ECE 333

Green Electric Energy

Lecture 7

Intro to Wind Energy Conversion

Professor Andrew Stillwell

Department of Electrical and Computer Engineering

Slides Credit Prof. Tim O'Connell and Prof George Gross

Announcements

- Reminder: HW3 is due Thursday, Jan. 13th beginning of class
- Today:
  - Begin Wind Energy Conversion Systems (Chapter 7)
- Start reading Masters Section 7

Wind Power Systems

Wind Resources

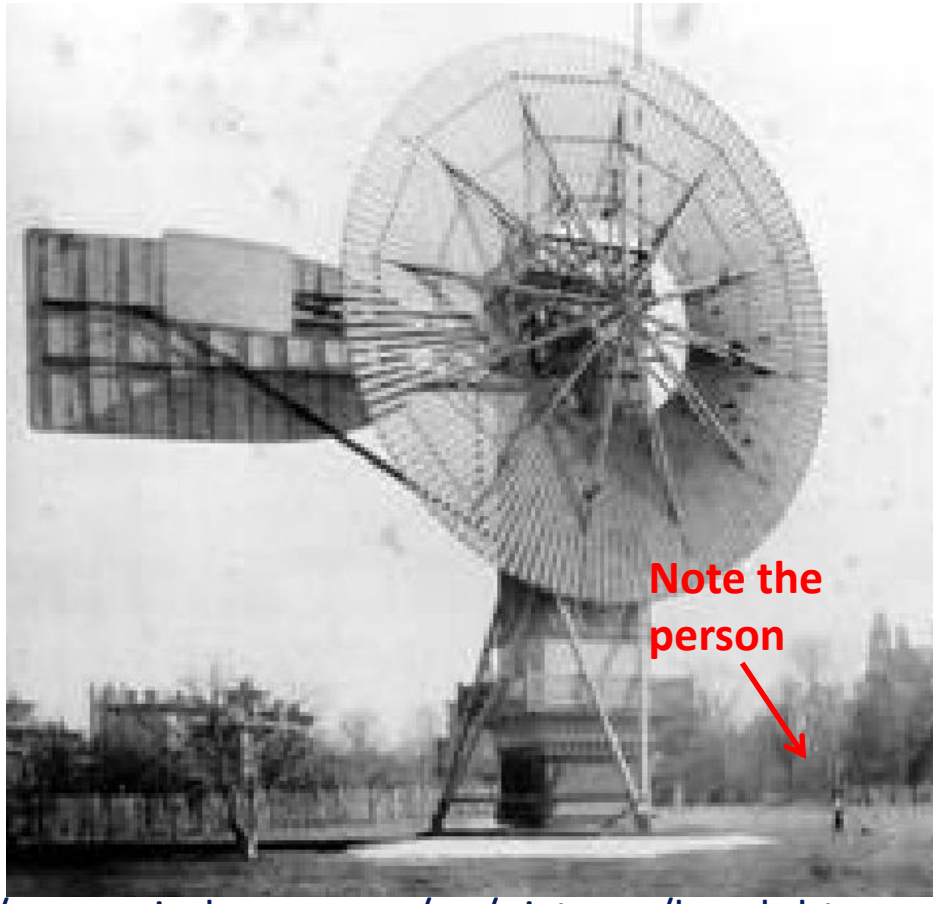
- Wind is becoming a significant generation source in the US, $Europe$ and $China$
- Today's over $600\ GW$ of global wind capacity contributes to lowered CO_2 emissions
- The technological advances over the past two decades have dramatically reduced the costs of wind generated electricity
- In this set of lectures on wind, we explore its key characteristics, its physical limitations, the economics of wind generation and its global status

Smoky Hill Wind Farm Near *Ellsworth, KS*

Historical Development of Wind Power

- The first known wind turbine for producing electricity was by Charles F. Brush, in Cleveland, Ohio in 1888

- 12 kW
  - (Illinois solar house in 2009 had roughly 9 kW)
- Used electricity to charge batteries in the cellar of the owner's mansion
- Fun fact: Also the year Tesla invented the induction machine



http://www.windpower.org/en/pictures/brush.htm

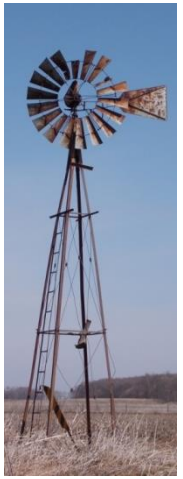
Historical Development of Wind Power

- First wind turbine outside of the U.S. to generate electricity was built by Poul la Cour in 1891 in Denmark

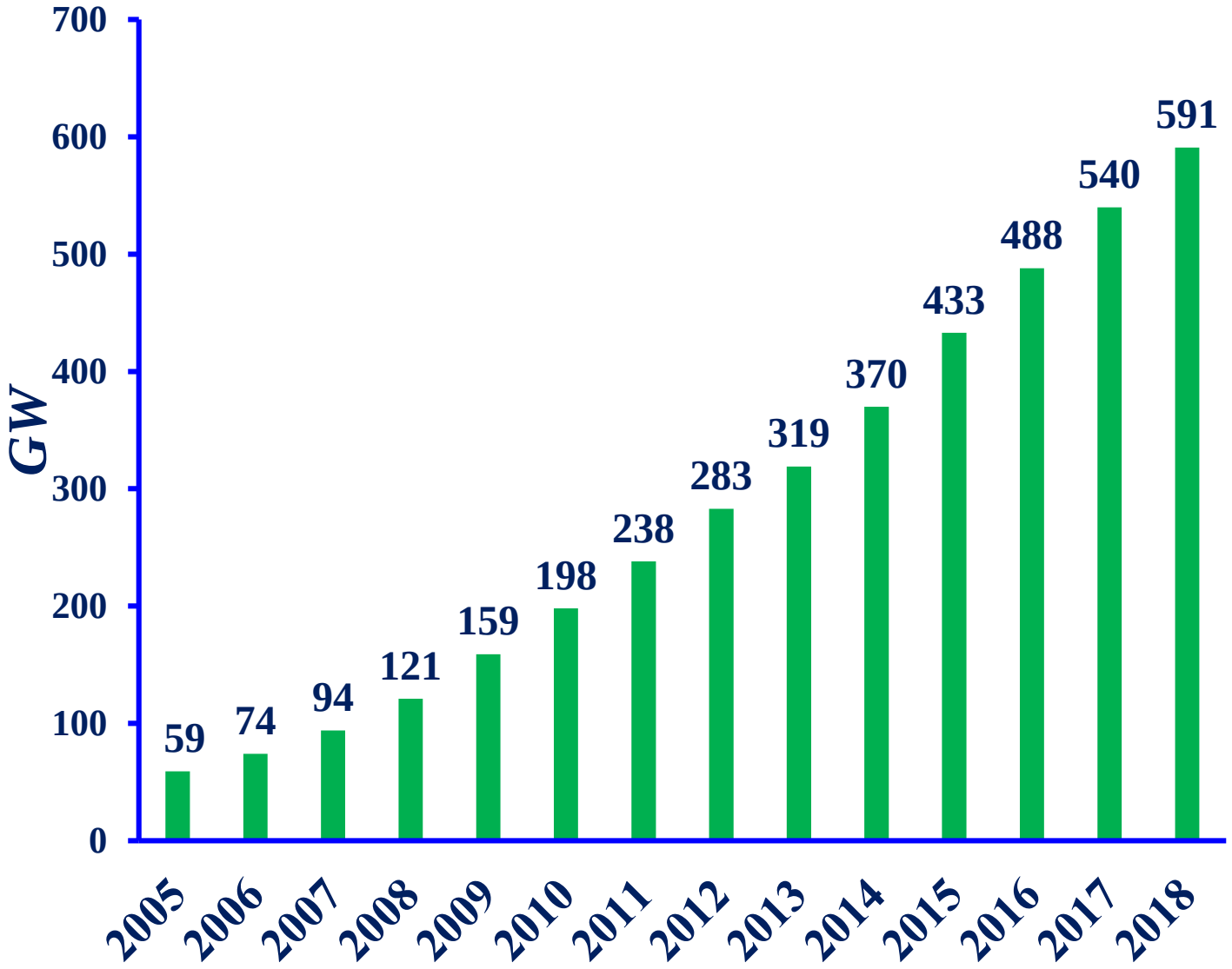
- Used electricity from his wind turbines to electrolyze water to make hydrogen for the gas lights at the local schoolhouse

Historical Development of Wind Power

- In the US - first wind-electric systems built in the late 1890's
- By 1930s and 1940s, hundreds of thousands were in use in rural areas not yet served by the grid
- Interest in wind power declined as the utility grid expanded and as reliable, inexpensive electricity could be purchased (thanks, largely, to Samuel Insull)
- Oil crisis in 1970s created a renewed interest in wind until US government stopped giving tax credits
- Renewed interest again since the 1990s

