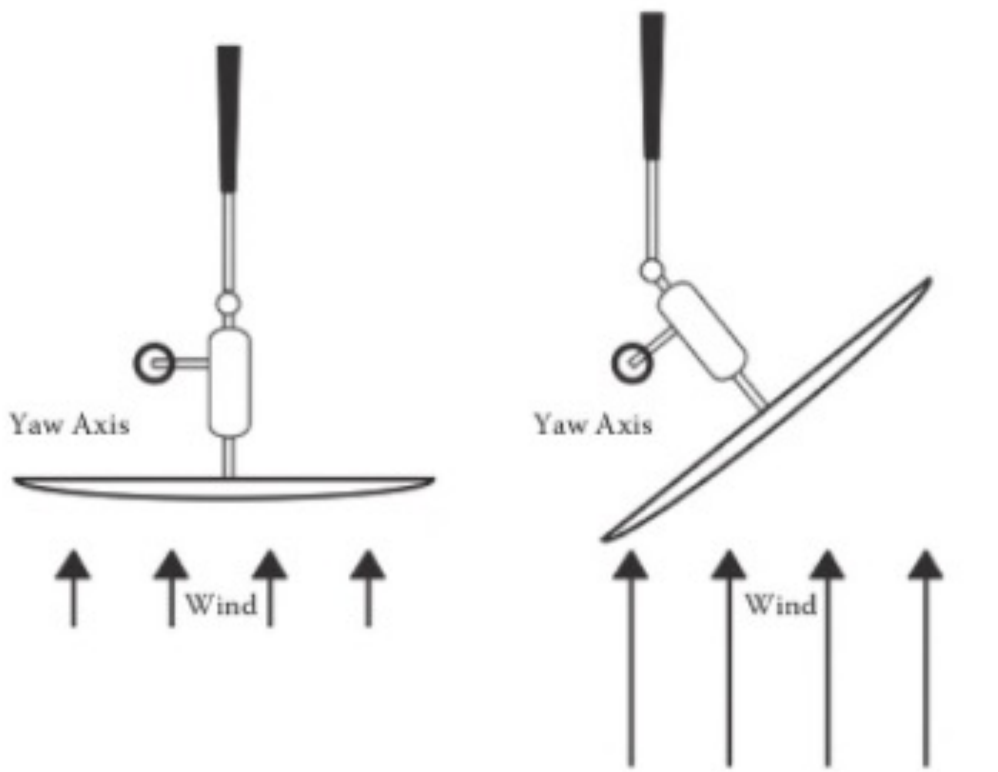


FIGURE 6.24 Furling diagram of rotor axis offset from tower (yaw axis) with hinged tail.

FIGURE 6.19 International Wind Systems 300-kW system on 49-m pole tower with guy wires and gin pole.

FIGURE 6.18 Small (1.8 kW) wind turbine mounted on-10 m pole tower, no guy wires, with gin pole. Note sweep blades.

Power Coefficient
Electrical Power/Wind Power

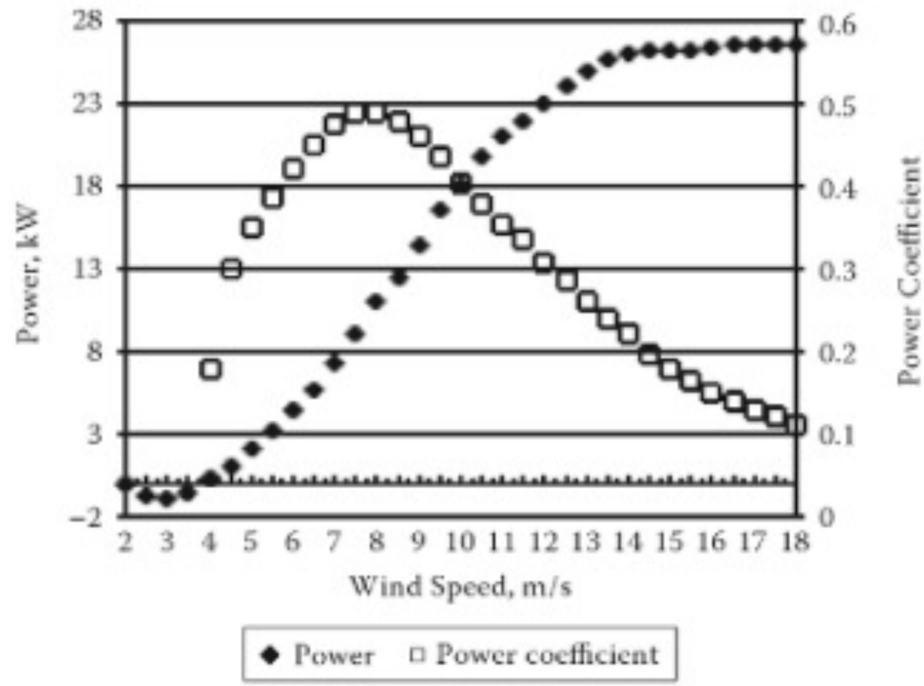


FIGURE 6.13 Experimental power and power coefficient for a Carter 25 rated 25 kW, 10 m in diameter. At 3 m/sec, the turbine uses power (energy for field coils of induction generator).

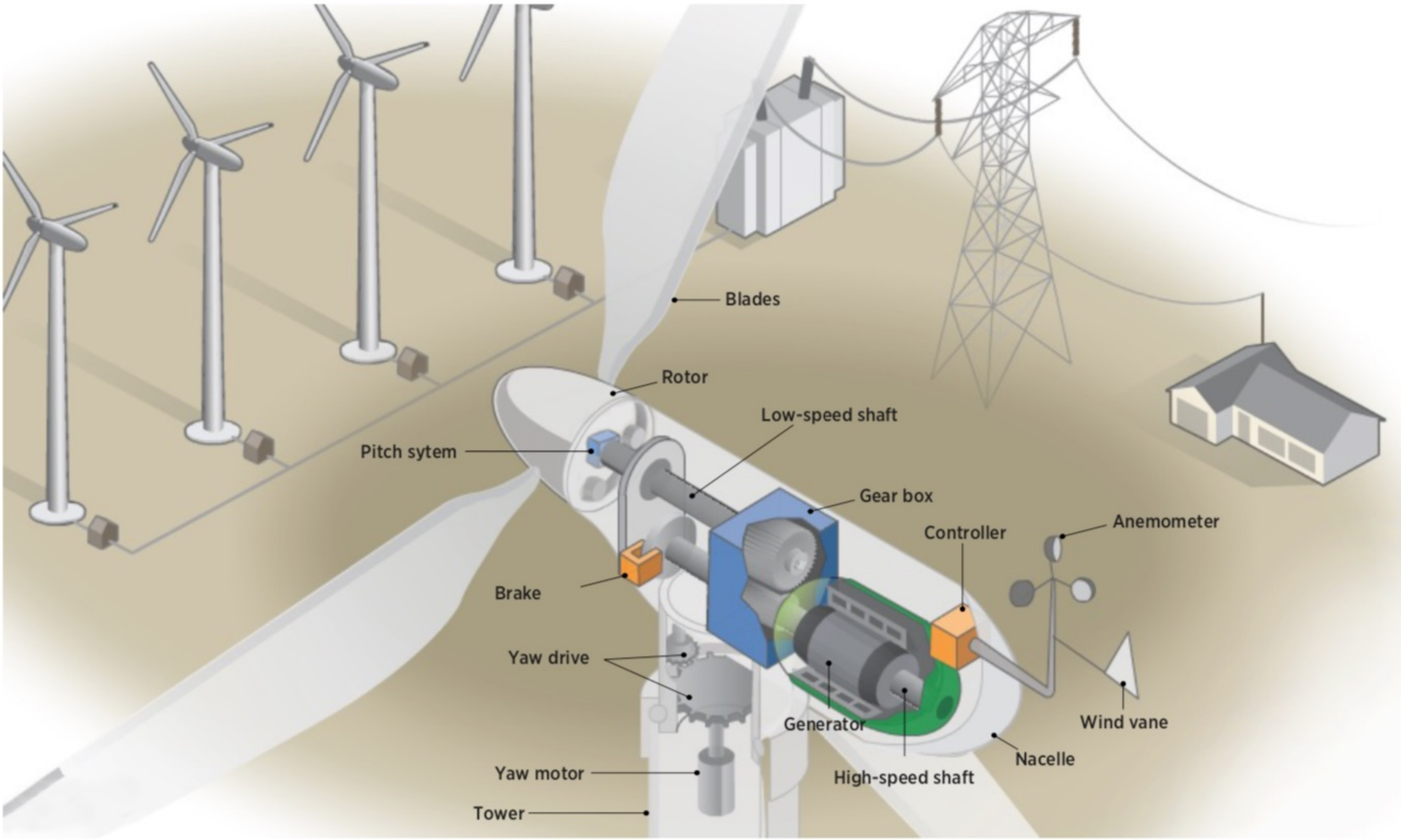
Twisting blades

Some very small wind turbines use flexible plastic blades that bend, twist and flutter when power input gets too high for the generator to handle. This technique is effective, but also noisy. Some of the extra power in the wind is being turned directly into noise, and the sound of blades fluttering at high speed is very distinctive. It's only used on very small turbines, and is effective only using modern plastic blades that are highly resistant to fatigue.

Construction of a Large Wind Turbine on Land

This is generally done by power companies like Duke
So Chemical Engineers often become involved in managing
These large scale power production projects

Components of A Wind Farm



Components of A Wind Farm

Nacelle: the box located on the top of the tower, made of fiberglass, that contains approximately 8,000 subcomponents and connects them to the rotor. The size and weight of the nacelle vary depending on capacity (75 tonnes for a 2 megawatt (MW) turbine).

•Rotor and blades: the rotor is typically composed of three rotor blades, the rotor hub that holds the blades in position as they turn and a pitch mechanism that allows the blade to rotate in the direction of the wind, maximising its capacity to harness wind.

• Tower: the nacelle is mounted on the top of a high tower that allows using the best winds and avoiding obstacles. Towers for large wind turbines may be either tubular steel towers, concrete towers, or lattice towers.

In addition to the wind turbine, other components are needed to install and operate a wind farm, such as the following:

•Transformers to increase the voltage of the electricity generated. The system inverters generate power output at approximately 480 volts. Electricity grids operate usually in kilovolts.

Capacitors to adjust the power factor and reduce the reactive energy generated.

The electric installation requires cables to connect wind turbines to the inverters, transformers and grid. The installation includes contactors, circuit breakers and bypass contactors.

• Control equipment compromising microprocessor control, feeding source, heat resistors and coils.

• Electric protection equipment with relays and contactors of auxiliary or protection elements.

• Metering equipment to measure and control the quantity of electricity produced and supplied to the grid, and the reactive power.

