ECE 333 – Green Electric Energy

4. Wind as an Energy Resource

George Gross

Department of Electrical and Computer Engineering

University of Illinois at Urbana-Champaign

WIND RESOURCES

- Wind is becoming a significant source of generation in the US and Europe
- Today's nearly $350\ GW$ 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, we explore the key characteristics of wind, its physical limitations and the economic issues in wind generation

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 various terms used today for generators that convert wind into electricity; terms include "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

OLD WINDMILL

WIND TURBINE CLASSIFICATION

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

WIND FARM

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 any commercial success is the Darrieus rotor
- The wind hits the rotor blades – so-called aerofoils – and obtains lift to put the blades in a spin
- Blades are, typically, closer to ground where wind speeds are lower

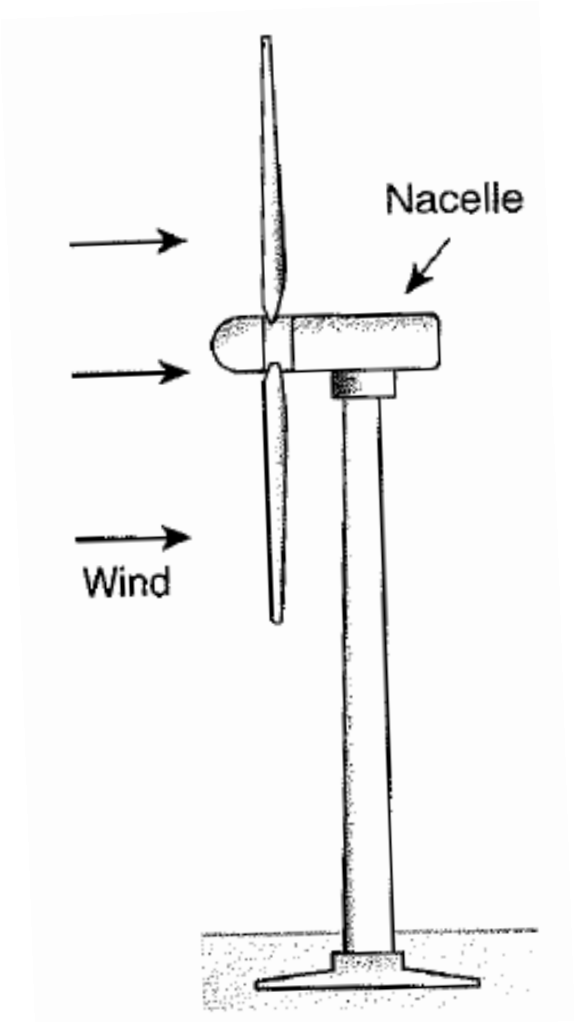
Source: http://reuk.co.uk/Darrieus-Wind-Turbines.htm

VAWT

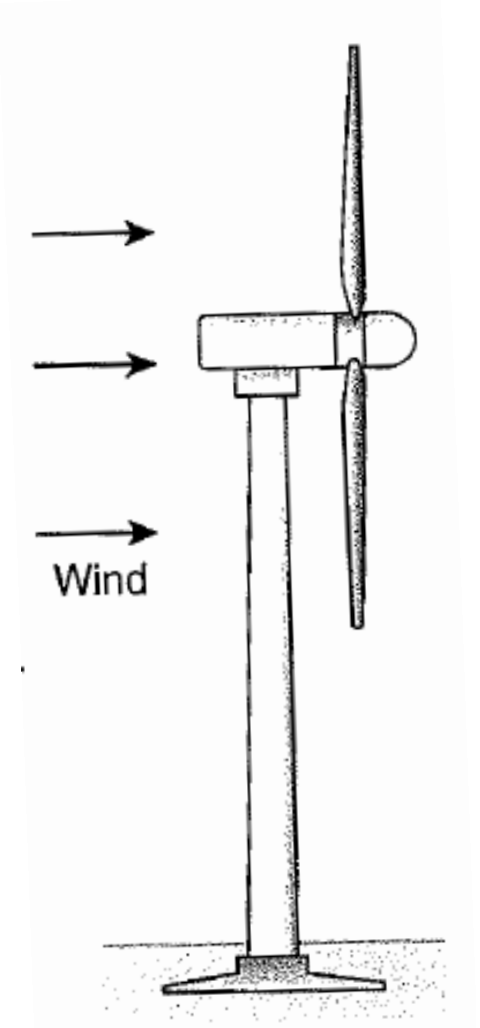
- A *VAWT* requires no yaw (rotation about vertical axis) control to keep the blades facing into the wind
- The nacelle containing heavy generator and gearbox is located down on the ground and so is easily serviced
- The lightened tower need not be as strong as for *HAWT*s; in some land installations,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

HAWT

upwind



downwind



DOWNWIND *HAWT*

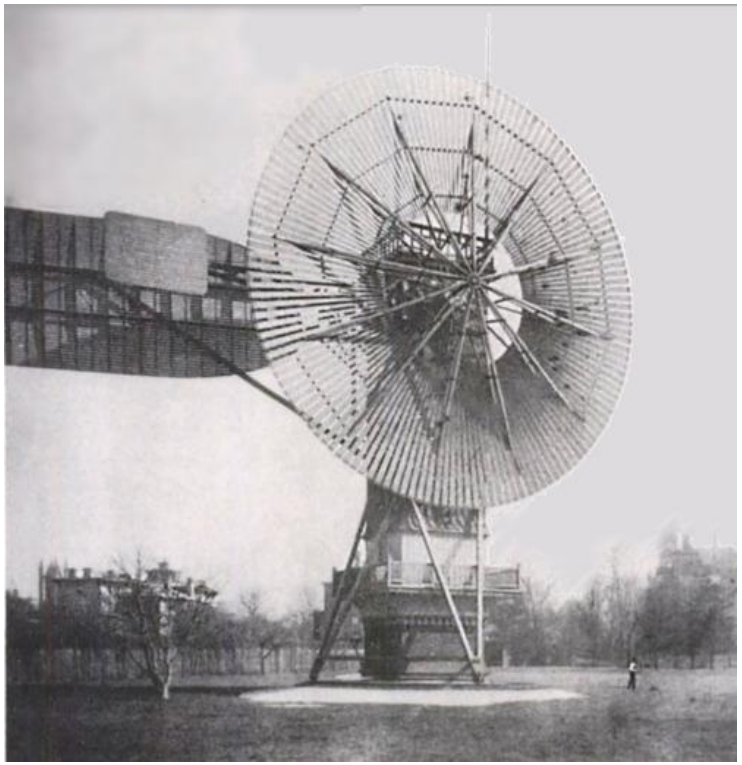
- A downwind *HAWT* requires no yaw control to regulate the left-right motion as it naturally orients itself in line with the wind direction
- A downwind *HAWT* suffers from the shadowing effects of the tower: when a blade swings behind the tower, the wind it encounters is reduced over a brief period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