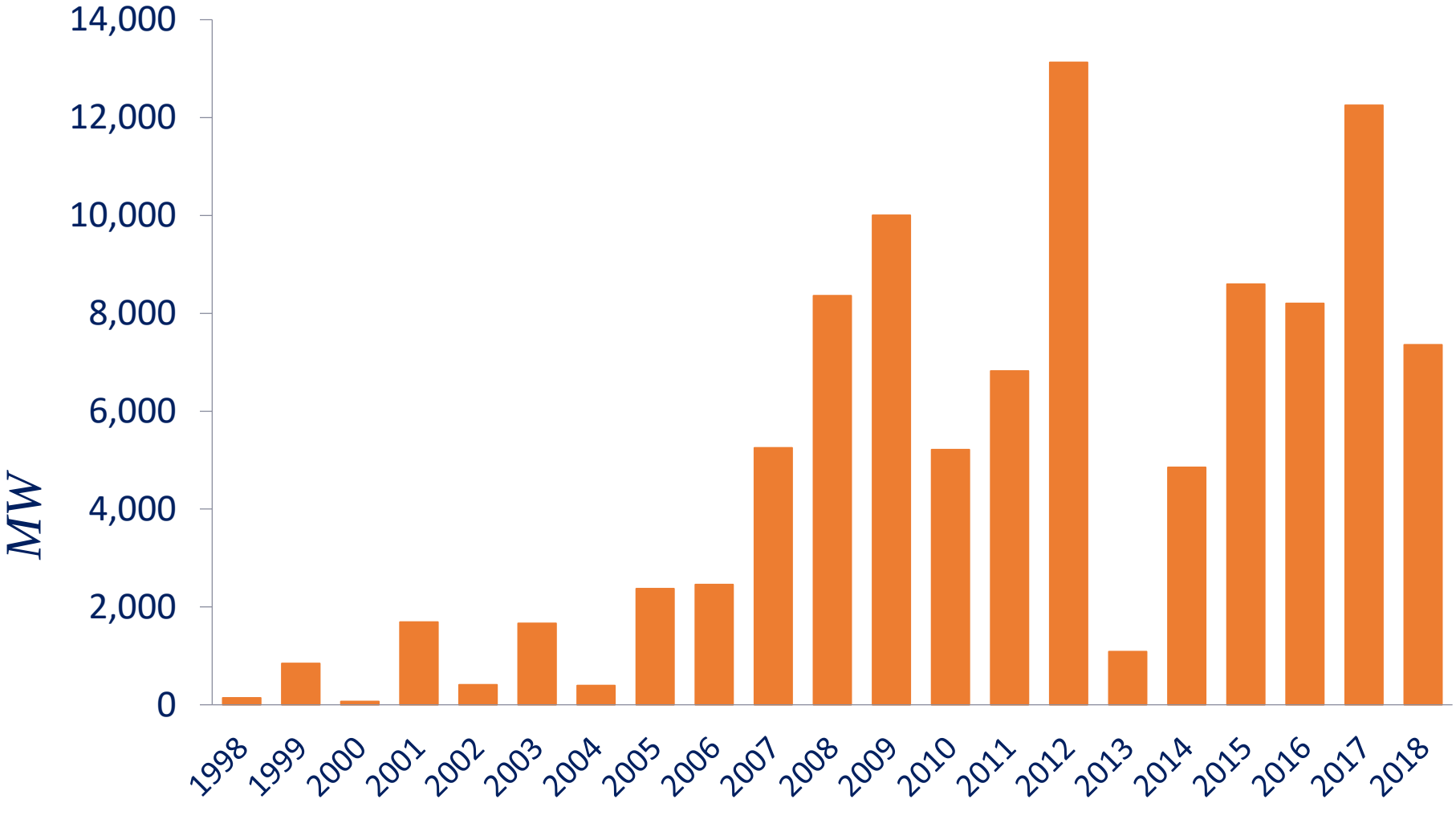


2005 – 2018 Global Wind Capacity



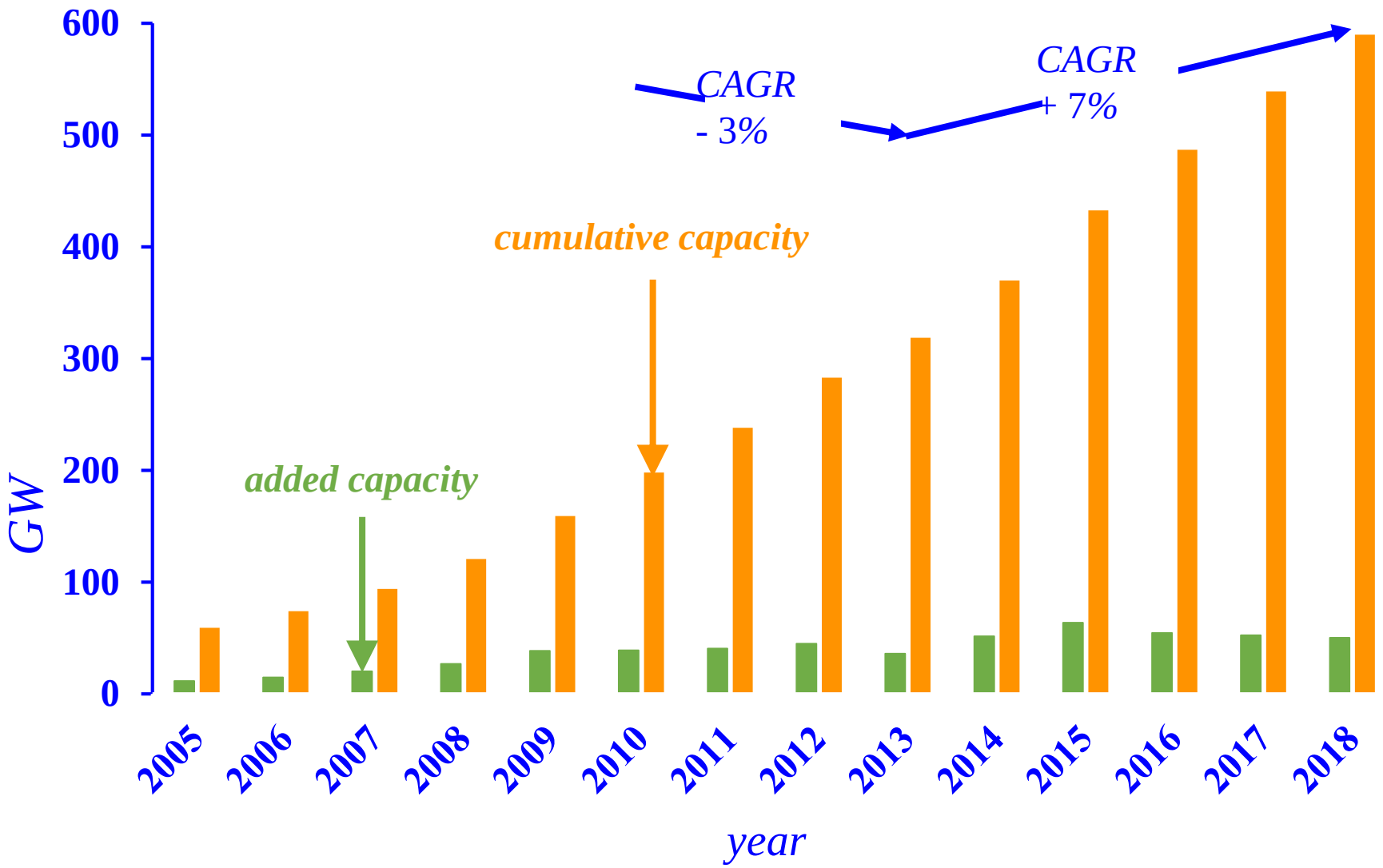
Source: 2018 Wind Technologies Market Report, US Department of Energy, p. 6; available on-line at https://www.energy.gov/eere/wind/downloads/2018-wind-technologies-market-report

1998–2018 Installed *US* Wind Capacity Additions



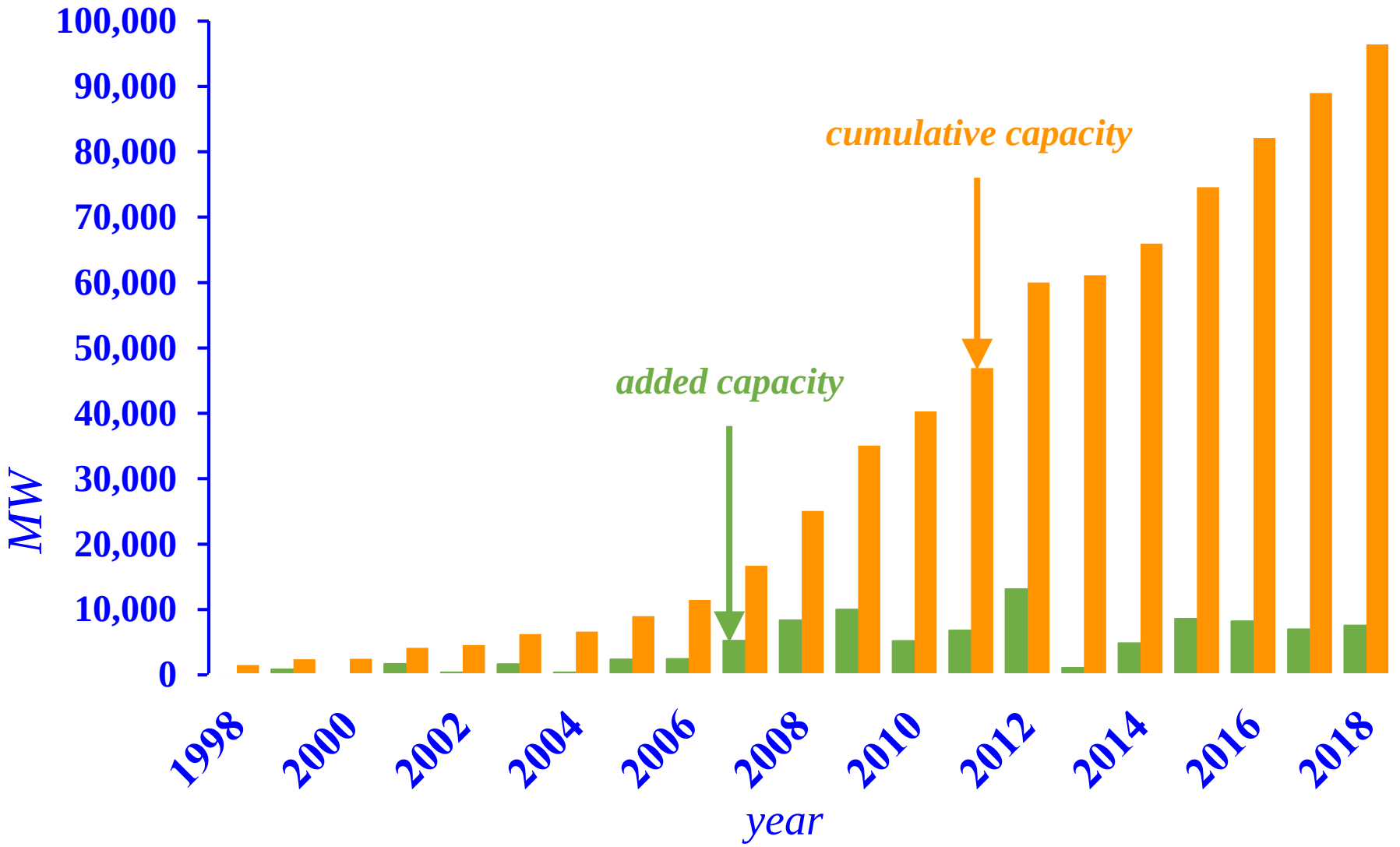
Source: 2018 *Wind Technologies Market Report, US Department of Energy, p. 6.*

2005 – 2018 Global Annual Added and Cumulative Wind Capacity



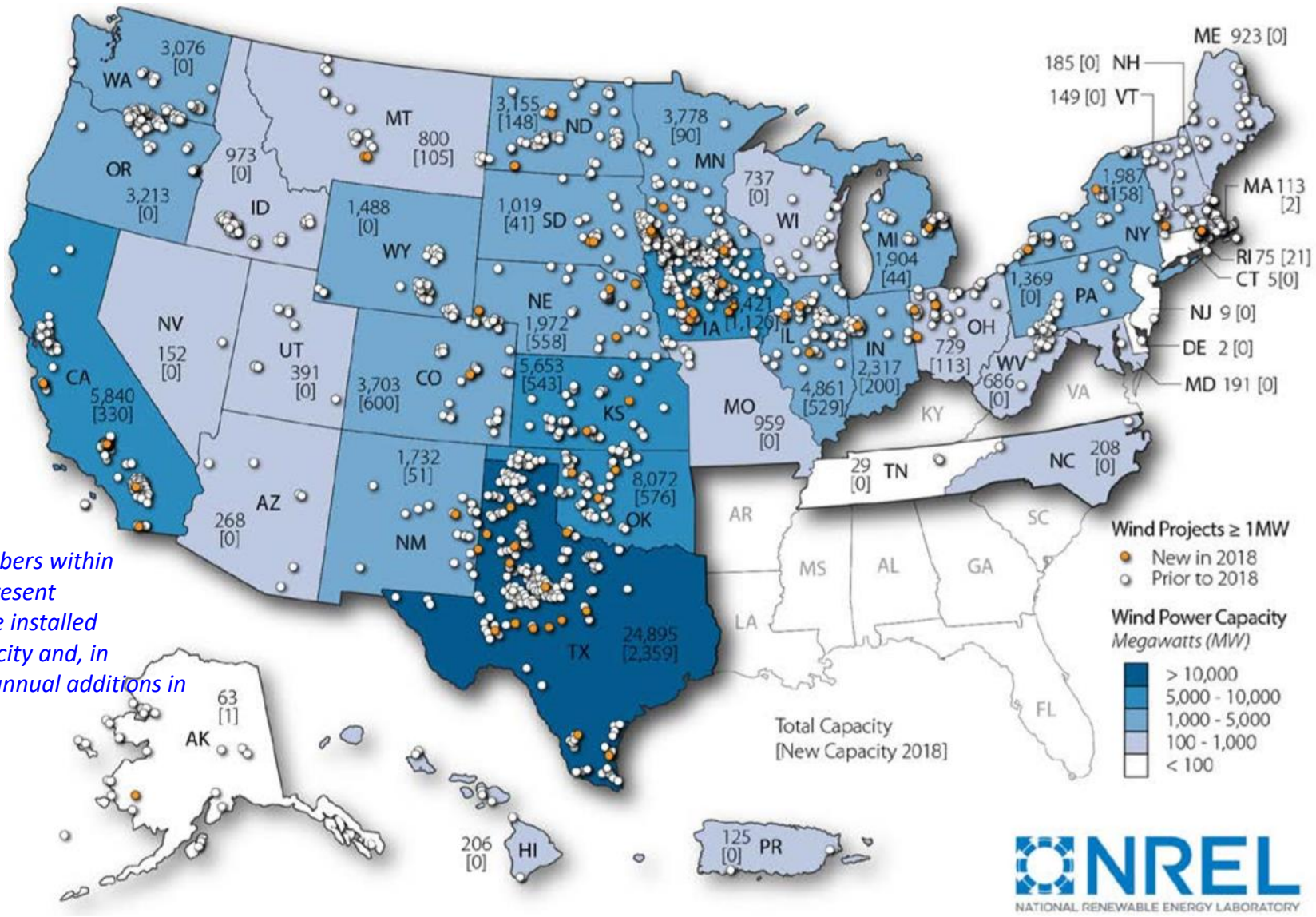
Source: 2018 Wind Technologies Market Report, US Department of Energy, p. 6.

