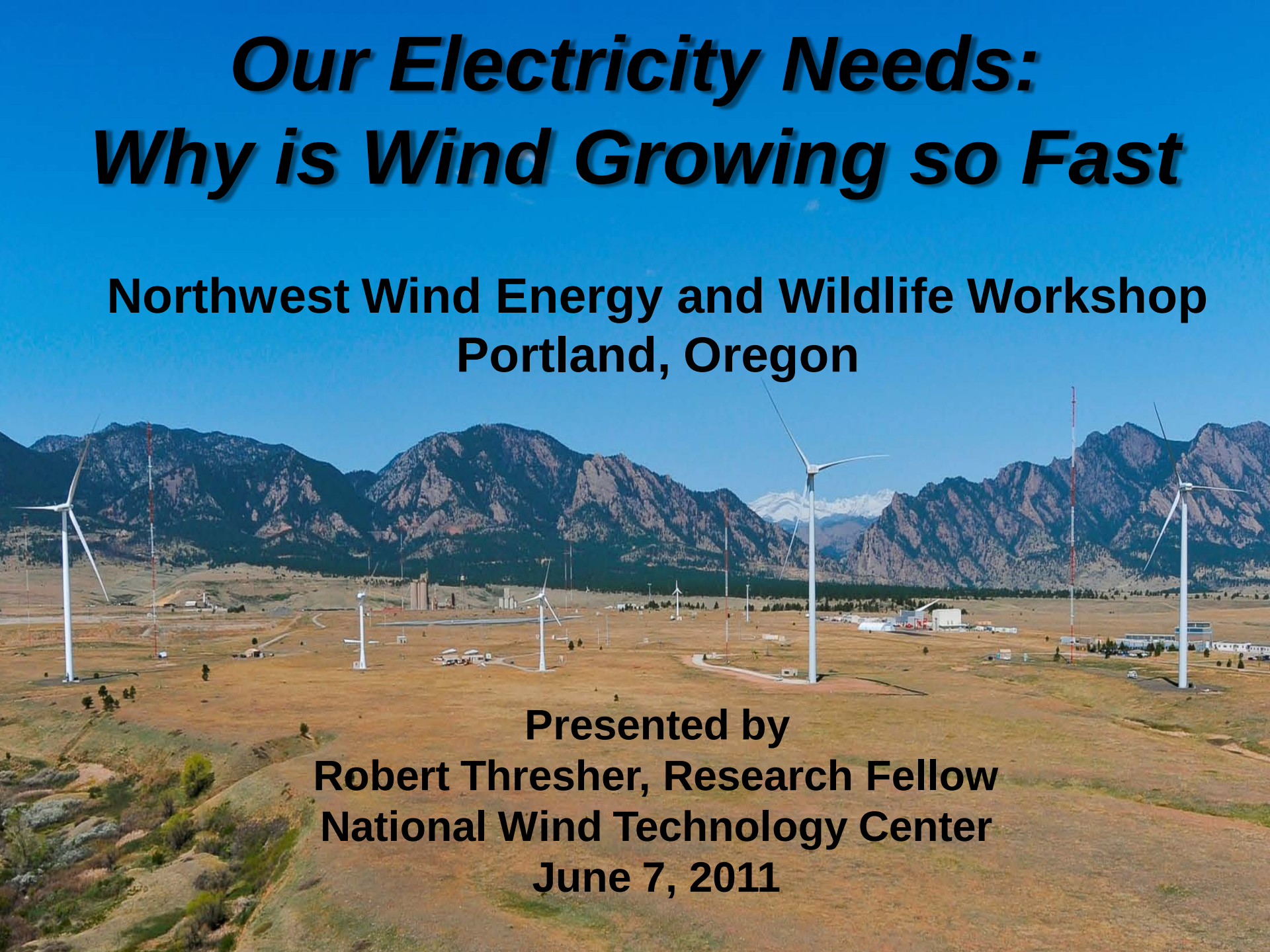
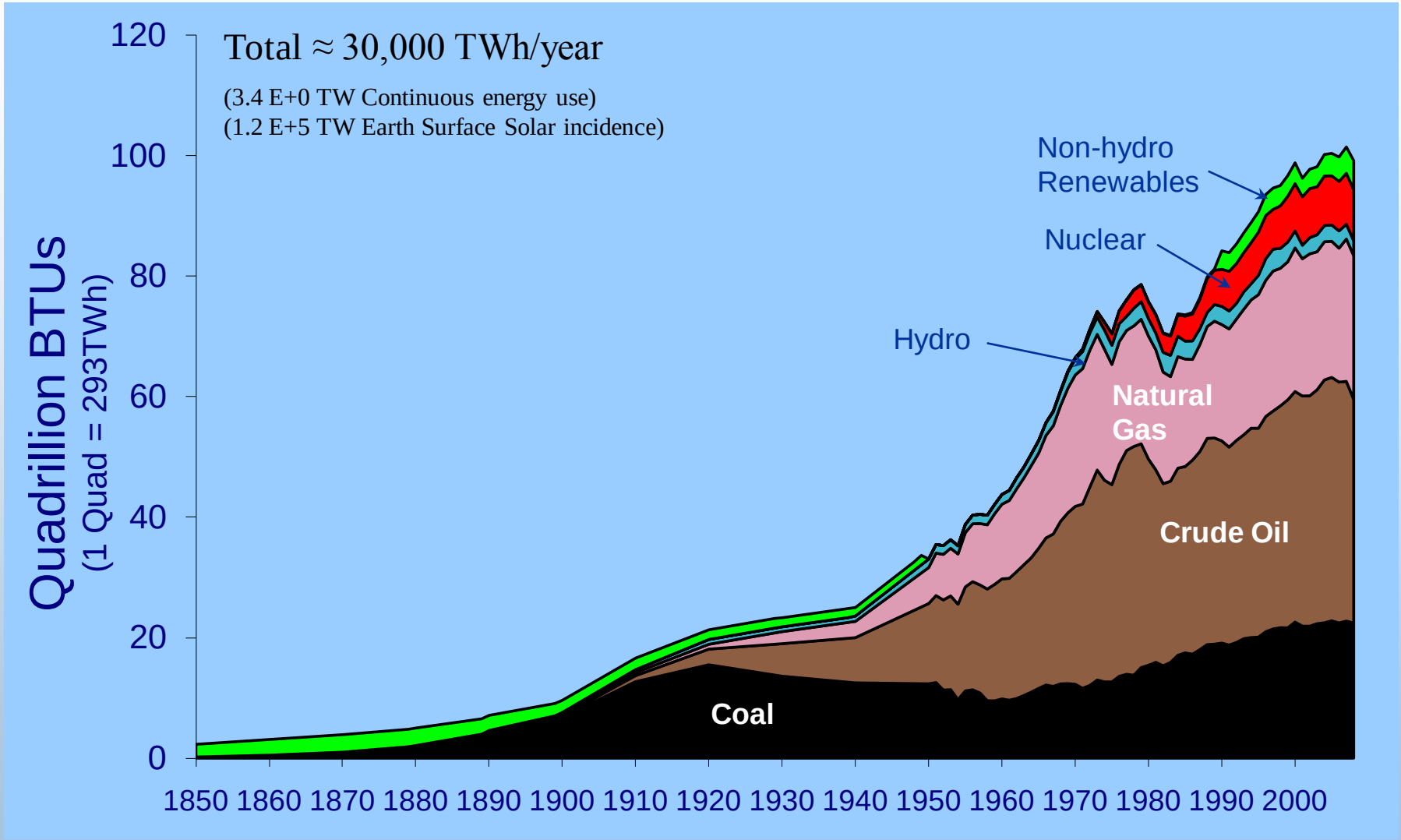
Our Electricity Needs: Why is Wind Growing so Fast

Northwest Wind Energy and Wildlife Workshop
Portland, Oregon



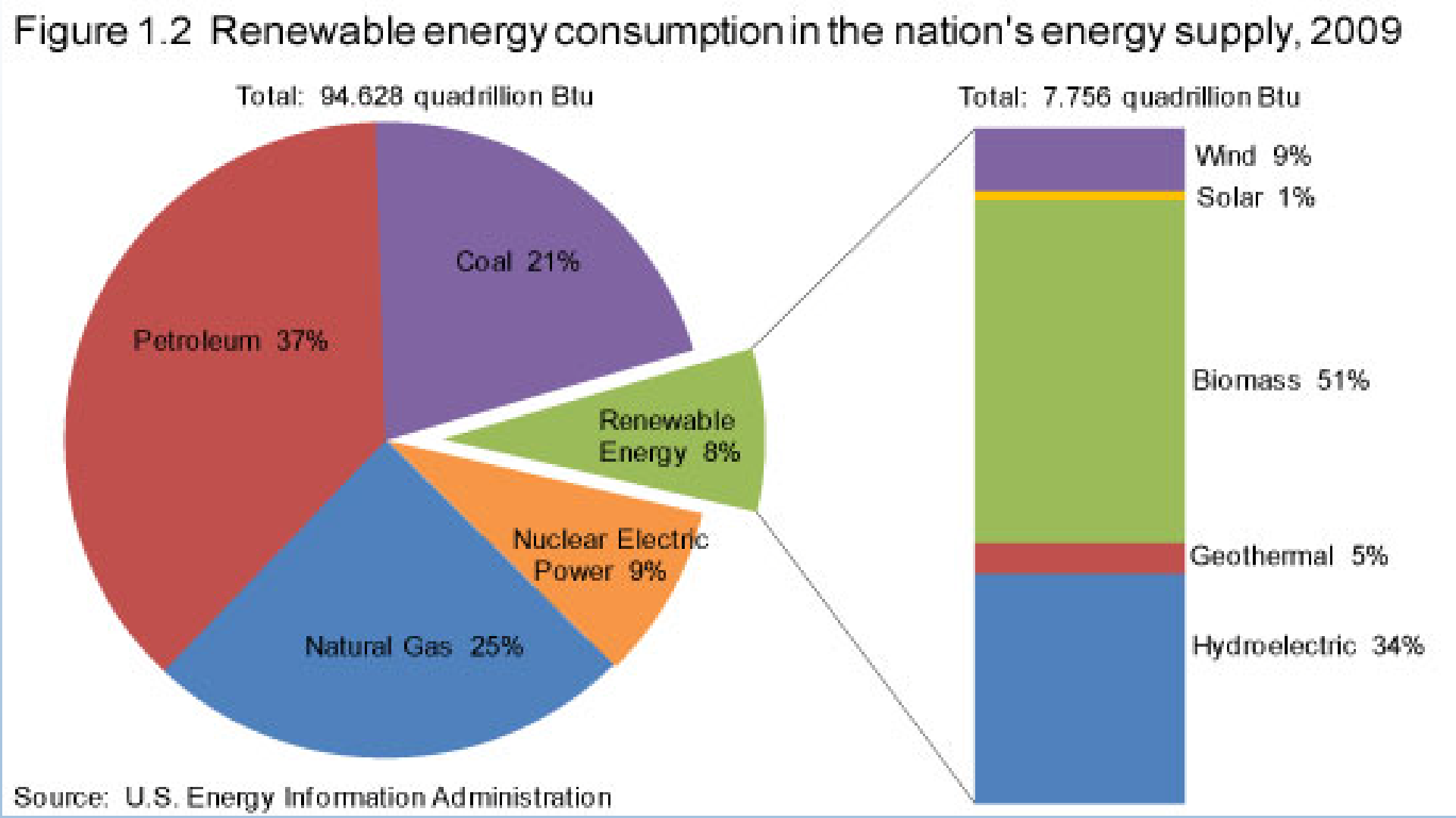
Presented by
Robert Thresher, Research Fellow
National Wind Technology Center
June 7, 2011

