ECE 333 – GREEN ELECTRIC ENERGY

4. Wind as an Energy Resource

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TRANSPORTATION OF A LARGE WIND TURBINE BLADE

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.

WIND RESOURCES

- Wind is becoming a significant generation source in the *US*, *Europe* and *China*
- The over 743 *GW* of wind capacity installed around the world contributes to lowered CO_2 emissions
- The technological advances over the past two decades have dramatically reduced the costs of wind generated electricity
- In these wind lectures, we explore the key characteristics/physical limitations of wind generation, the economics, effective utilization and status

HARNESSING WIND POWER

- Many early wind turbines were used to grind grain into flour and thus the term "windmill"
- We do *not* use the term windmill for machines that pump water or generate electricity
- There are many terms used today for devices that convert wind into electricity, including *wind–driven generator, wind generator, wind turbine, wind–turbine generator* (*WTG*), *wind energy conversion system* (*WECS*)
- We, typically, use the term *wind turbine* in ECE 333

AN OLD WINDMILL

SMOKY HILL WIND FARM NEIGHBORS A WINDMILL NEAR *ELLSWORTH, KS*

WIND TURBINE CLASSIFICATION

- One way we categorize wind turbines is in terms of the axis around which the turbine blades rotate
  - large wind turbines are, virtually, all *horizontal axis wind turbines* (*HAWTs*)
  - some smaller turbines have blades that rotate around the vertical axis and are called *vertical axis wind turbines* (*VAWTs*)
- Groups of wind turbines are located in what we call either a *wind farm* or a *wind park*

WIND TURBINE CLASSIFICATION

- The *HAWT*s are either
  - upwind machines that directly face the wind
  - or downwind machines that have their rotors behind the wind
- A key design decision is the number of blades – either 2 or 3; virtually, all large wind turbines have 3 blades

VAWT

- **The only vertical axis machine with some commercial success is the *Darrieus rotor***
- **The wind hits the rotor blades – the so–called aerofoils – and obtains lift to put the blades in a spin**

Source: http://reuk.co.uk/Darrieus-Wind-Turbines.htm

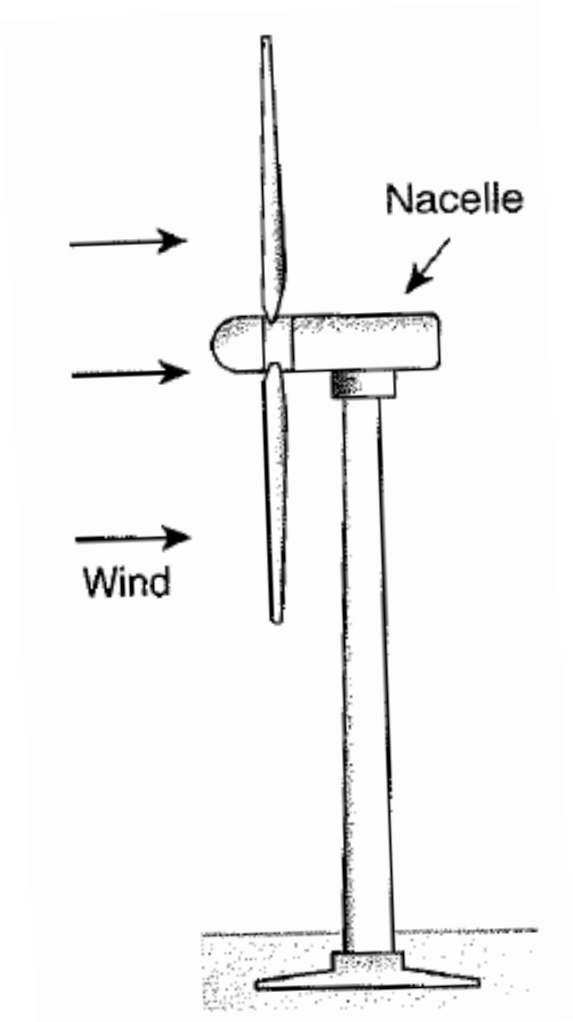
- **Blades are, typically, closer to ground, where the wind speeds are lower than on top of high towers**

VAWT

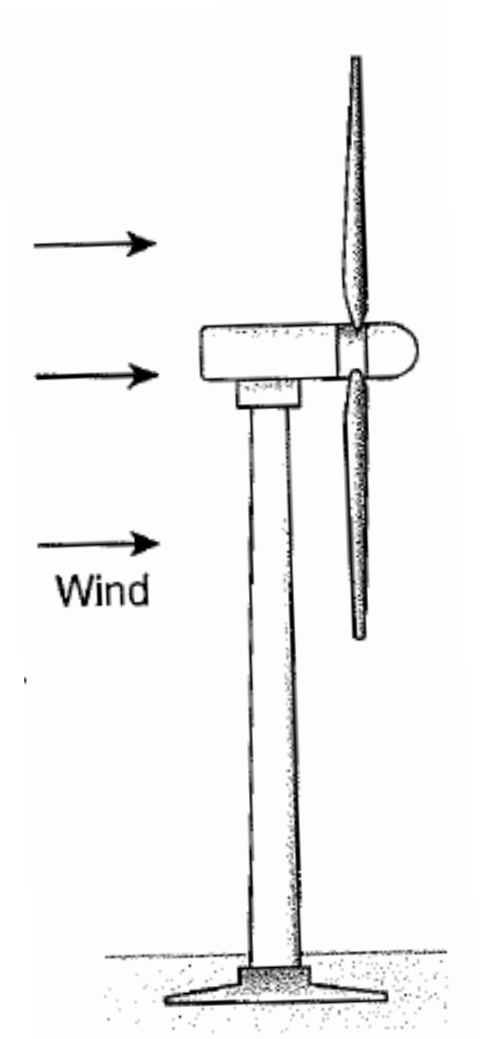
- A *VAWT* requires no yaw – rotation about vertical axis – control to keep the blades facing into the wind
- The nacelle contains the heavy generator and the gearbox and is located down on the ground and so is easily accessible for service/maintenance
- The lightened tower need not be as strong as those used for *HAWT*s; in some land installations, guy wires may be used

HAWT

upwind



downwind



UPWIND *HAWT*

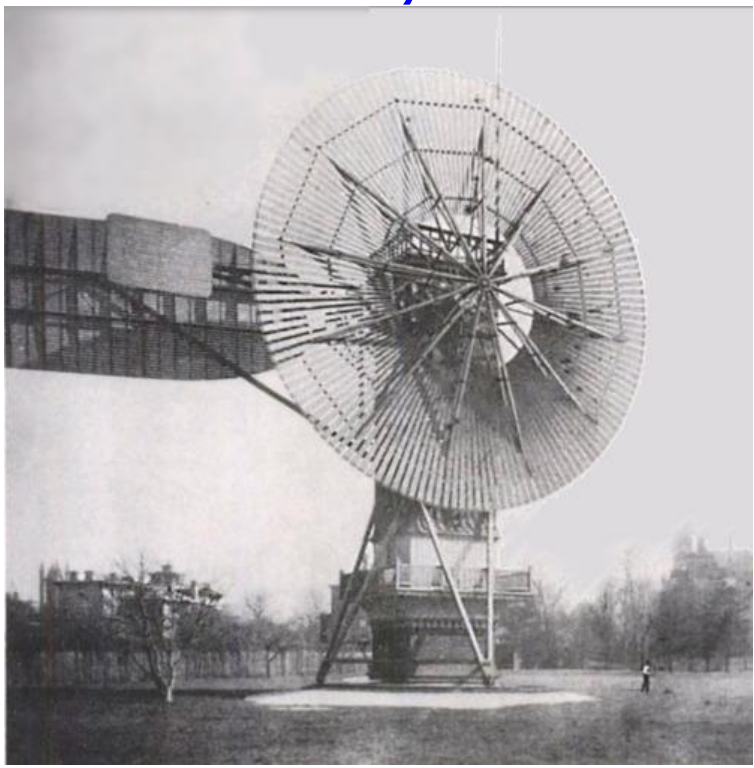
- Most modern wind turbines are of the upwind *HAWT* type
- An upwind *HAWT* requires a rather complex yaw control mechanism to keep the blades oriented in a direction that they keep facing into the wind
- Upwind *HAWT*s, typically, operate more smoothly and generate more power than downwind turbines