UPWIND *HAWT*

- Most modern wind turbines are of the upwind *HAWT* type
- An upwind *HAWT* requires a somewhat complex yaw control to keep the blades facing into the wind
- Upwind *HAWT*s operate more smoothly and deliver more power than downwind turbines

WIND POWER DEVELOPMENT HISTORY

- The first known wind turbine for electricity production was developed in 1888 by Charles F. Brush, in Cleveland, Ohio
- The 12 kW turbine electricity was used to charge the batteries in the cellar of the owner's mansion
- The first wind turbine to generate electricity was built in 1891 by Poul la Cour in Denmark



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

WIND POWER DEVELOPMENT HISTORY

- La Cour used the electricity generated by his wind turbines to electrolyze water to produce hydrogen 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

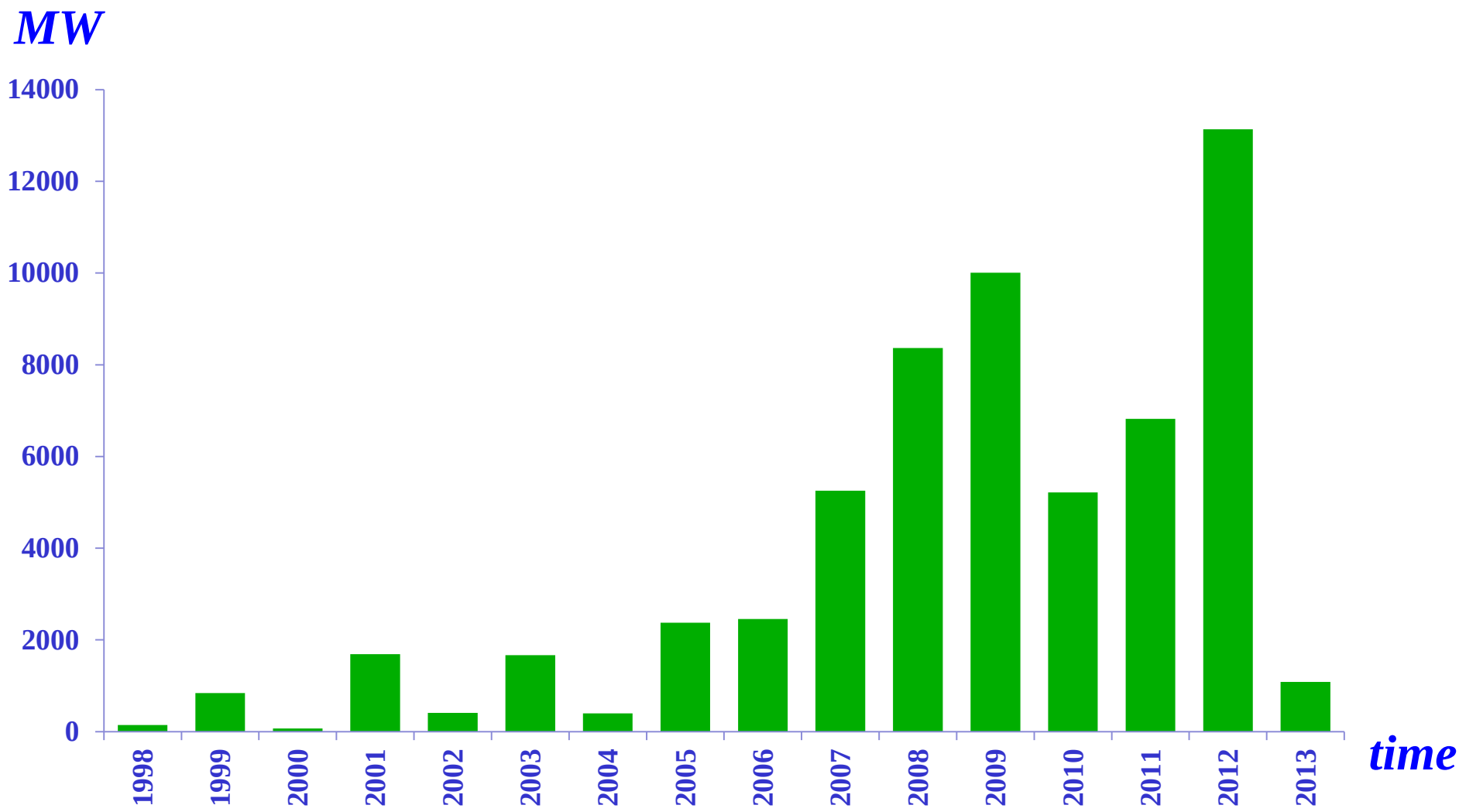
WIND POWER DEVELOPMENT HISTORY

- 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, since inexpensive electricity became widely available
- The oil shocks of the early 1970's created a new interest in wind power and large wind farm developments were set up in California