1998 – 2018 *US* Annual Added and Cumulative Wind Capacity



Source: 2018 Wind Technologies Market Report, US Department of Energy, p. 6.

2018 *US* Wind Power Projects Status

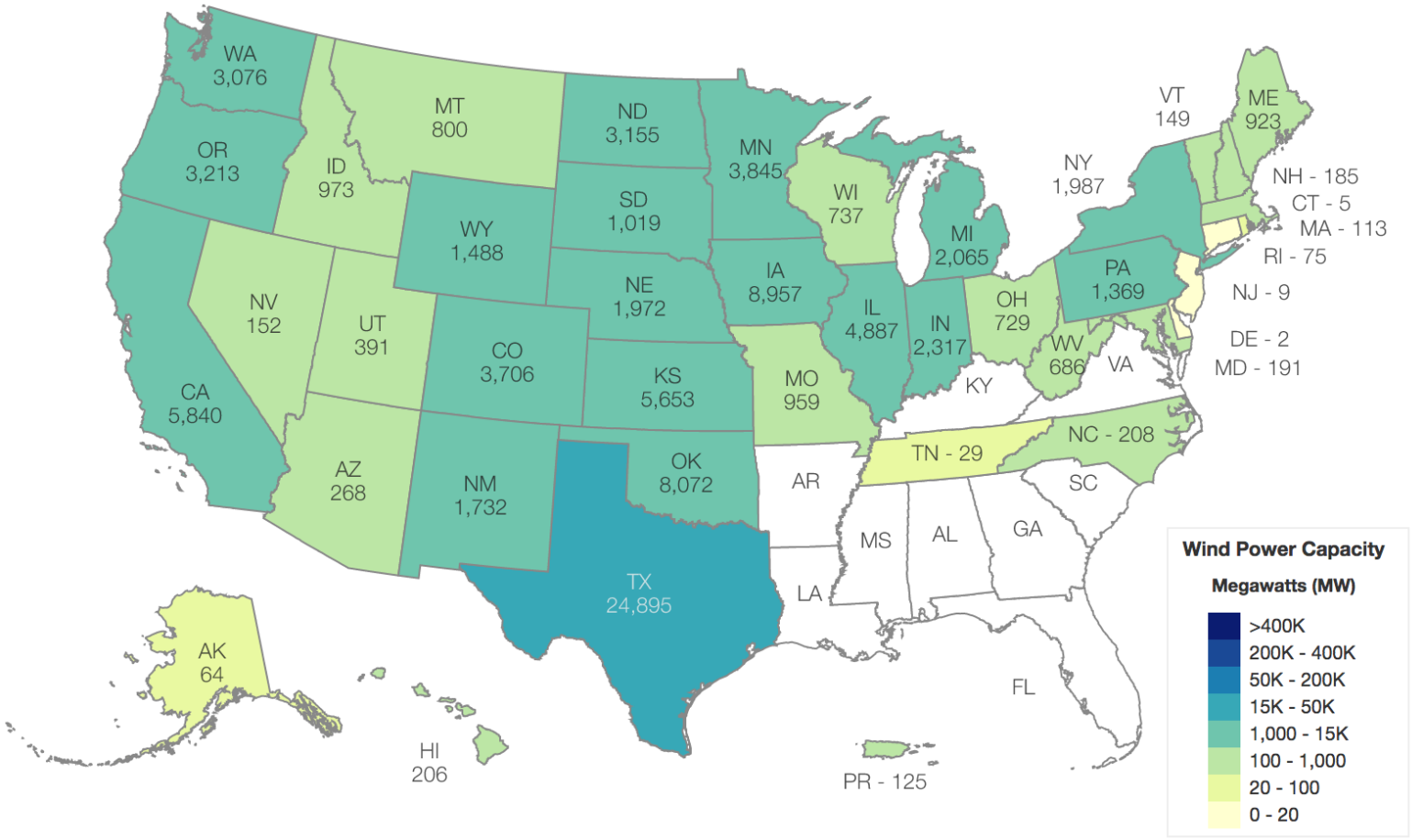


Note: numbers within states represent cumulative installed wind capacity and, in brackets, annual additions in 2017

Source: 2018 Wind Technologies Market Report, US Department of Energy, p. 7.

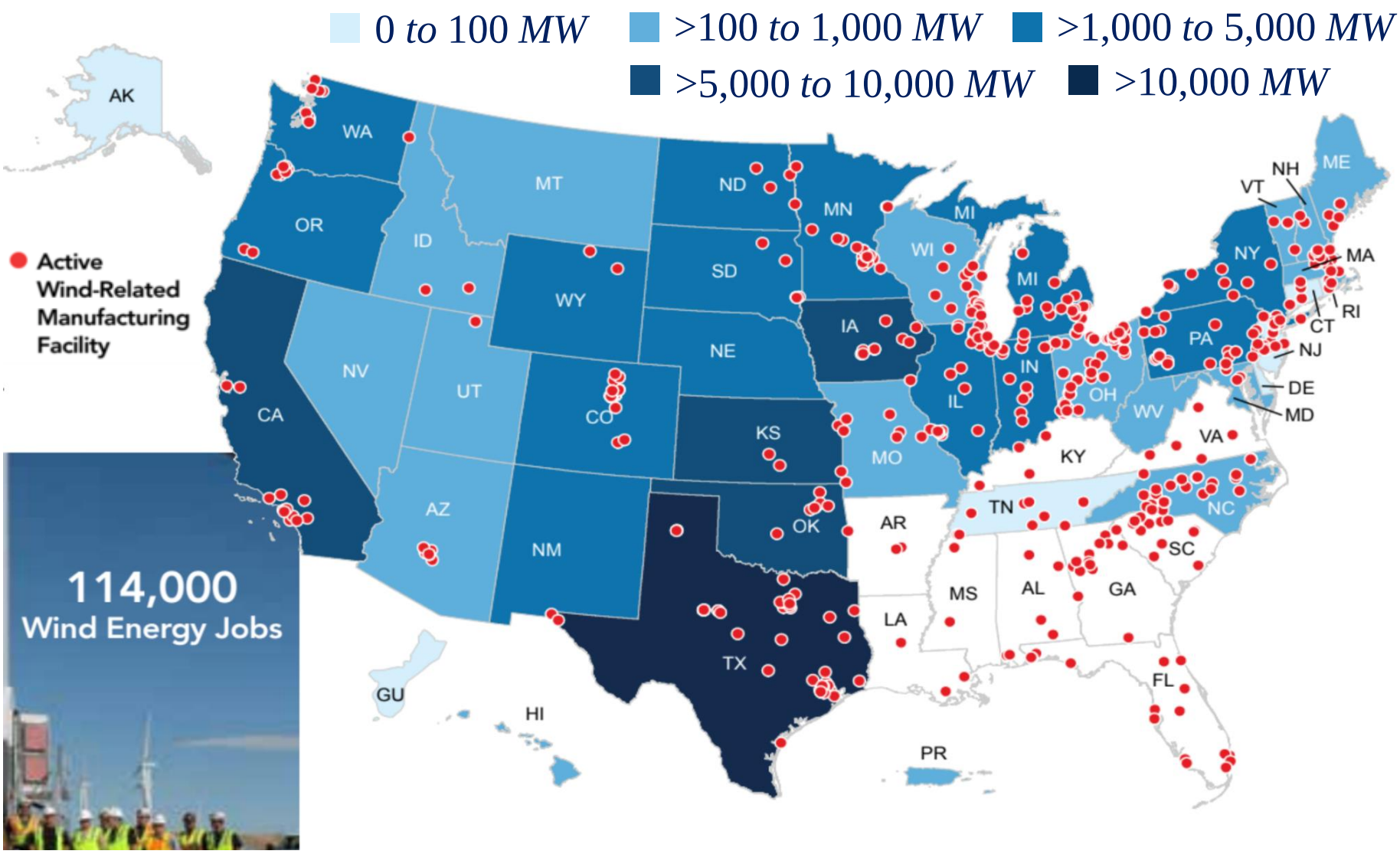
2019 *Q1* *US* Wind Capacity by State

total installed wind capacity: 97,227 *MW*



Source: *AWEA, available online at https://windexchange.energy.gov/maps-data/321*

US Wind Energy Industry Manufacturing Facilities



Source: AWEA 2018 Annual Market Report Executive Summary

2018 Wind Capacity Addition and Cumulative Wind Total

annual capacity in MW	
China	21, 855
United States	7, 588
Germany	3, 371
India	2, 191
Brazil	1, 939
United Kingdom	1, 901
France	1, 565
Mexico	929
Sweden	720
Canada	566
rest of the world	7, 493
total	50, 118

cumulative capacity in 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 the world	91, 466
total	589, 872