DOWNWIND *HAWT*

- A downwind *HAWT* requires no yaw control to regulate the left–right motion as it naturally orients itself to be *in line with the wind direction*
- A downwind *HAWT* suffers from the shadowing effects of the tower: when a blade swings behind the tower, the wind it encounters is reduced over a brief period and the blade flexes; such blade flexing increases blade noise, reduces power output and may, eventually, lead to blade failure

WIND POWER DEVELOPMENT: BRIEF HISTORY

- The world's first automatically operated wind turbine for electricity production was developed in 1888 by Charles F. Brush, in Cleveland, OH
- The 12–kW turbine electricity was used to charge the batteries in the cellar of the owner's mansion
- Poul la Cour's inventions laid the foundation of wind turbine technology and wind power plants in Denmark



Source: http://www.eng.src-vertical.com/files/images/firstwindmill.jpg

WIND POWER DEVELOPMENT: BRIEF HISTORY

- La Cour used the electri–city generated by his wind turbines to electrolyze water to produce hydro–gen for the gas lights in the local schoolhouse

Source: http://eye-ball.info/blog/wp-content/uploads/2012/07/LaCourWindTurbinesLARGE.jpeg

- In the *US*, the first wind–electric systems were built in the late 1890's

WIND POWER DEVELOPMENT: BRIEF HISTORY

- By the 1930's and 1940's, hundreds of thousands of small–capacity, wind–electric systems were in use in rural areas not yet served by utilities
- As the transmission grid expanded, interest in wind power waned, as inexpensive electricity became widely available
- The oil shocks of the early 1970's created a new interest in wind power and the first large *wind farm* projects were built in California

WIND FARMS

WIND POWER DEVELOPMENT: BRIEF HISTORY

- The *US* government termination of tax credits put a stop for nearly a decade to the installation of new wind developments
- The renewed interest started in the mid 1990's
- Various wind turbine technology development projects were undertaken in Denmark, Spain and Germany that led the continual reductions in the cost of wind–produced electricity
- China has become the leading nation in wind electricity installations

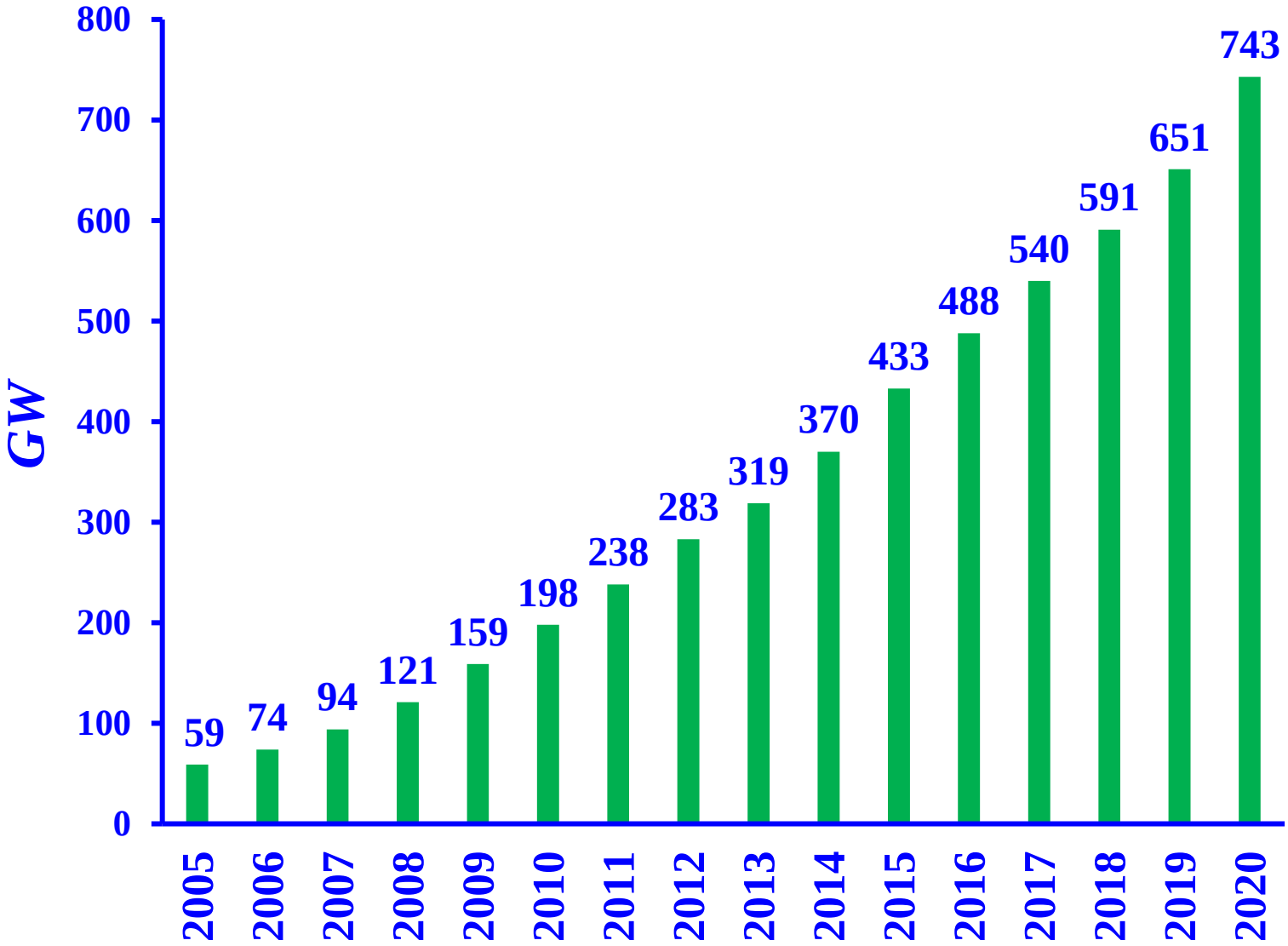
THE DEFINITIVE WIND STATUS REPORT

Source: *Land-based Wind Market Report*: 2021 *Edition, Berkeley Lab*; *https://eta.lbl.gov/publications/land-based-wind-market-report*-2021

The *US Department of Energy* publishes every two years the *Land-Based Wind Market Report.* The text of the 2021 edition has been prepared by the staff of *Lawrence Berkeley National Laboratory* and is available at *https://emp.lbl.gov/wind-technologies-market-report*

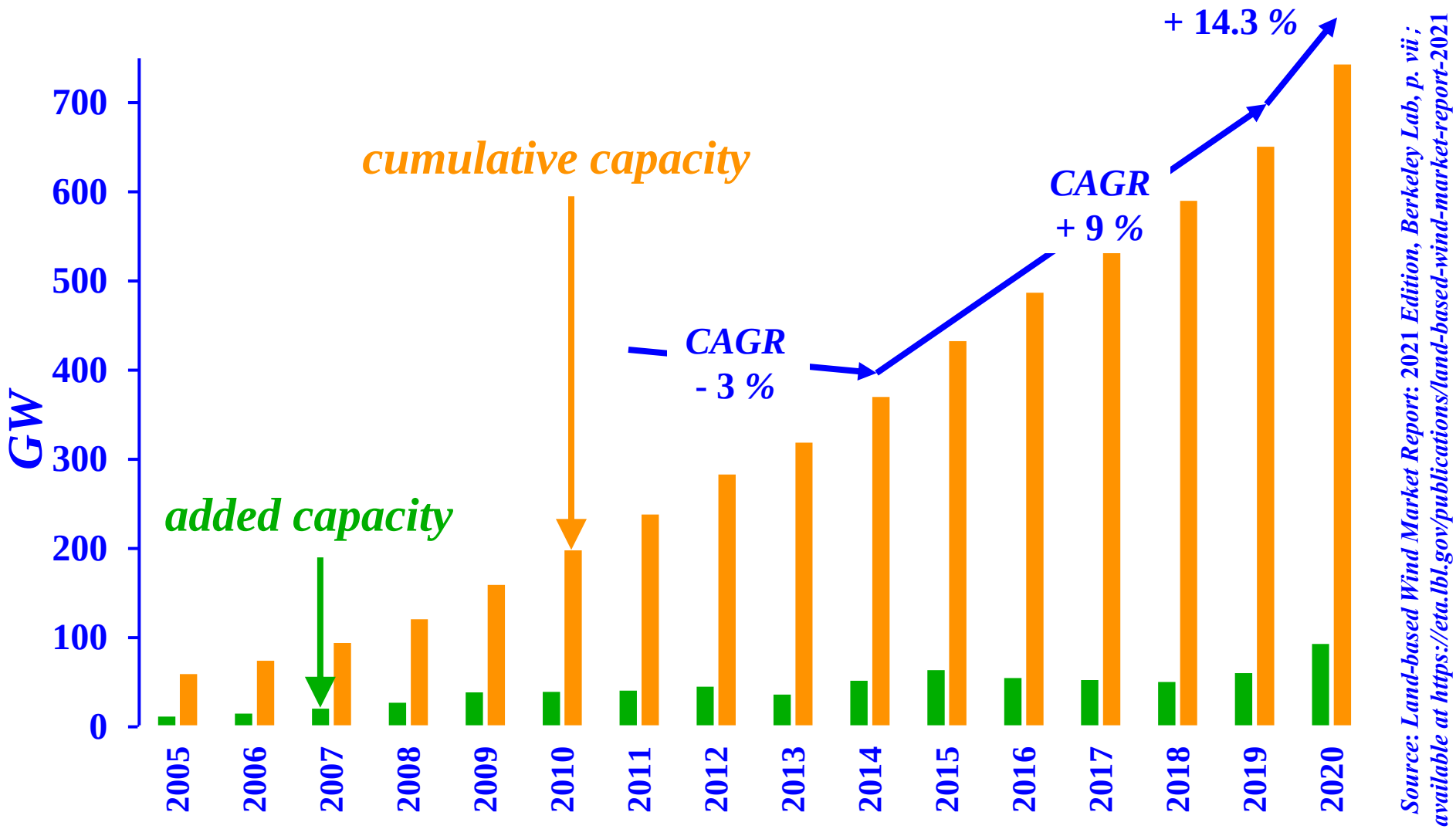
The data on the developments on wind energy presented in *ECE* 333 make extensive use of the information presented in the 2021 edition of the *Land-Based Wind Market Report.*