Table 2.1 **Activities in the onshore wind energy value chain**

SEGMENT OF THE VALUE CHAIN PHASE	ACTIVITIES
Project planning	1.1. Site selection
	1.2. Technical and financial feasibility studies
	1.3. Engineering design
	1.4. Project development
Procurement	2.1. Identification of specifications
	2.2. Assessment of the local availability of materials
Manufacturing	3.1. Nacelle manufacturing and assembly
	3.2. Blades manufacturing
	3.3. Tower manufacturing and assembly
	3.4. Monitor and control system manufacturing
Transport	4.1. Transport of equipment
Installation	5.1. Site preparation and civil works
	5.2. Assembling equipment
Grid connection and commissioning	6.1. Cabling and grid connection
	6.2. Commissioning
Operation and maintenance	7.1. Operation
	7.2. Maintenance
Decommissioning	8.1. Planning the decommissioning
	8.2. Dismantling the project
	8.3. Disposing/recycling the equipment
	8.4. Clearing the site

Table 2.2 **Human resources required for the project planning of a 50 MW wind farm (person-days) and breakdown by activity**

TYPE OF HUMAN RESOURCES	Site selection	Feasibility analysis	Engineering design	Project development	Total by occupation
Legal, energy regulation, real estate and taxation experts	140	60	100	720	**1,020**
Financial analysts	-	30	-	700	**730**
Logistic experts	-	-	-	360	**360**
Electrical/civil/mechanical/ energy engineers	50	90	150	-	**290**
Environmental experts	50	30	-	-	**80**
Health and safety experts	-	-	50	-	**50**
Geotechnical experts	50	-	-	-	**50**
Total (as %)	**290** (11%)	**210** (8 %)	**300** (12 %)	**1,780** (69 %)	**2,580**

Figure 2.2 **Distribution of human resources required for the project planning of a 50 MW wind farm, by occupation**

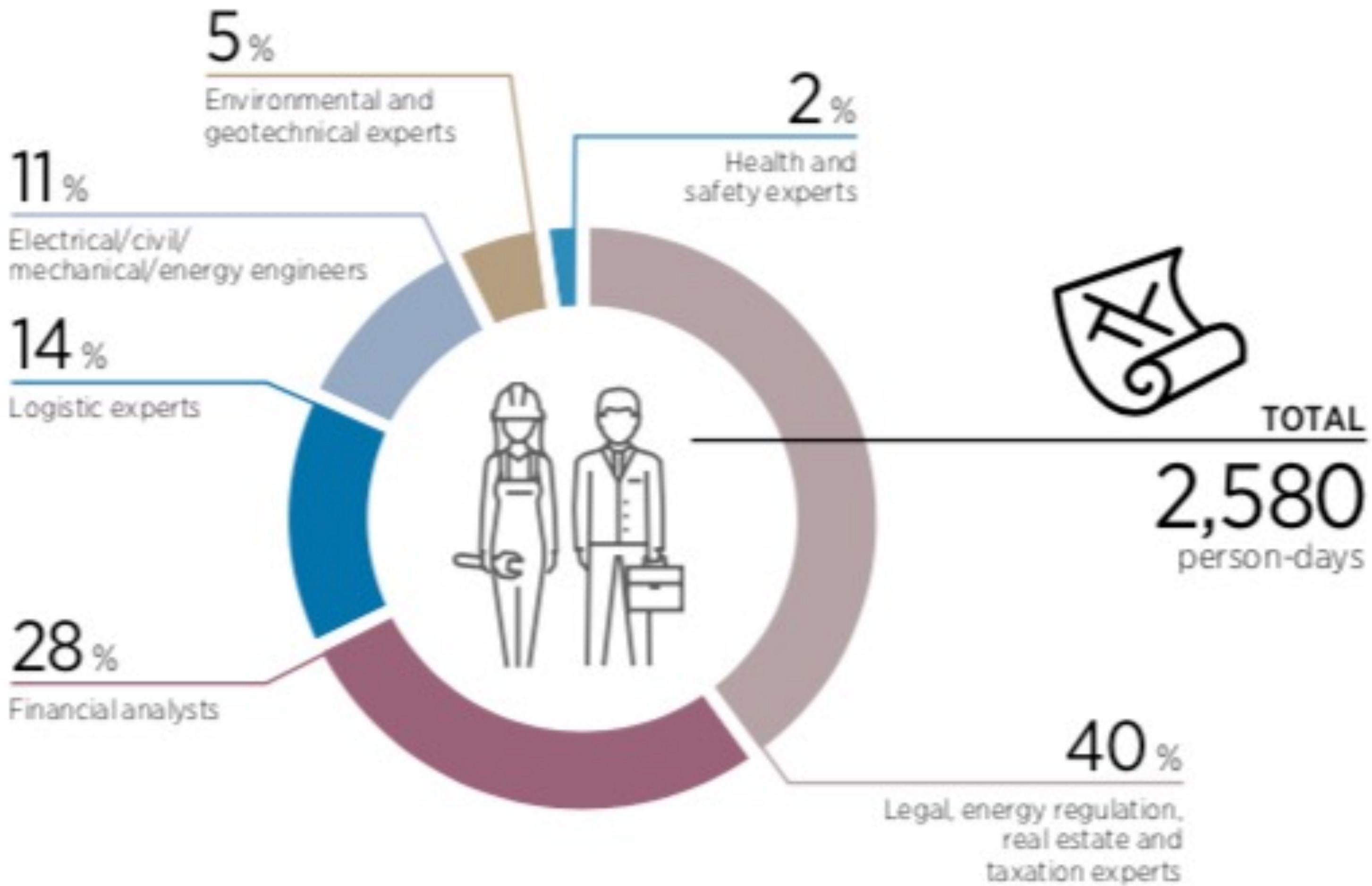
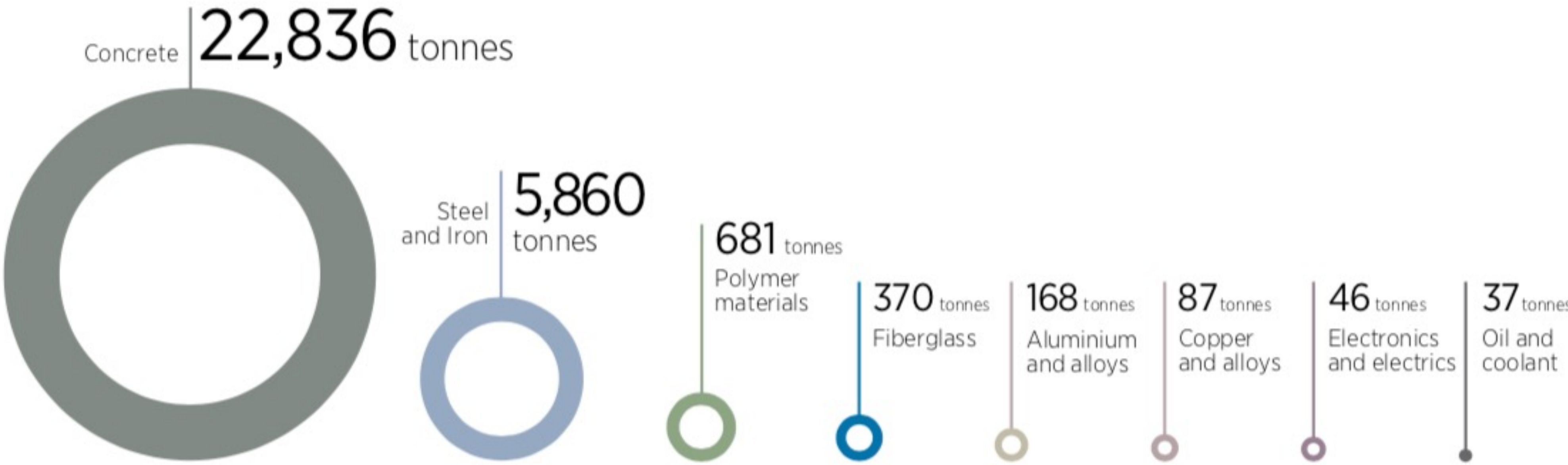


Figure 2.3 ■ **Materials needed to develop a 50 MW wind farm (tonnes)**



Source: Vestas, 2015

Table 2.3 Distribution of the materials needed to develop a 50 MW wind farm (tonnes), by component

MATERIAL	Turbines	Foundations	Cables	Site switch-gears and transfomers
Concrete	–	22,836	–	–
Steel and iron	4,607	1,228	–	25
Fiberglass	368	–	1	1
Polymer materials	325	1	355	–
Electronics/electrics	46	–	–	–
Copper and alloys	32	1	41	13
Oil and coolant	18	–	–	19
Aluminium and alloys	9	–	159	–

Table 2.4 Investment breakdown of wind turbine manufacturing and assembling[5]

ONSHORE WIND TURBIN COST BREAKDOWN	
COMPONENT	% OF TOTAL INVESTMENT OF WIND FARM
Wind turbine	64 - 85
Tower	16 - 18
Rotor blades	13 - 15
Rotor hubs	0.8 - 0.9
Rotor bearings	0.7 - 0.8
Main shaft	1.2 - 1.3
Main frames	1.7 - 1.9
Gearbox	7.8 - 9.7
Generator	2.1 - 2.3
Yaw system	0.76 - 0.84
Pitch system	1.6 - 1.8
Power converter	3.0 - 3.4
Transformer	2.2 - 2.4
Break system	0.8 - 0.9
Nacelle housing	0.8 - 0.9
Others	7.7 - 8.5

Table 2.5 **Human resources required to manufacture the main components of 50 MW wind farm (person-days) and breakdown by main component**

TYPE OF HUMAN RESOURCES	Nacelle	Blades	Tower	Monitor and control system	Total by occupation
Factory workers	5,890	3,400	2,850	300	**12,440**
Health and safety experts	620	125	300	30	**1,075**
Logistic experts	620	125	300	15	**1,060**
Quality control experts	620	125	300	15	**1,060**
Marketing and sales personnel	480	290	230	45	**1,045**
Industrial engineers	480	277	232	15	**1,004**
Administrative personnel	480	113	230	45	**868**
Management	185	110	90	–	**385**
Telecommunication and computer engineers	–	–	–	15	**15**
Regulation and standardisation experts	–	–	–	15	**15**
Total (as %)	**9,375** (49%)	**4,565** (24%)	**4,532** (24%)	**495** (3%)	18,967

Figure 2.4 ■ **Distribution of human resources required to manufacture the main components of a 50 MW wind farm, by occupation**