The U.S. Energy Picture 1850-2008

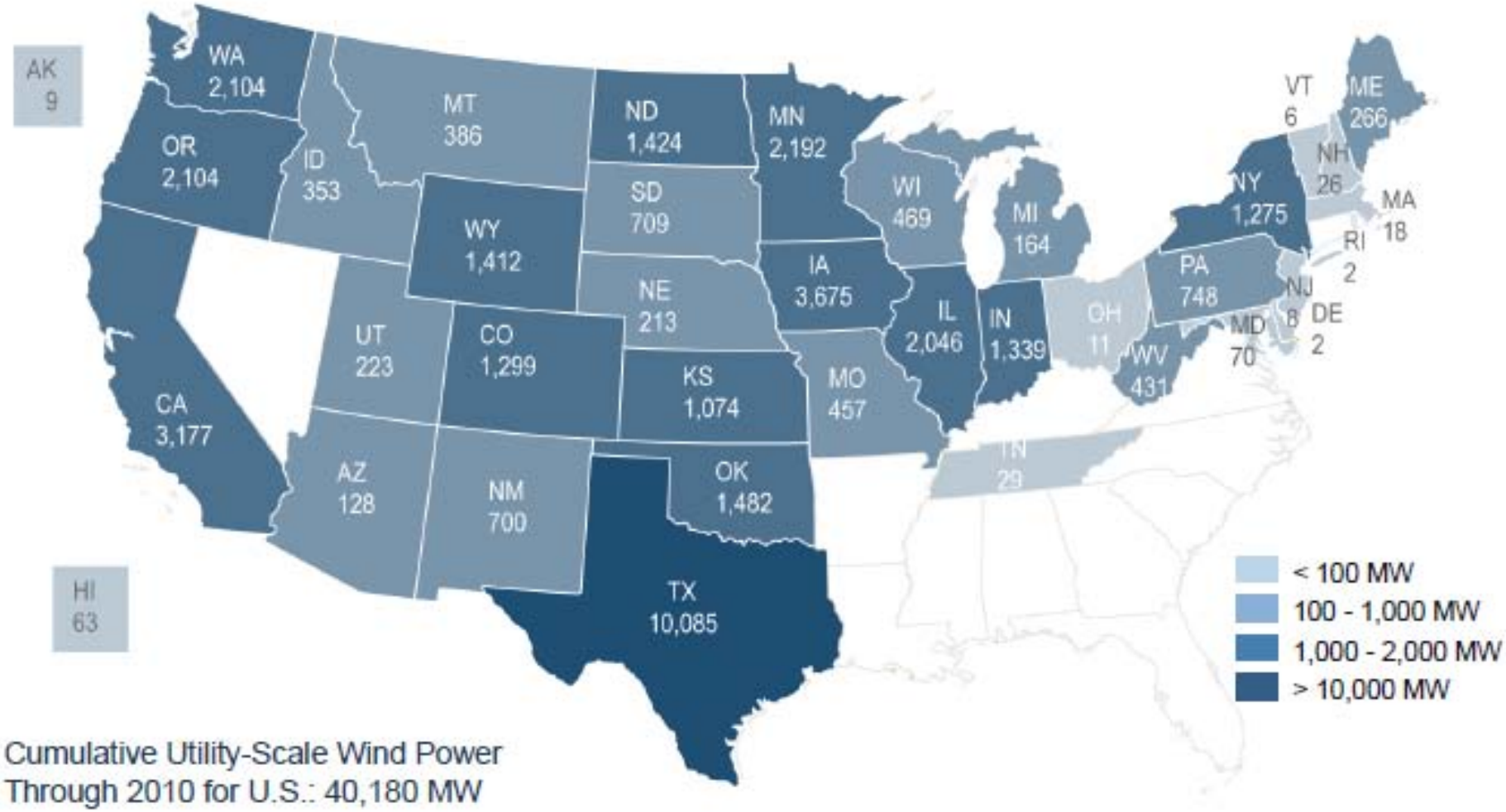


Source: 1850-1949, Energy Perspectives: A Presentation of Major Energy and Energy-Related Data, U.S. Department of the Interior, 1975; 1950-1996, Annual Energy Review 1996, Table 1.3. Note: Between 1950 and 1990, there was no reporting of non-utility use of renewables. 1997-2008, Annual Energy Review 2008, Table F1b.

