

Wind Power



ME 416/516

Source: www.nordex-online.com

THE UNIVERSITY OF
ALABAMA
ENGINEERING

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Web Resources

- <http://www.windpower.org/en/core.htm>
- <http://www.awea.org>
- http://www.eere.energy.gov/windpoweringamerica/where_is_wind.html
- <http://rredc.nrel.gov/wind/pubs/atlas/>

Windmills of the Past

- Wind power is an ancient technology that is again booming as a renewable energy source
- Dutch windmills have operated for hundreds of years to power grinding mills and to pump water in the recovery of land from the sea

Name: De Oude Doorn

Type: Octagonal thatched drainage mill

Radius: 25 m - Built in: the 18th century



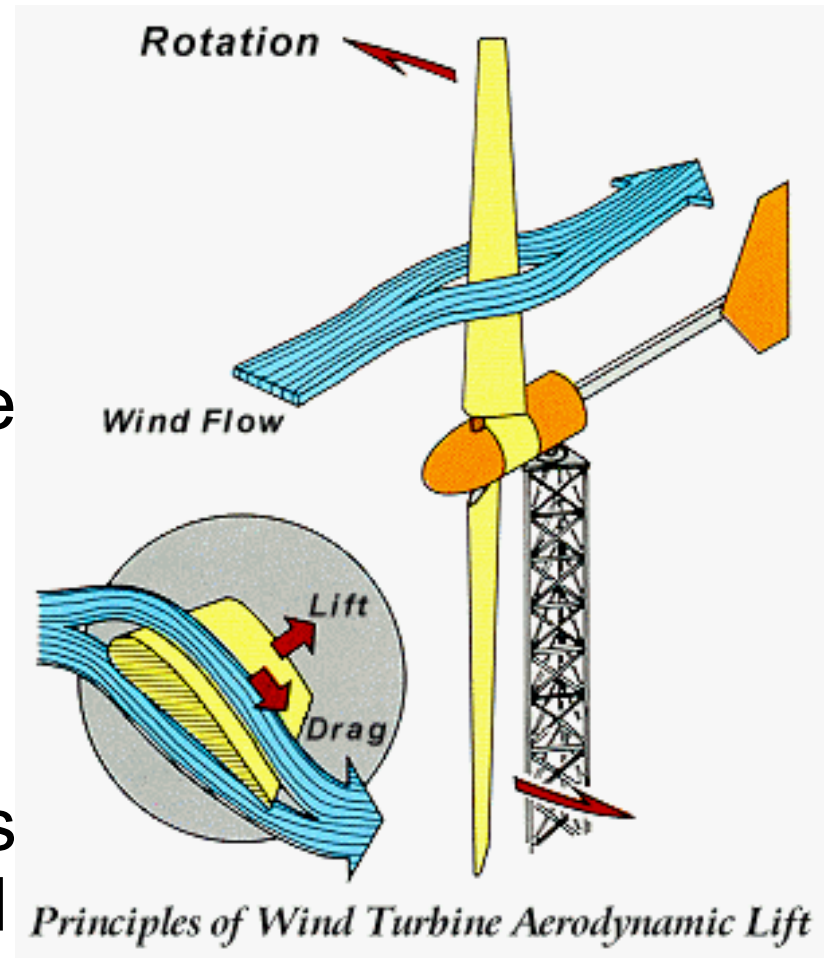
Windmills of the Past



- Windmills are a vanishing symbol of the American Prairie and West
- These small windmills drove water pumps that made cattle ranching possible
- Modern wind turbines are much larger and more efficient

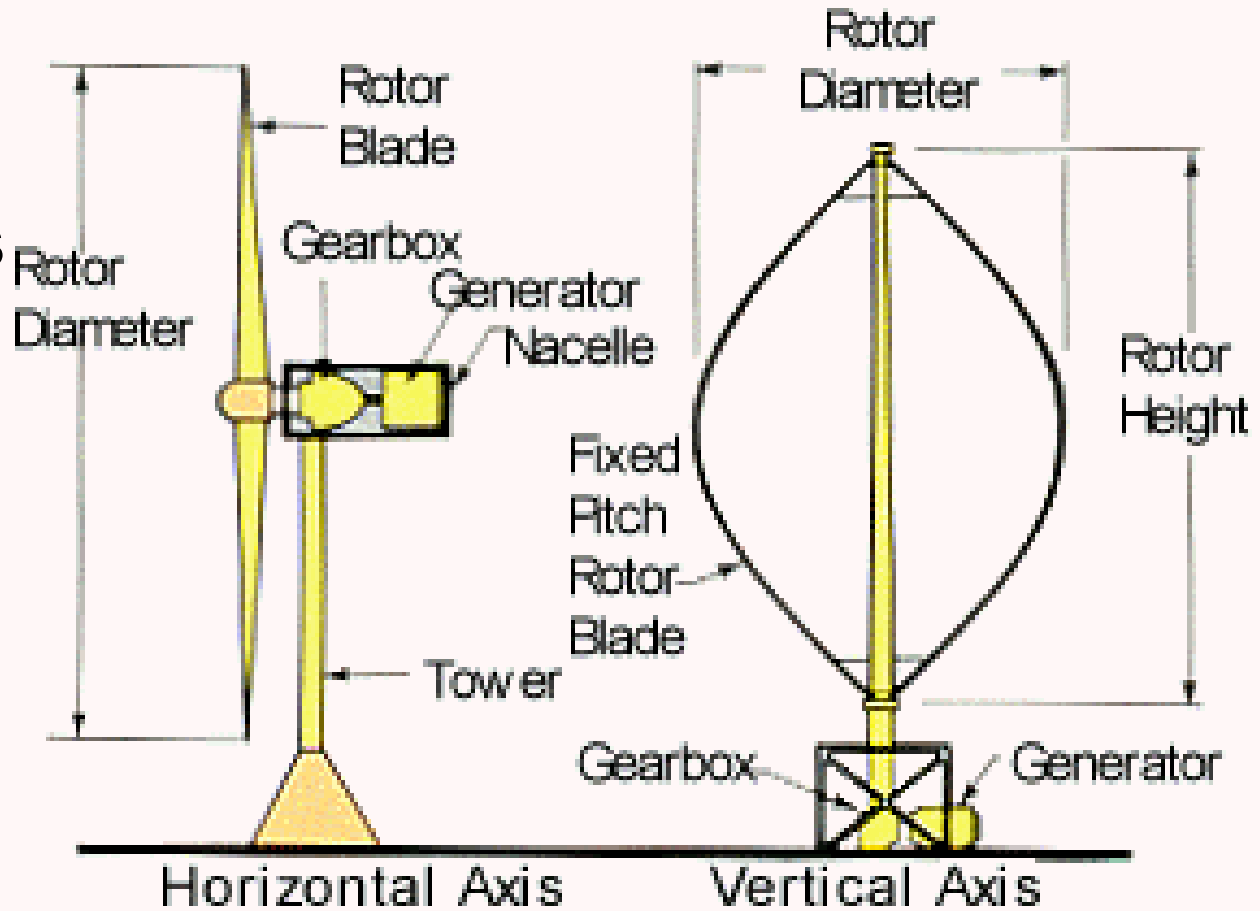
Wind Energy Principles

- The wind turbine blade is an airfoil, like an aircraft's wing, and generates lift and drag
- The lift generates a torque that turns a generator mounted to the turbine shaft
- The blade shape is optimized along the radius for varying average speed