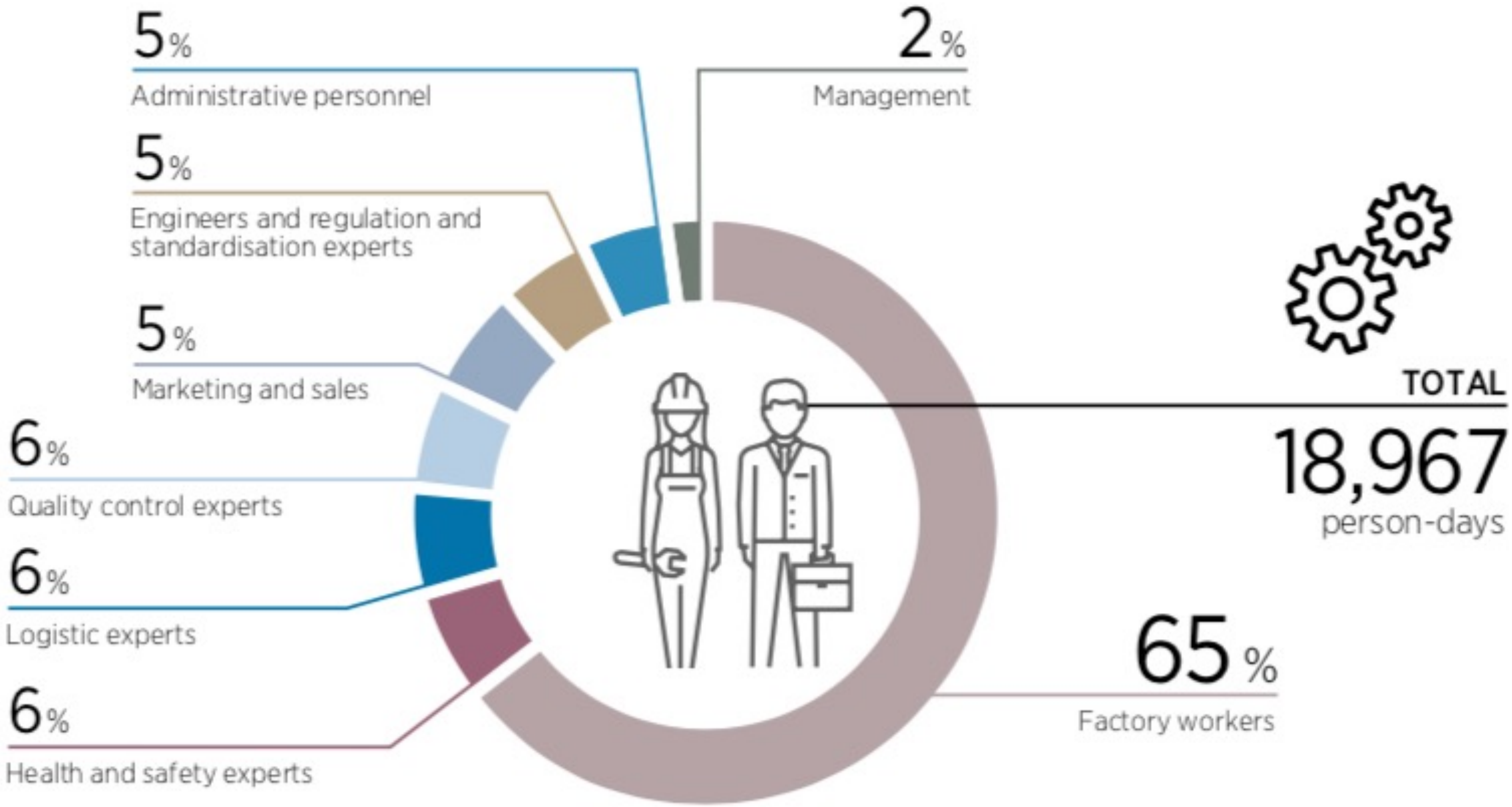


Table 2.6 Materials needed to manufacture the main components of a 2 MW wind turbine (kilograms)

Component	Nacelle			Rotor			Tower	Total
MATERIAL	Gearbox	Frame	Other	Blades	Hub	Other		
Steel and iron	8,159	2,963	26,221	898	-	5,992	188,179	**232,412**
Casting	8,008	10,900	4,730	-	8,360	1,086	-	**33,084**
Fiberglass	-	-	10	12,152	-	-	-	**12,162**
Glass-reinforced plastic	3	-	1,713	-	-	186	-	**1,902**
Painting	38	1	36	682	-	-	580	**1,336**
Aluminium	3	54	978	-	-	50	237	**1,322**
Wires	-	-	1,280	-	-	-	-	**1,280**
Electronics/ electrics	192	-	713	-	-	-	-	**905**
Copper	-	-	522	53	-	2	-	**577**
Adhesive	-	-	-	1,475	-	-	-	**1,475**

Source: Gamesa, 2013

Figure 2.5 ■ **Composition of the main components of a 2 MW turbine**

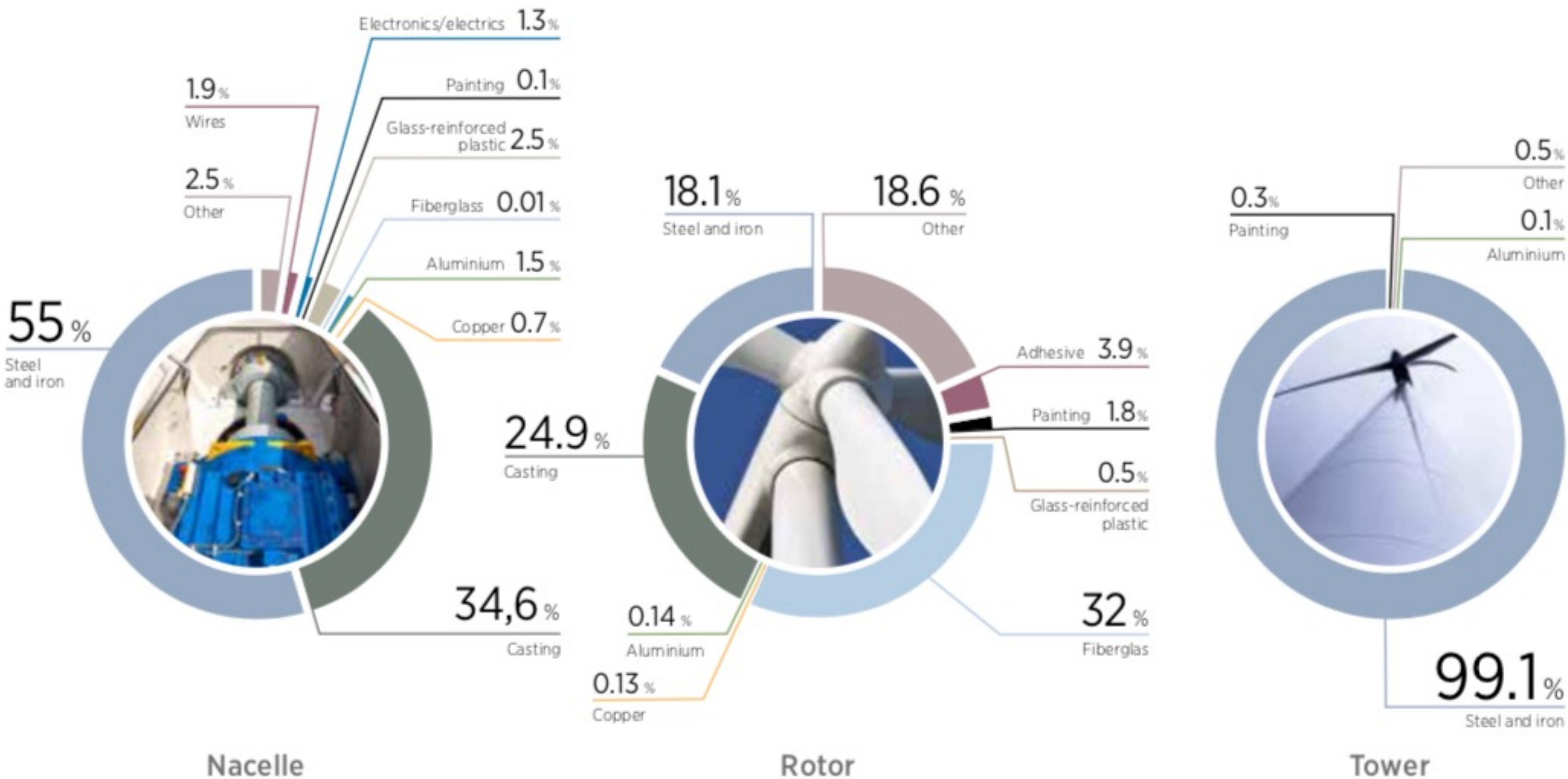
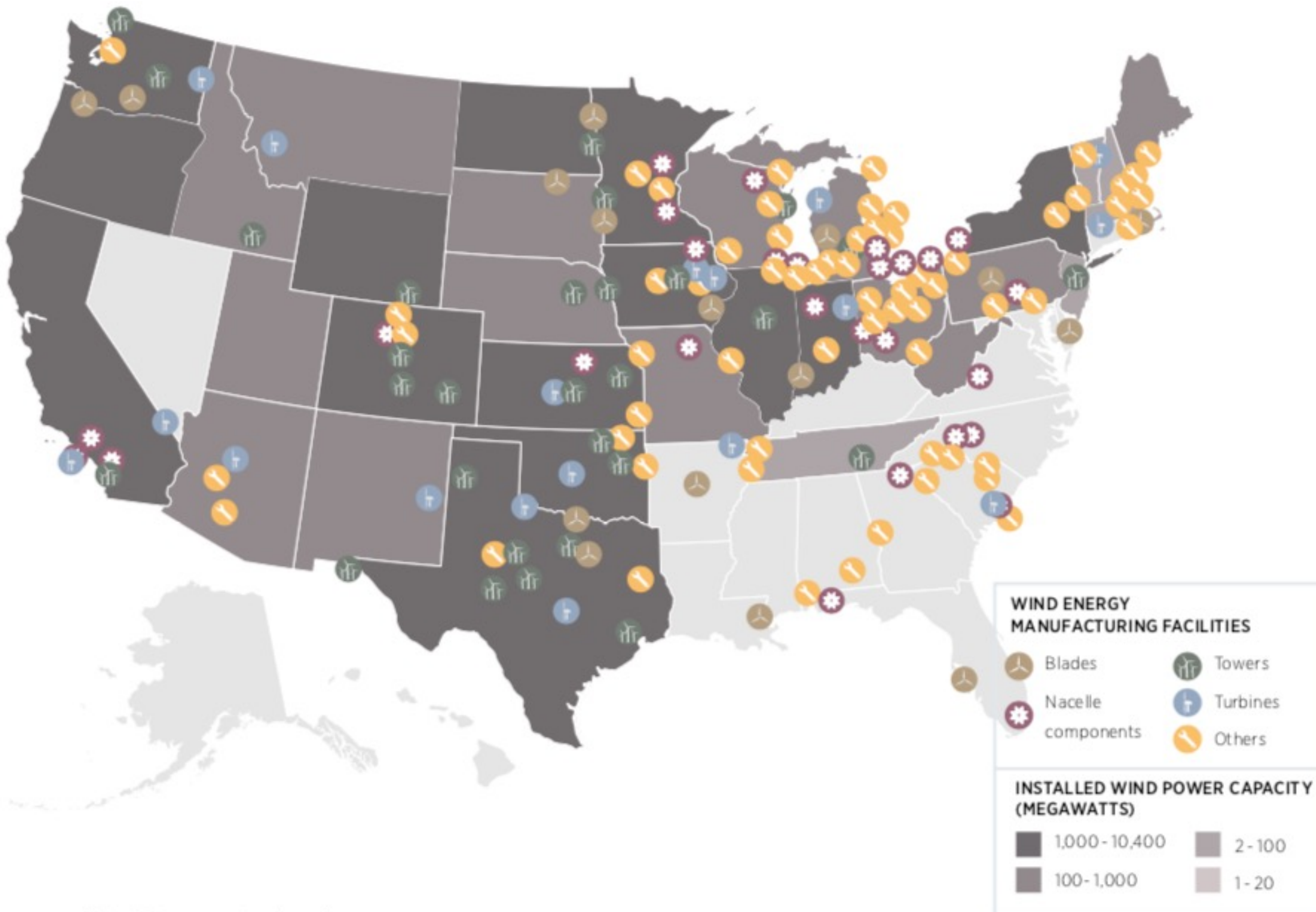