WIND POWER DEVELOPMENT HISTORY

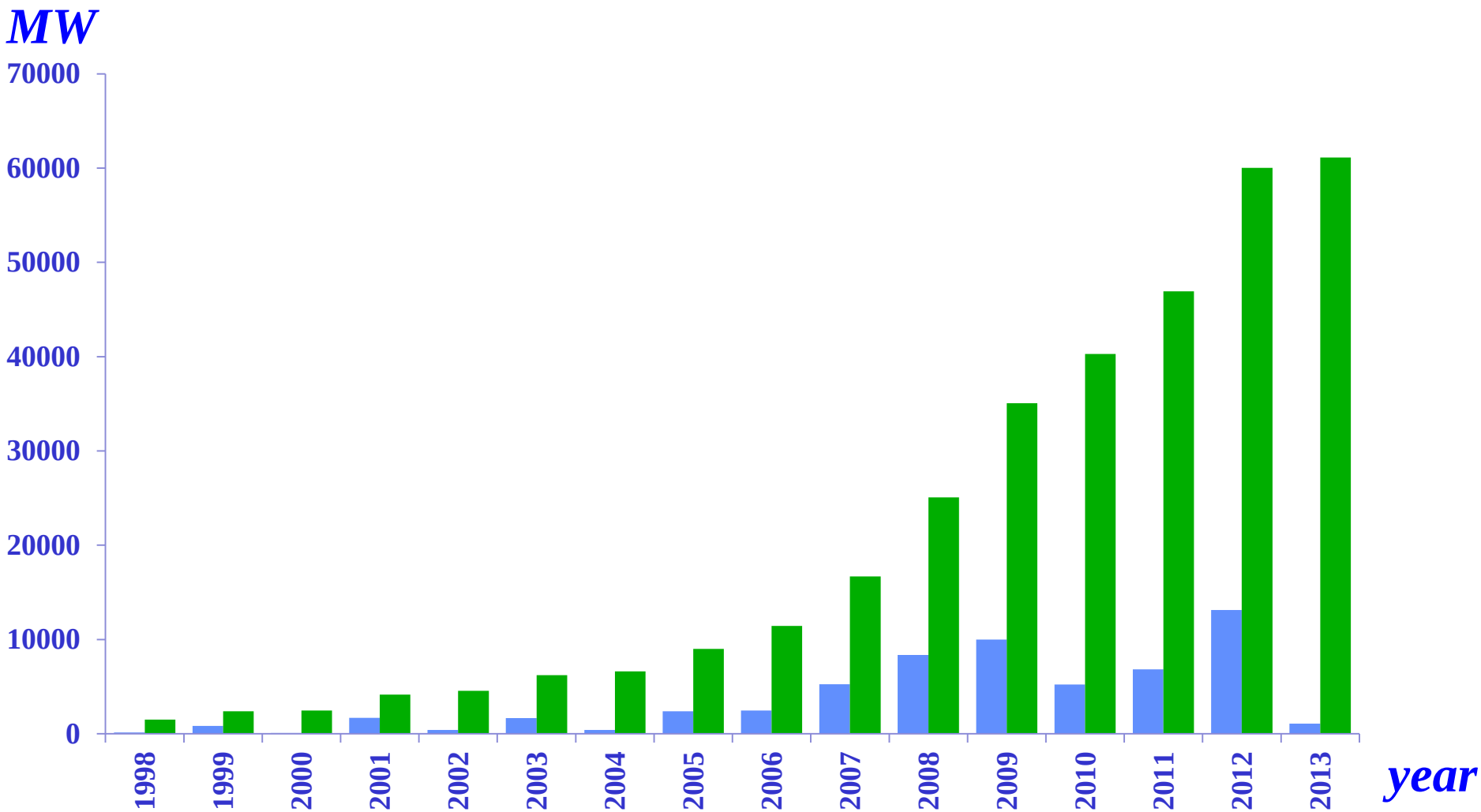
- The *US* government termination of tax credits put a stop for nearly a decade to the installation of new wind developments
- The renewed interest started in the mid 1990's
- Various wind turbine technology development projects were undertaken in Denmark, Spain, and Germany that led the continual reductions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

ANNUAL INSTALLED WIND CAPACITY



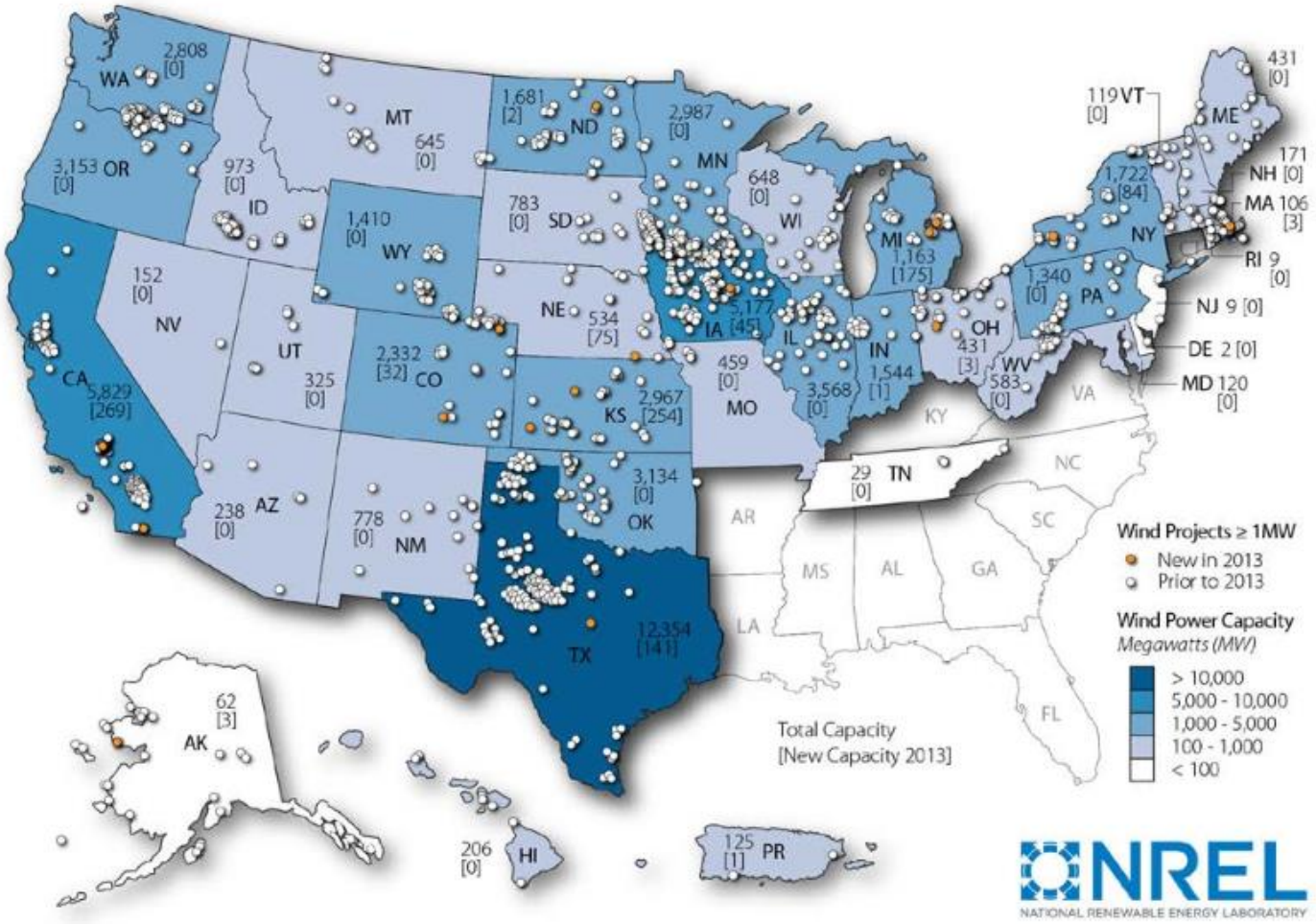
Source: http://energy.gov/eere/wind/downloads/2013-wind-technologies-market-report-data