Energy sources in the United States in 2009

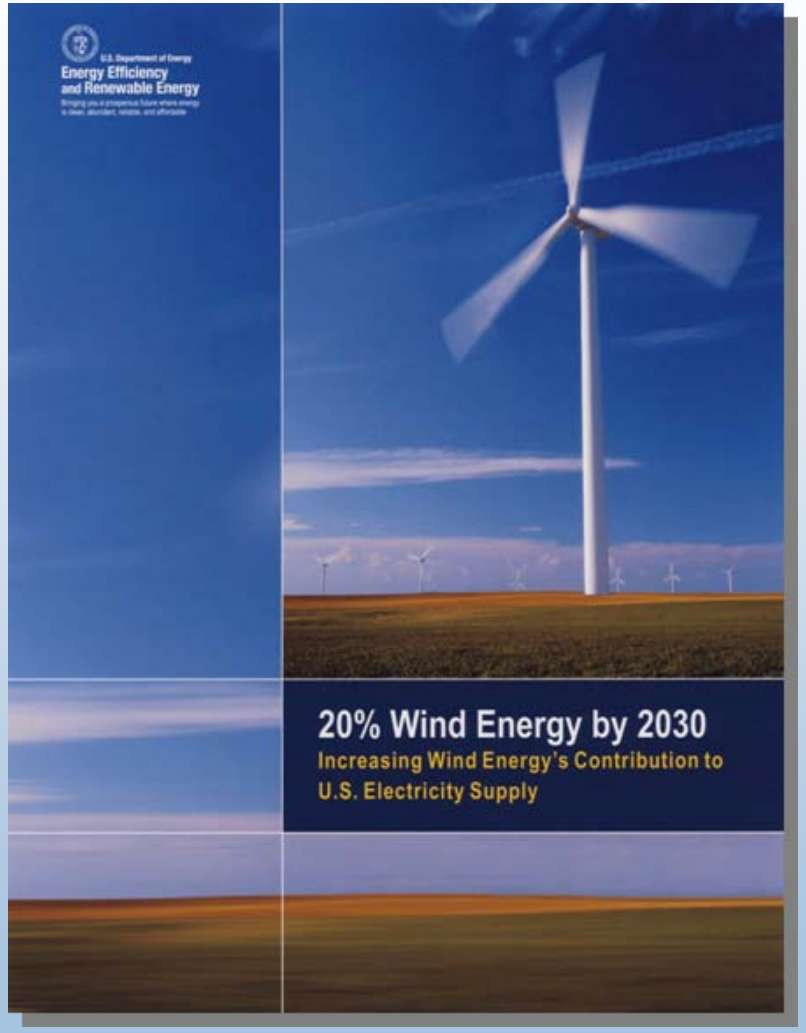


Installed Capacity by State



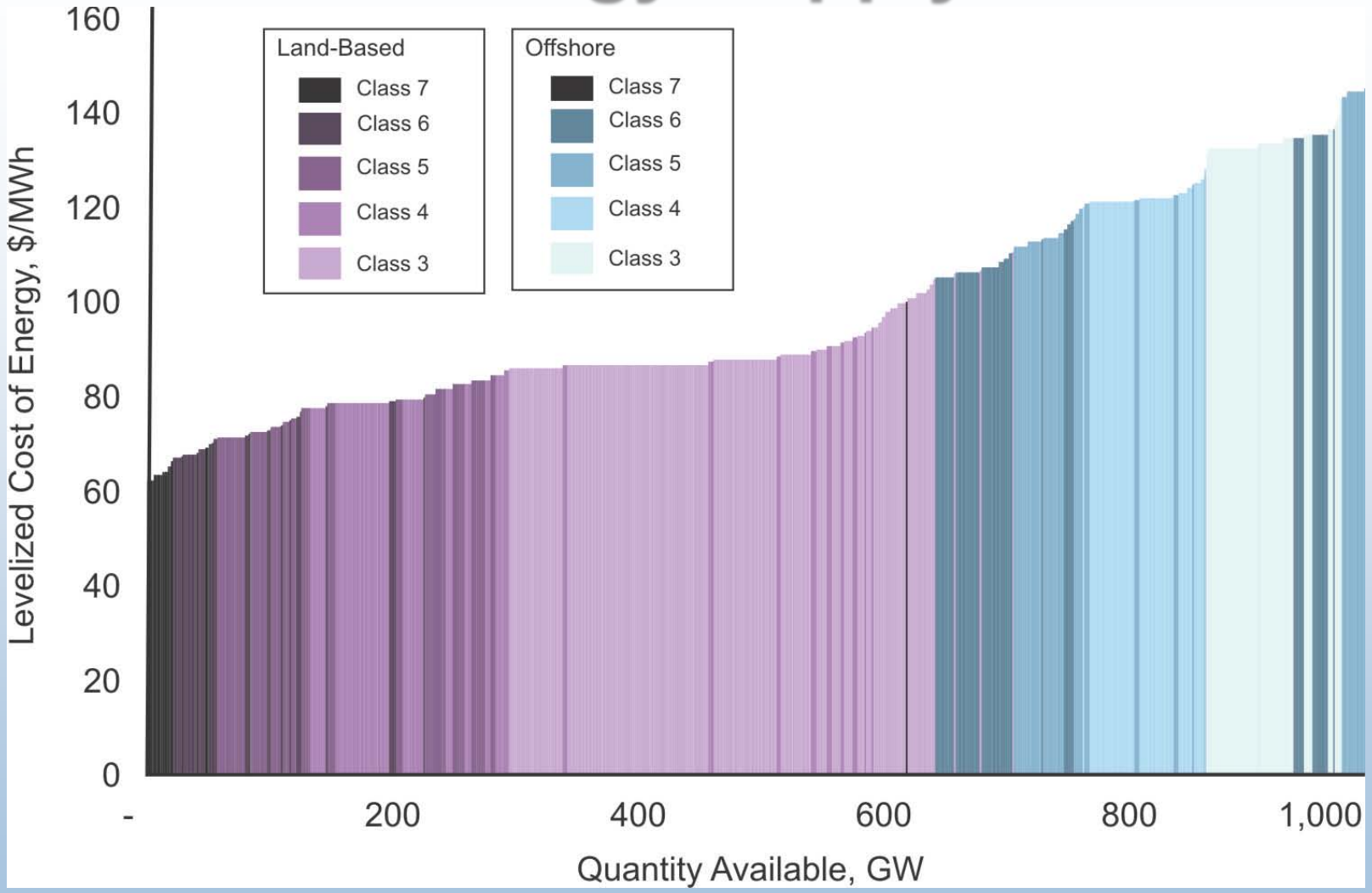
Cumulative Utility-Scale Wind Power
Through 2010 for U.S.: 40,180 MW

A New Vision for Wind Energy
"20% Wind Energy by 2030"



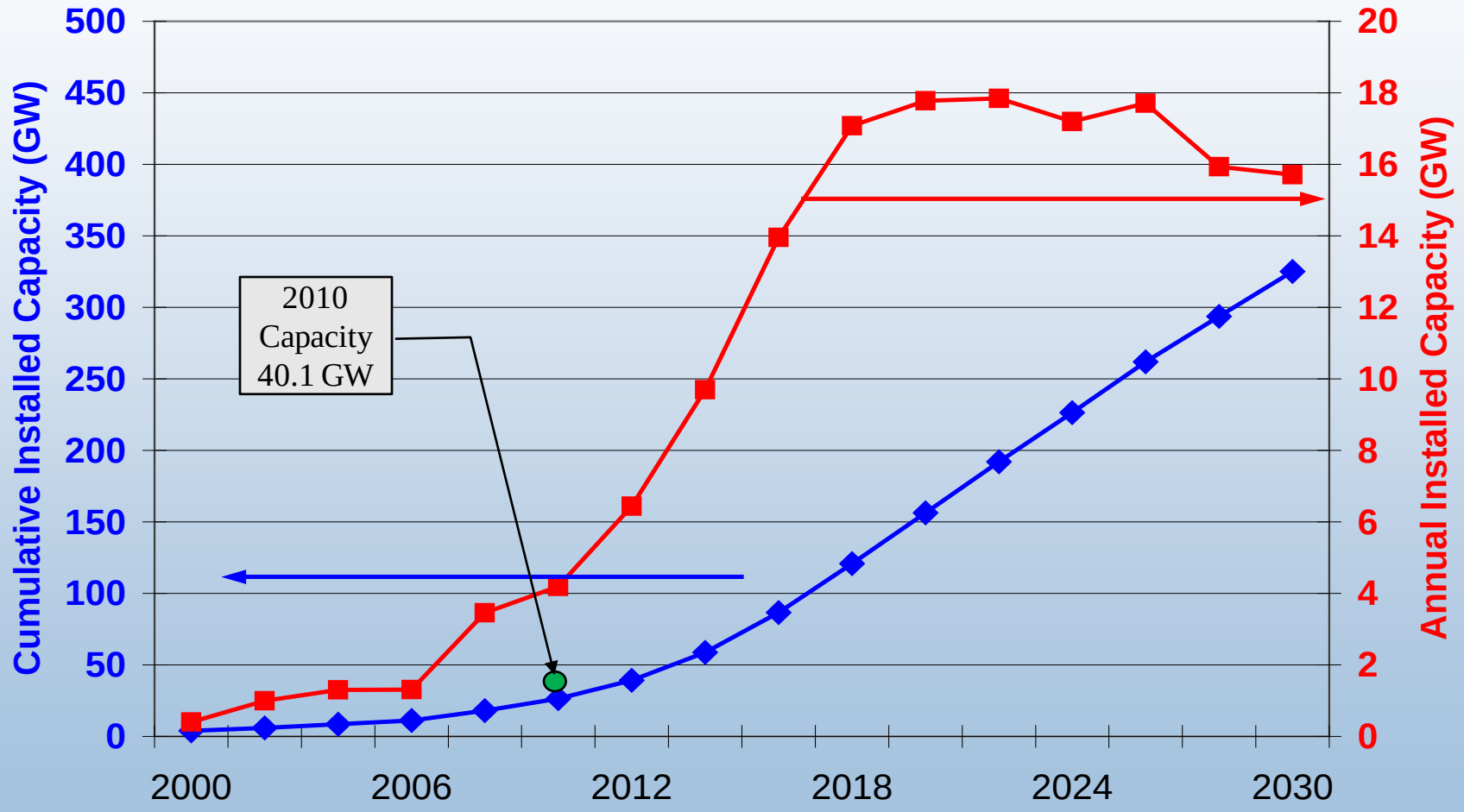
www.eere.energy.gov/windandhydro

Wind Energy Supply Curve



Excludes PTC, includes transmission costs to access 10% existing electric transmission capacity within 500 miles of wind resource.

What does 20% wind electricity look like?