Wind Turbine Configurations

- Horizontal axis
- Vertical axis



Source: AWEA

Wind Turbine Configurations

Wind Turbine Components

- Blade or rotor, which converts the energy in the wind to rotational shaft energy
- Drive train, usually including a gearbox and a generator
- Tower that supports the rotor and drive train
- Other equipment, including controls, electrical cables, ground support equipment, and interconnection equipment
- For high wind protection, turbine should be capable of automatically parking in a safe configuration

Construction of 1.2 MW Windmill by Canadian Hydro



Constructing the base



The base is backfilled and compacted to the top of the concrete base



One section of the two piece tower arriving by truck



This is the access door to the tower



Three blades will be mounted on this hub when the nacelle is in place on the tower



Three blades are ready to be lifted into place
(despite the age of the car, this is late 2002)



Completion of the tower and turbine blade installation



1.3 MW Nordex Windmill



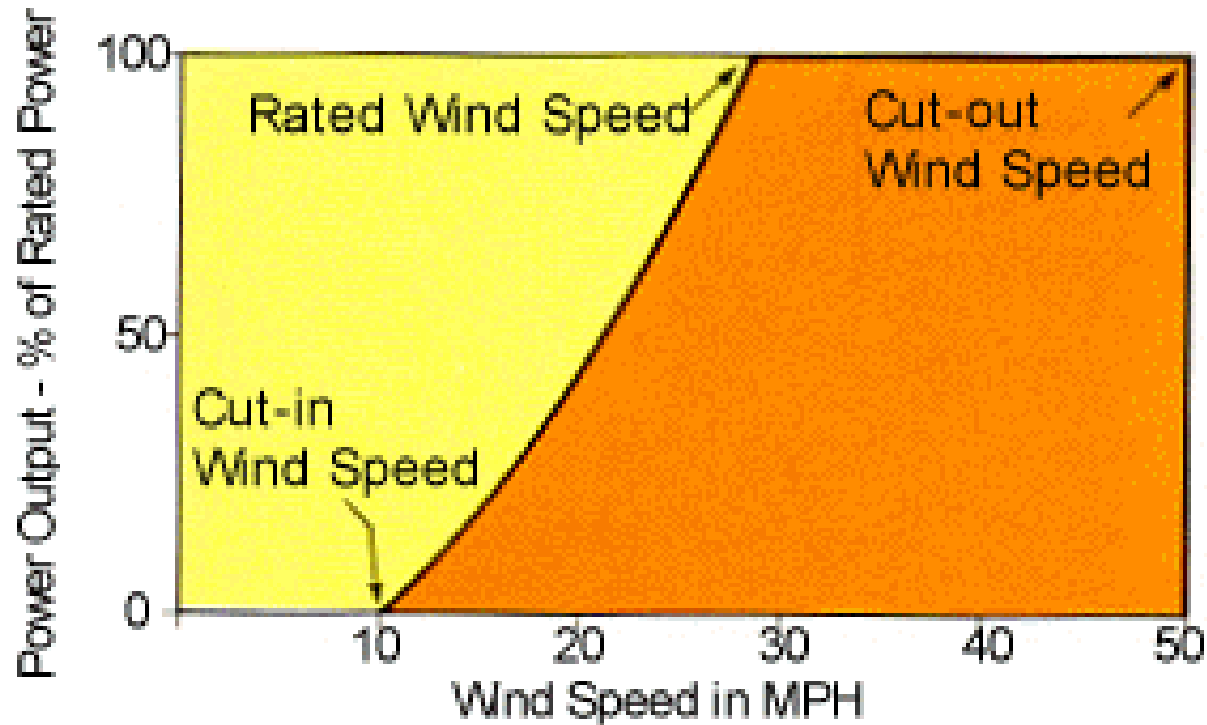
Wind “Energy” vs. “Power”

- Turbines usually classified by power, but the amount of energy produced is more important
- Best indication of power is rotor diameter, which determines the **swept area** of the turbine
- The annual energy output (kWh) can be calculated from the **capacity factor** at the site’s average wind speed
- The capacity factor is the actual energy output divided by potential output if the turbine ran continuously at its rated power output

Wind “Energy” vs. “Power”

- Typical wind turbine capacity factors are 0.25 to 0.3; a capacity factor of 0.4 would be exceptional
- Capacity factor is very sensitive to average wind speed- need to know the capacity factor at the average wind speed of the intended site
- Without a calculated capacity factor, the machine's power curve can provide a crude indication of the annual energy output of any wind turbine.
- The predicted power output at the average wind speed of the wind turbine site can be found using the power curve

Wind Turbine Power Curve



Idealized Power Curve for a Wind Turbine

Source: AWEA

The Cubic Power Law



- Analogous to the fan power law, the theoretical power available from the wind is proportional to the wind speed cubed

Source:
www.nordex-online.com

Wind Turbine Power Calculation

- Wind turbine power is given by:

$$P = \frac{1}{2} \rho \cdot A \cdot V^3 \cdot C_p \cdot \eta_g \cdot \eta_b$$

- where:

- P is power
- ρ is air density
- A is rotor swept area
- V is wind velocity
- C_p is the coefficient of performance, a max of 0.59, typ. 0.35
- η_g is the generator efficiency, typically 0.8 or higher
- η_b is the bearings/gearbox efficiency, as high as 0.9 to 0.95

Turbine Factors that Affect kWh

- **cut-in speed**- wind speed at which it begins to produce power
- **blade airfoil shape and geometry** determines power produced at moderate wind speeds
- **cut-out speed**- wind speed at which the turbine must be shut down to protect the rotor and drive train machinery from damage
- **operating characteristics**- e.g., low speed on-off cycling, shut-down behavior and reliability
- **efficiency** of drive train components, such as the generator and gear box

Small Windmills

- Size: 0.3 – 50 kW
- Small windmills for off-grid power for remote locations, e.g., water pumps, remote homes
- Costs range from \$2000 to \$6000 per kW
- Designed for reliability and low maintenance
- Require ~10 mph wind speed to function



Small (≤ 10 kW)

- Homes
- Farms
- Remote Applications
(e.g. water pumping, telecom sites, icemaking)