US WIND POWER CAPACITY GROWTH



Source: http://energy.gov/eere/wind/downloads/2013-wind-technologies-market-report-data

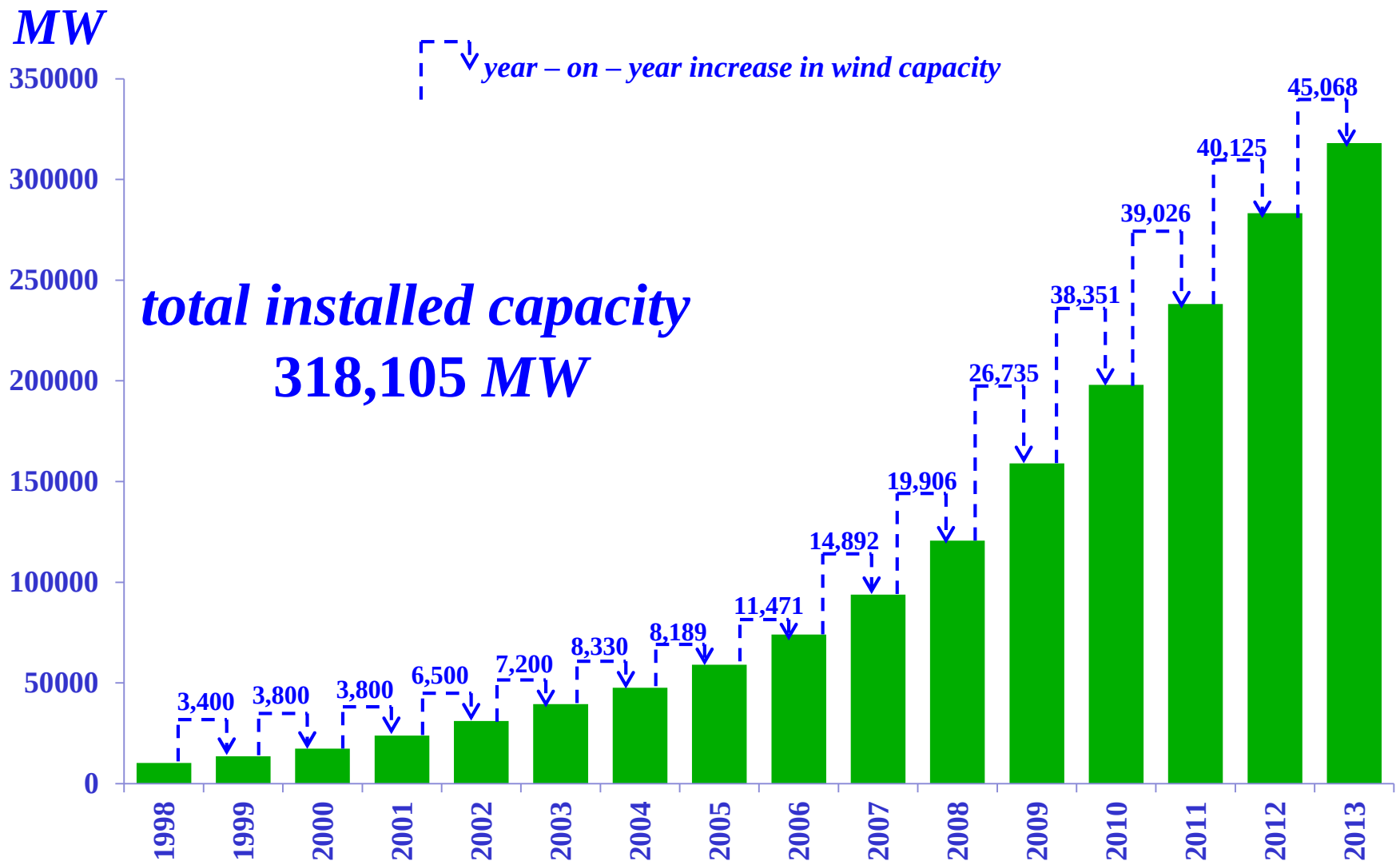
WIND POWER CAPACITY INSTALLATIONS 2013



Note: Numbers within states represent cumulative installed wind capacity and, in brackets, annual additions in 2013.