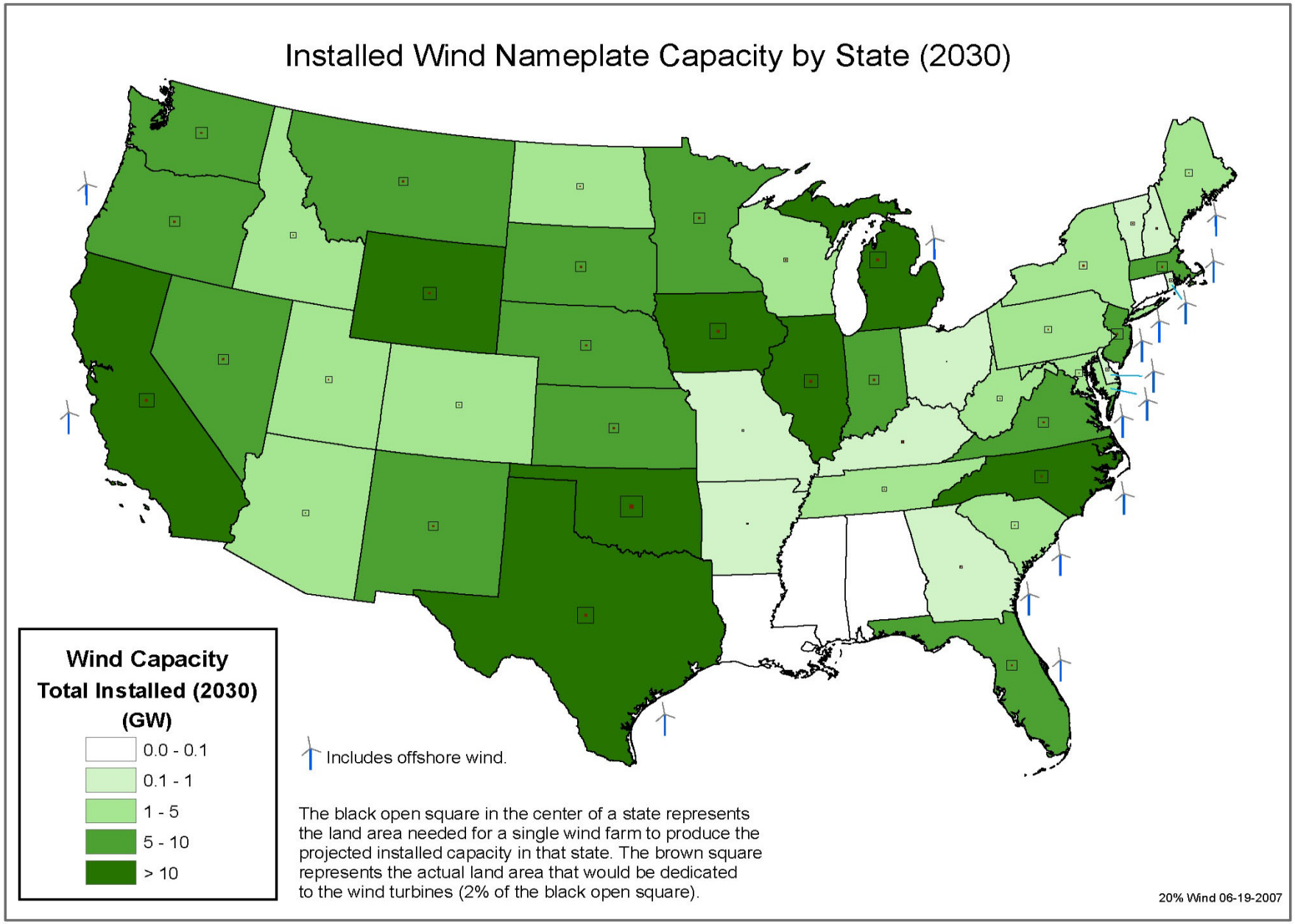

Installed Wind Nameplate Capacity by State (2030)
Wind Capacity
Total Installed (2030)
(GW)
0.0 - 0.1
0.1 - 1
1 - 5
5 - 10
> 10
Includes offshore wind.
The black open square in the center of a state represents the land area needed for a single wind farm to produce the projected installed capacity in that state. The brown square represents the actual land area that would be dedicated to the wind turbines (2% of the black open square).
20% Wind 06-19-2007

Fig 1-6

Minnesota – Economic Impacts

from 1000 MW of new wind development

Wind energy's economic "ripple effect"

Direct Impacts

Payments to Landowners:
- $2.7 million/year

Local Property Tax Revenue:
- $2.8 million/year

Construction Phase:
- 1455 new jobs
- $188.5 M to local economies

Operational Phase:
- 232 new long-term jobs
- $21.2 M/yr to local economies

Indirect & Induced Impacts

Construction Phase:
- 1530 new jobs
- $150.6 M to local economies

Operational Phase:
- 177 local jobs
- $18.2 M/yr to local economies

Totals
(construction + 20yrs)

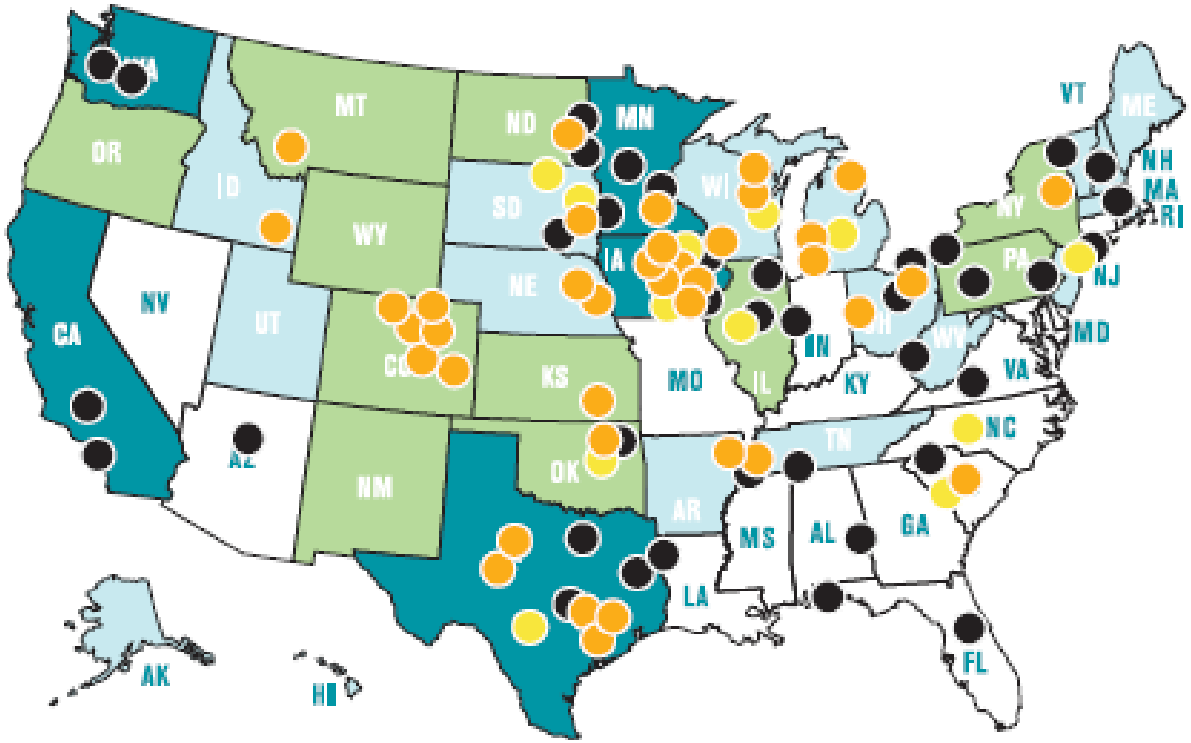
Total economic benefit = $1.1 billion

New local jobs during construction = 2985

New local long-term jobs = 409

Construction Phase = 1-2 years
Operational Phase = 20+ years

Wind Power Jobs: Revitalizing Our Domestic Manufacturing Base

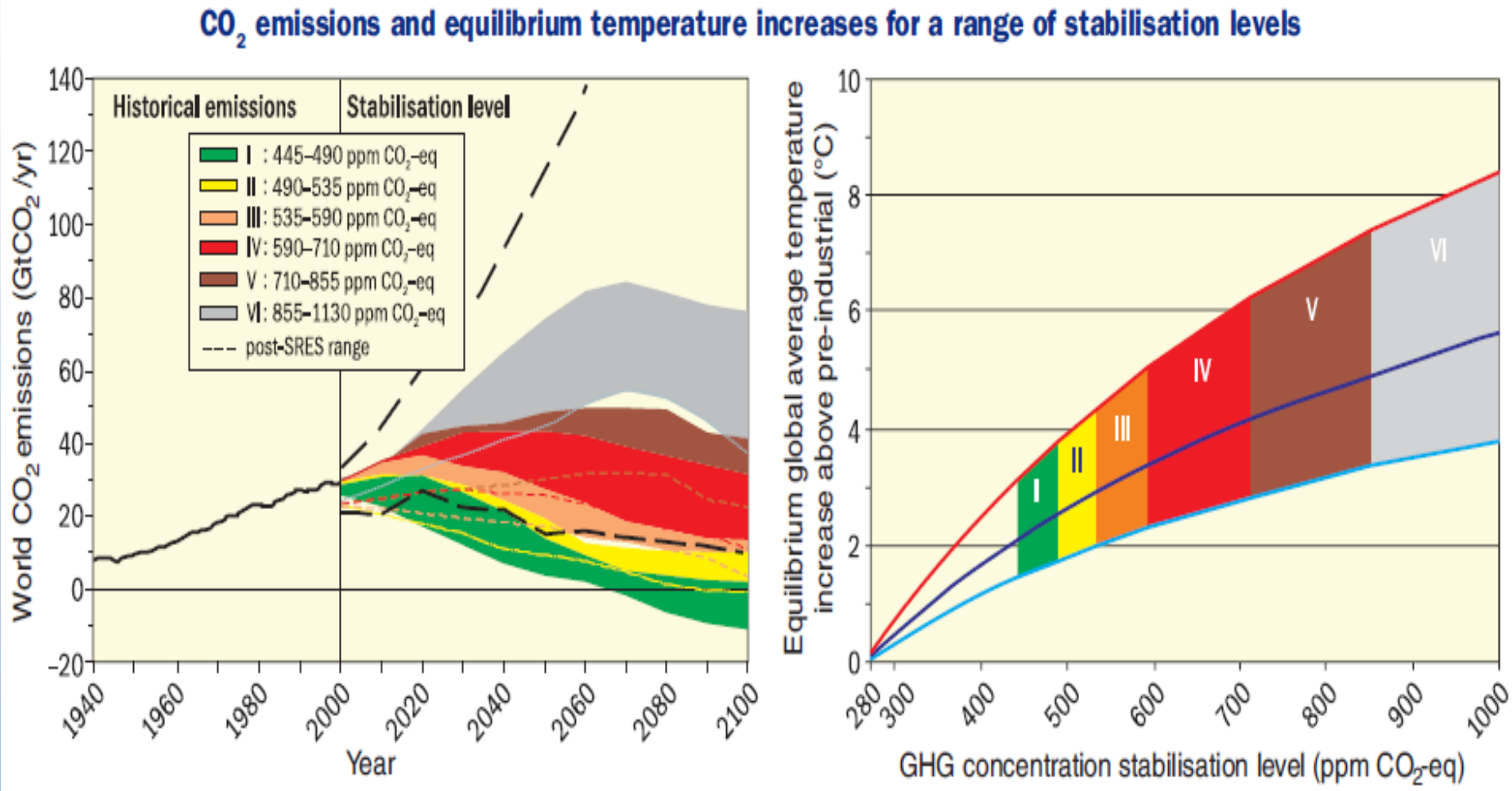


Wind generation capacity installed (megawatts, MW*)	Manufacturing facilities (existing or announced)
> 1000 MW	Online Prior to 2007
> 100 MW	Online, Expanded or Announced in 2007
< 100 MW	Online, Expanded or Announced in 2008

* One MW generated enough electricity to power the equivalent of 250-300 average homes.