2005 – 2020 GLOBAL WIND CAPACITY

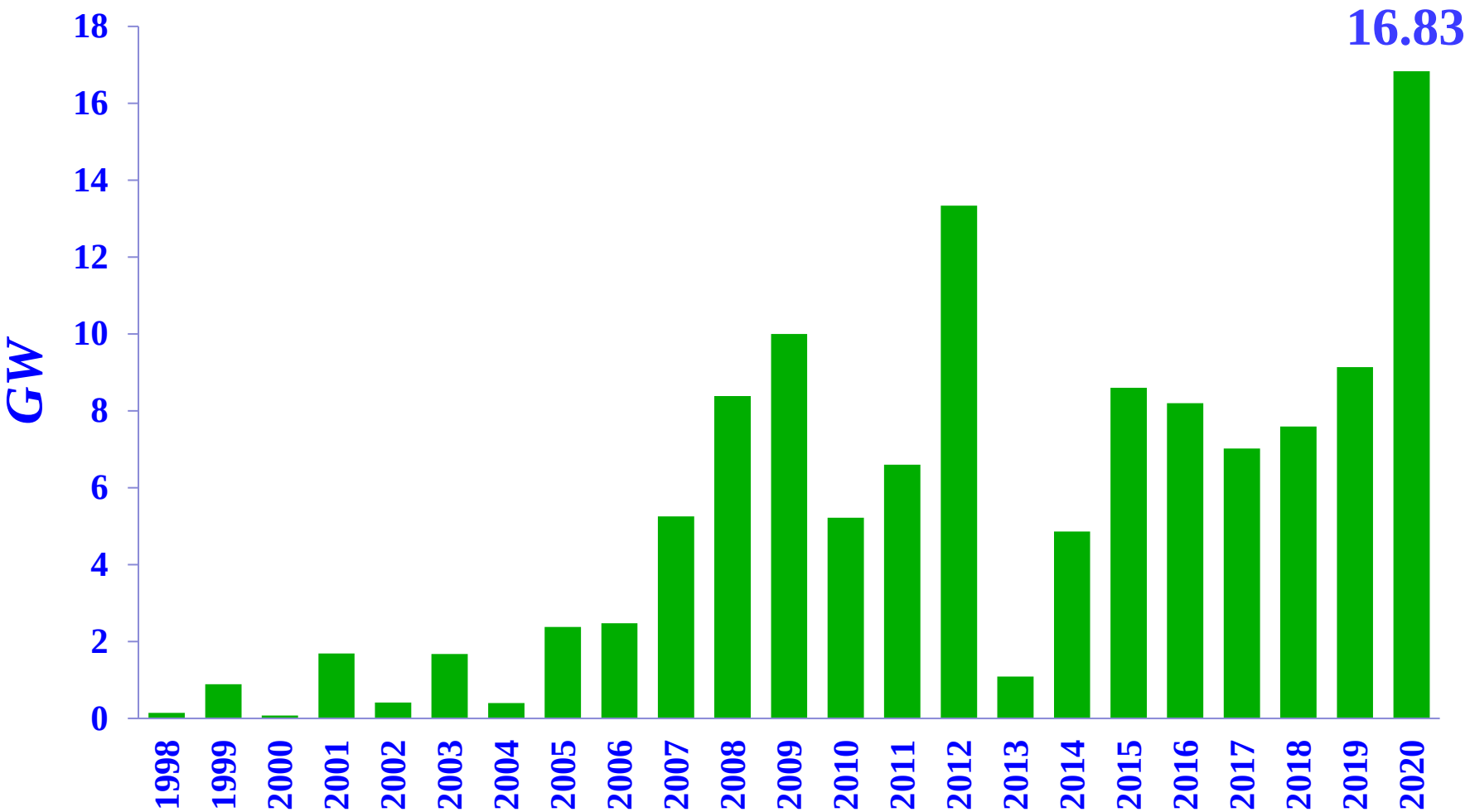


Source: Land-based Wind Market Report: 2021 Edition, Berkeley Lab, p. 5; available at https://eta.lbl.gov/publications/land-based-wind-market-report-2021