Source: 2013 Wind Technologies Market Report, US Department of Energy

1998 – 2013 GLOBAL WIND CAPACITY



Source: http://www.gwec.net/wp-content/uploads/2014/04/GWEC-Global-Wind-Report_9-April-2014.pdf

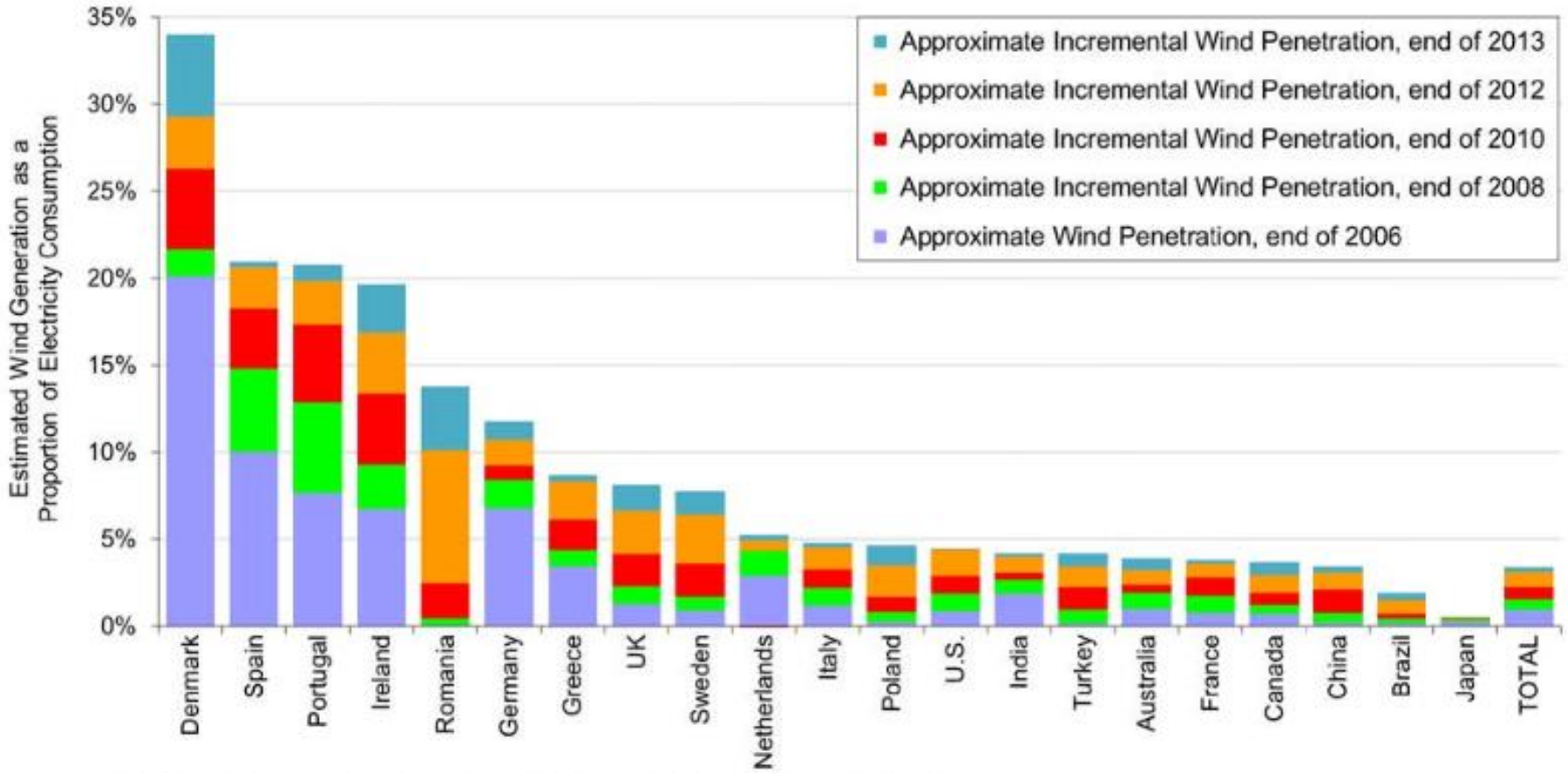
LEADING NATIONS IN WIND ENERGY CONSUMPTION

ANNUAL CAPACITY (2013, MW)	
China	16,088
Germany	3,238
India	1,729
United Kingdom	1,883
Canada	1,599
United States	1,084
Brazil	953
Poland	894
Sweden	724
Romania	695
Rest of the World	6,402
TOTAL	35,289

CUMULATIVE CAPACITY (2013, MW)	
China	91,412
Germany	34,250
India	20,150
United Kingdom	10,531
Canada	7,803
United States	61,091
Brazil	3,461
Poland	3,390
Sweden	4,470
Romania	2,600
Rest of the World	78,947
TOTAL	318,105

Source: http://www.gwec.net/wp-content/uploads/2014/04/GWEC-Global-Wind-Report_9-April-2014.pdf

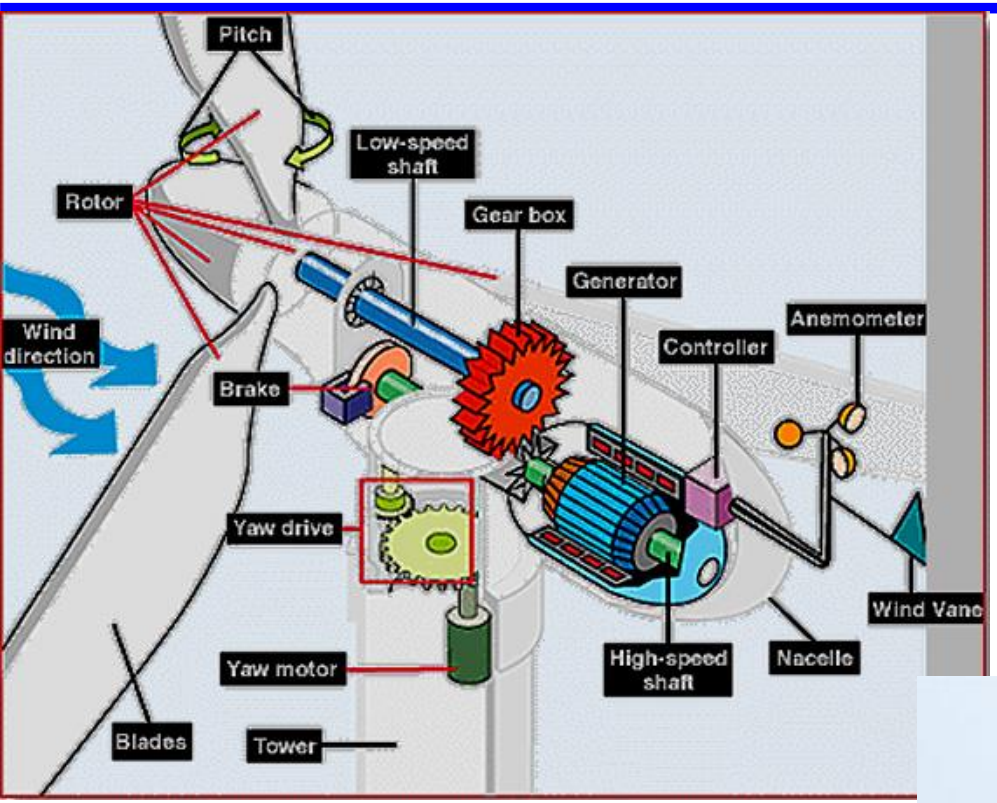
2013 WIND CAPCITY ADDITIONS AND CUMULATIVE TOTAL