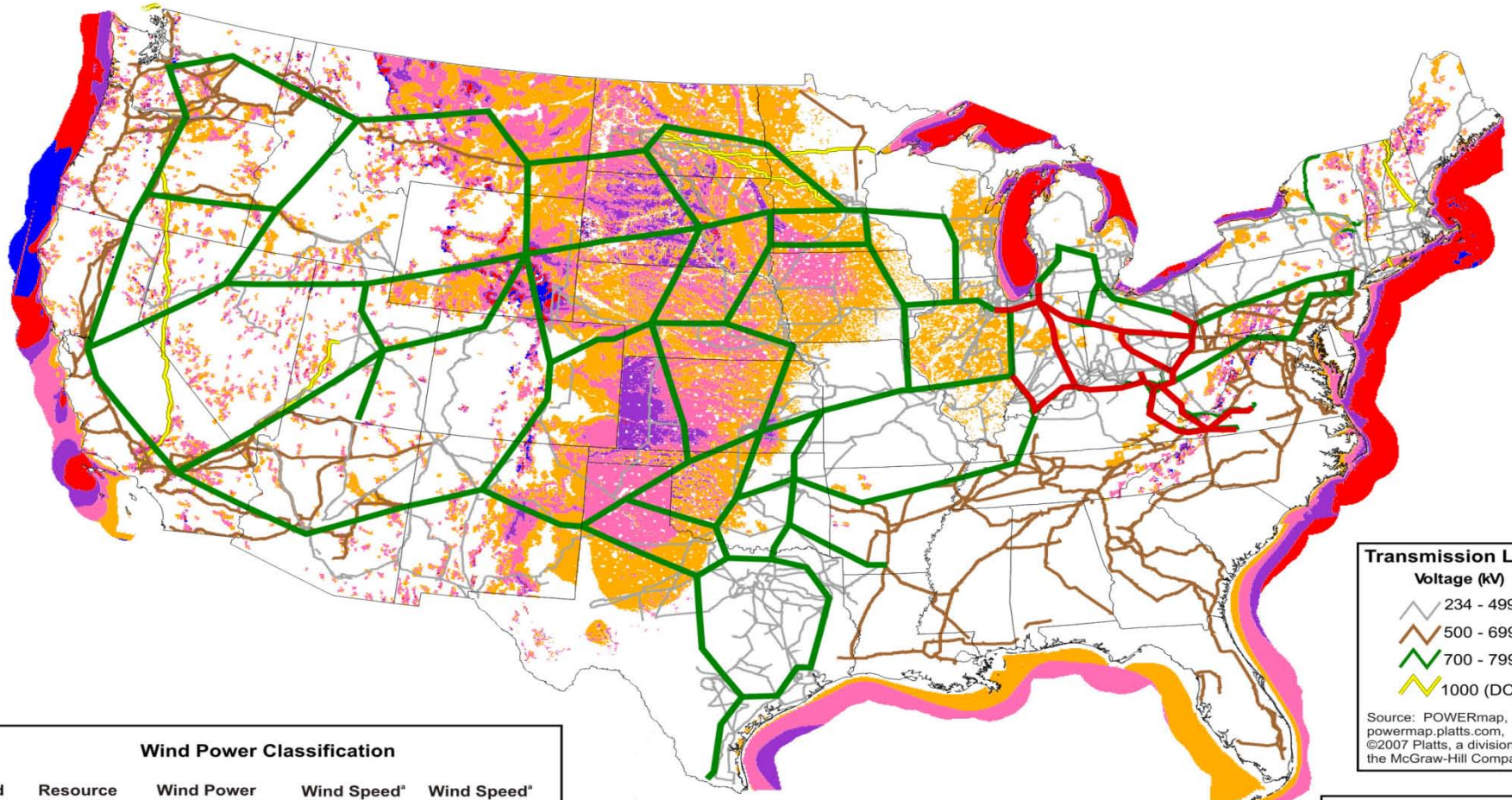
Source: The Governors' Wind Energy Coalition

Climate Change Concerns and the Projected Impacts (A big concern in Europe and no so big in the U.S.)



Source: IPCC 2007

Conceptual Transmission Overlay
from the 20% Wind Scenario
(~ 20,000 Miles of new transmission)



Transmission Lines
Voltage (kV)
- 234 - 499
- 500 - 699
- 700 - 799
- 1000 (DC)

Source: POWERmap, powermap.platts.com, ©2007 Platts, a division of the McGraw-Hill Companies

Wind Power Classification

Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m²	Wind Speed[a] at 50 m m/s	Wind Speed[a] at 50 m mph
3	Fair	300 - 400	6.4 - 7.0	14.3 - 15.7
4	Good	400 - 500	7.0 - 7.5	15.7 - 16.8
5	Excellent	500 - 600	7.5 - 8.0	16.8 - 17.9
6	Outstanding	600 - 800	8.0 - 8.8	17.9 - 19.7
7	Superb	800 - 1600	8.8 - 11.1	19.7 - 24.8

[a] Wind speeds are based on a Weibull k value of 2.0

This map shows the wind resource data used by the WinDS model for the 20% Wind Scenario. It is a combination of high resolution and low resolution datasets produced by NREL and other organizations. The data was screened to eliminate areas unlikely to be developed onshore due to land use or environmental issues. In many states, the wind resource on this map is visually enhanced to better show the distribution on ridge crests and other features.

Conceptual 765 kV Network
- Existing 765 kV
- New 765 kV
- AC-DC-AC Link

Source: American Electric Power (AEP)

Considerations for Siting a Wind Farm

Each project is a stand alone profit center must make a profit for the investors which requires:

- Income = Energy Output ~ (Wind Speed)^3
- Transmission Access
- Power Purchase Agreement with Utility
- Land with landowner willing to lease
- Permits: Minimal Wildlife & NIMBY
- Turbines at a Competitive Price
- Financing
- Minimize Project Risk

A Utility Scale 1.5 MW Wind Turbine

Theoretical Maximum Extraction Efficiency

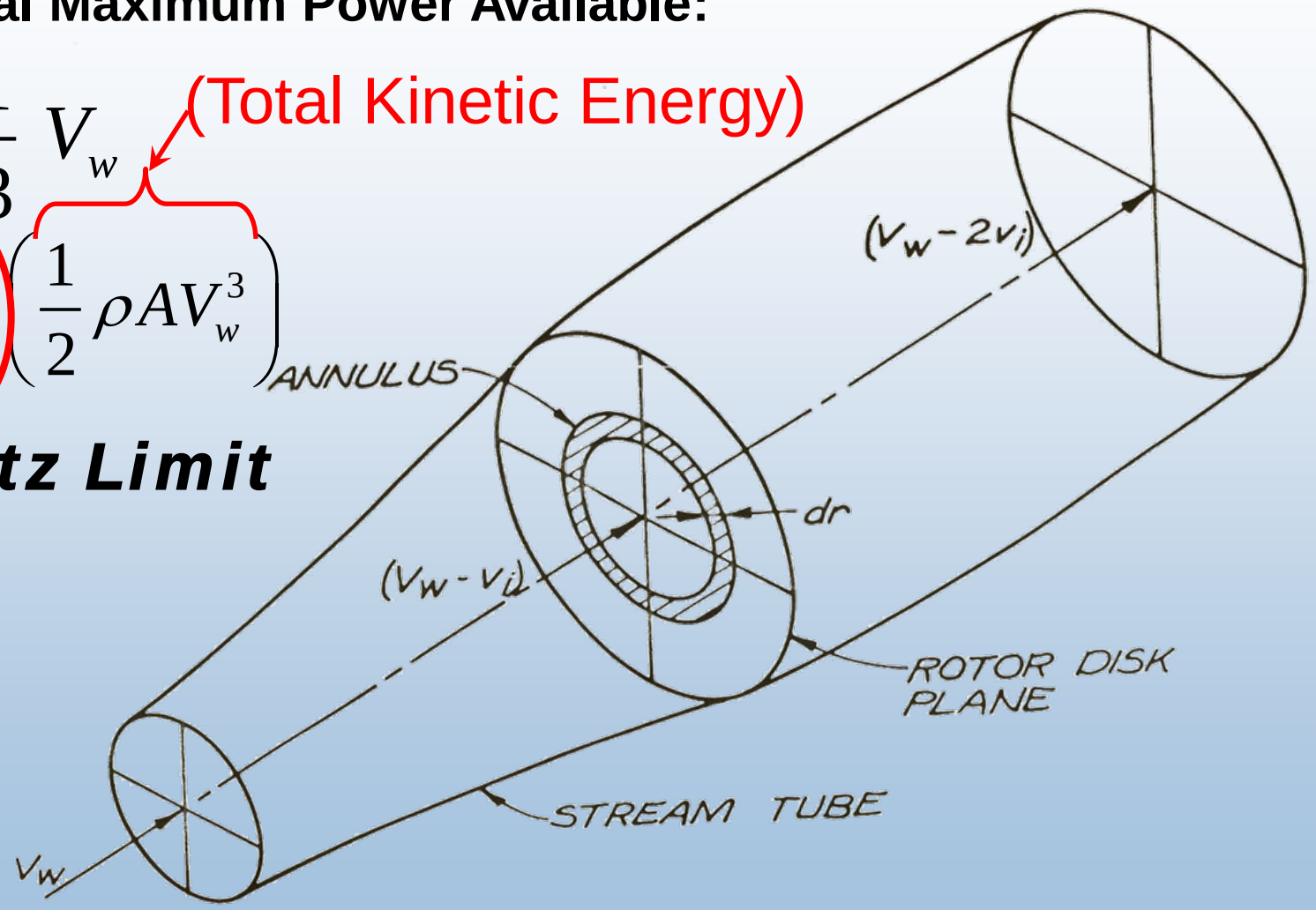
Theoretical Maximum Power Available:

$$V_i = \frac{1}{3} V_w$$

(Total Kinetic Energy)