Source: NREL

Intermediate Sized Windmills



Intermediate
(10-100 kW)

- Village Power
- Hybrid Systems
- Distributed Power

- Costs in the \$1000 to \$2500/kW range
- Could be used at remote outposts with no access to grid power

Source: NREL

Large Wind Turbines



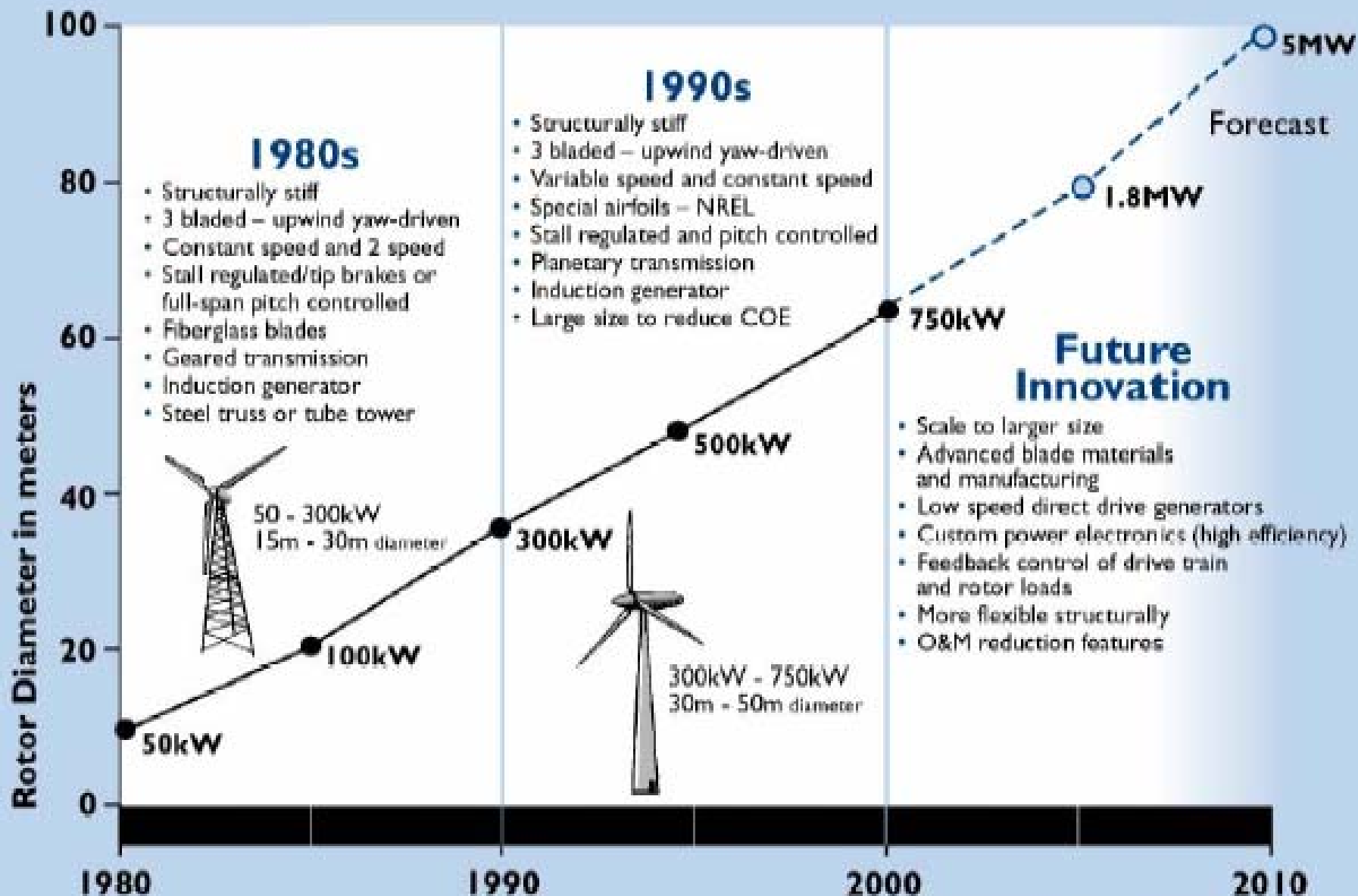
Source: NREL

Large (660 kW - 2+MW)

- Central Station Wind Farms
- Distributed Power

- Size ranges from 500 kW to over 2 MW
- Primary application is central station wind farms to allow utilities to sell “Green Power”
- Cost less than \$1000/kW
- Typically require 13+ mph wind speeds

Evolution of Commercial Wind Power



Factors Driving Wind Power

- Declining Wind Costs
- Fuel Price Uncertainty
- Federal and State Policies
- Economic Development
- Green Power
- Energy Security



Source: NREL

Determining Economic Factors for Wind Power

- Wind Resource
- Financing and Ownership Structure
- Taxes and Policy Incentives
- Plant Size: equipment, installation and O&M economies of scale
- Turbine size, model, and tower height
- Green field or site expansion
- What is included: land, transmission, ancillary services