Table 2.7 **Equipment needed to manufacture wind turbines**

Nacelle	Blade	Tower
• Lifting equipment • Welding equipment • Shot peening machines • Polishing equipment • Automated Paint Machines • Testing dock	• Vacuum bag moulding machine • Resin transfer moulding – LITE machine • Vacuum infusion moulding machine • Open moulding (hand lay-up, spray-up) machine • Liquid moulding composite machine • In mould coating (IMC) • Bonding and assembly • Composite tooling manufacture • Robotic routing and water jet • Automated paint machines • Painted or gel-coated surface finishers	• Heavy cranes • Rolling machine • Welding machines (different technologies depending on process) • Shot peening machines • Material handling equipment • Automated Paint Machines • Inspection equipment (NDT)

Figure 2.6 ■ **Current location of wind energy equipment in the United States**



Note: Data are not exhaustive.
Source: U.S. Department of Energy , 2013

Box 2.1 **Sub-components of a nacelle**

- The gear-box (when existent) connects the low-speed shaft to the high-speed shaft and increases the rotational speed from about 30-60 rotations per minute (rpm) to approximately 1,000–1,800 rpm, required by most generators to produce electricity. A gearbox should be robust to manage the frequent changes in torque generated by changes in the wind speed, and it should be well lubricated. It is a costly component. Some wind turbines do not have a gearbox, using a direct drive system connecting directly the rotor and the electromagnet. The electromagnet is moved, generating a changing magnetic field which generates an electric current by means of induction. A heat exchanger ensures that the generator temperature is not too high.
- The generator converts the mechanical energy into electrical energy, at alternating current.
- The yaw drive is the system that keeps the rotor facing the wind, adjusting the position of the nacelle to changes in the wind direction.
- The brake systems stop the rotor in case of emergency. It can be mechanically, electrically or hydraulically activated.
- The controller starts and shuts off the wind turbine. Wind turbines start operating at a set speed, which varies depending on many factors, and is automatically shut down at higher wind speeds due to risk of damage at the cut-out speed.
- The turbine includes a number of sensors which collect and transmit information about the speed and the direction of the wind, power generation, rotor speed, blades' pitch angle, vibration levels, temperature and pressure of the lubricants and other relevant variables. A computer analyses these variables, ensuring that the turbine works properly.
- There is a safety system, able to stop the turbine if it is working in dangerous conditions (*e.g.* high speed) and ensures that the electricity is generated at the proper frequency, voltage and current.
- A wind vane measures the direction of the wind, transmitting this information to the yaw to orient the turbine properly with respect to the wind.
- An anemometer measures the wind speed, and transmits wind speed data to the controller.

FIGURE 6.20 Placing rebar for pad foundation for 2-MW wind turbine. Finished pad required 32 metric tons of rebar and 270 cubic meters of concrete.

FIGURE 6.21 Finished pad foundation for 2.3-MW wind turbine. Note copper wire for grounding.

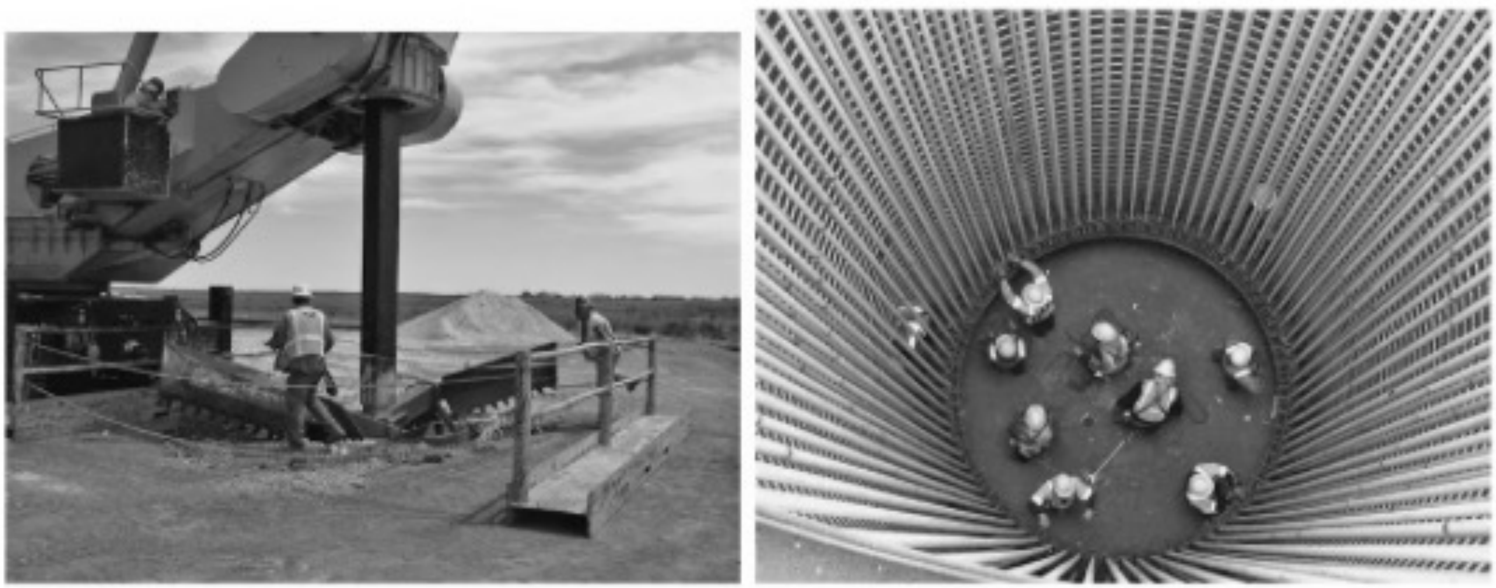


FIGURE 6.22 Pier foundation, concentric cans, for 3-MW wind turbine. Right: bolt rods are in place and starting to attach rebar.

FIGURE 6.23 Photos showing stages of erection of 3-MW wind turbine.

https://www.youtube.com/watch?v=SBbBh5xZ1gQ

High Speed Construction of a Wind Turbine Site

https://www.youtube.com/watch?v=MHS10eGjNq8

100Seconds

FIGURE 6.17 Blade cross sections for megawatt wind turbine.

Hand Layout of Turbine Blades

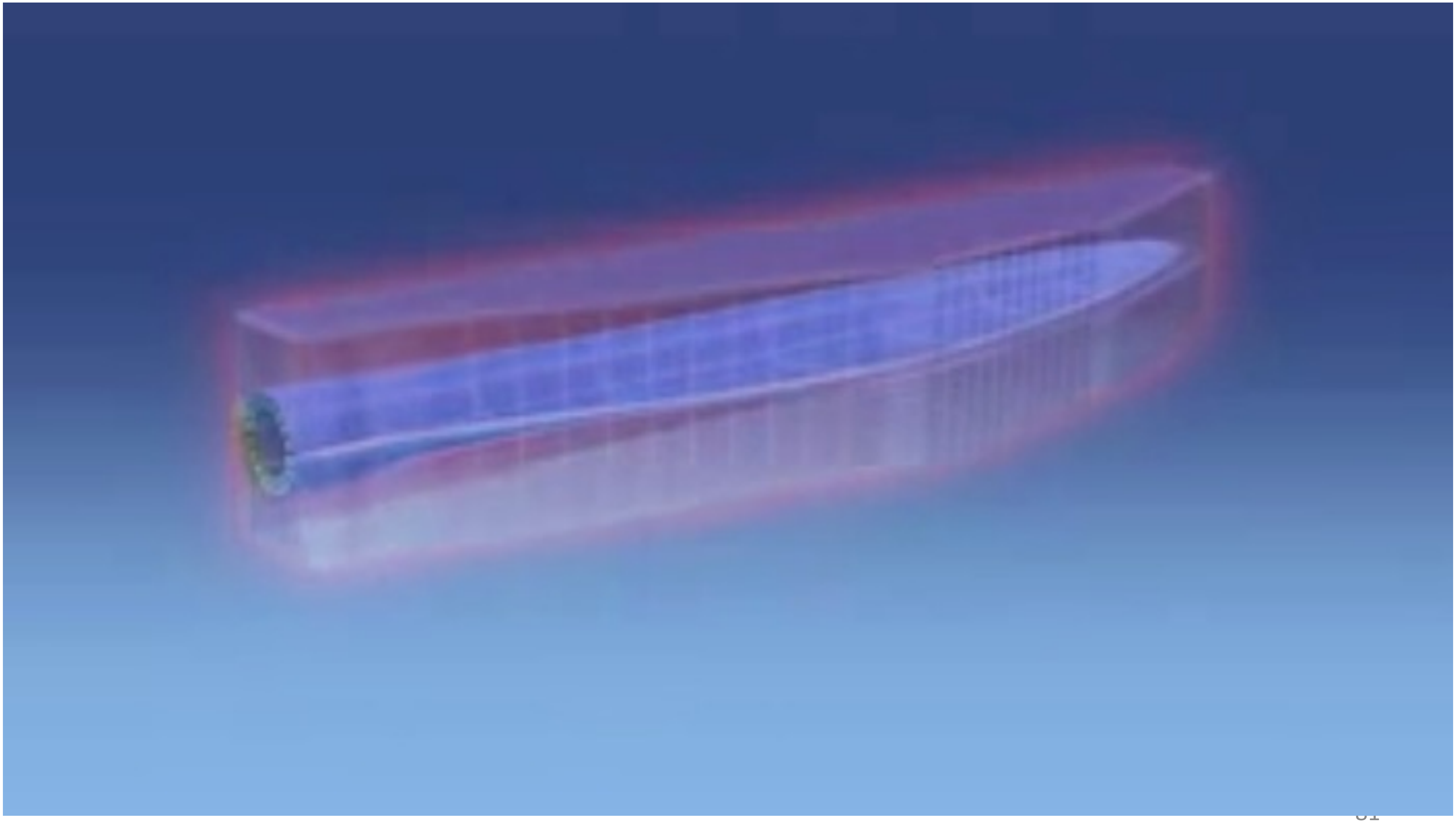
https://www.youtube.com/watch?v=XVj_YyvgMbE

NREL's new CoMET facility in Boulder, Colorado innovates wind-turbine blade manufacturing by letting researchers design, prototype, and test composite blades and other components in one place.

In addition to prototyping of new blade materials and production methods, NREL's CoMET facility will also offer workforce development and training for the composites industry.