$$P = \frac{16}{27}\left(\frac{1}{2}\rho A V_w^3\right)$$

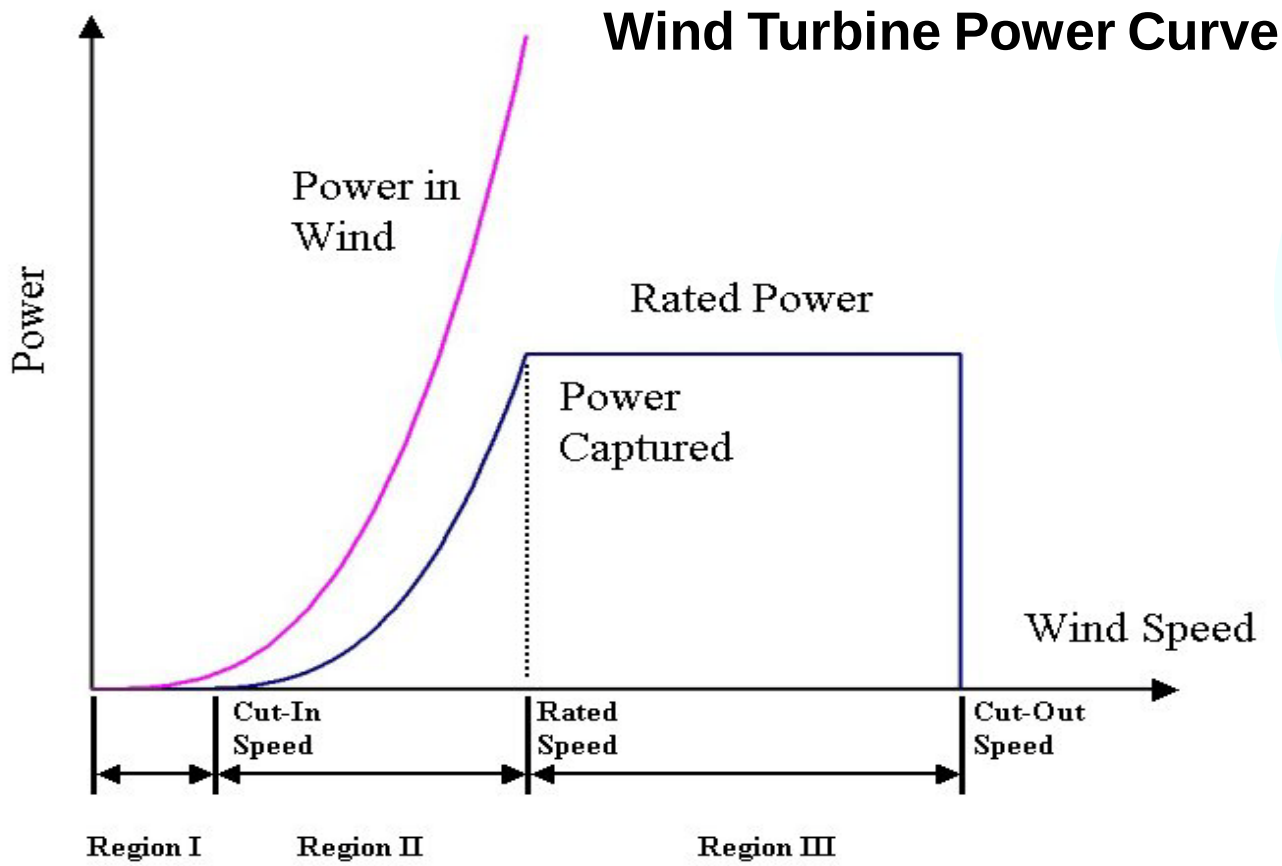
The Betz Limit

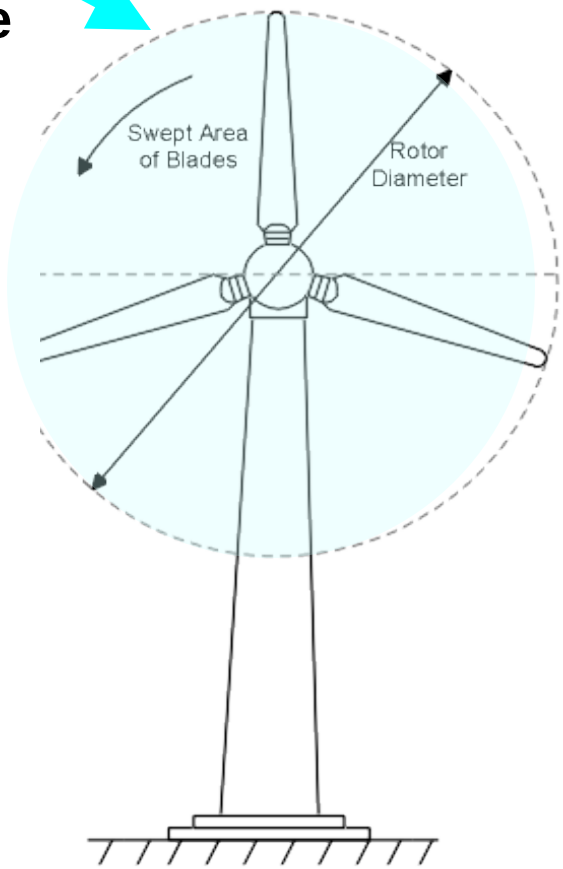


Turbine Power Basics

Power in the Wind = $\frac{1}{2}\rho A V^3$

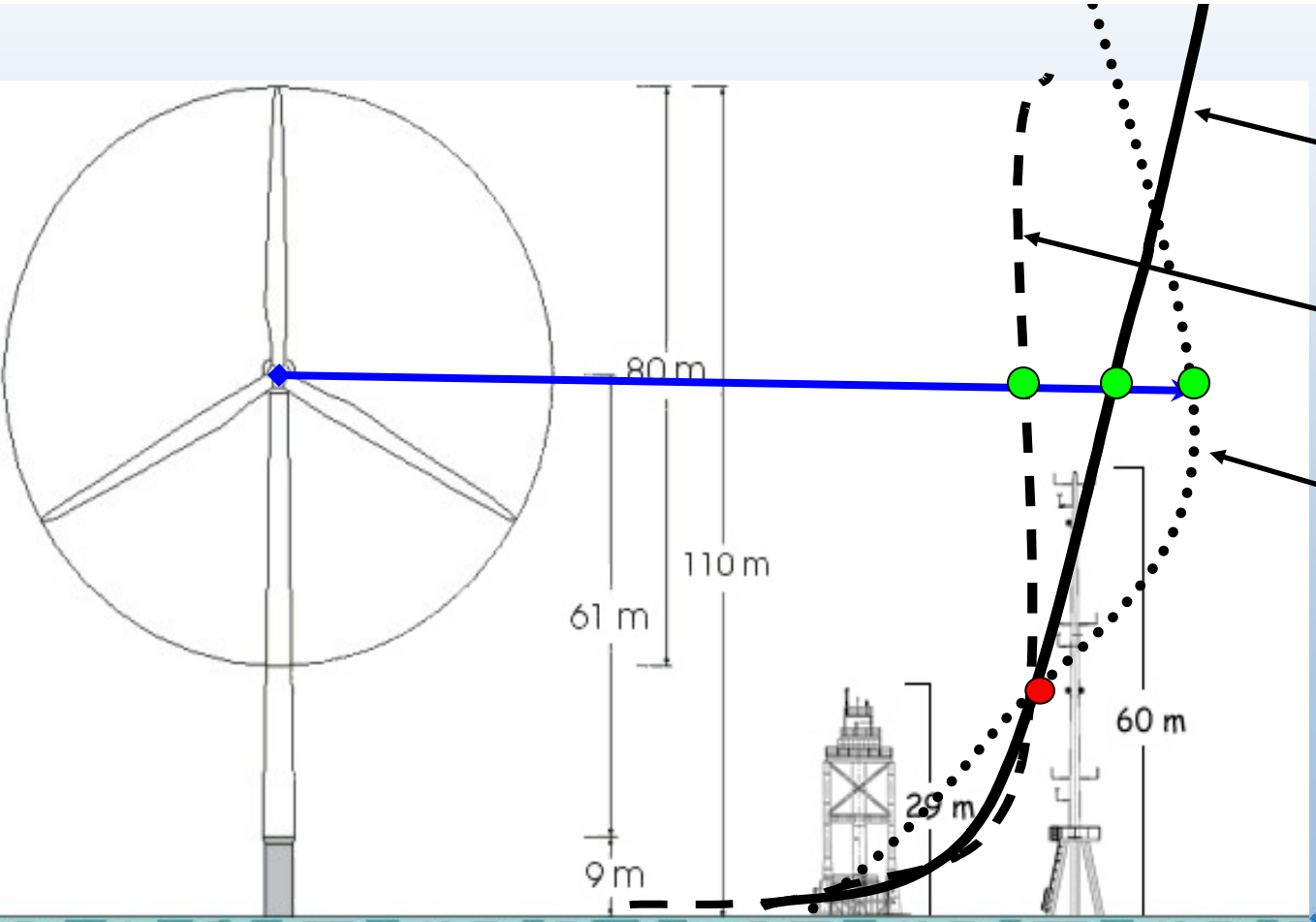
A - Area of the circle swept by the rotor
ρ = Air density
V = Wind Velocity





What is the wind speed at the hub?