Source: NREL



Wind Energy Cost Trend

1979: 40 cents/kWh

2000:
4 - 6 cents/kWh



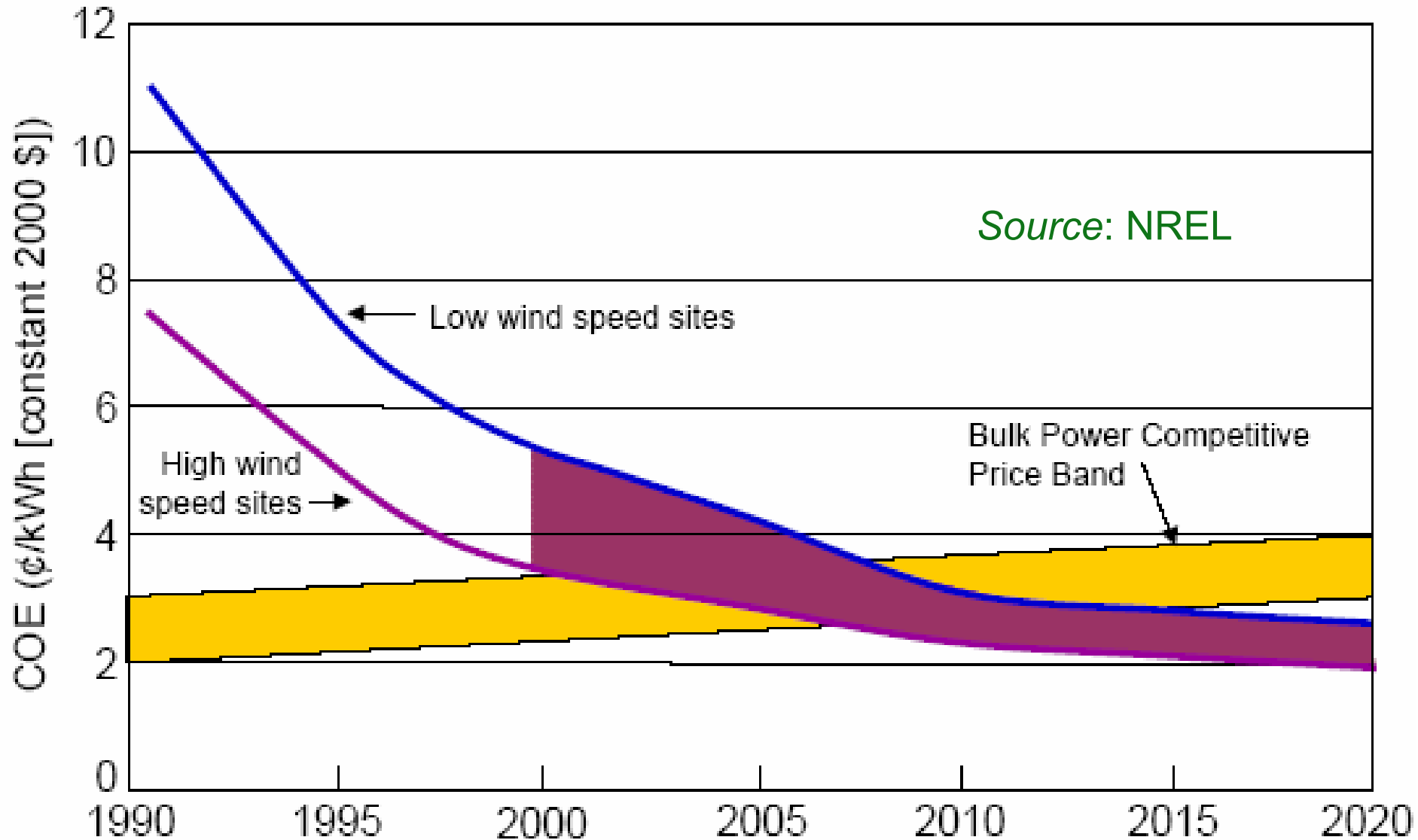
NSP 107 MW Lake Benton wind farm
4 cents/kWh (unsubsidized)

2004:
3 – 4.5 cents/kWh

Source: NREL

- Increased Turbine Size
- R&D Advances
- Manufacturing Improvements

Cost of Wind Power Trend



Source: NREL

Issues Affecting Growth of Wind Power

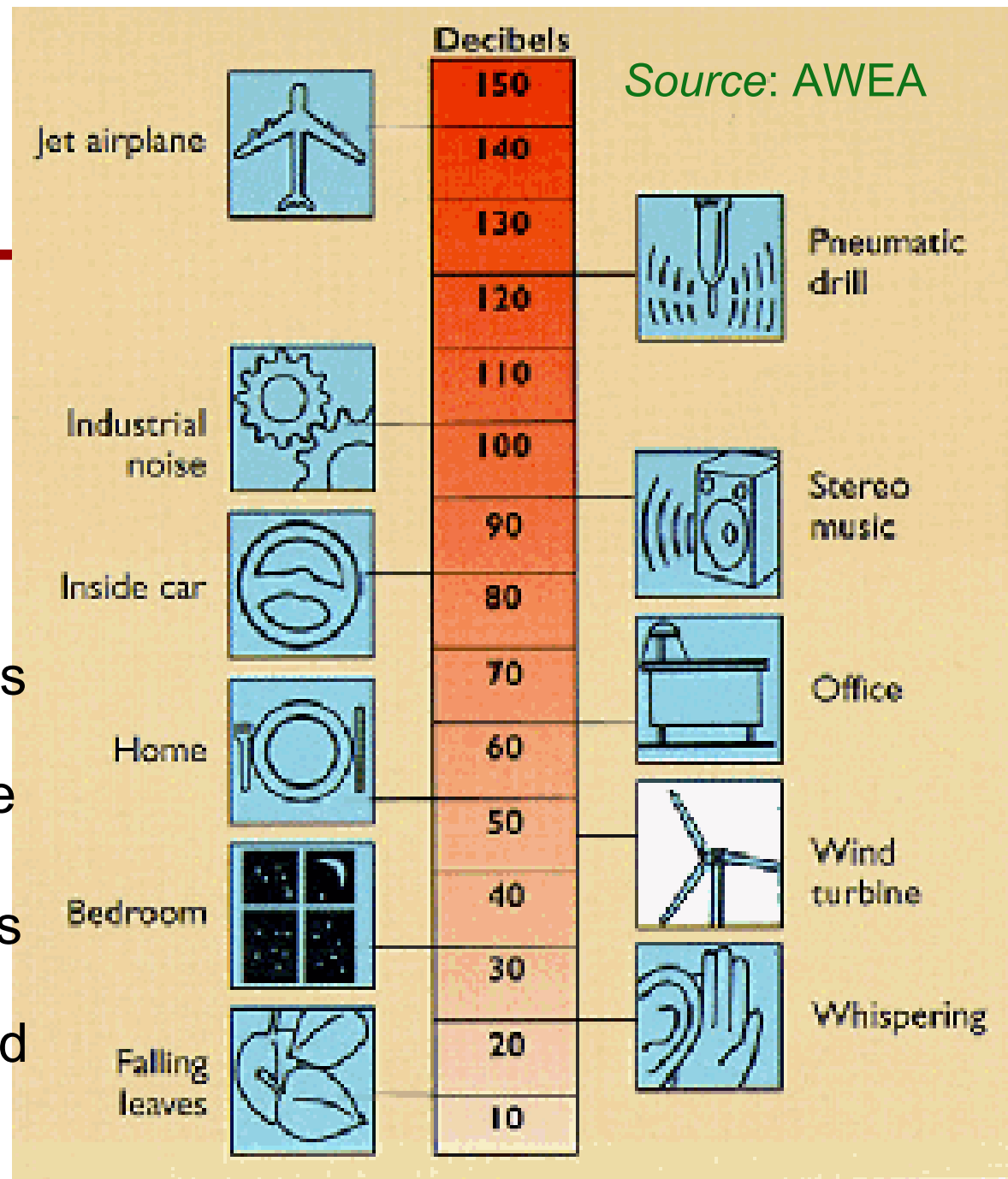
- Restructuring and Policy Uncertainty
- Transmission: access, RTO formation and rules, new lines
- Operational impacts: intermittency, ancillary services, allocation of costs
- Siting and Permitting: avian, noise, visual, federal land
- Accounting for non-monetary value: green power, no fuel price risk, reduced emissions