Source: 2018 *Wind Technologies Market Report, US Department of Energy, p. 6.*

Top 10 Countries - Installed Wind Capacity

- Then (2002) and now (2017)…

2002

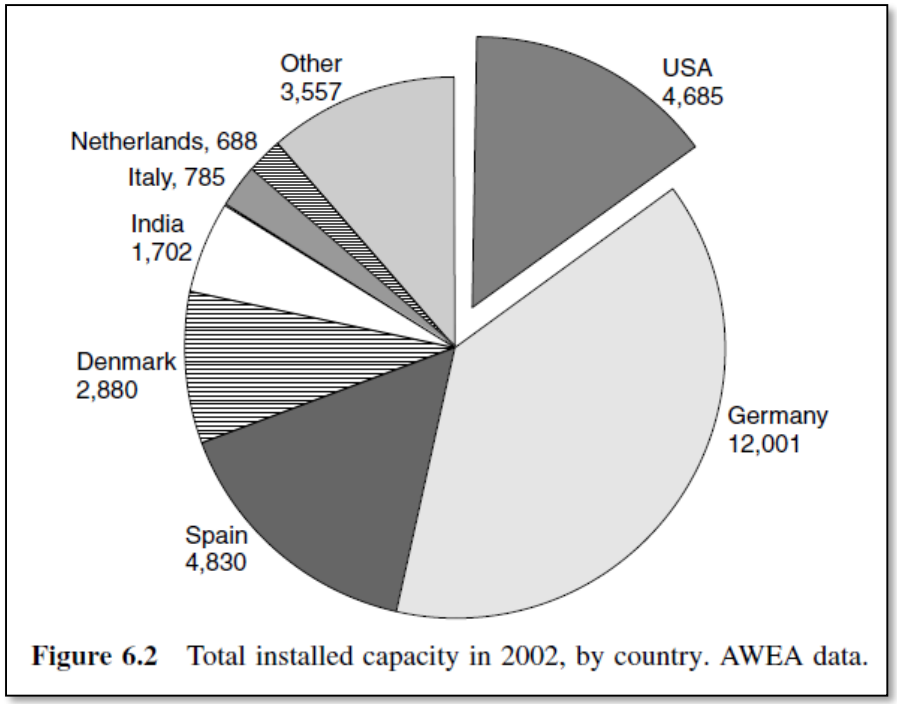
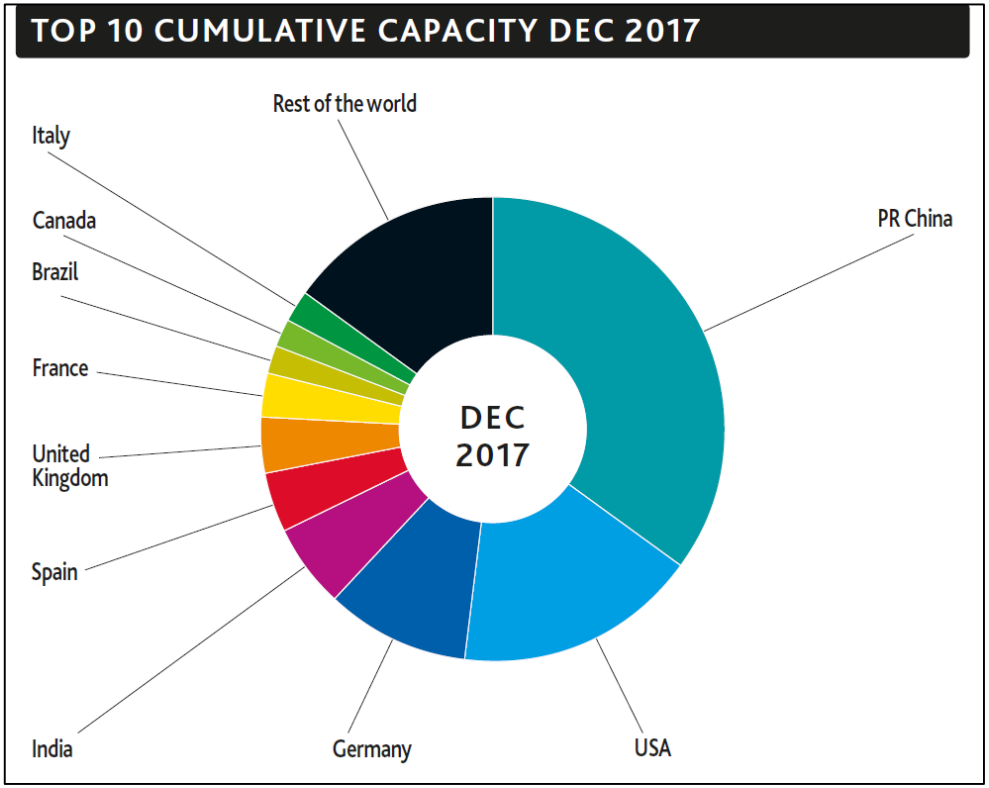
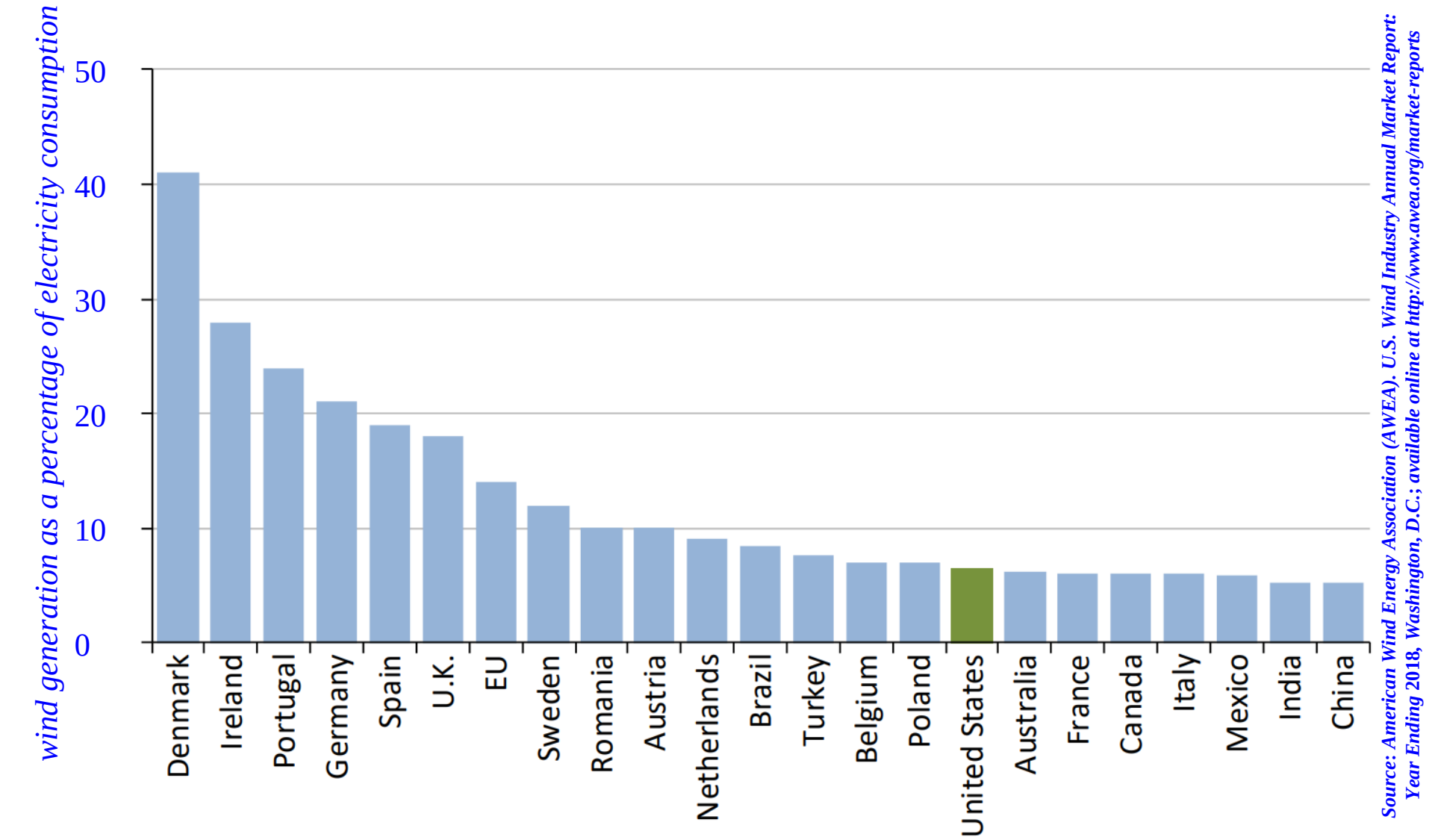


Figure 6.2 Total installed capacity in 2002, by country. AWEA data.