2005 – 2020 GLOBAL ANNUAL ADDED AND CUMULATIVE WIND CAPACITY

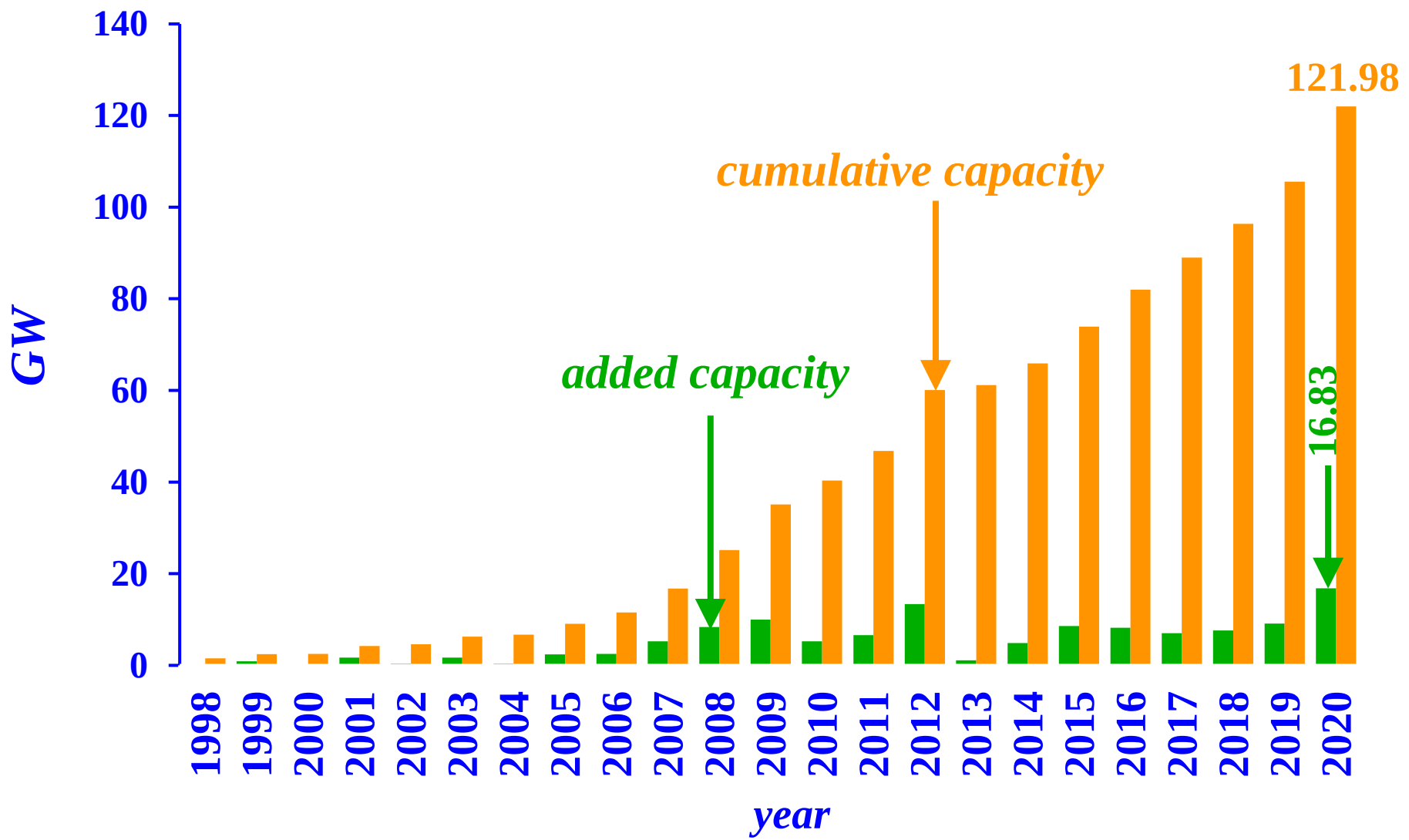


1998 – 2020 ANNUAL INSTALLED *US* WIND CAPACITY ADDITIONS



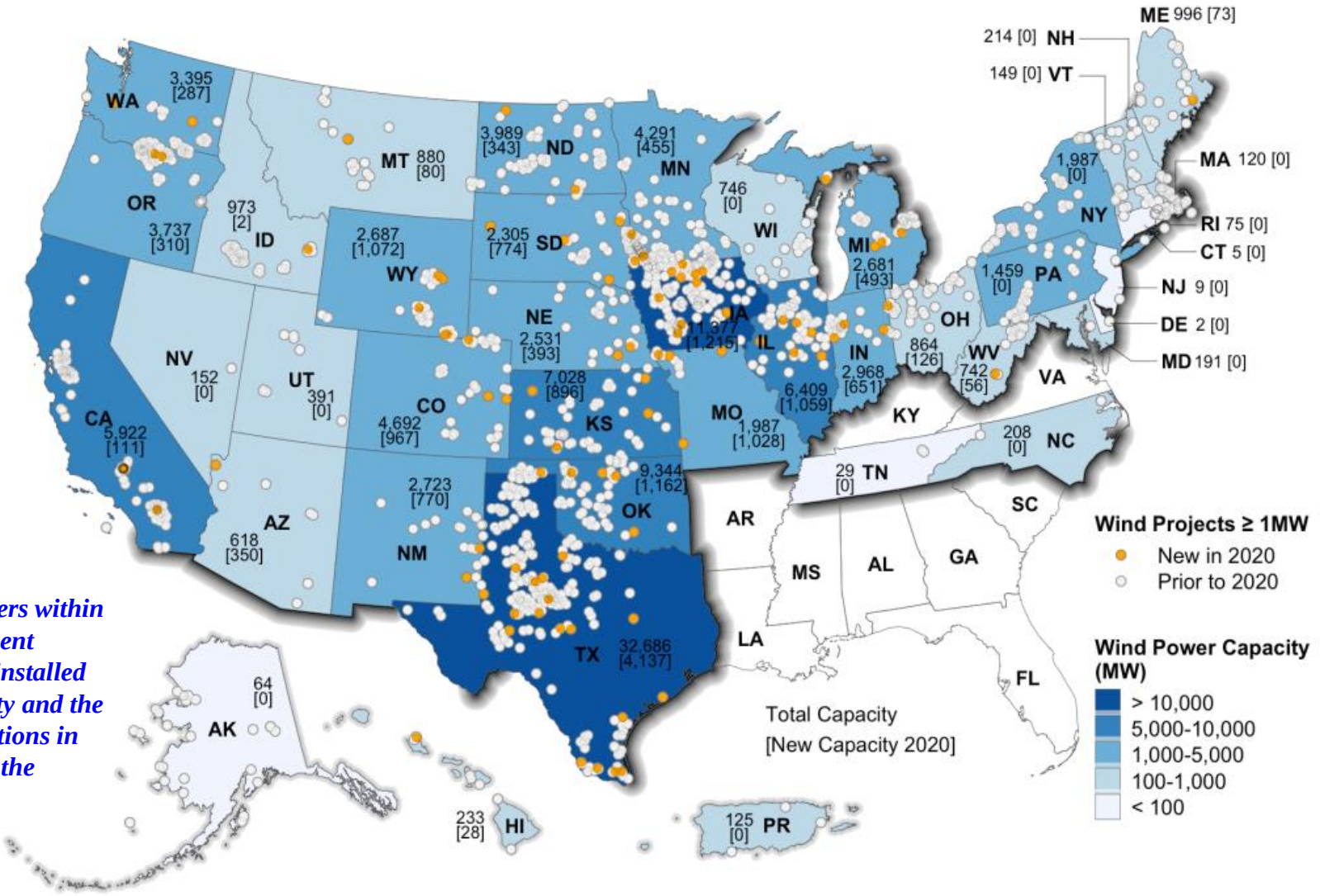
Source: Land-based Wind Market Report: 2021 Edition, Berkeley Lab, p. 3; available at https://eta.lbl.gov/publications/land-based-wind-market-report-2021

1998 – 2020: ANNUAL AND CUMMULATIVE INSTALLED WIND CAPACITY IN *US*



Source: Land-based Wind Market Report: 2021 Edition, Berkeley Lab, p. 3; available at https://eta.lbl.gov/publications/land-based-wind-market-report-2021