- Long term wind measurements typically made lower than hub height.
- How do we correct for to hub height?
- Earths boundary layer changes with time and location – stable vs. unstable, wind shear variations



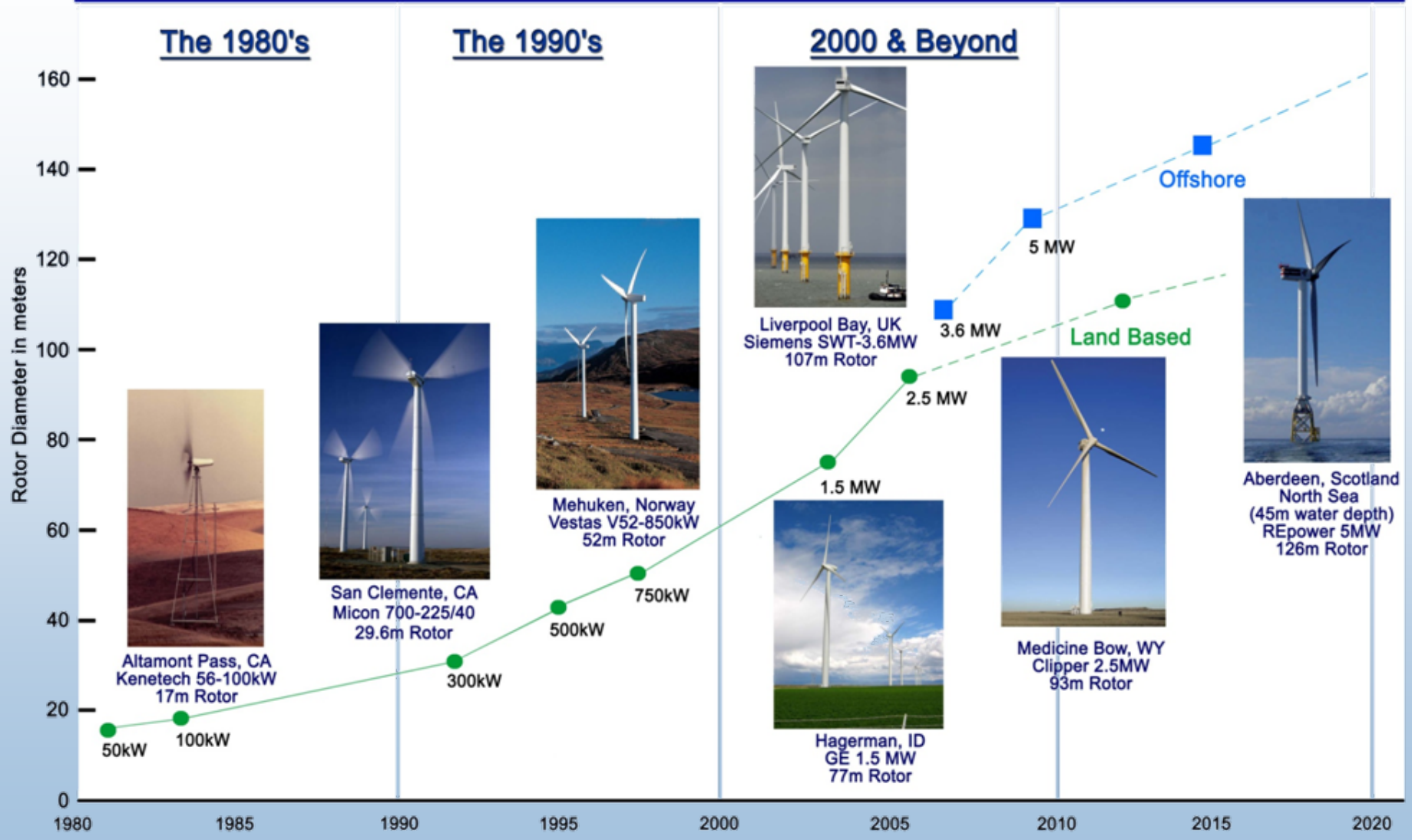
Neutral Boundary Layer

Convective Boundary Layer

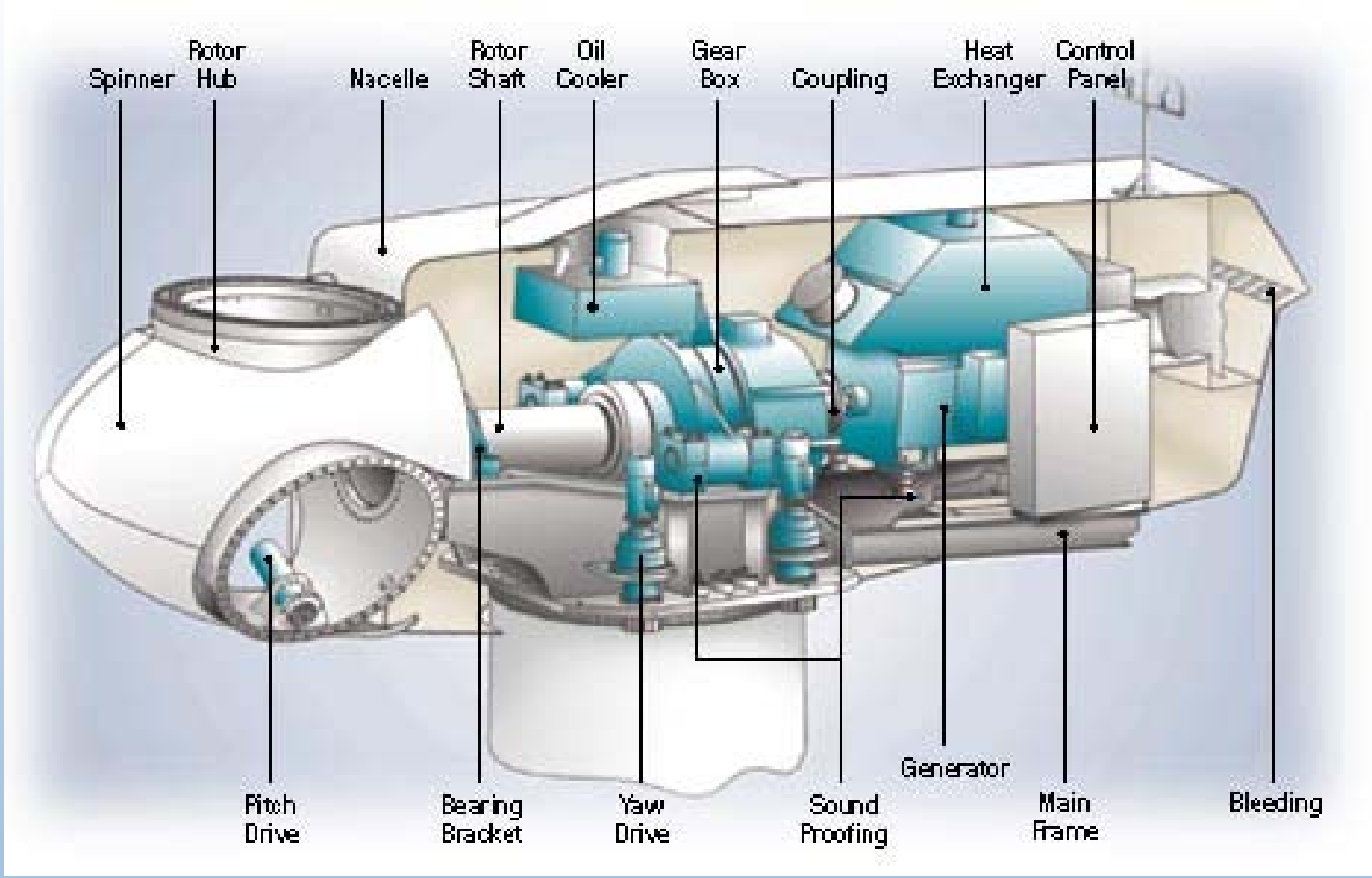
Stable Boundary Layer with Low Level Jet