2017

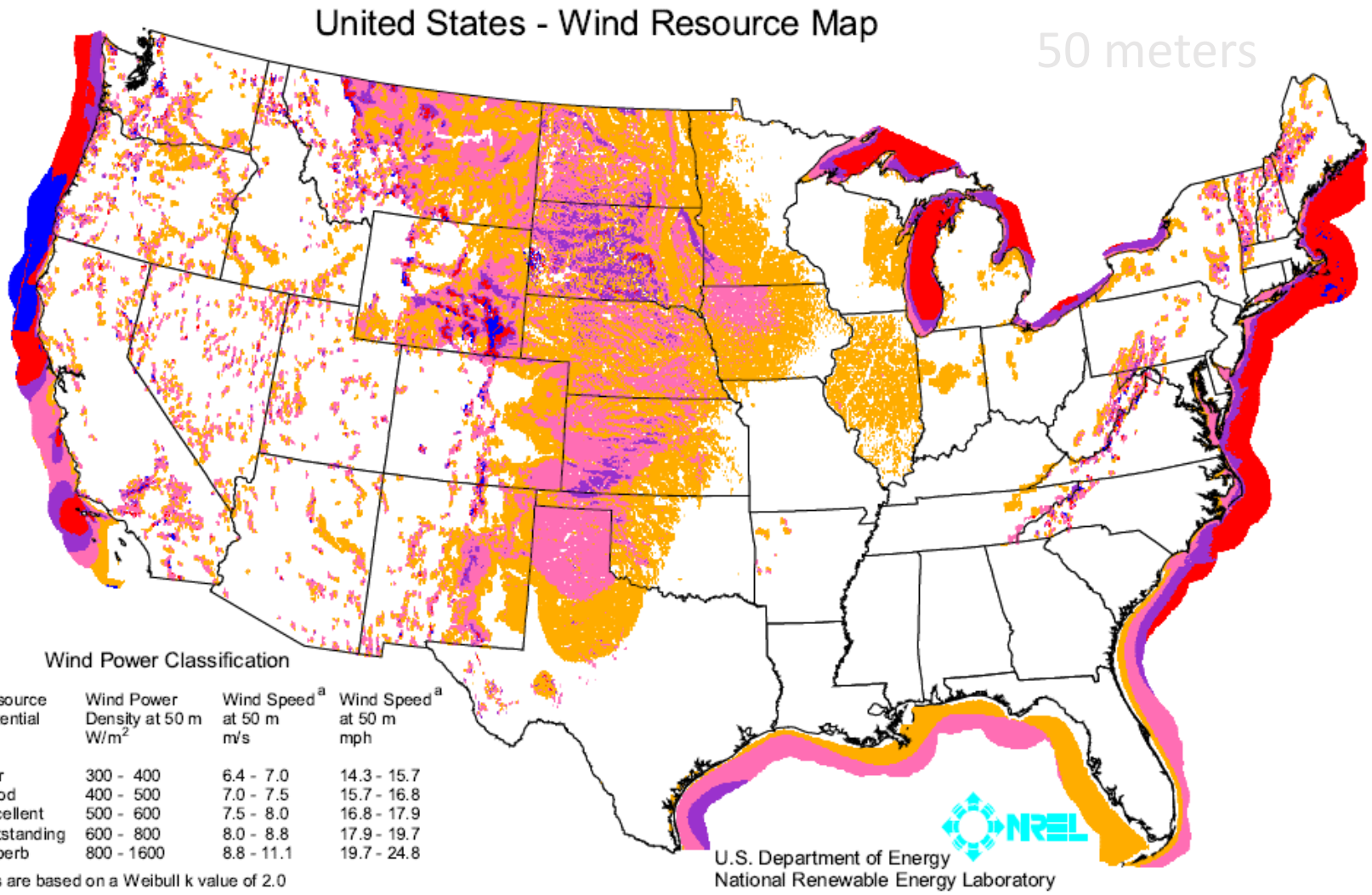


Leading Nations in Wind Energy Consumption in 2018



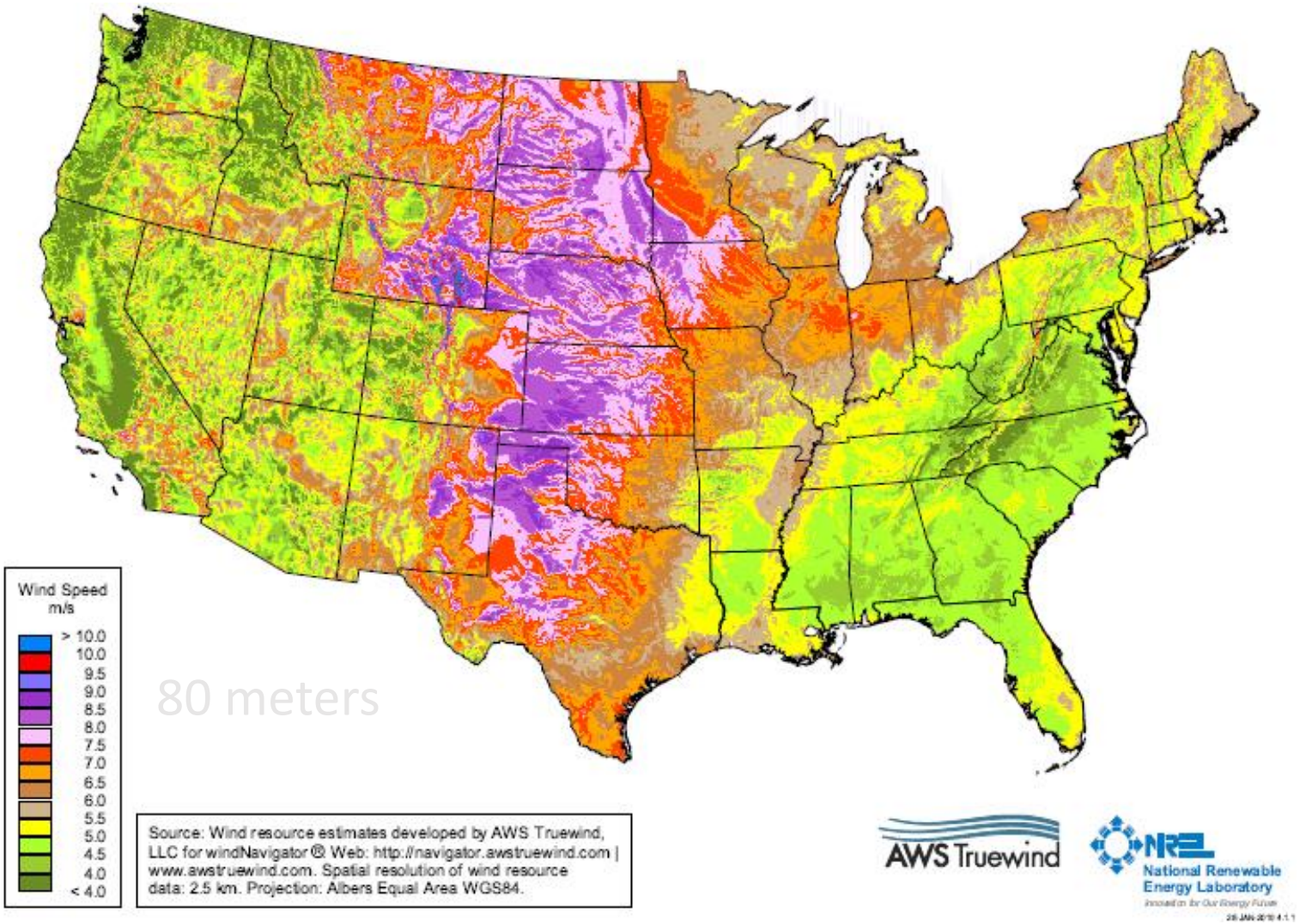
Source: American Wind Energy Association (AWEA). U.S. Wind Industry Annual Market Report: Year Ending 2018, Washington, D.C.; available online at http://www.awea.org/market-reports

US Wind Resources



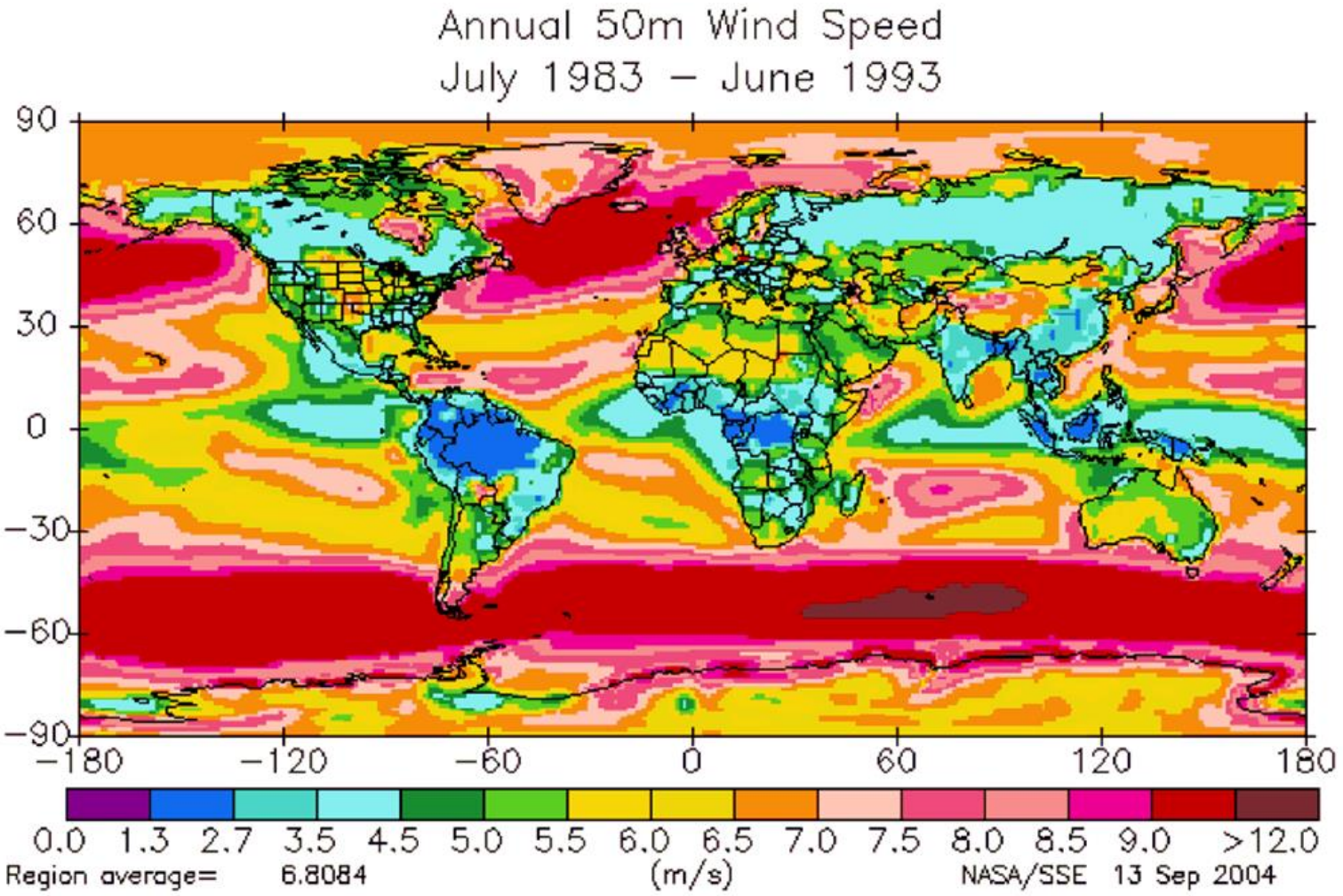
http://www.windpoweringamerica.gov/pdfs/wind_maps/us_windmap.pdf

US Wind Resources



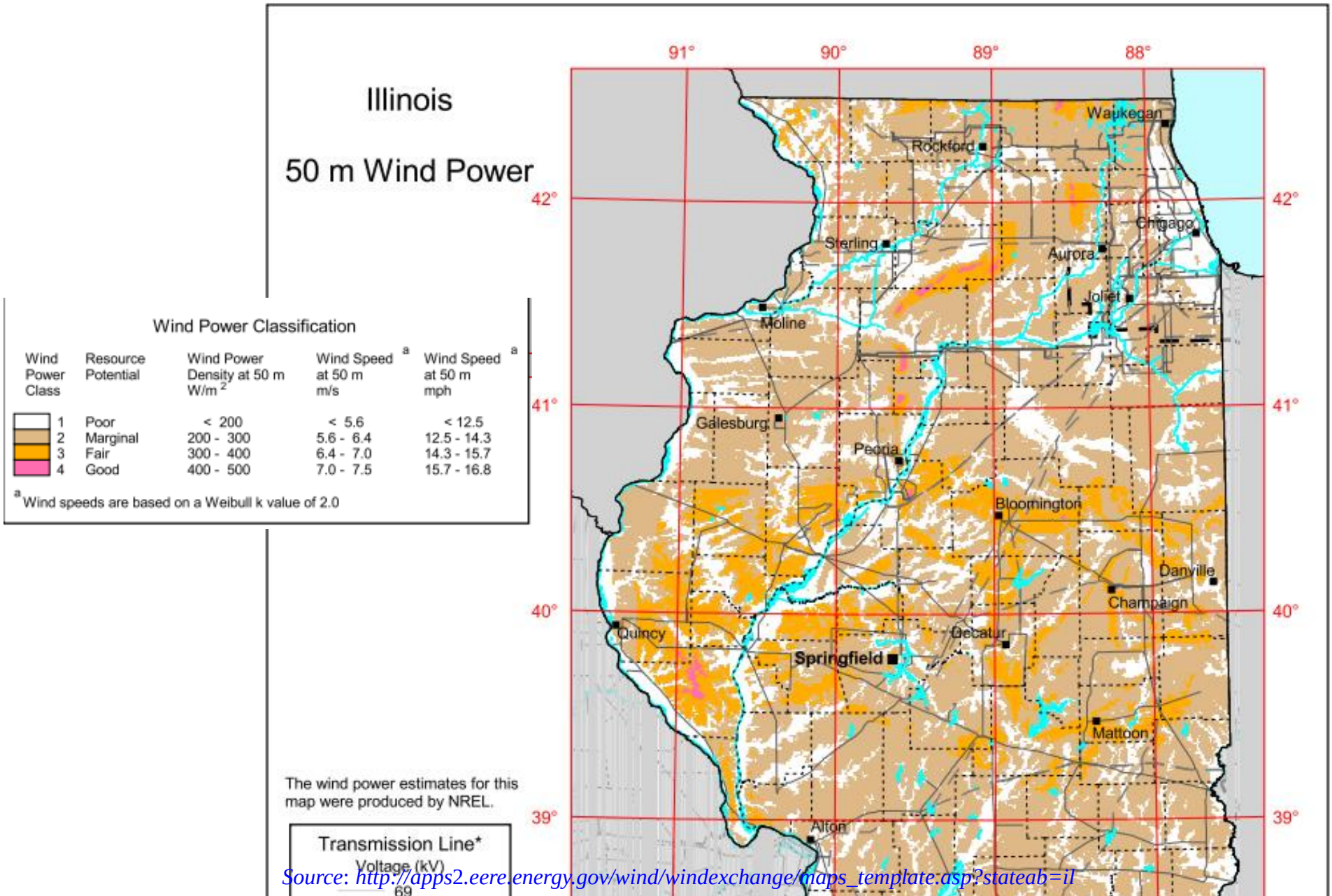
http://www.windpoweringamerica.gov/pdfs/wind_maps/us_windmap_80meters.pdf