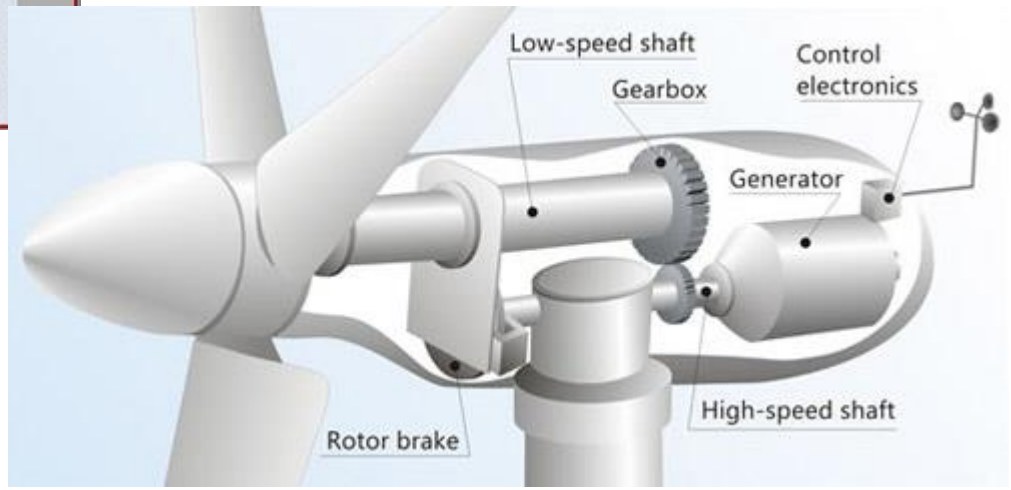


Source: Berkeley Lab estimates based on data from Navigant, EIA, and elsewhere

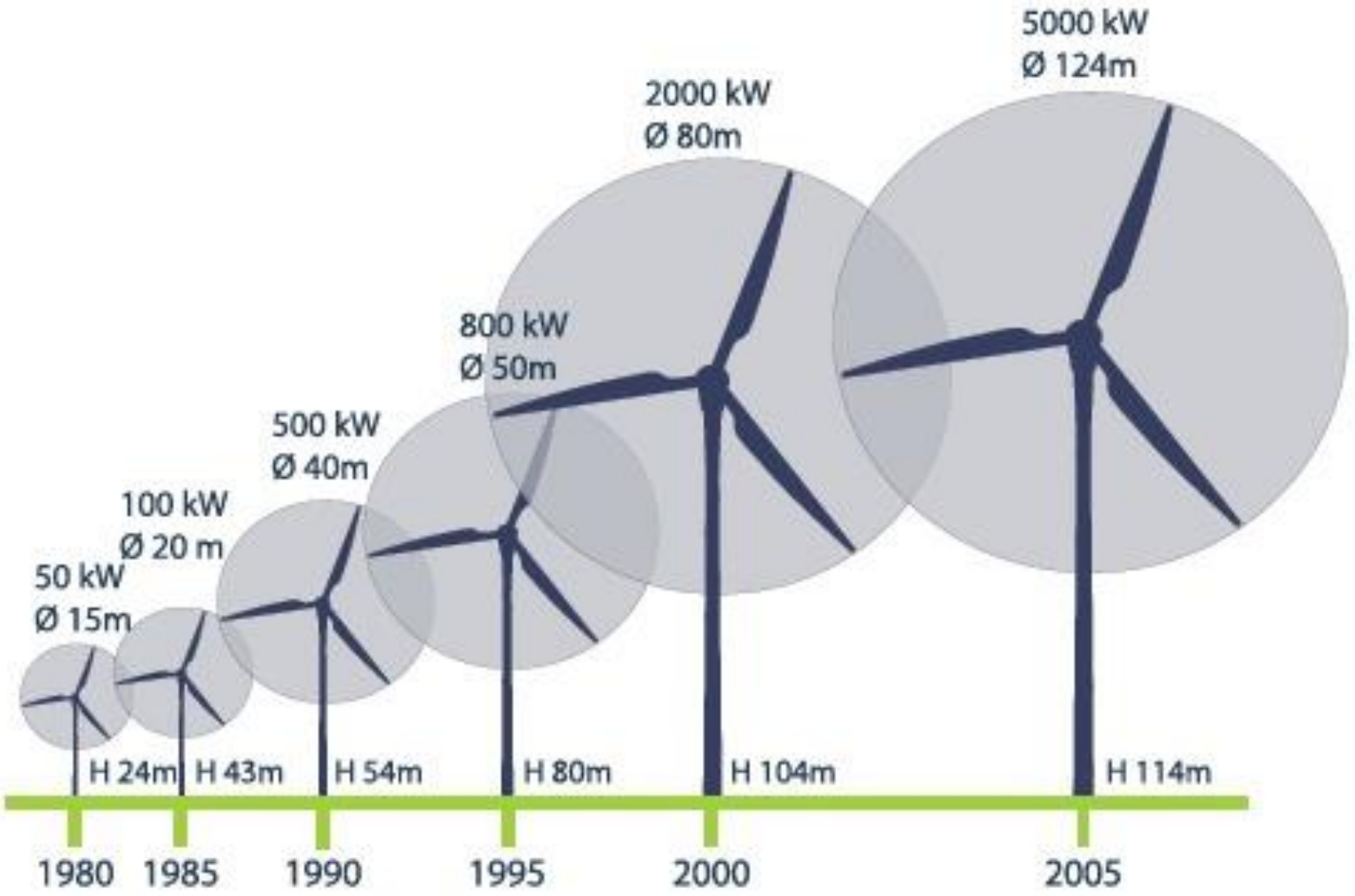
Source: 2013 Wind Technologies Market Report, US Department of Energy