2020 *US* WIND POWER PROJECTS STATUS

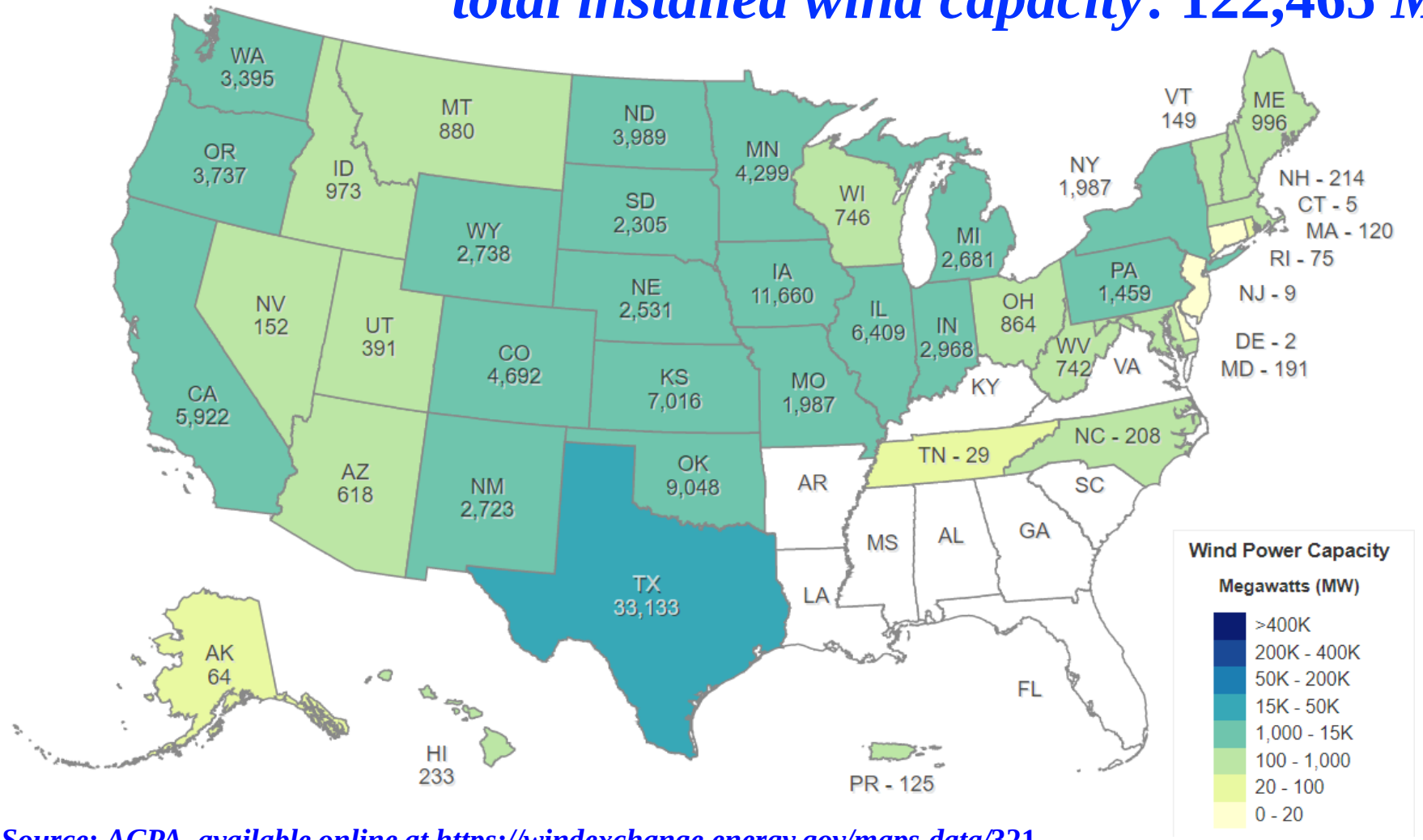


Note: numbers within states represent cumulative installed wind capacity and the annual additions in 2020 within the brackets

Source: Land-based Wind Market Report: 2021 Edition, Berkeley Lab, p. 7; available at https://eta.lbl.gov/publications/land-based-wind-market-report-2021

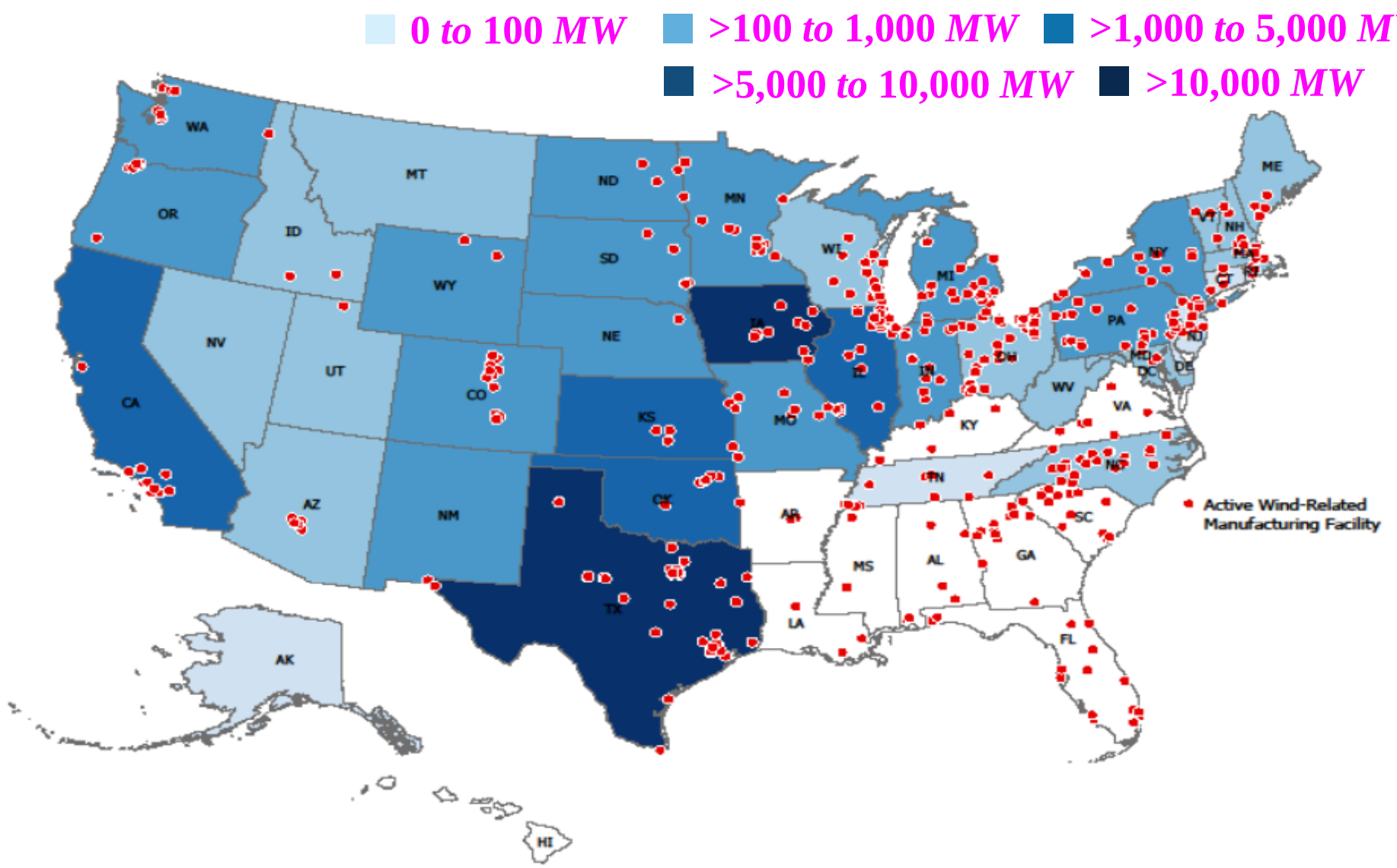
2020 *Q4* *US* WIND CAPACITY BY STATE

total installed wind capacity*: 122,465 *MW



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

2020 *US* WIND ENERGY INDUSTRY MANUFACTURING FACILITIES



Source: Land-based Wind Market Report: 2021 Edition, Berkeley Lab, p. 14; available at https://eta.lbl.gov/publications/land-based-wind-market-report-2021