Worldwide Wind Resource Map



Source: www.ceoe.udel.edu/WindPower/ResourceMap/index-world.html

Wind Map for *Illinois*



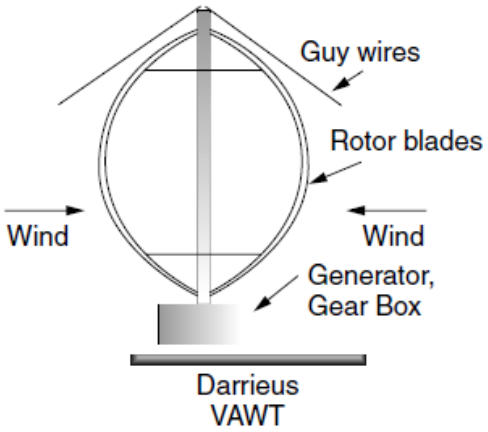
Source: http://apps2.eere.energy.gov/wind/windexchange/maps_template.asp?stateab=il

Types of Wind Turbines

- "Windmill"- used to grind grain into flour
- Many different names - "wind-driven generator", "wind generator", "wind turbine", "wind-turbine generator (WTG)", "wind energy conversion system (WECS)"
- One way to characterize wind turbines is in terms of the axis around which the turbine blades rotate
  - Horizontal axis wind turbines (HAWT)
  - Vertical axis wind turbines (VAWT)
- Groups of wind turbines are located in what is called either a "wind farm" or a "wind park"

Vertical Axis Wind Turbines

- **Darrieus rotor** - the only vertical axis machine with any commercial success
  - Wind hitting the vertical blades, called airfoils, generates lift to create rotation
  - No yaw (rotation about vertical axis) control needed to keep them facing into the wind
  - Heavy machinery in the nacelle is located on the ground
  - Blades are closer to ground where wind speeds are lower



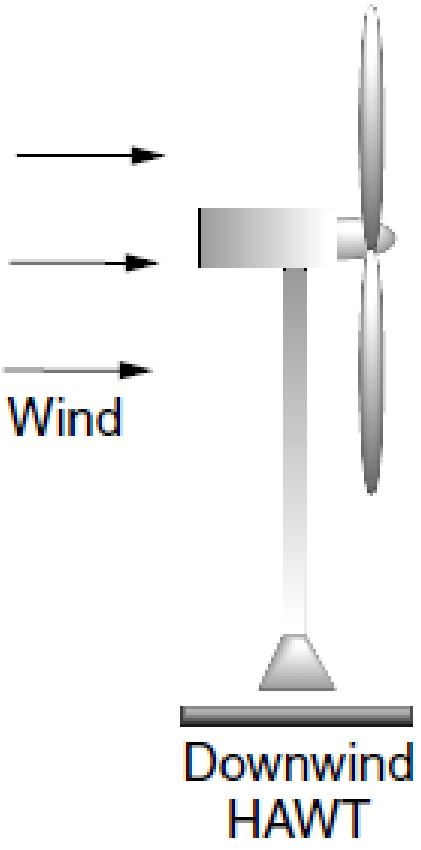
More Vertical Axis Wind Turbines

4.5 kW/turbine

Image credit: https://www.greenoptimistic.com/chicago-vertical-axis-wind-turbines-20110126/

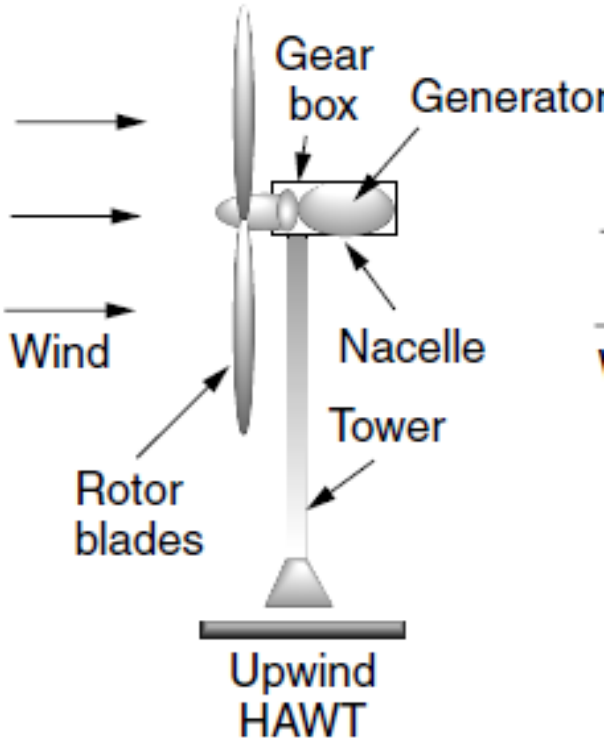
Horizontal Axis Wind Turbines (HAWTs)

- **"Downwind" HAWT** – a turbine with the blades behind (downwind from) the tower
  - No yaw control needed- they naturally orient themselves in line with the wind
  - *Shadowing effect* – when a blade swings behind the tower, the wind it encounters is briefly reduced and the blade flexes

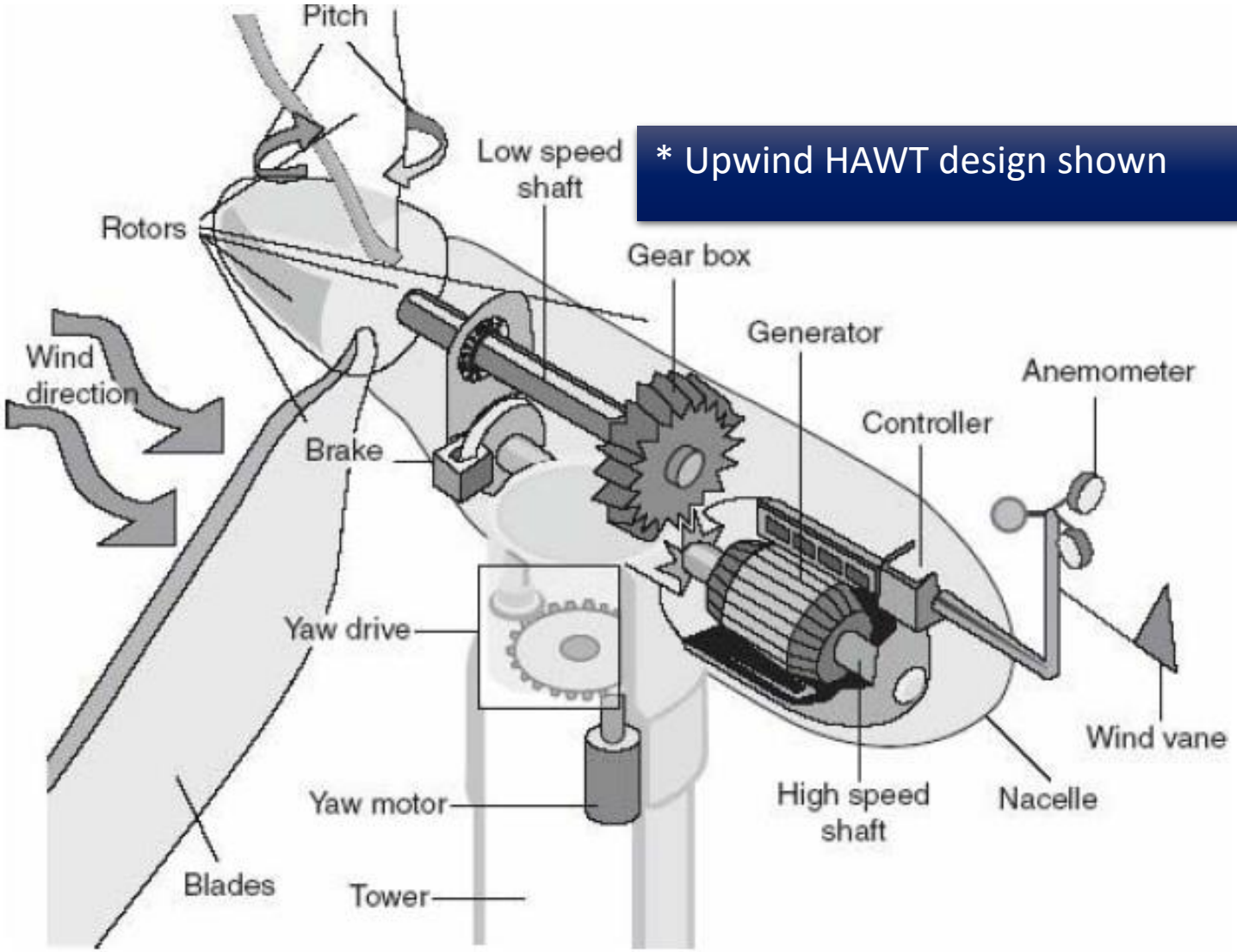


Horizontal Axis Wind Turbines (HAWTs)

- **"Upwind" HAWT** – blades are in front of (upwind of) the tower
  - Almost all modern wind turbines are this type
  - Blades are "upwind" of the tower
  - Require somewhat complex yaw control to keep them facing into the wind
  - Operate more smoothly and deliver more power (no shadowing)