KEY COMPONENTS OF A WIND TURBINE



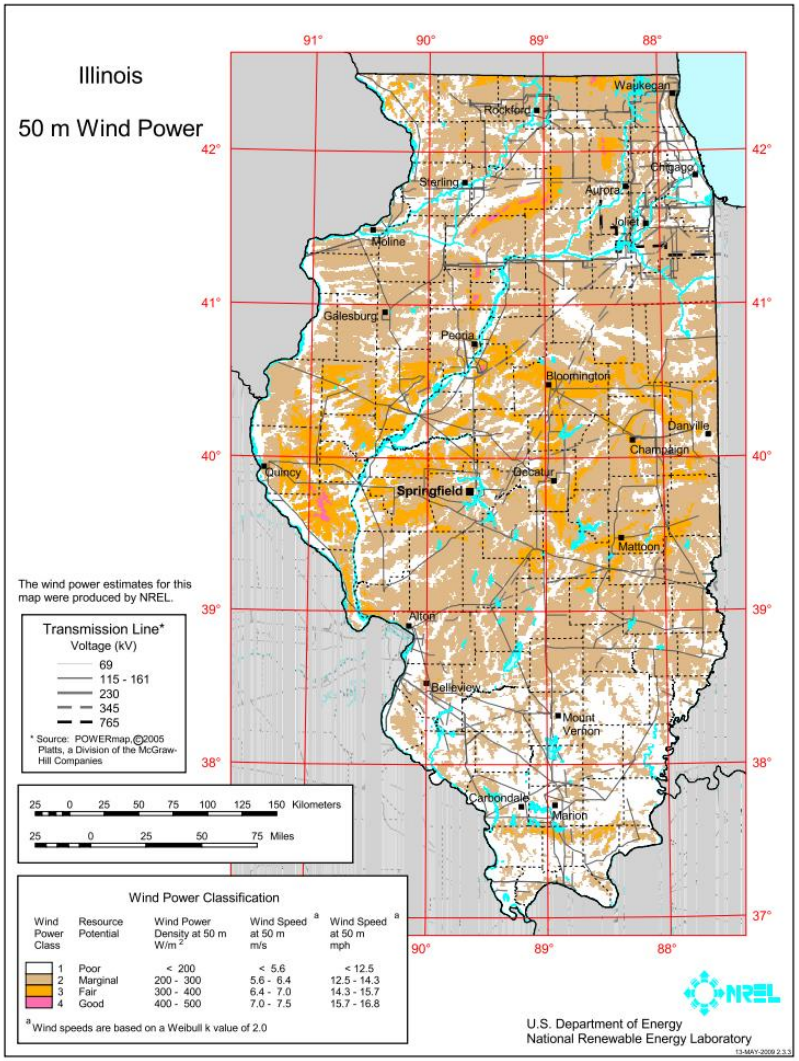


THE TREND TO LARGER WIND TURBINES



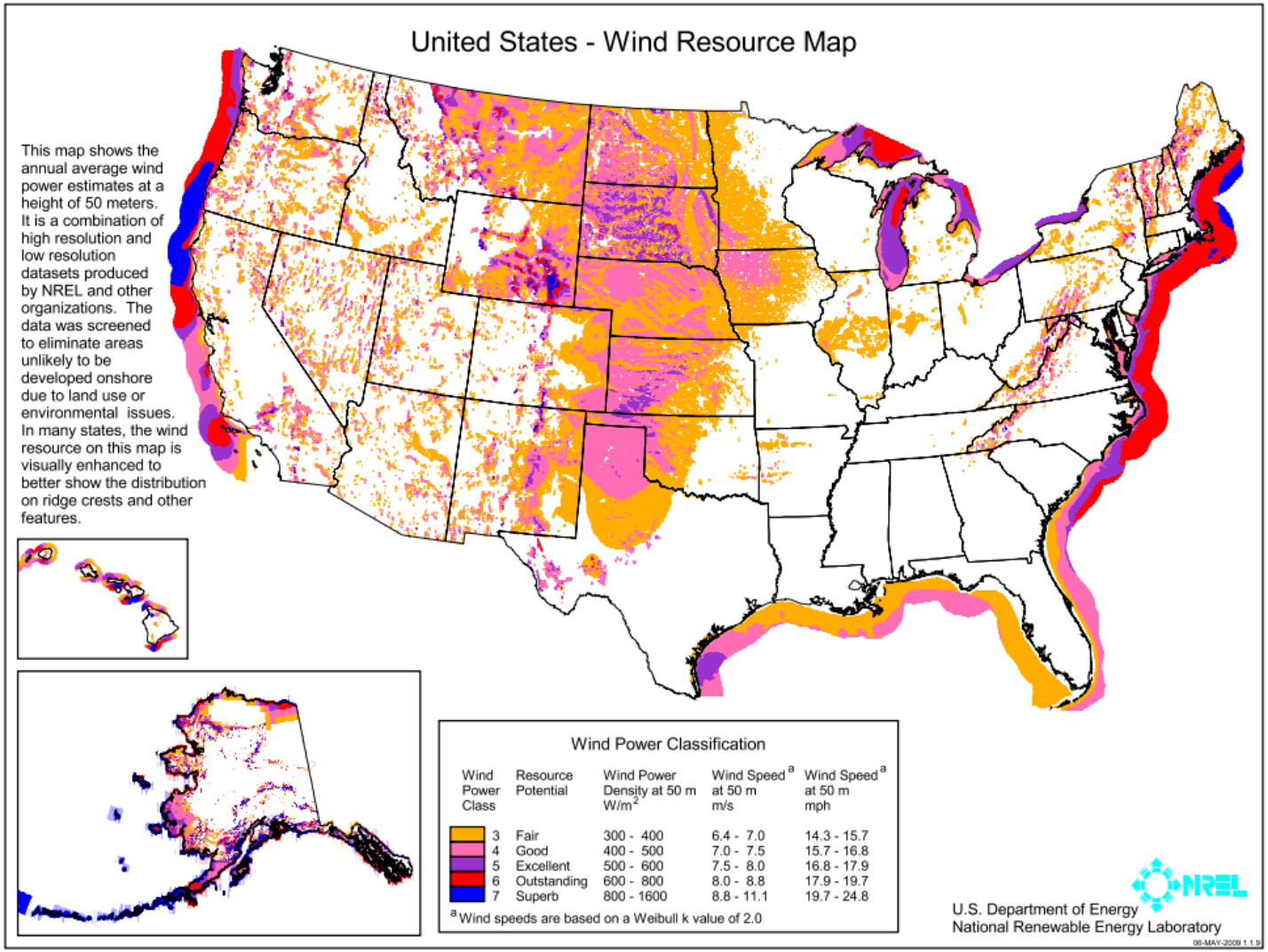
Source: http://www.kingislandrenewableenergy.com.au/stand-alone-power-systems/renewable-energy