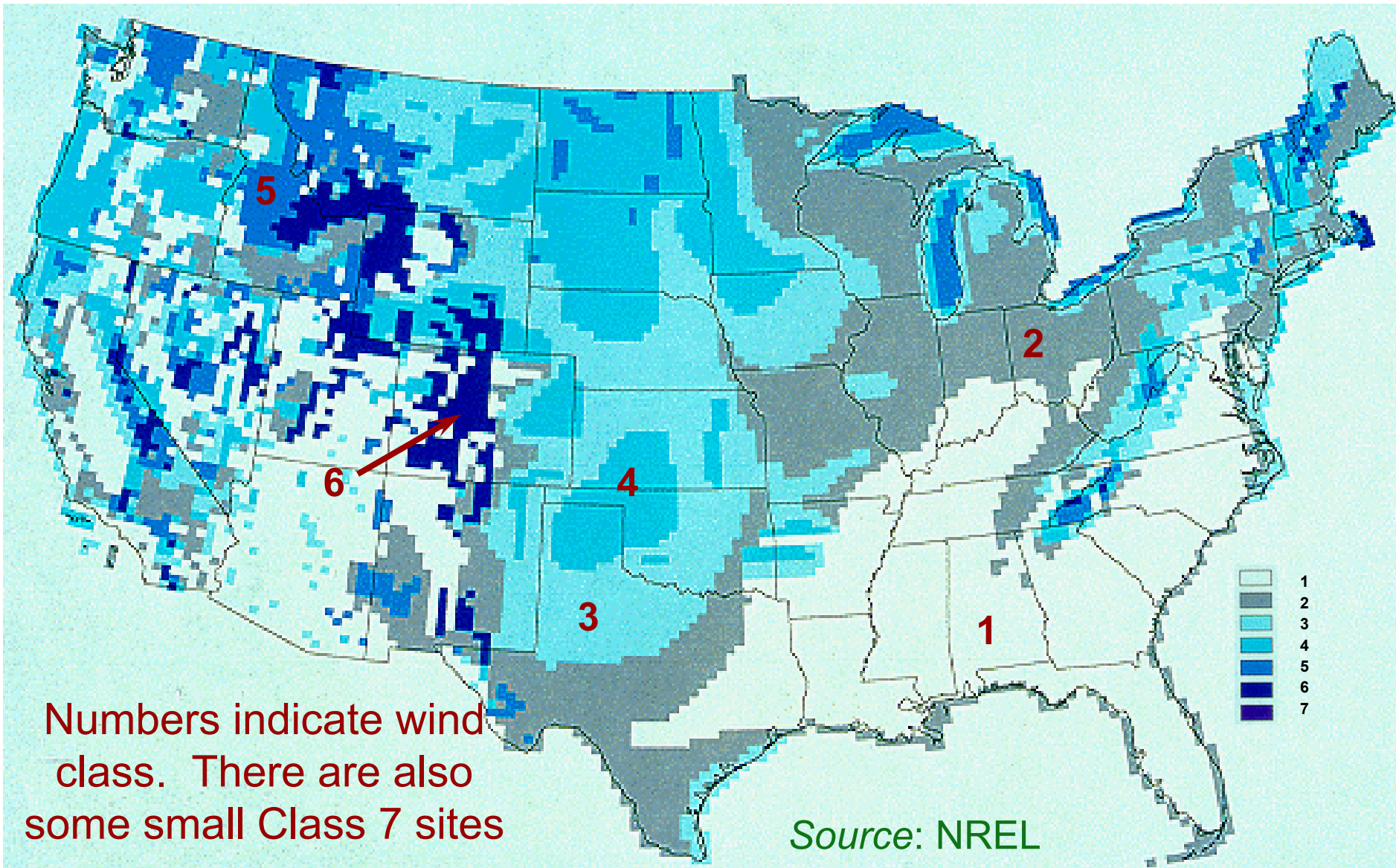
Source: NREL

Noise

- **Noise** was an issue with early wind turbines
- Noise reduced by adjusting the thickness of the blades' trailing edges and by orienting blades upwind of the turbine tower
- appropriate setbacks from nearby residences also used