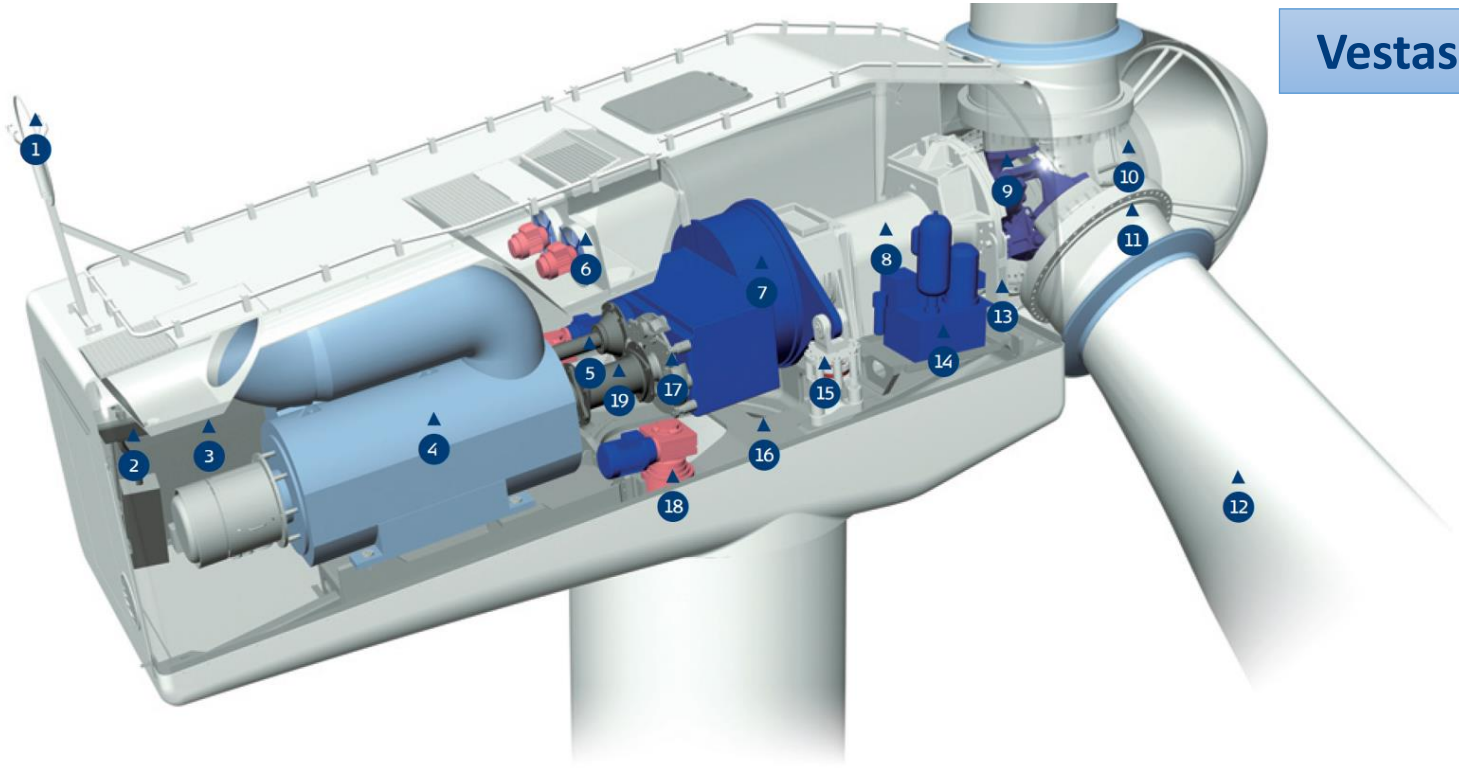
Wind Energy Conversion System (WECS) Components



* Upwind HAWT design shown

Wind Energy Conversion System (WECS) Components

Vestas V52-850 kW



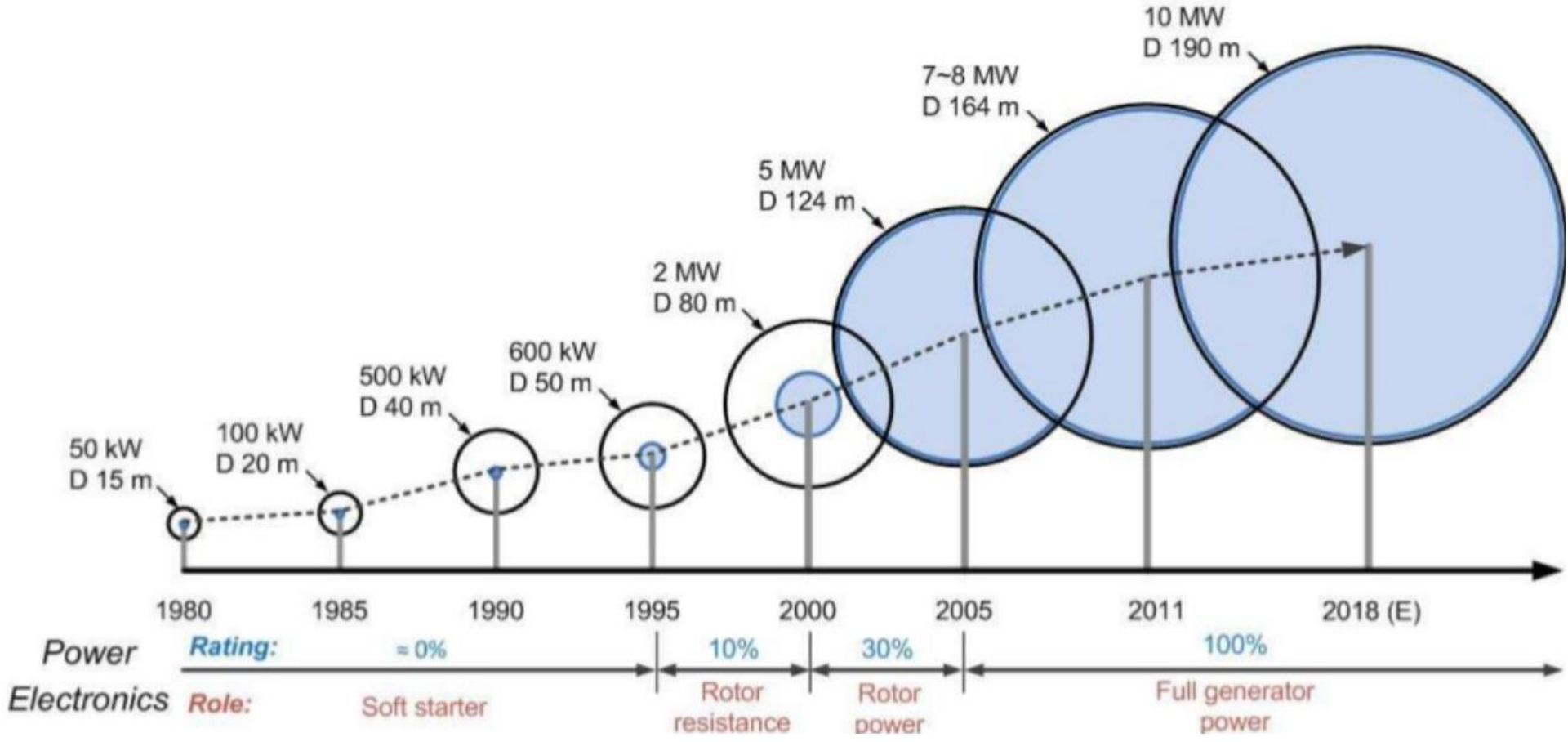
1. Ultrasonic wind sensor
2. Service crane
3. VMP-Top controller with converter
4. OptiSpeed® Generator
5. Pitch cylinder
6. Oil and water coolers
7. Gearbox
8. Main shaft
9. Pitch system
10. Blade hub
11. Blade bearing
12. Blade
13. Rotor lock system
14. Hydraulic unit
15. Torque arm
16. Machine foundation
17. Mechanical disc brake
18. Yaw gear
19. Composite disc coupling

Number of Rotating Blades

- "Old-school" windmills have multiple blades
  - need to provide high starting torque to overcome weight of the pumping rod
  - must be able to operate at low wind speeds to provide nearly continuous water pumping
  - a larger area of the rotor faces the wind
- Turbines with many blades operate at much lower rotational speeds - as the speed increases, the turbulence caused by one blade impacts the other blades
- **Almost all modern wind turbines have three blades now**

The Trend to Larger Wind Turbines

Source: *https://www.slideshare.net/ManasaSushmitha/power-electronics-in-wind-turbine-systems?next_slideshow=1*

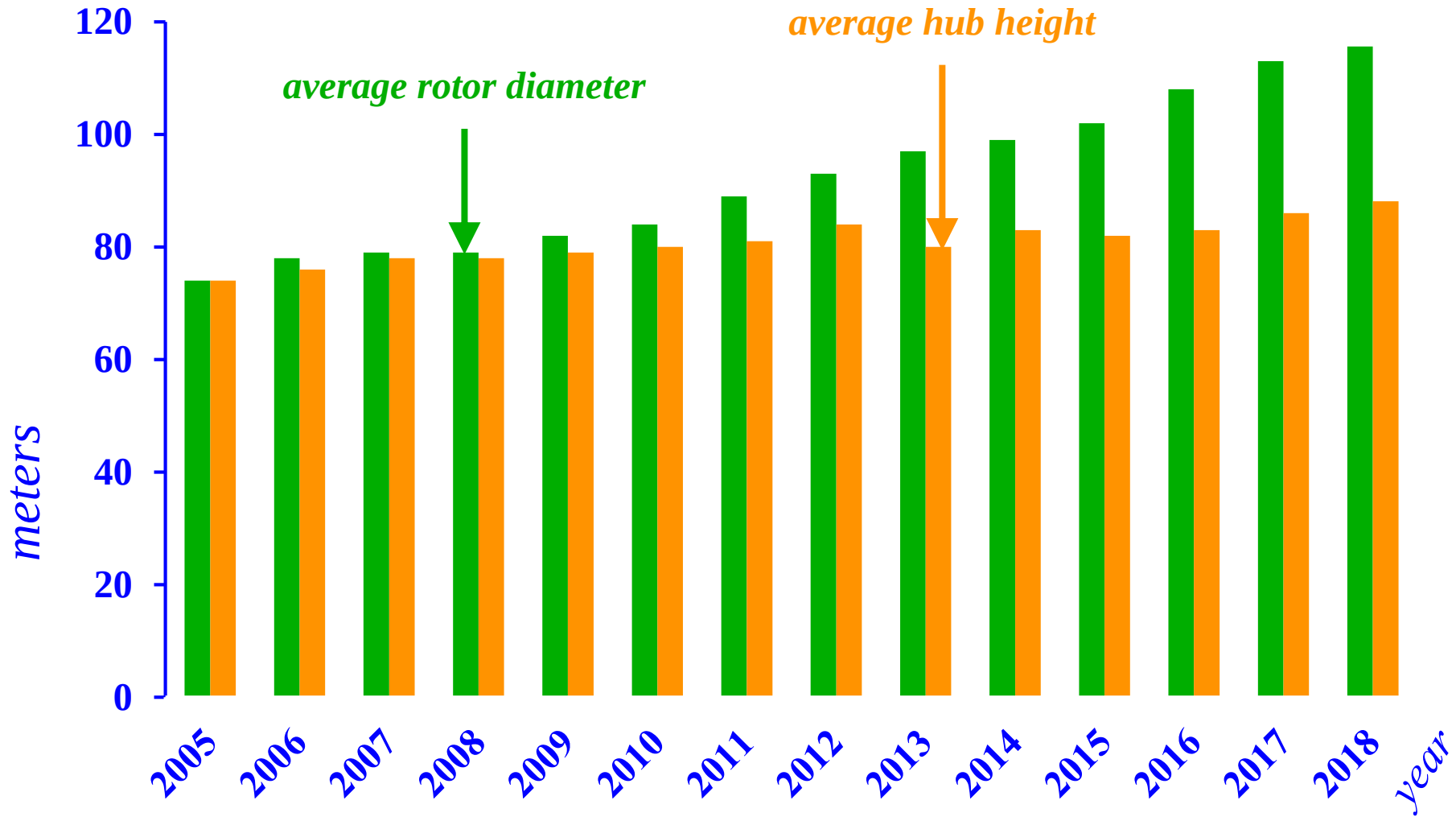


Turbine Blade Transportation

***Source*: *http://energy.gov/sites/prod/files/2015/05/f22/QER%20Full%20Report_0.pdf*; *pg* 209; *Issued April* 2015**

As wind turbines continue to grow in size, project developers will face greater challenges in transporting components. This 80-meter blade is being transported to a 7-MW test turbine in Scotland.