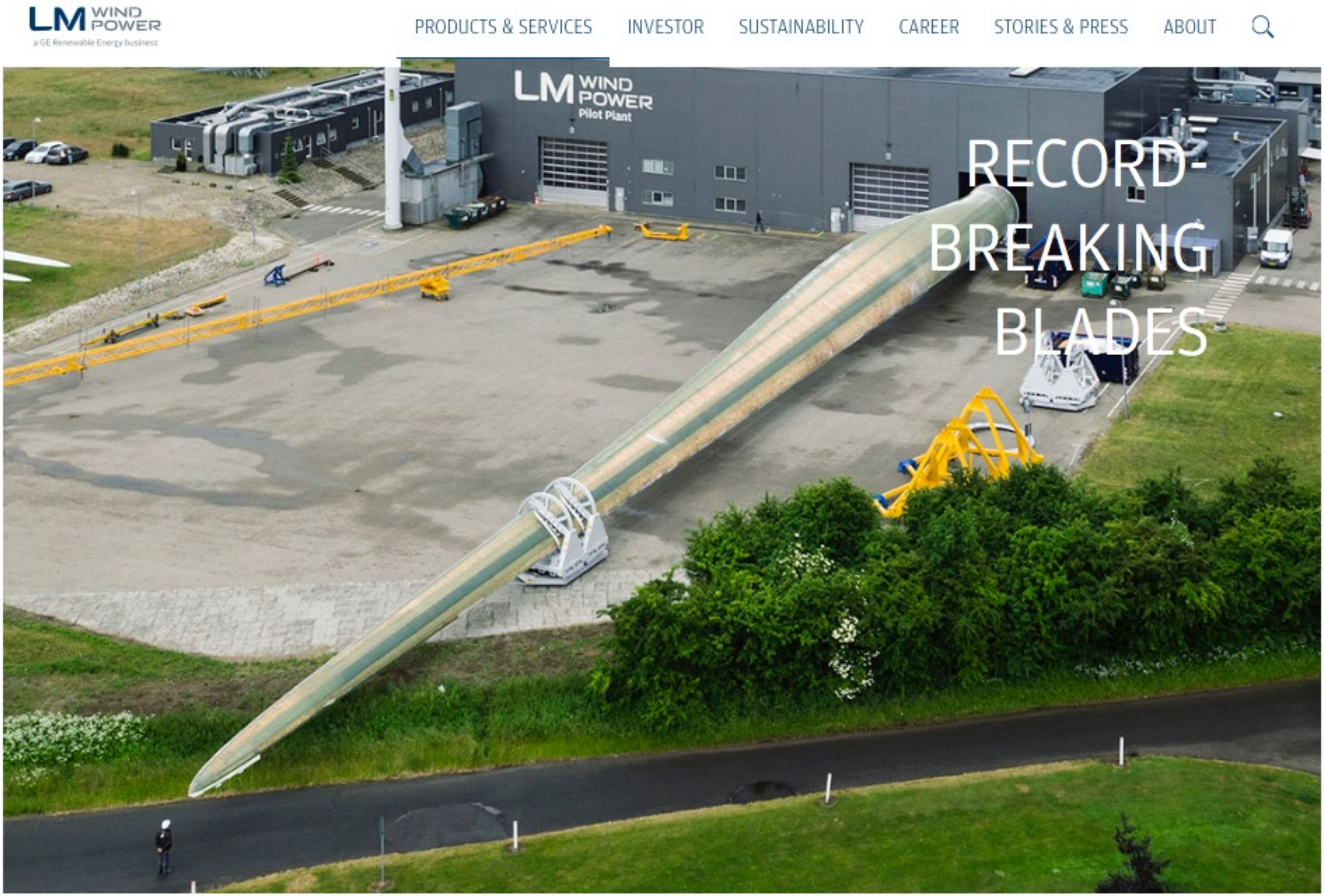
https://www.youtube.com/watch?v=iY0oBGo0-W4

Large Scale Layout



For off-shore wind farms to become an economically feasible alternative energy source, each turbine needs to be big. Like, really big. That's why the latest turbine blade from Siemens is gigantic—just a hair shorter than the wingspan of an Airbus 380.

Fiberglass-reinforced epoxy blades of Siemens SWT-2.3-101 wind turbines. The blade size of 49 meters[45] is in comparison to a substation behind them at Wolfe Island Wind Farm.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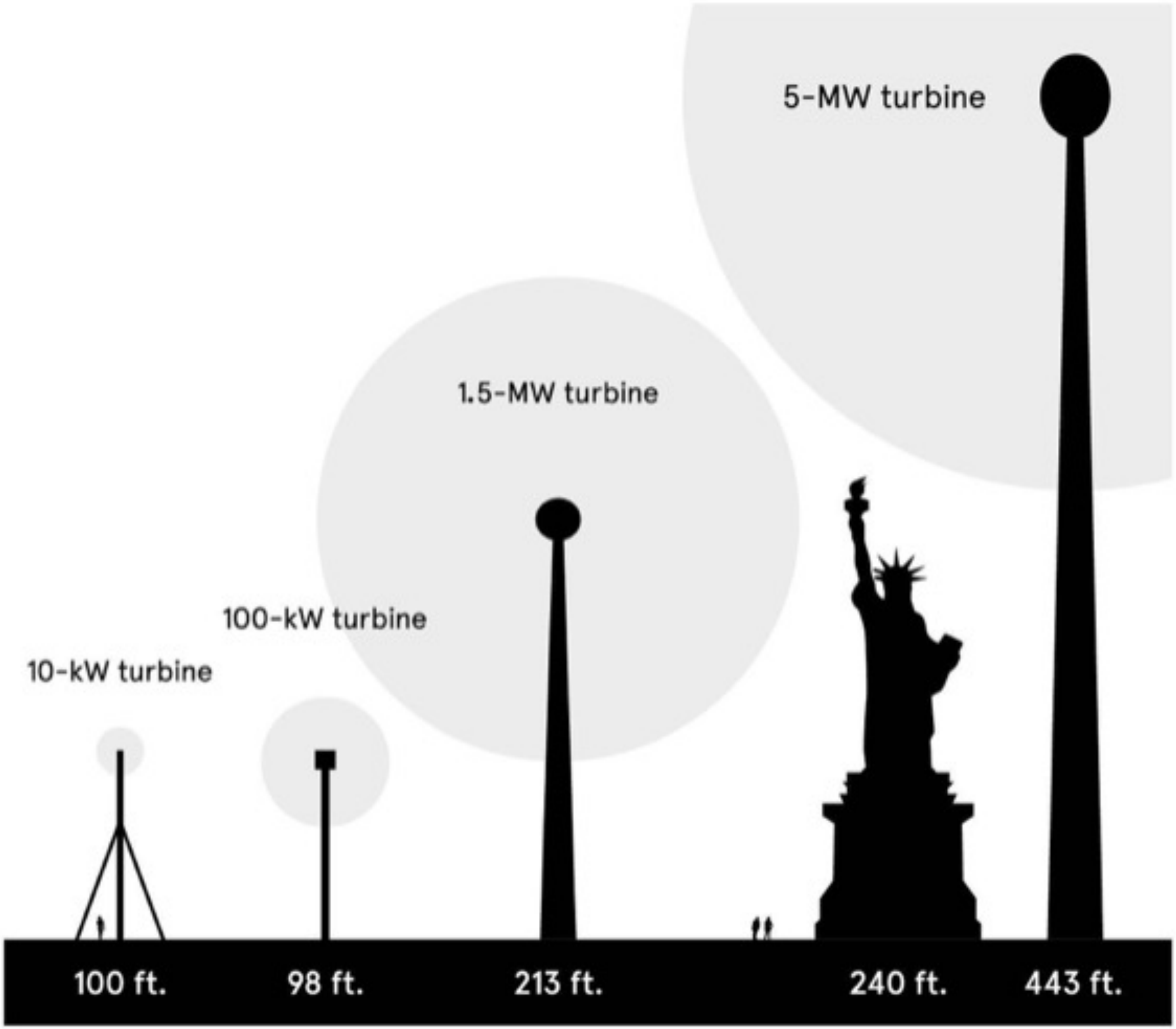


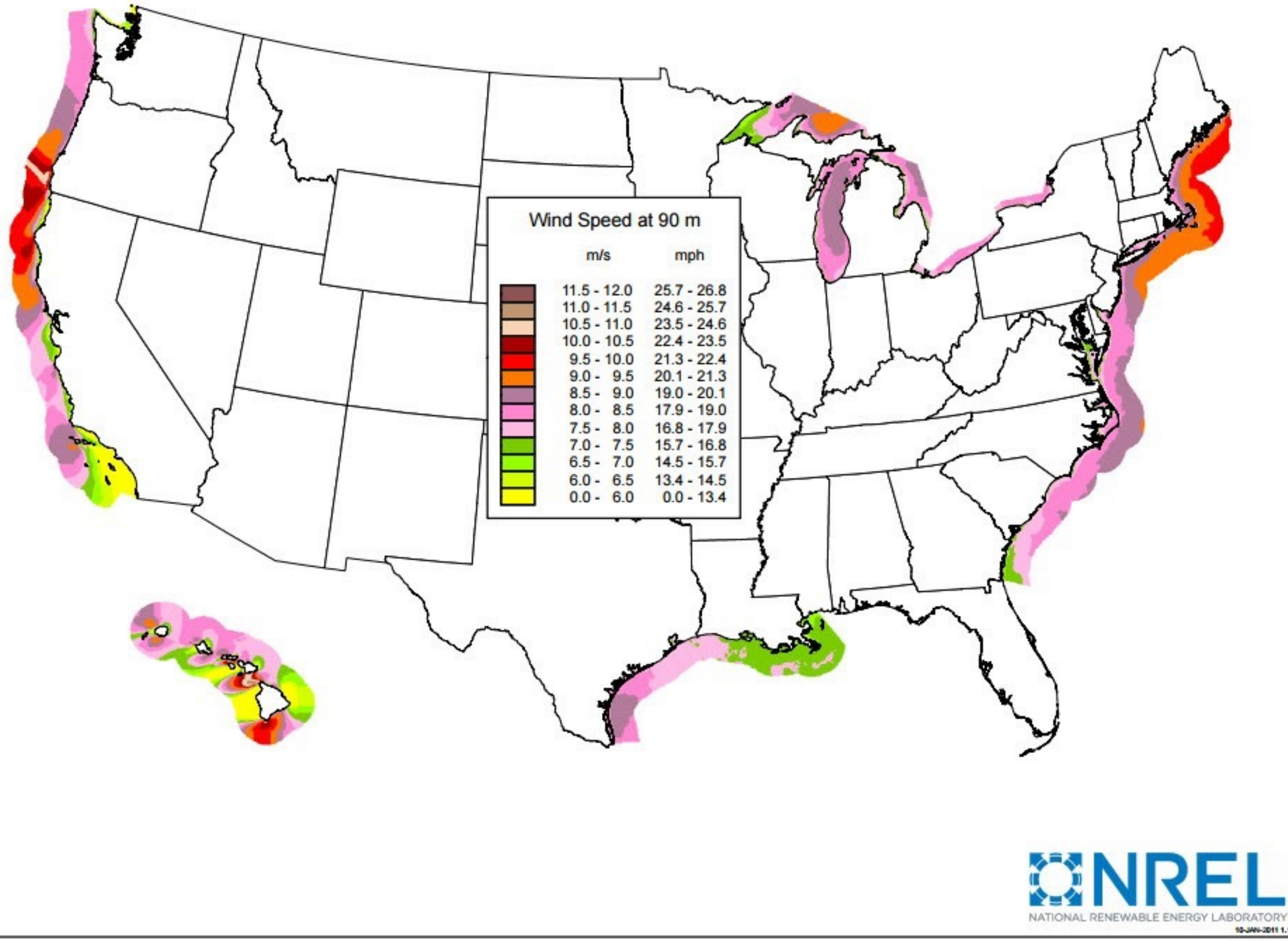
FIG 1 The height, swept area, and power rating of common wind turbines