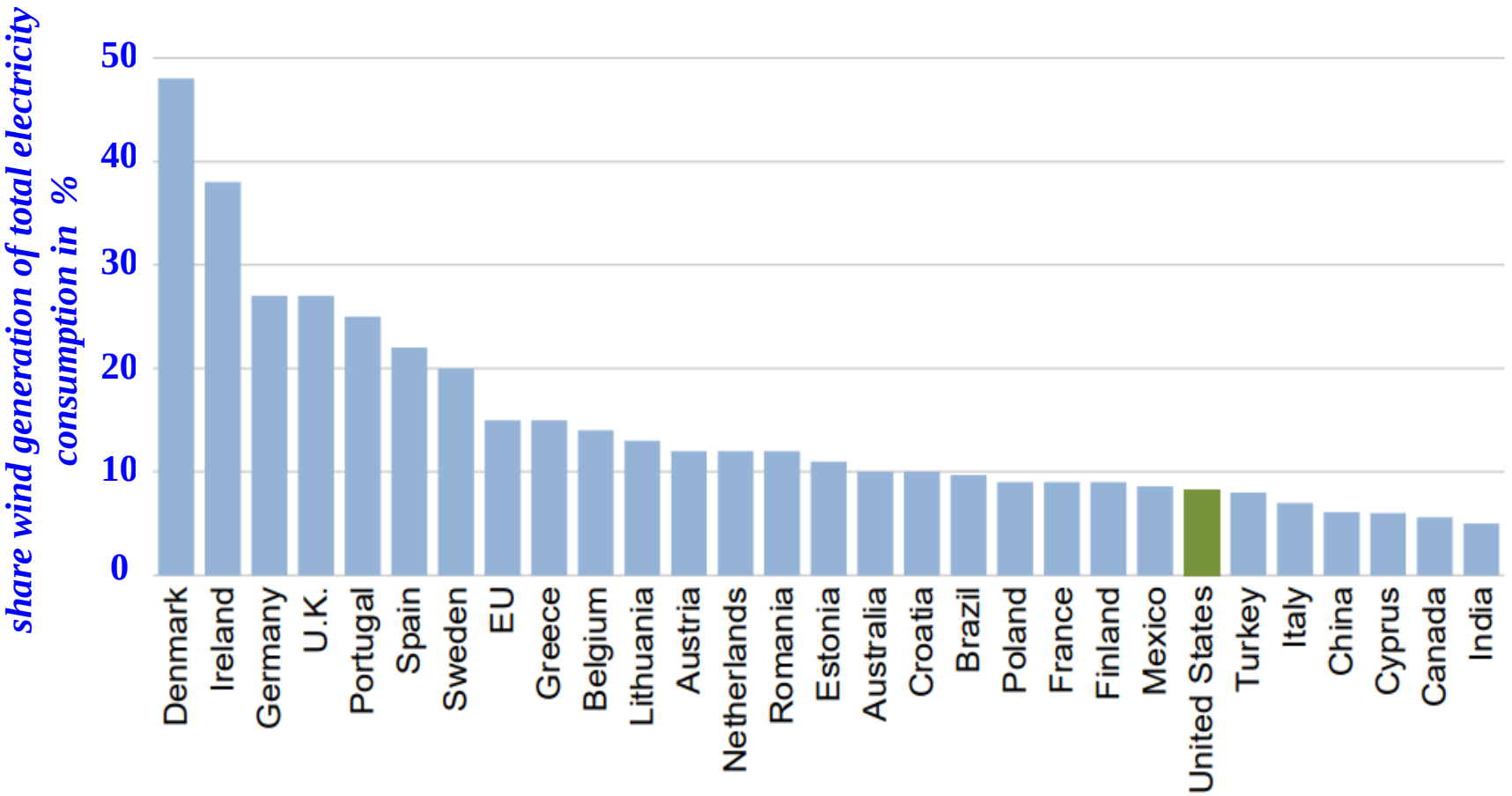
2020 WIND CAPACITY ADDITION AND CUMULATIVE TOTAL: TOP 10 NATIONS

annual capacity in MW	
China	52, 000
United States	16, 836
Brazil	2, 297
Netherlands	1, 979
Germany	1, 668
Norway	1, 532
Spain	1, 400
France	1, 318
Turkey	1, 224
India	1, 119
rest of world	11, 538
total	92, 910

cumulative capacity in MW	
China	288, 320
United States	121, 985
Germany	62, 850
India	38, 625
Spain	27, 250
United Kingdom	23, 937
France	17, 948
Brazil	17, 750
Canada	13, 578
Italy	10, 543
rest of world	119, 572
total	742,357

Source: Land-based Wind Market Report: 2021 Edition, Berkeley Lab, p. 6; available at https://eta.lbl.gov/publications/land-based-wind-market-report-2021

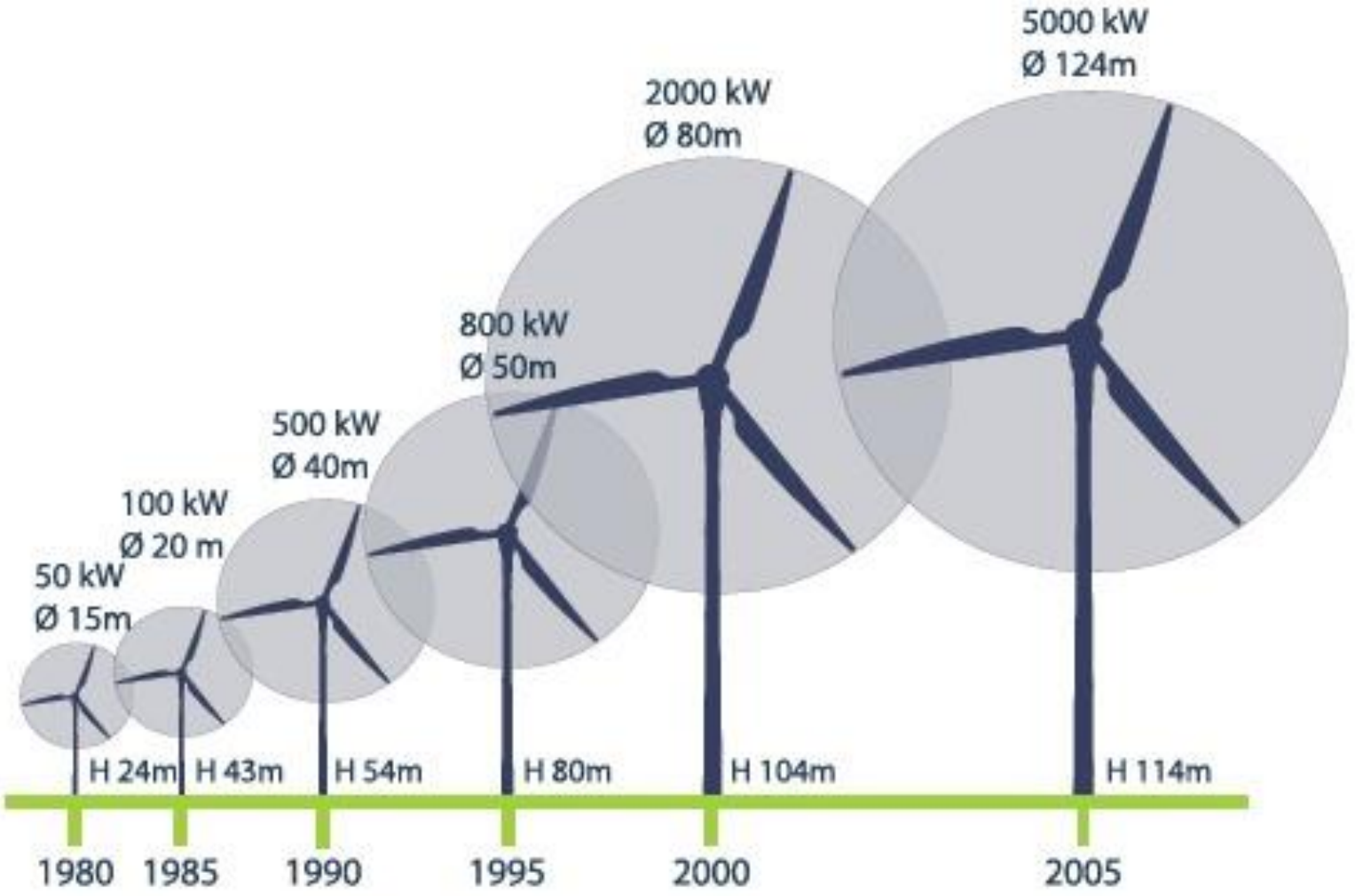
LEADING NATIONS IN WIND ENERGY CONSUMPTION IN 2020



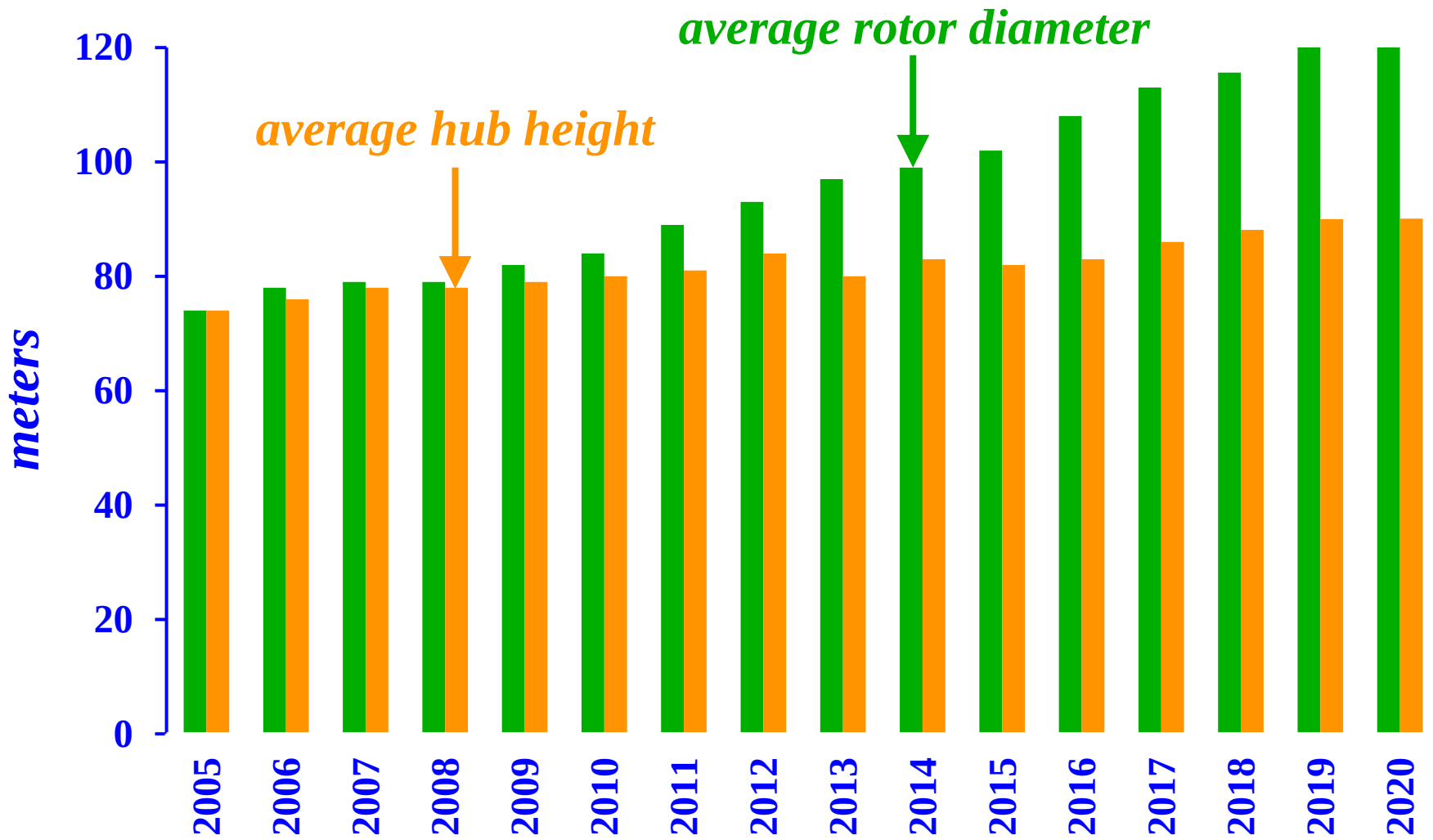
Source: Land-based Wind Market Report: 2021 Edition, Berkeley Lab, p. 6; available at https://eta.lbl.gov/publications/land-based-wind-market-report-2021