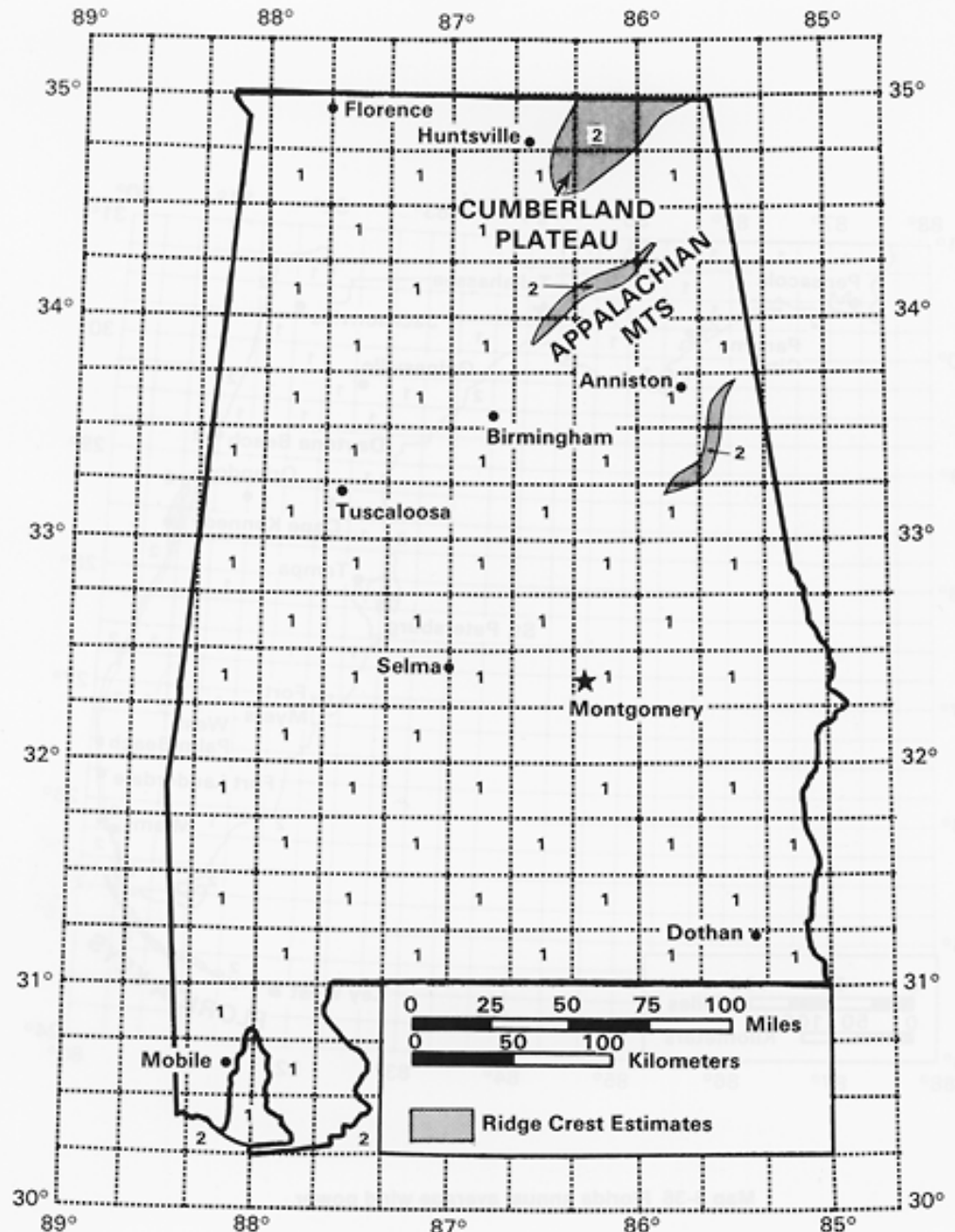
US Wind Resources



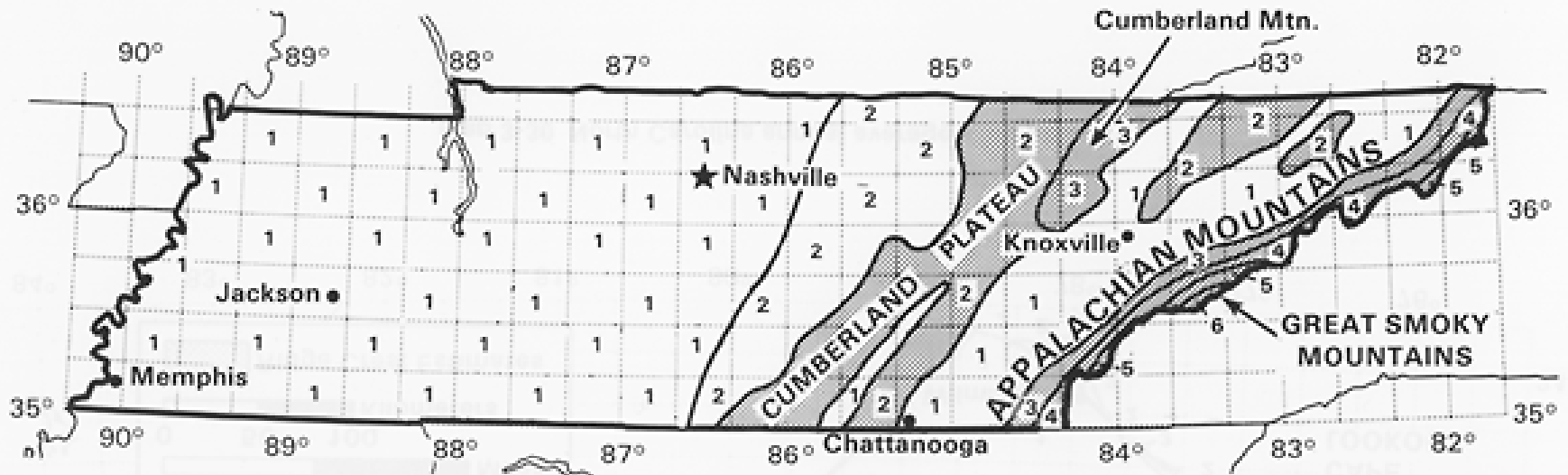
Alabama's Wind Resources

- Alabama is not blessed with wind (other than occasional hot air from Montgomery)
- Most commercially viable wind sources are class 3 or higher