Offshore Wind Power

Supplies from turbines will prove to be the next great energy revolution, IEA predicts

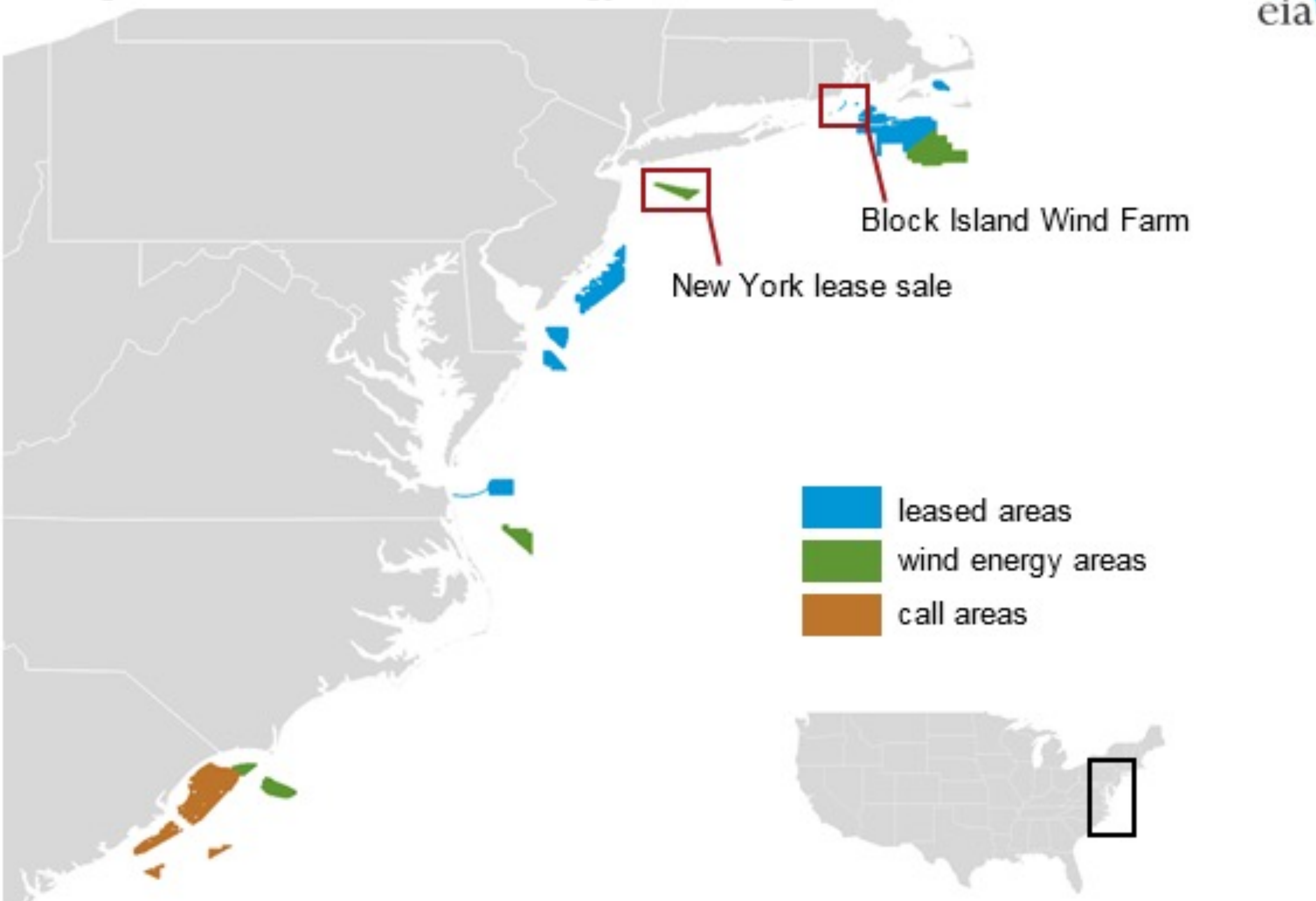
▲ A sailing boat passes the Kentish Flats offshore windfarm. Photograph: Gareth Fuller/PA

United States - Annual Average Offshore Wind Speed at 90 m

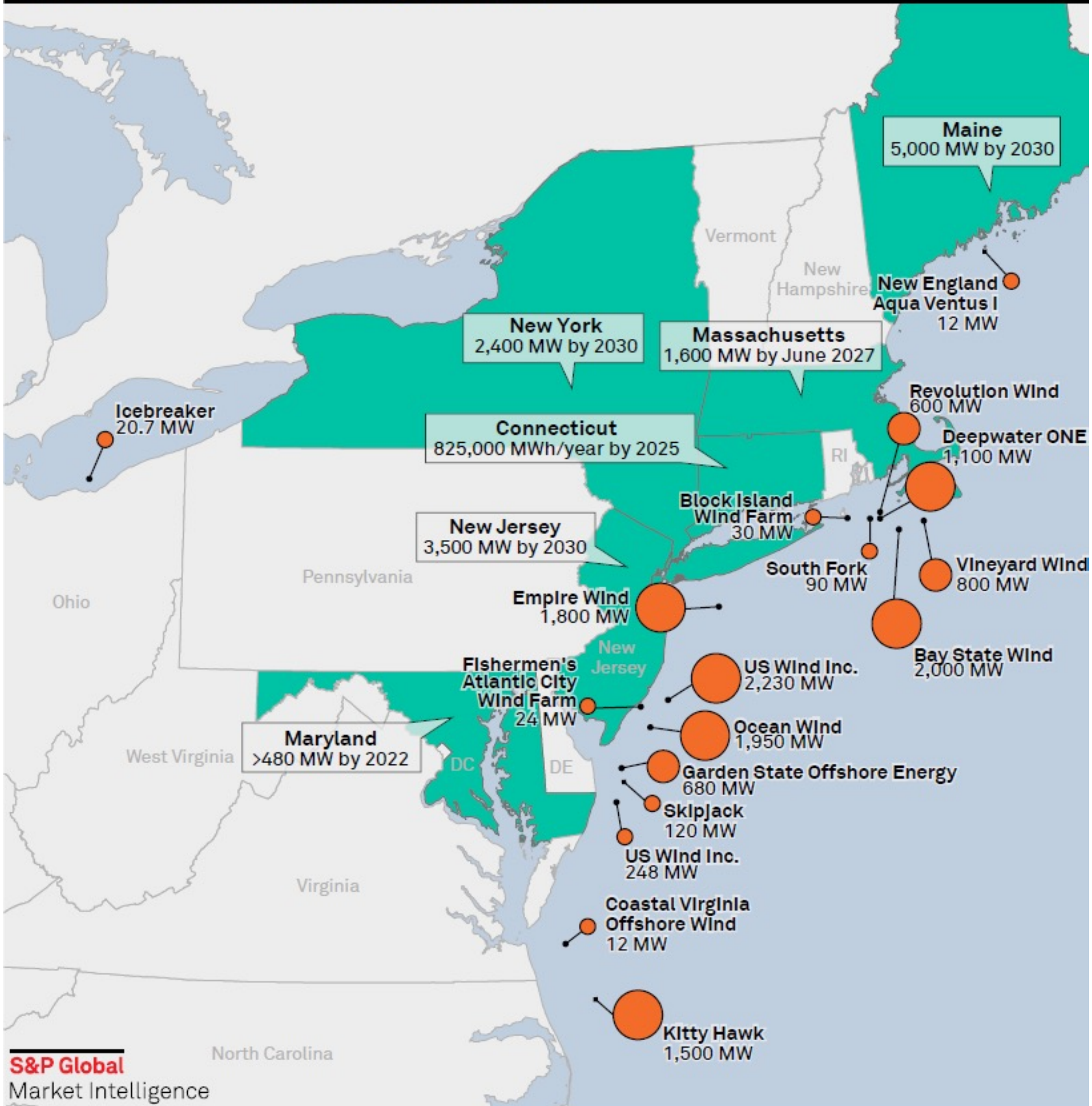


Offshore Wind Power

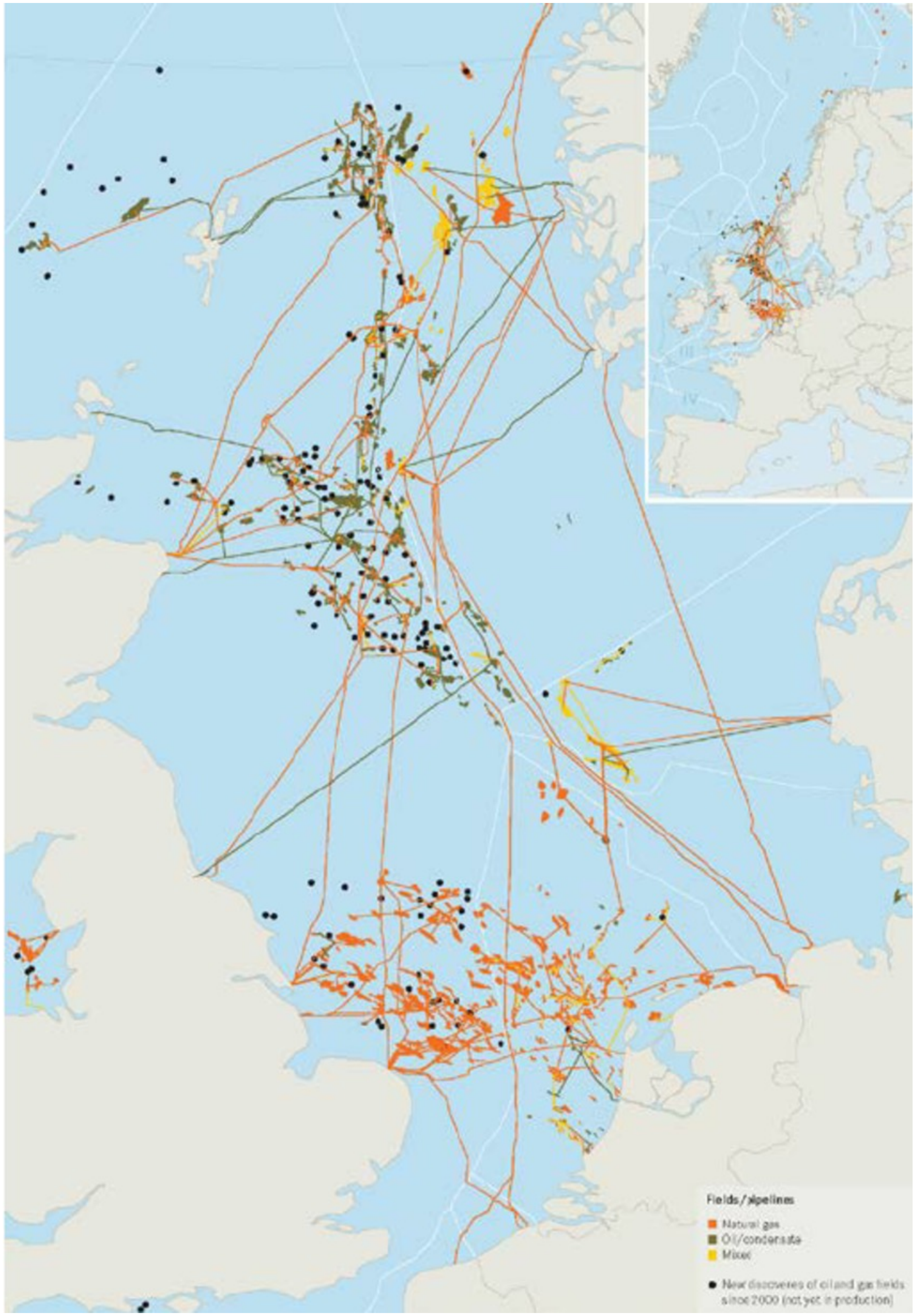
Leasing areas, call areas, and wind energy areas along the U.S. Atlantic coast