THE TREND TO LARGER WIND TURBINES

Source: http://www.kingislandrenewableenergy.com.au/stand-alone-power-systems/renewable-energy

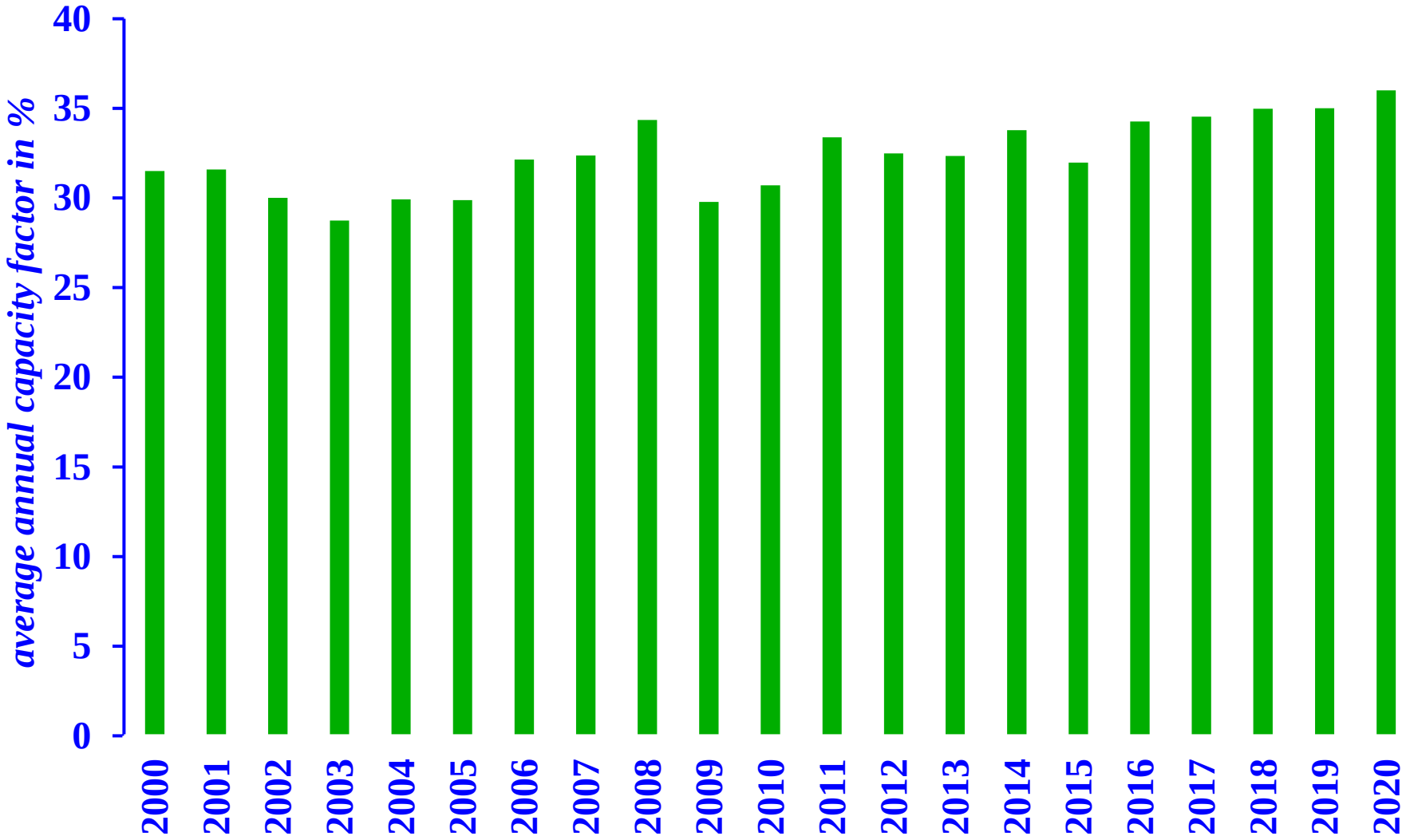


2005 – 2020 AVERAGE WIND TURBINE SIZE EVOLUTION



Source: Land-based Wind Market Report: 2021 Edition, Berkeley Lab, p. 23; available at https://eta.lbl.gov/publications/land-based-wind-market-report-2021

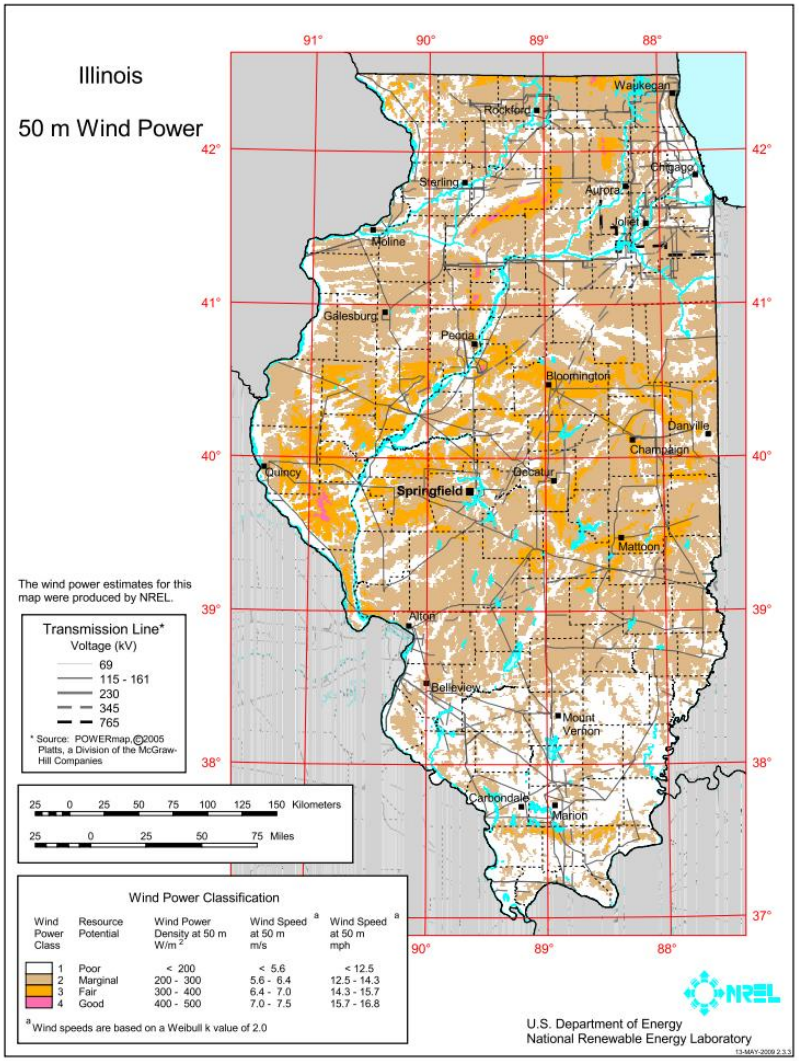
AVERAGE WIND CAPACITY FACTORS: 2000 – 2020