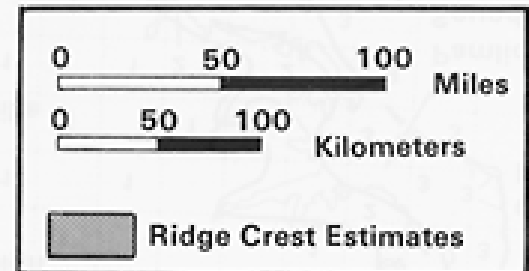
Source: NREL

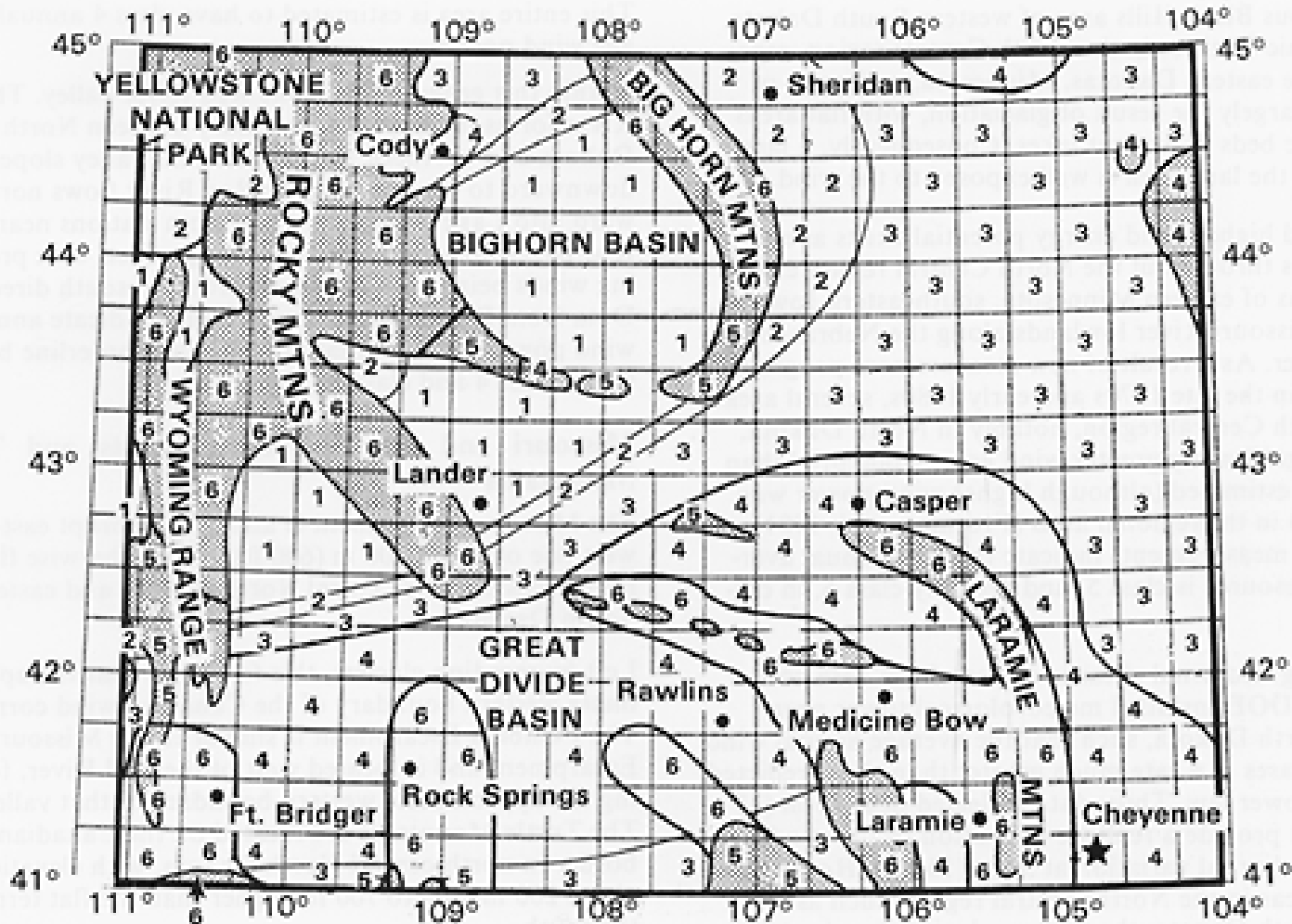


Tennessee has some good wind sites in Appalachian region

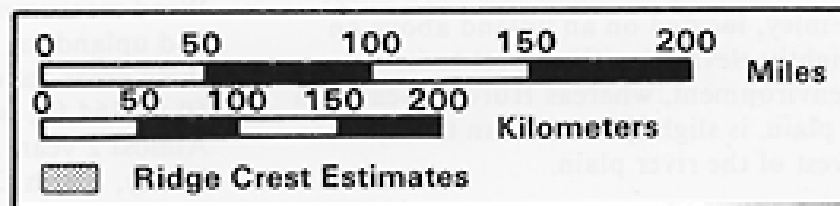


Source: NREL



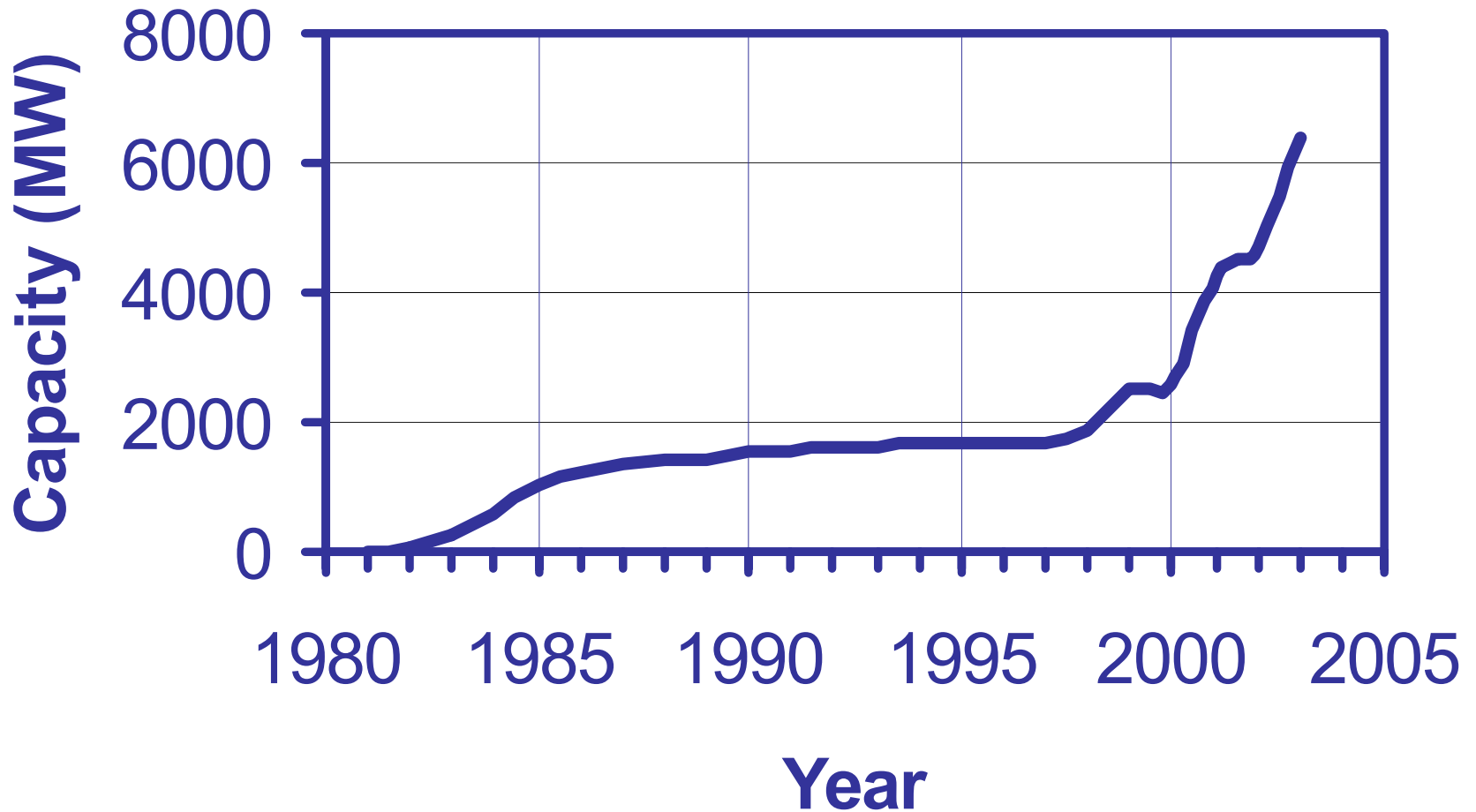


Source: NREL



Wyoming has abundant wind

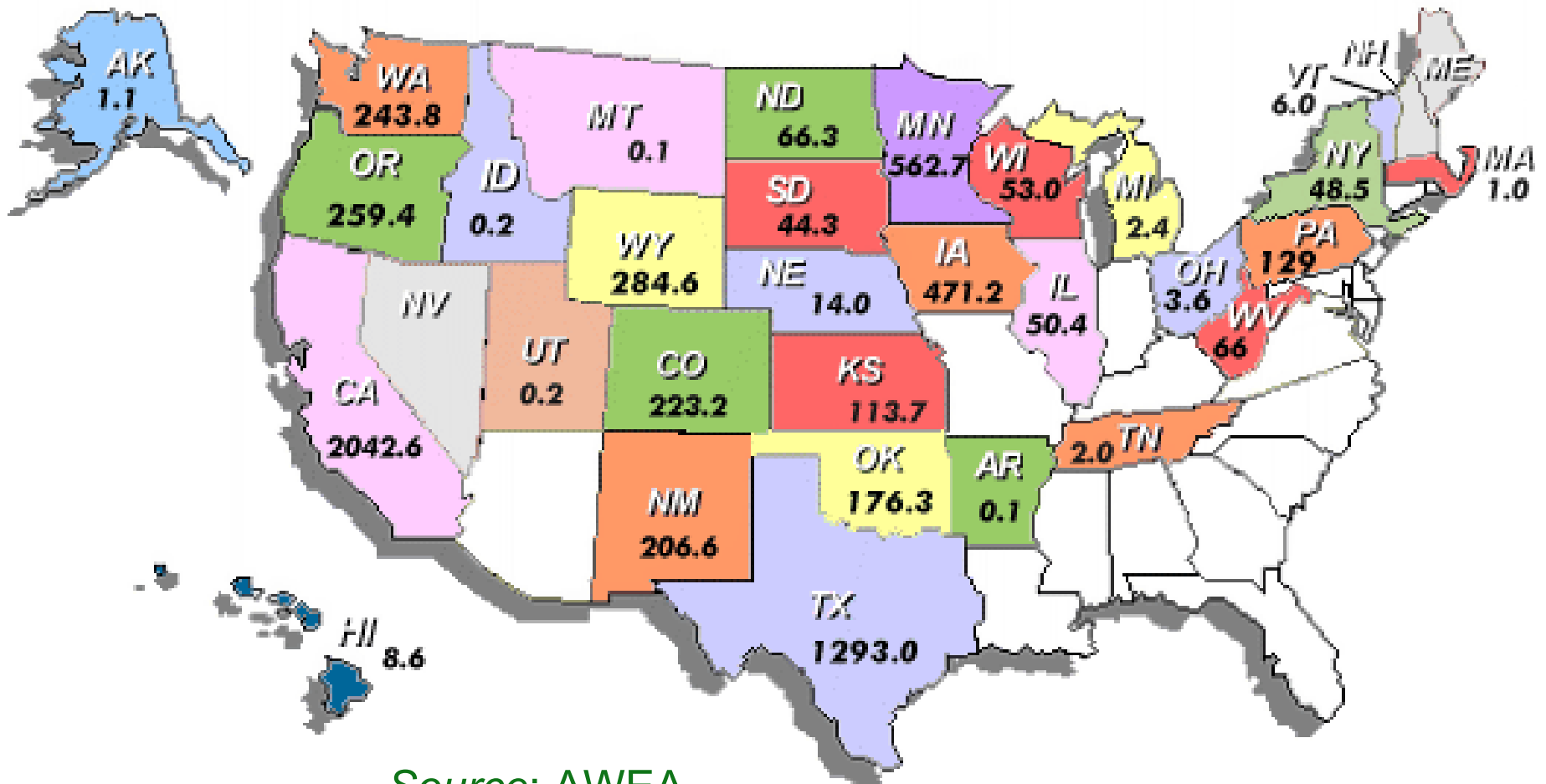