United States offshore wind targets and projects



As of June 2018.
Map credit: Elizabeth Thomas
Source: S&P Global Market Intelligence



Fields/pipelines
Natural gas
Oil/condensate
Mixed
New discoveries of oil and gas fields since 2000 (not yet in production)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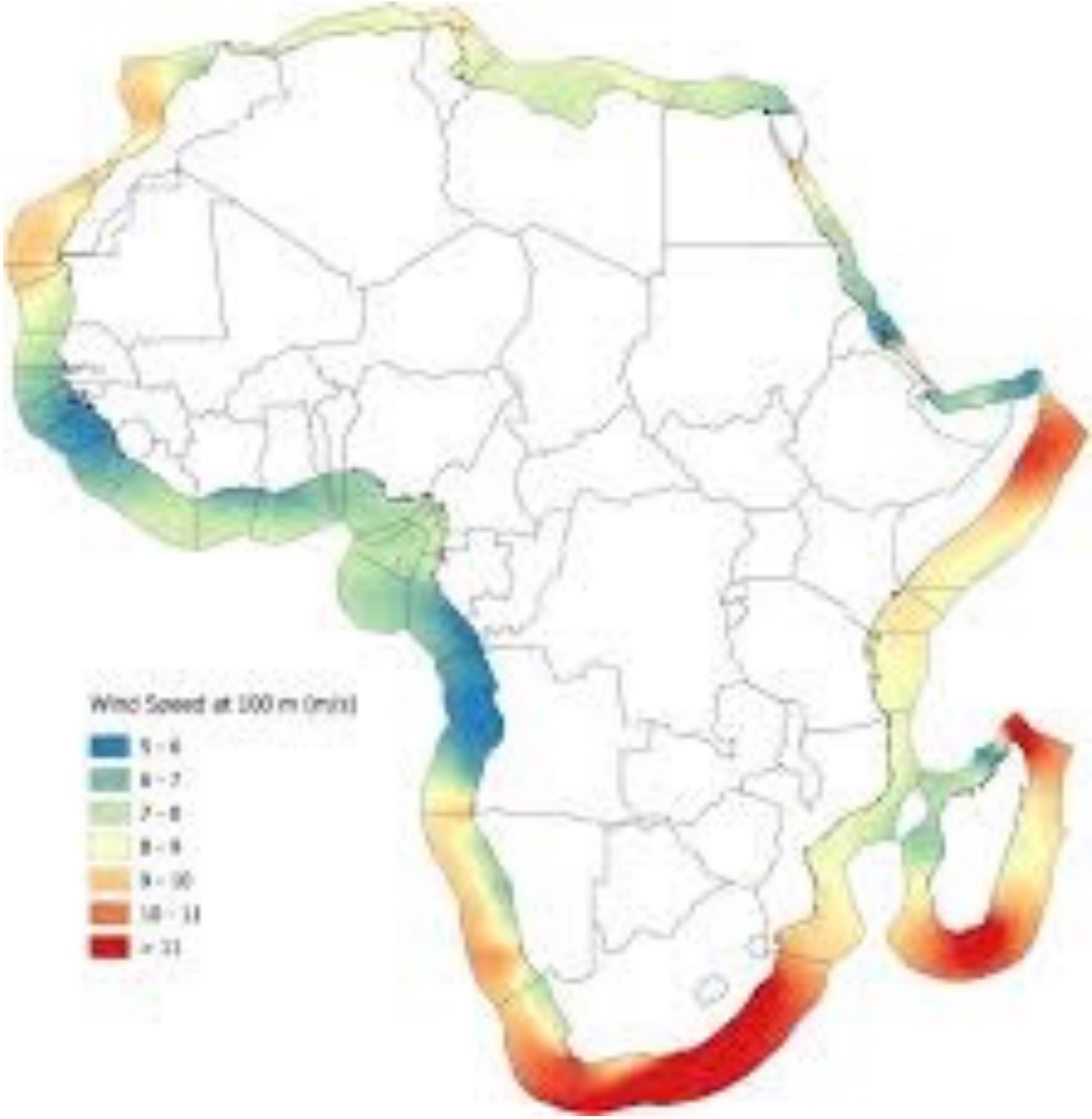
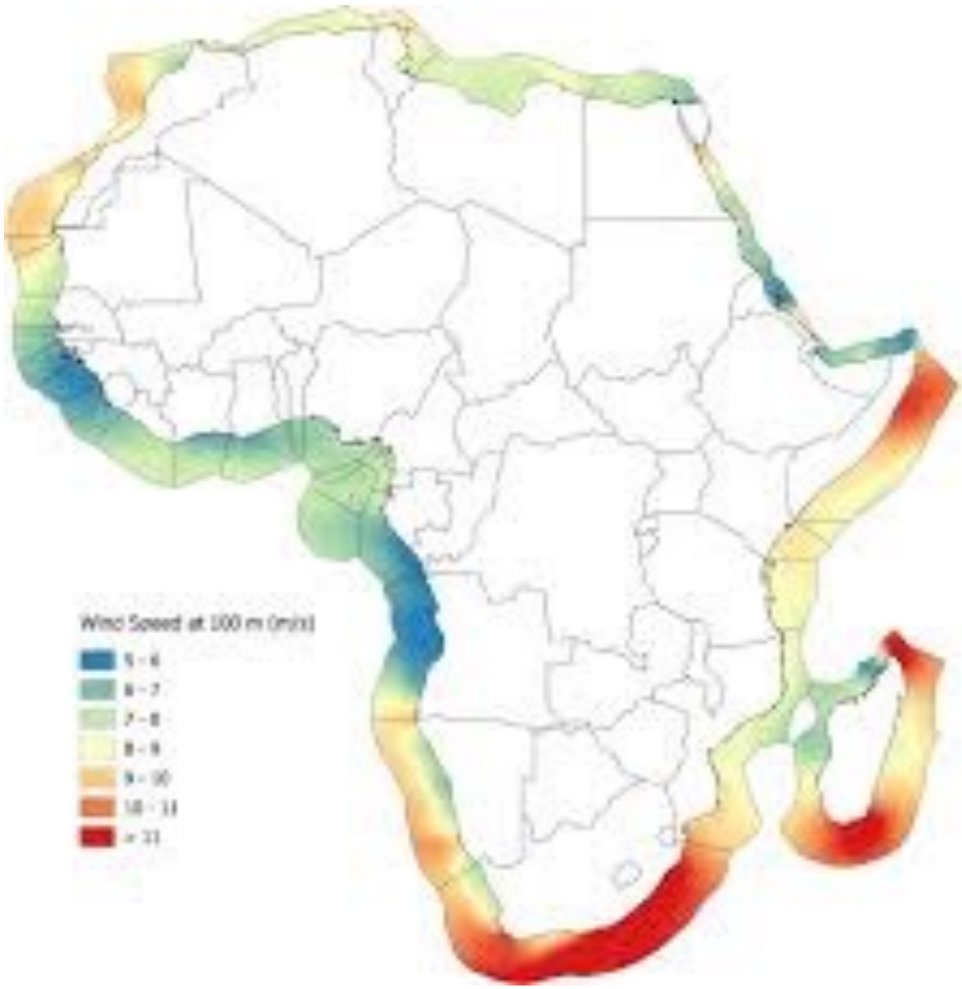
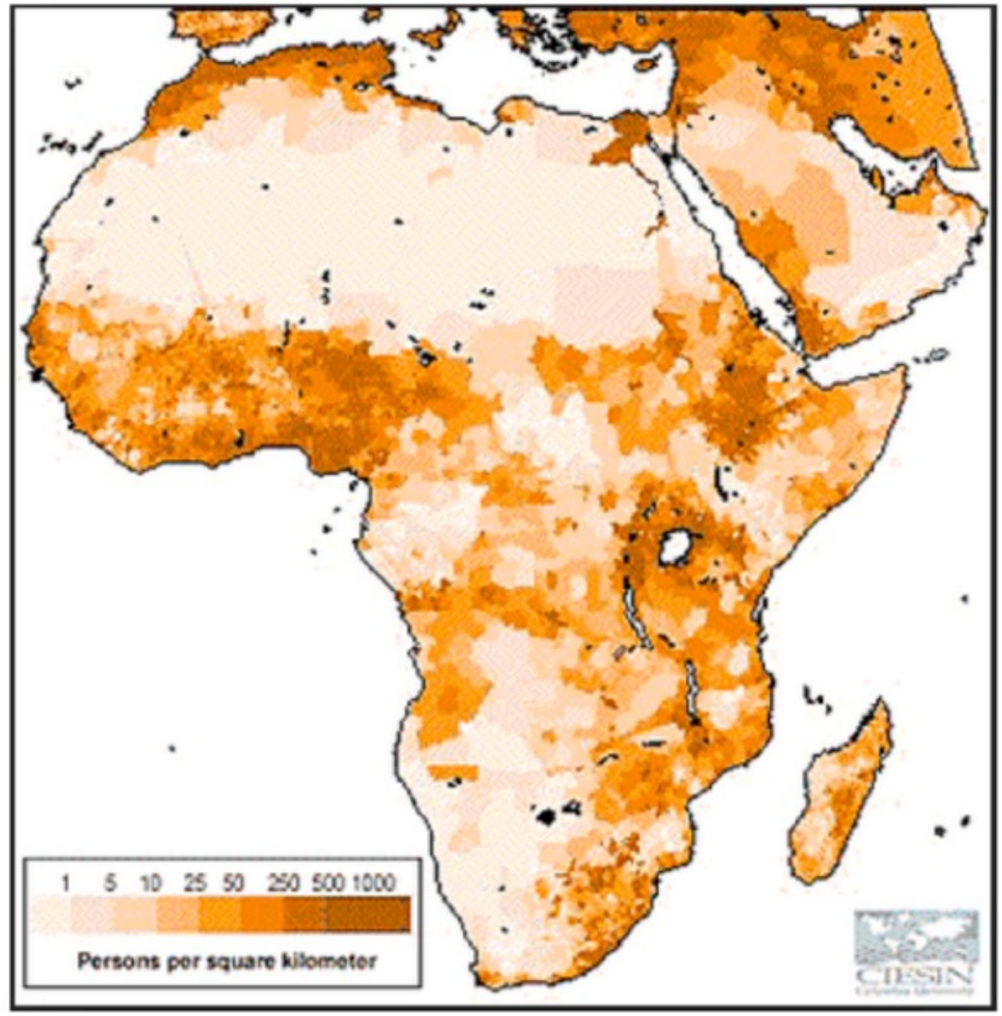
Offshore Wind Power



Offshore Wind Power





Offshore Wind Power

Analysis by the International Energy Agency (IEA) revealed that if windfarms were built across all useable sites which are no further than 60km (37 miles) off the coast, and where coastal waters are no deeper than 60 metres, they could generate 36,000 terawatt hours of renewable electricity a year. This would easily meeting the current global demand for electricity of 23,000 terawatt hours.