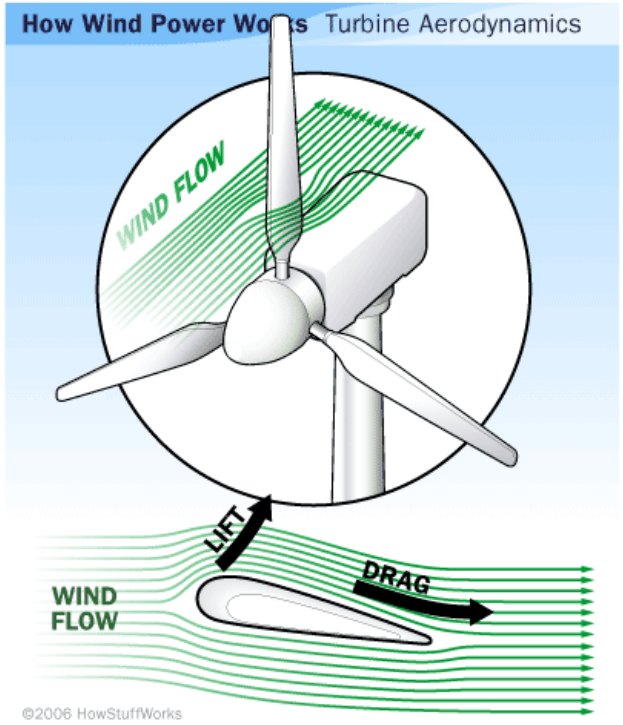
2005 – 2018 Average Wind Turbine Size Evolution



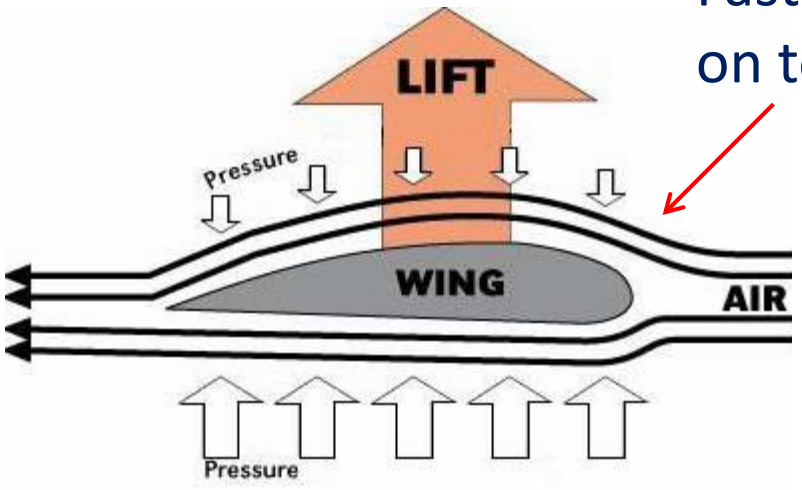
Source: 2018 Wind Technologies Market Report, US Department of Energy, p. 24.

Some Aerodynamics

- We need to control the blades to vary their speed
- Blades are like airplane wings (they are airfoils)
- Airfoils use Bernoulli's Principle to create lift



http://science.howstuffworks.com/environmental/green-science/wind-power3.htm



Faster air on top

www.energyeducation.tx.gov

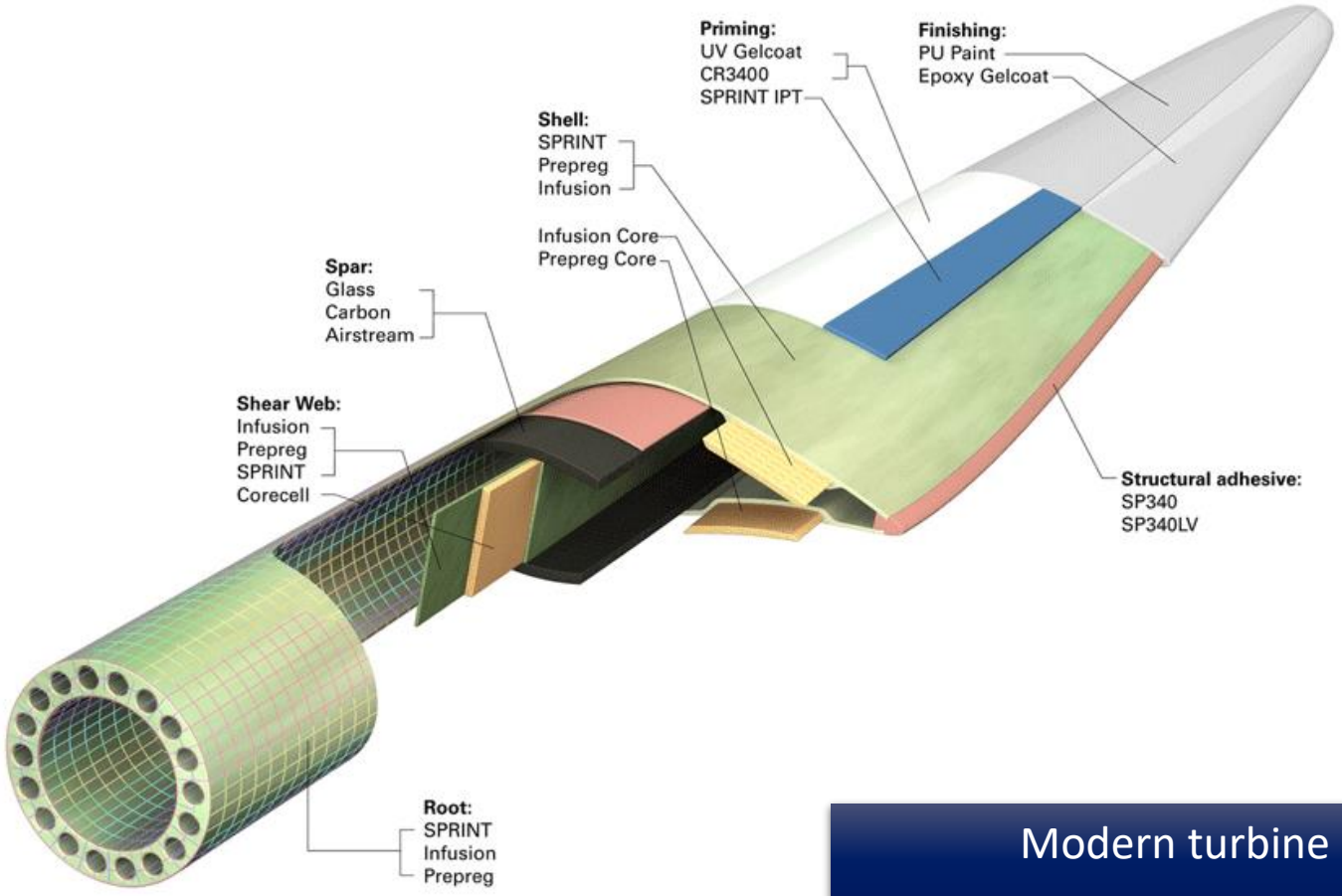
Some Aerodynamics

- Wind turbine blades are carefully engineered devices

cr4.globalspec.com

softsolder.com

Some Aerodynamics



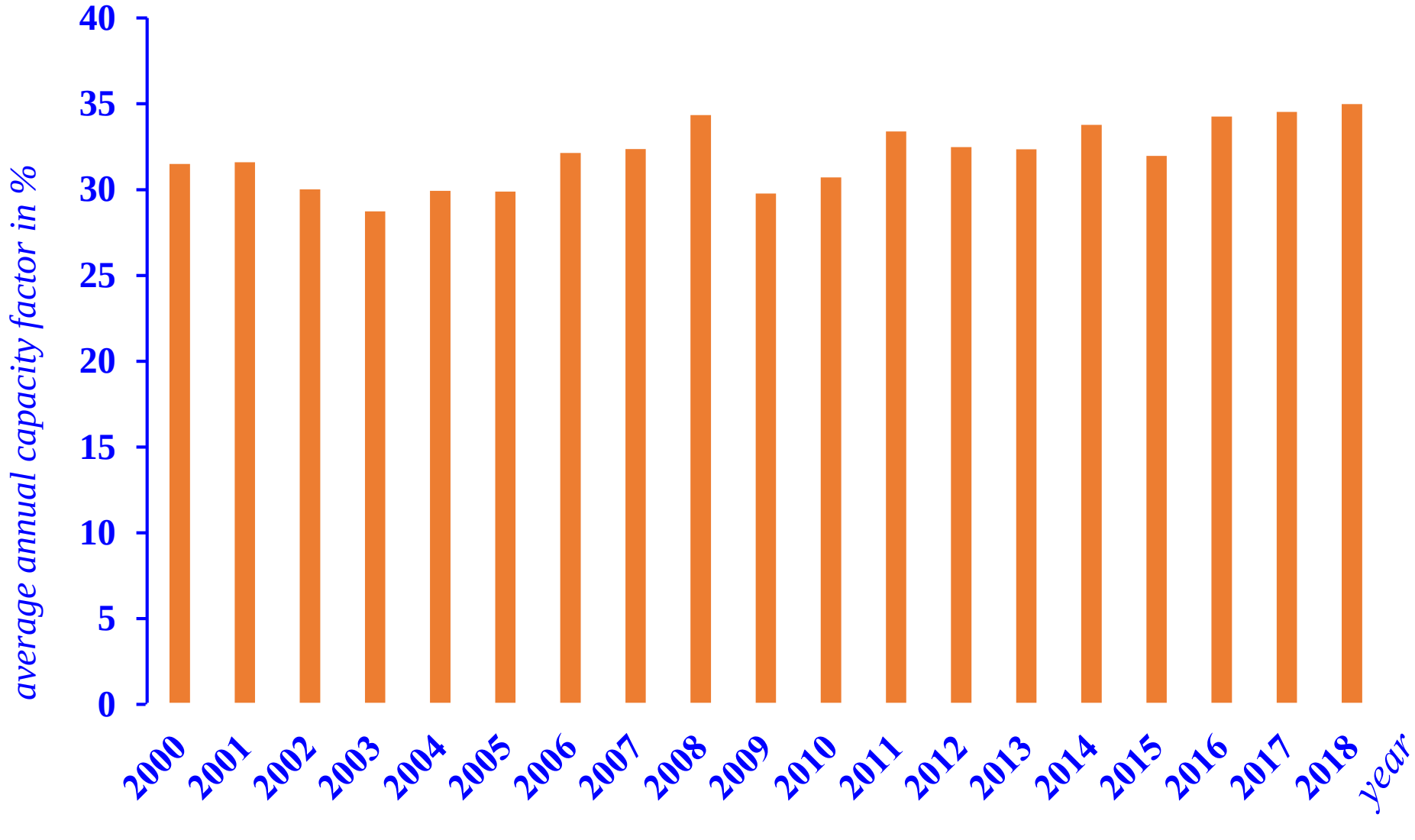
Modern turbine blade

Long Term

"Wind Turbine Blades Can't Be Recycled, So They're Piling Up in Landfills"

https://www.bloomberg.com/news/features/2020-02-05/wind-turbine-blades-can-t-be-recycled-so-they-re-piling-up-in-landfills

Average Wind Capacity Factors 2000 – 2018



Source: 2018 Wind Technologies Market Report, US Department of Energy, p. 39.