WIND MAP FOR NORTHCENTRAL IL



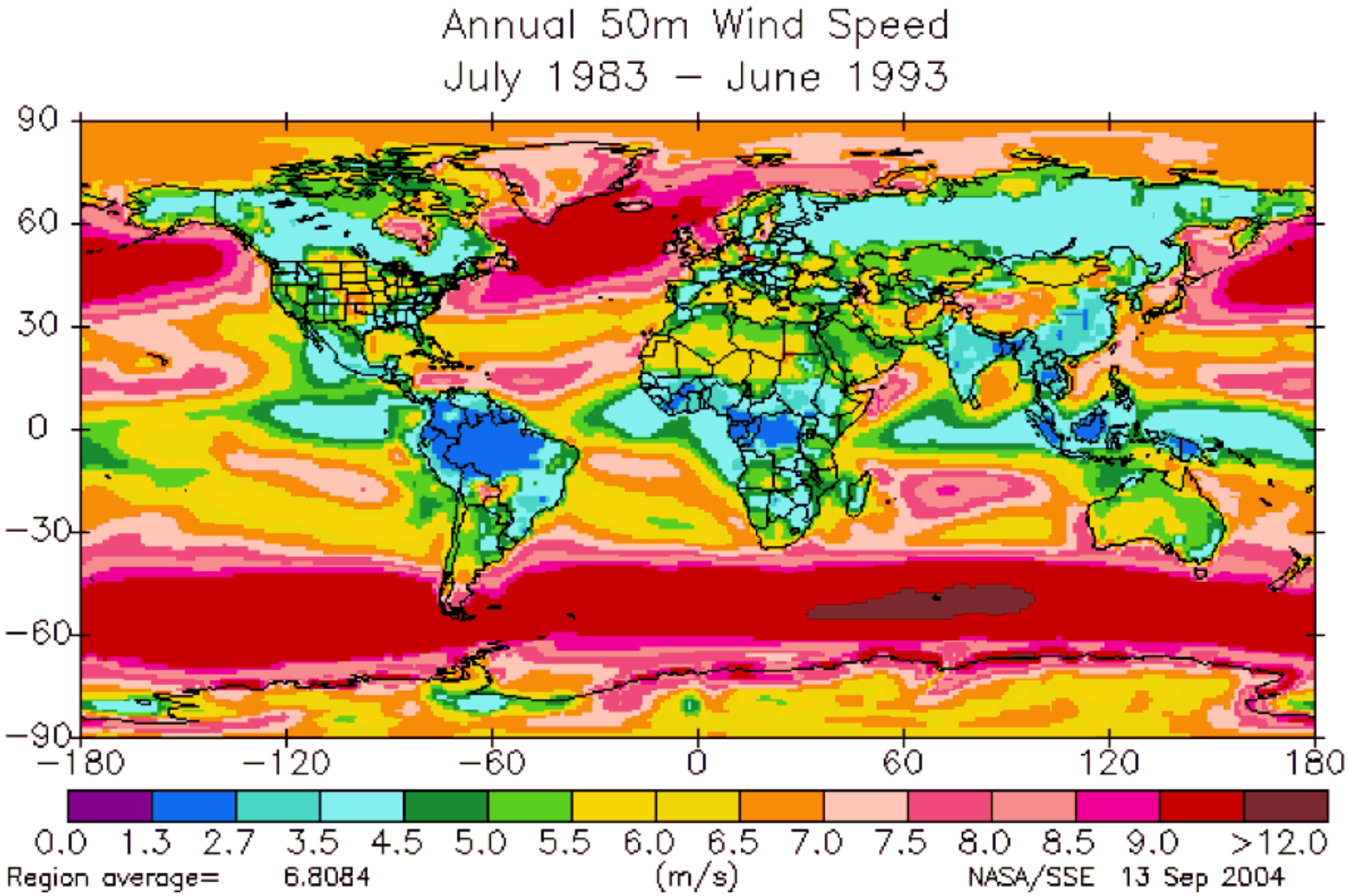
Source: http://apps2.eere.energy.gov/wind/windexchange/maps_template.asp?stateab=il

WIND RESOURCE MAP



Source: http://www.nrel.gov/gis/images/US-50m-wind-power-map.jpg

WORLDWIDE WIND RESOURCE MAP



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