Offshore Wind Power

Floating wind-to-hydrogen plan to heat millions of UK homes

Project aiming to deploy 4GW, £12bn 'green hydrogen' array in the North Sea is backed by UK government

The floating wind-to-hydrogen turbines would be completely independent of the power grid – a major contributor to cost reduction Kinsella, said. "Once you get a long way offshore it's the electrical infrastructure that dominates the costs." They will be equipped with an on-board energy storage unit to make them self-sufficient, with the ability to restart the turbine from a standstill.

Offshore Wind Power

[Scotland](#)

Offshore Wind Power

[Construction of the first floating wind farm]

Offshore Wind Power

Wind Turbine Engineer

Can/should you build a wind turbine?

http://www.instructables.com/id/DIY-1000-watt-wind-turbine/

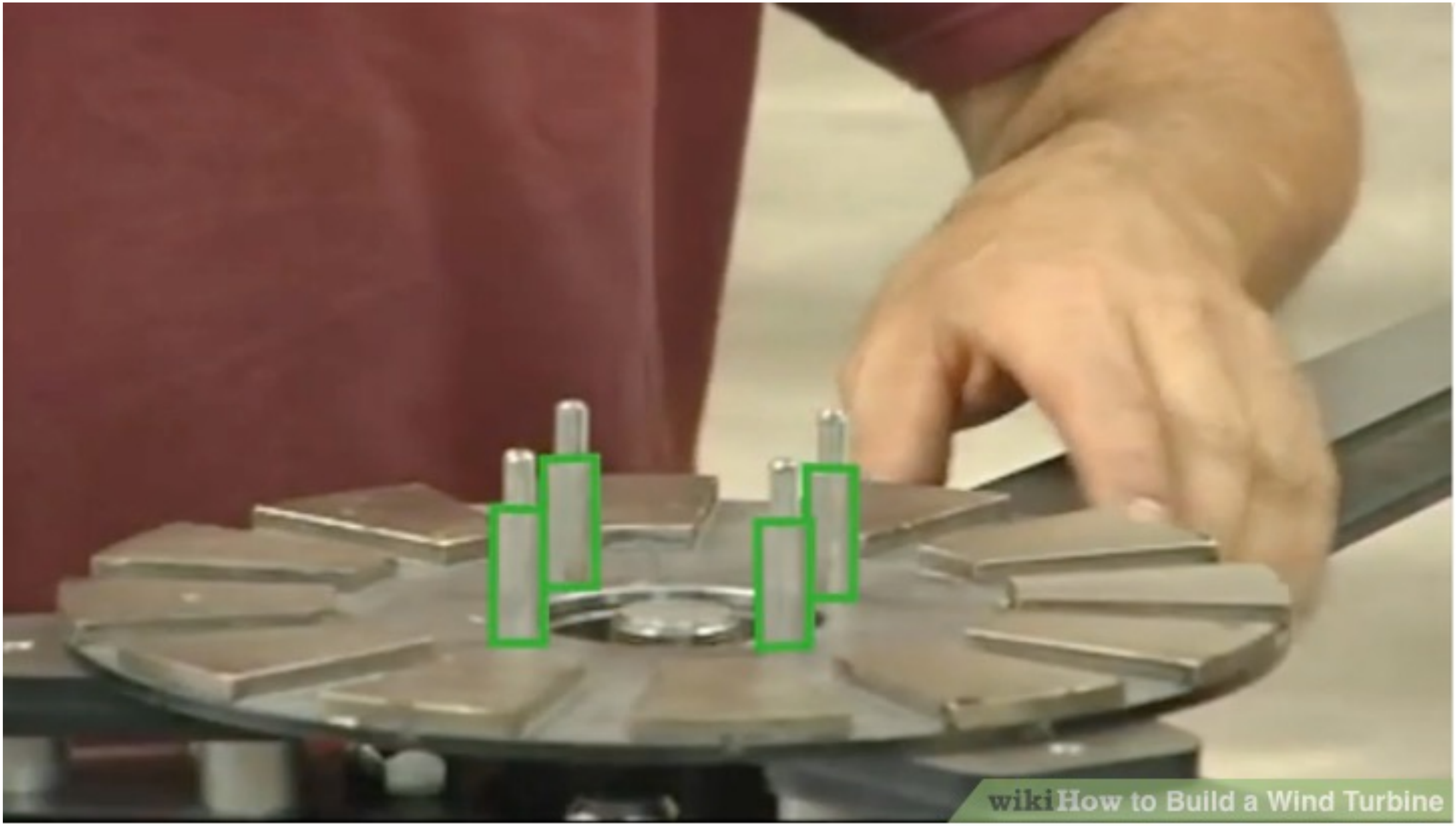
Step 1: Build the Magnet Disks

Step 2: Build the Coil Disk

Step 3: Build the Bearing Assembly

https://www.youtube.com/watch?v=o9EEHFKEckM

https://www.wikihow.com/Build-a-Wind-Turbine

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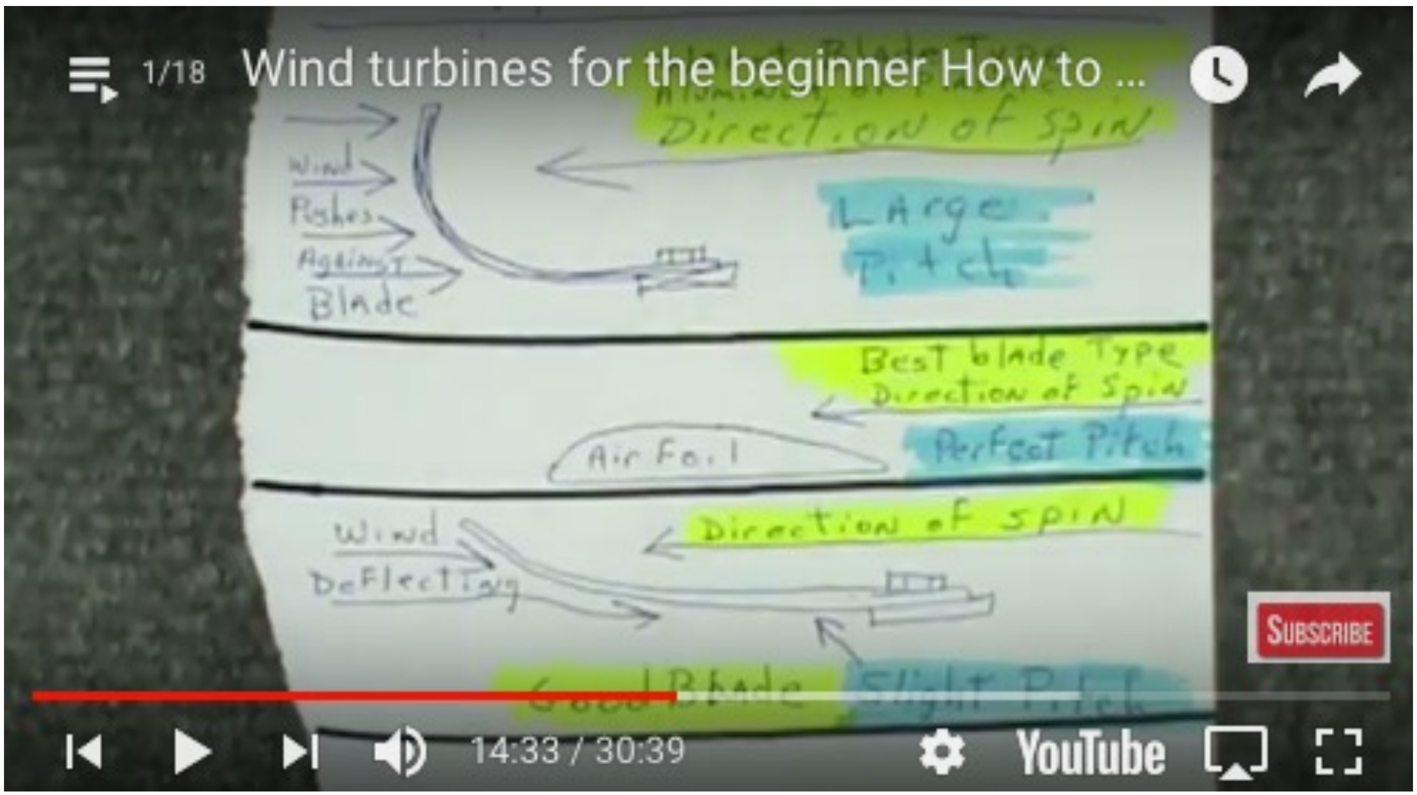
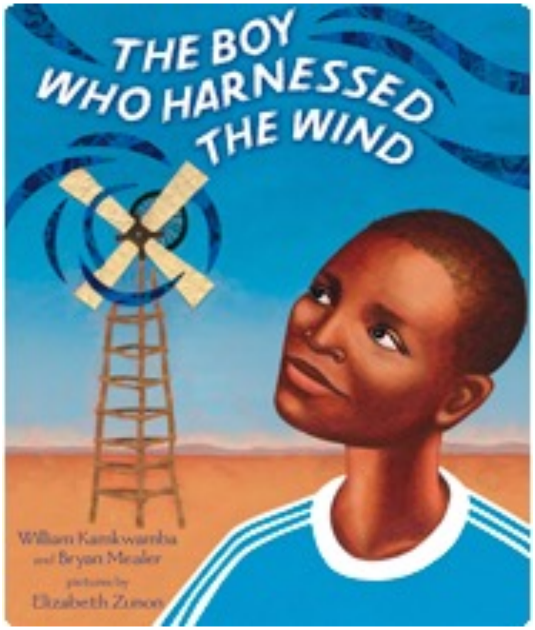
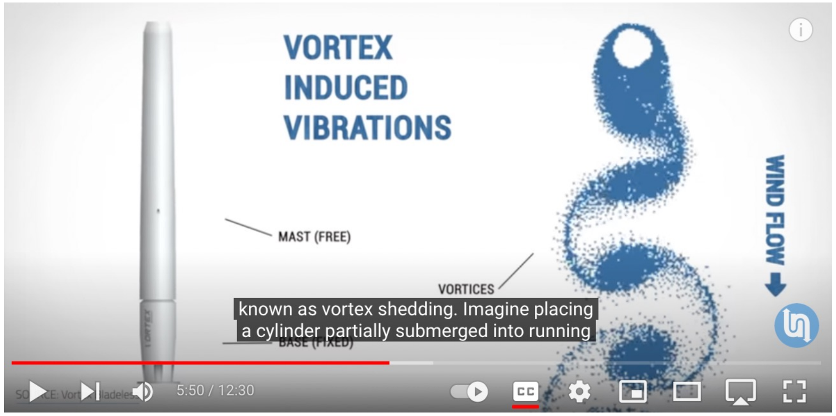


Intrepid Malawi youth William Kamkwamba



Future of Solid-State Wind Power Generation



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