Source: Land-based Wind Market Report: 2021 Edition, Berkeley Lab, p. 31; available at https://eta.lbl.gov/publications/land-based-wind-market-report-2021

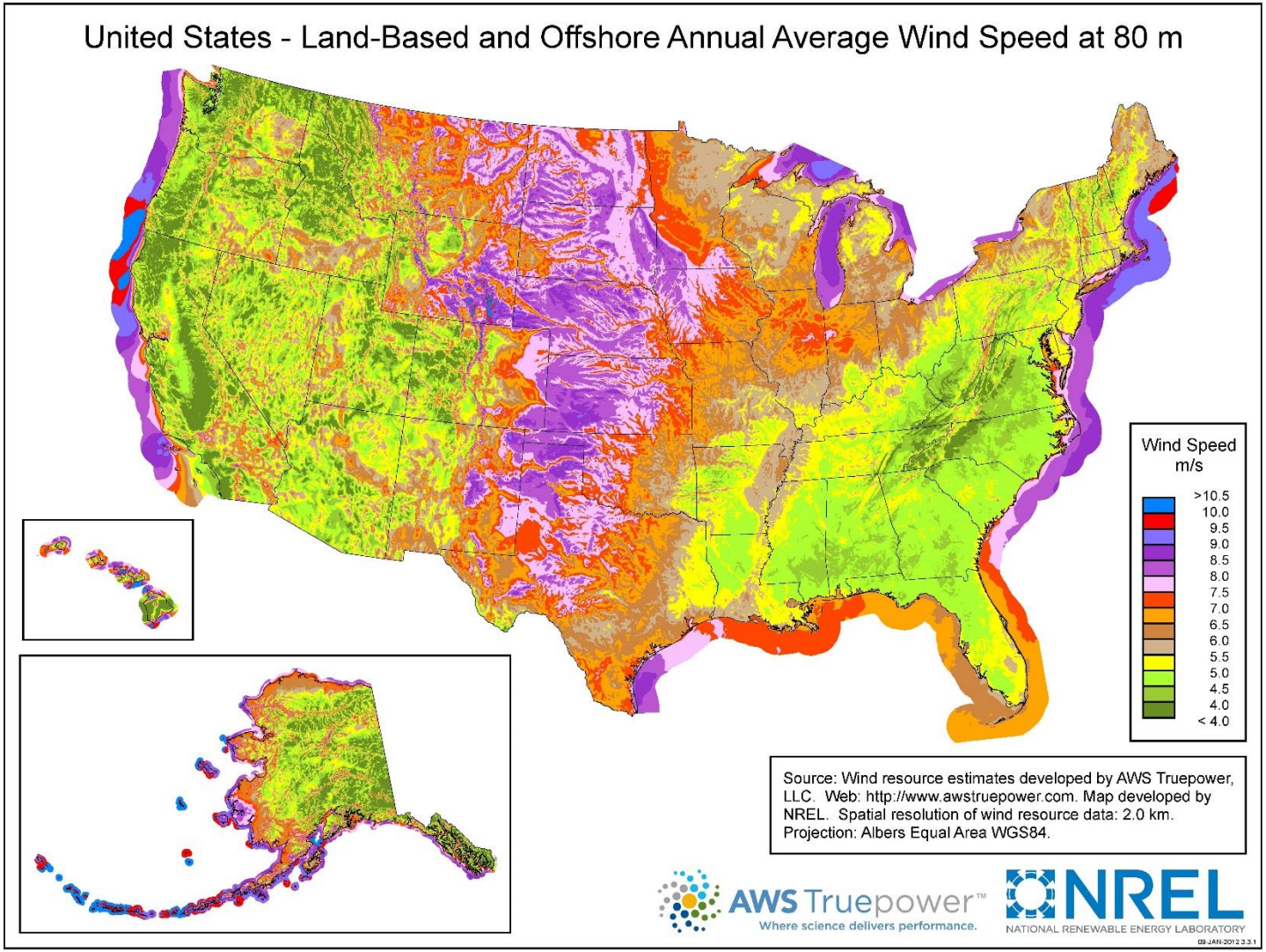
WIND MAP FOR *ILLINOIS*

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



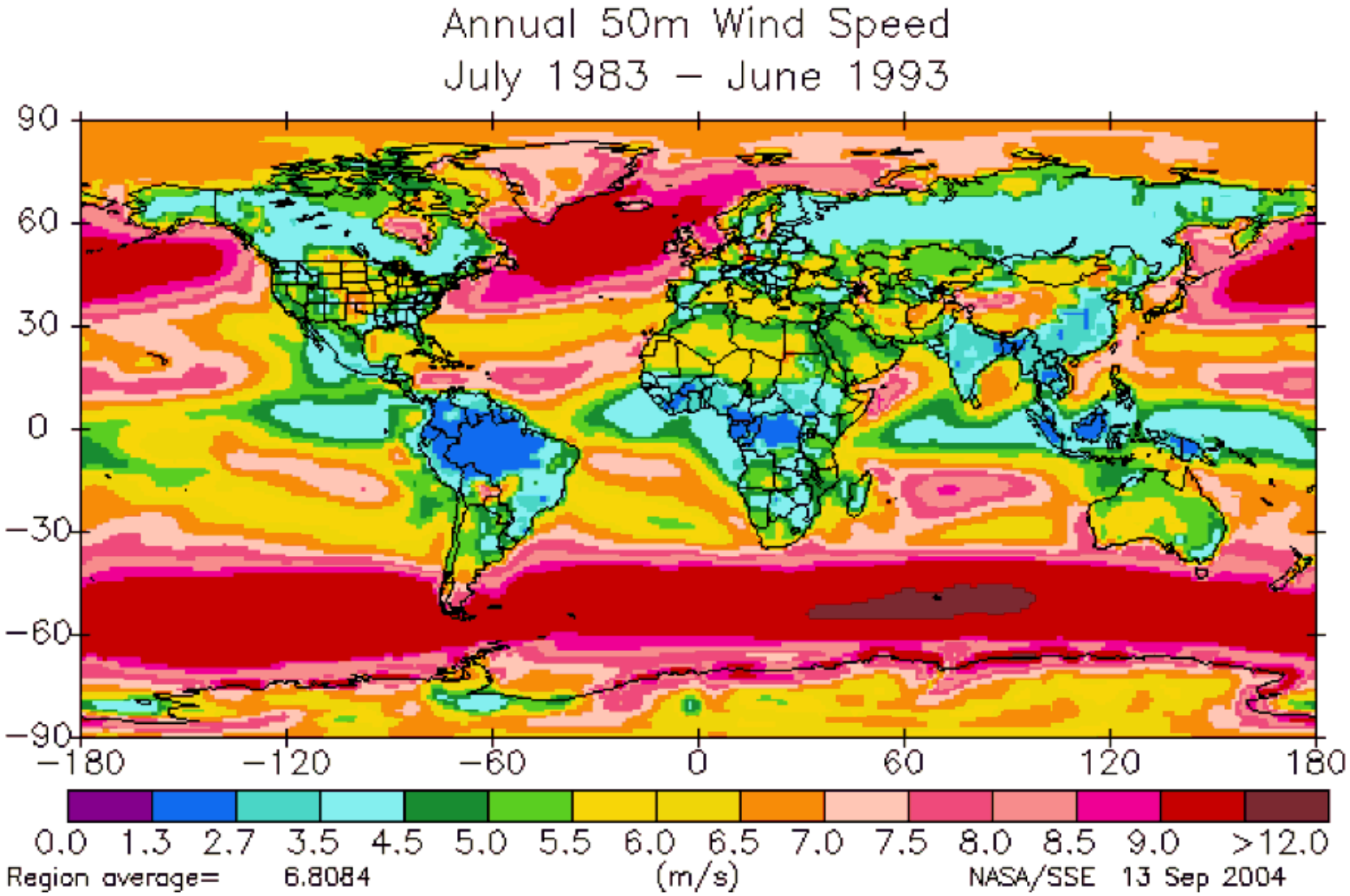
WIND RESOURCE MAP

Source: https://www.nrel.gov/gis/images/80m_wind/awstwspd80onoffbigC3-3dpi600.jpg



WORLDWIDE WIND RESOURCE MAP

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



KEY COMPONENTS OF A WIND TURBINE