Installed US Wind Power Capacity



Data Source: AWEA

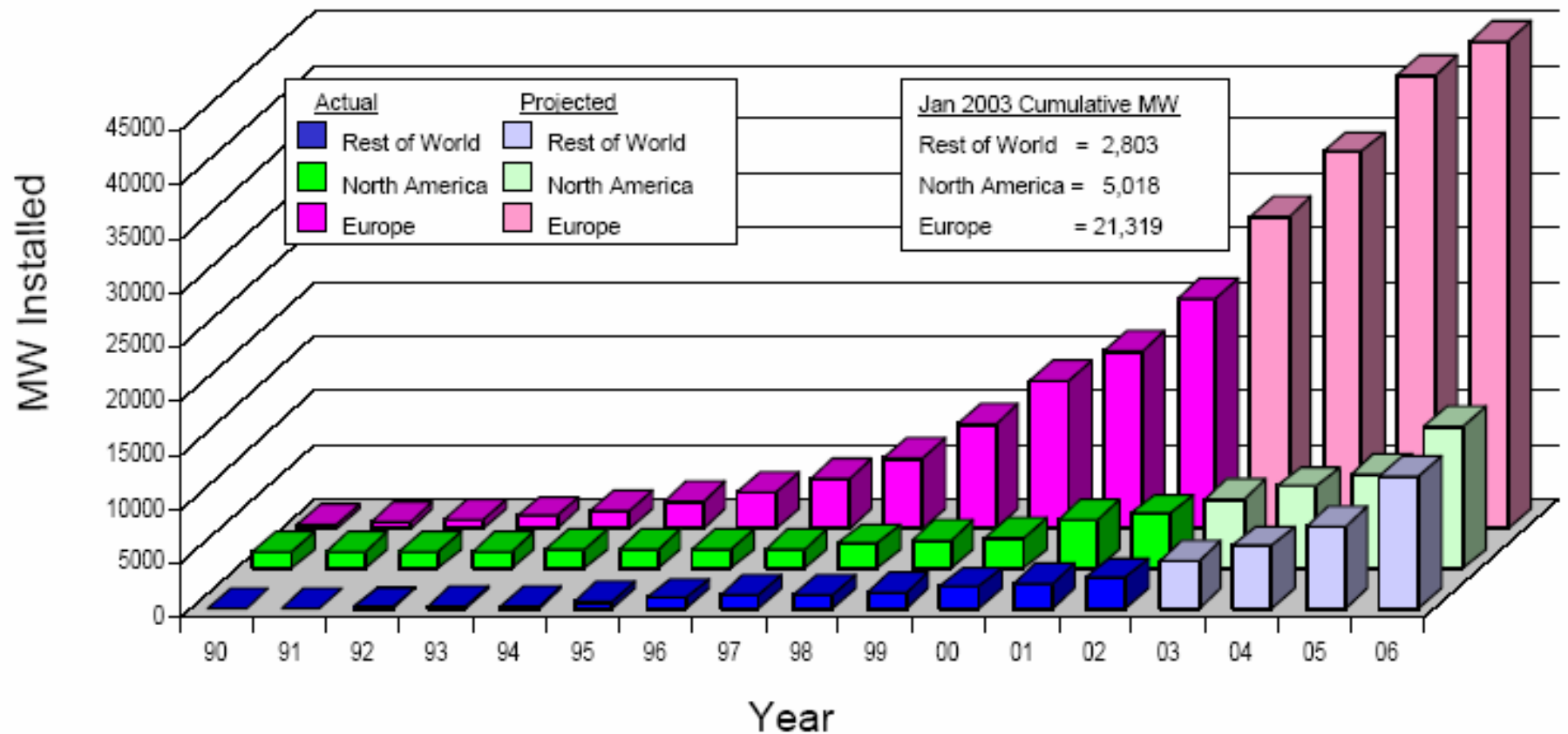
Installed Capacity by State

(Updated January 21, 2004)



Source: AWEA

Growth of Wind Energy Capacity Worldwide



Sources: BTM Consult Aps, March 2001

Wind Power- Primary Future Renewable Energy Source?