Graphic Credit: Bruce Bailey AWS Truewind

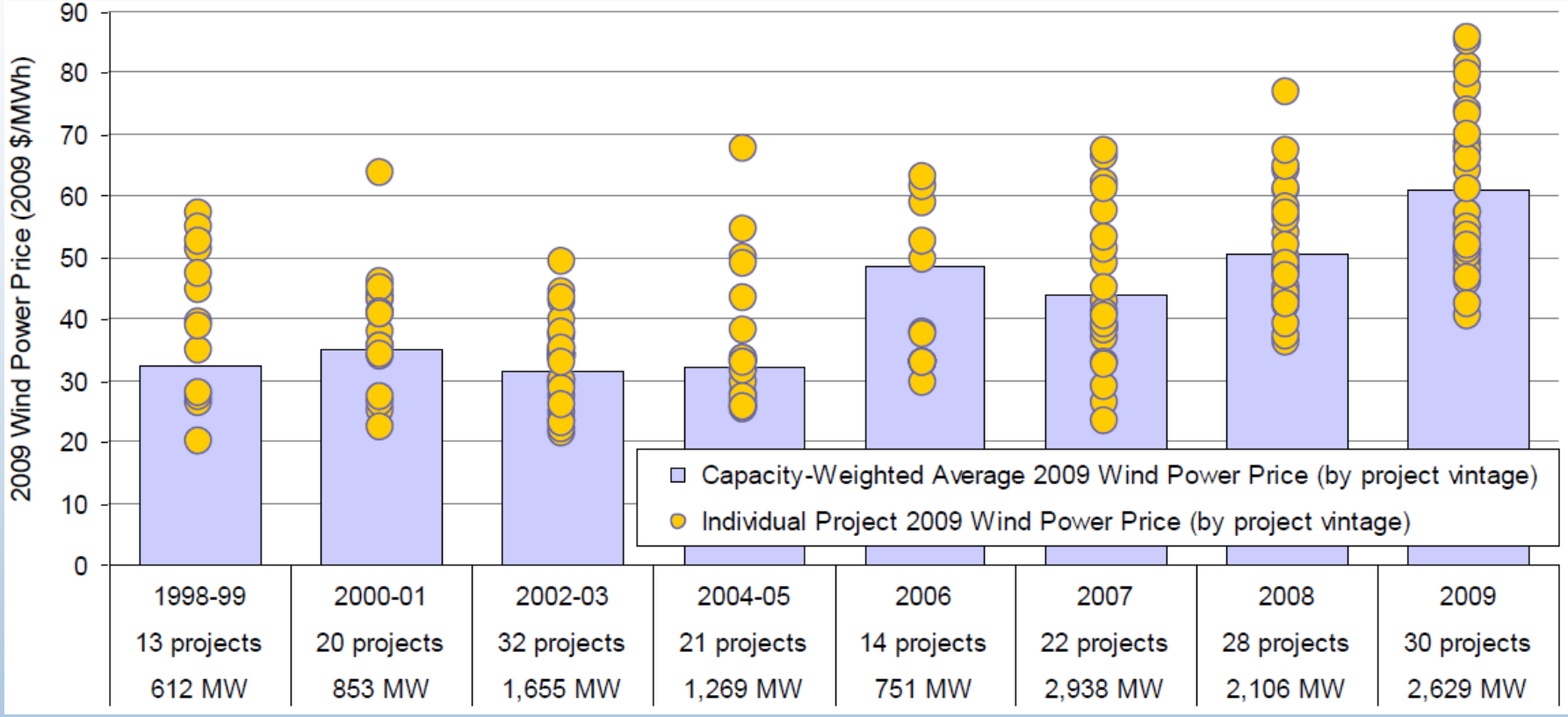
Evolution of Commercial Wind Technology



Typical Modern Turbine



Wind Power Purchase Price (Including PTC of 2 cents/kWh)



Source: Wiser, R. and M. Bolinger. (2010). *2009 Wind Technologies Market Report.* DOE/GO-102010-3107. U.S. Department of Energy Office of Energy Efficiency and Renewable Energy.

Offshore Wind: Why?

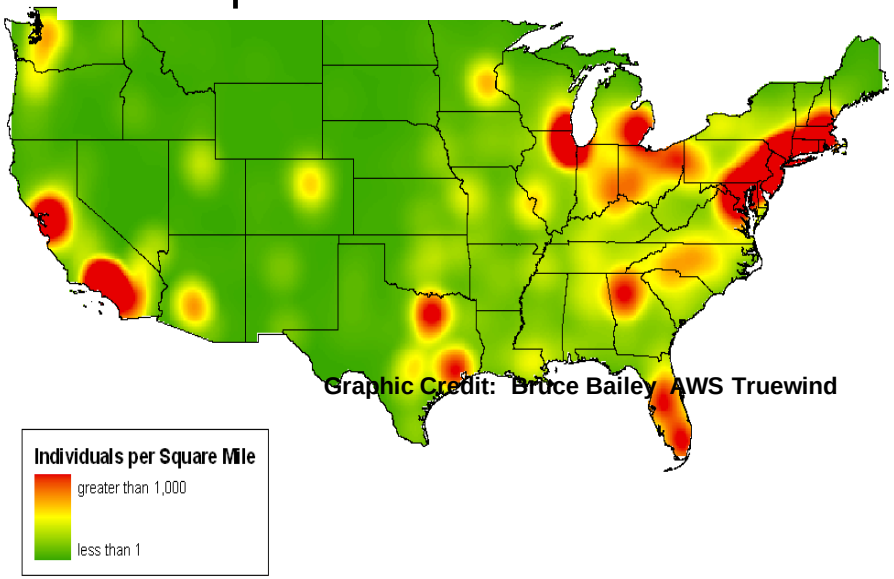
Land-based sites are not close to coastal load centers

Load centers are close to offshore wind sites

28 Coastal States Use 78% of Electricity

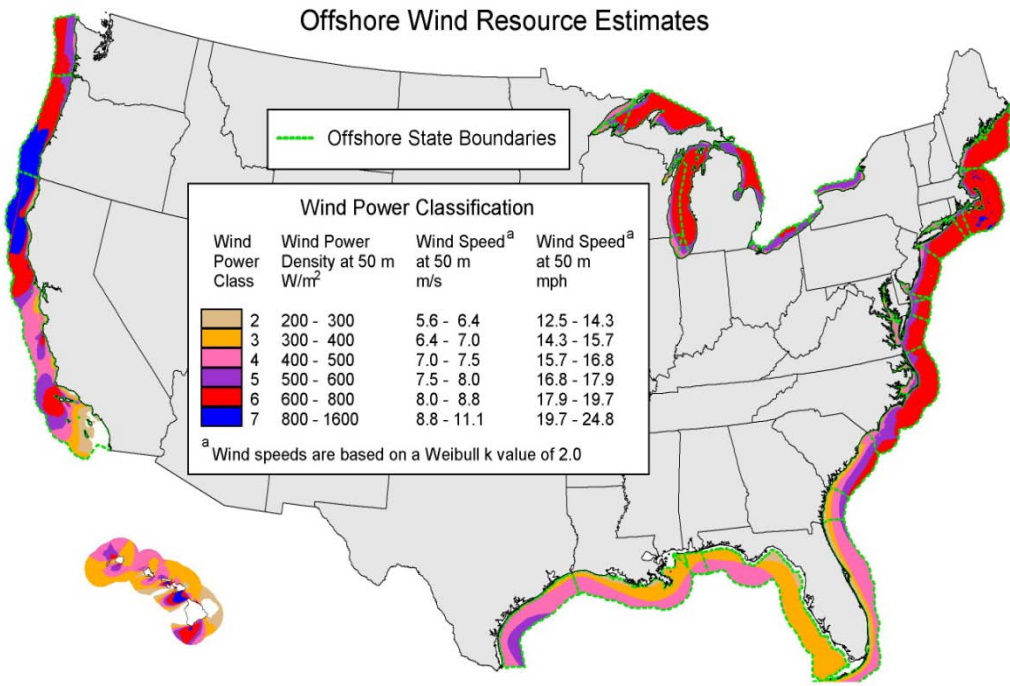
Population Density of the Counterminous United States

US Population Concentration

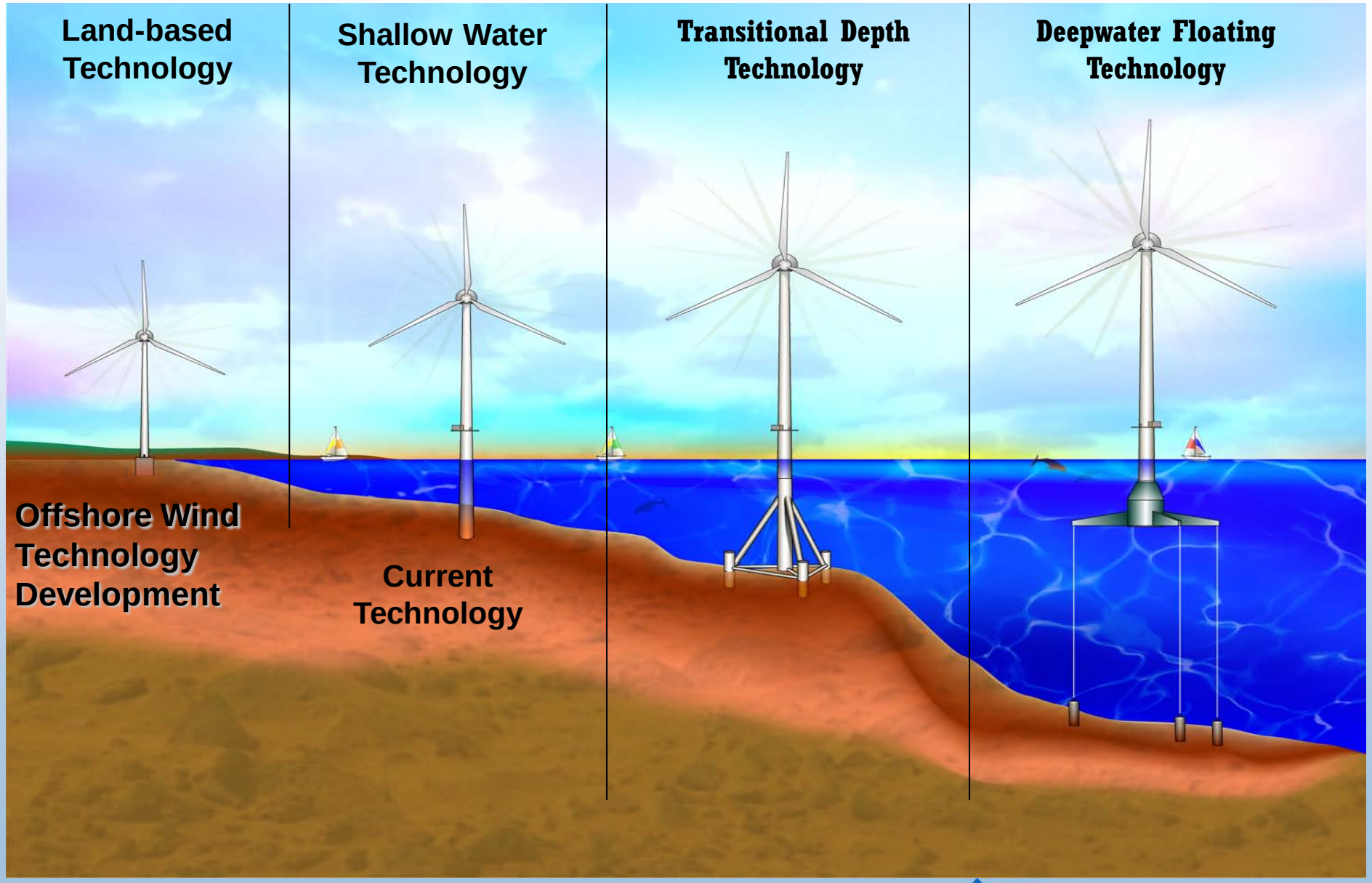


Graphic Credit: Bruce Bailey AWS Truewind

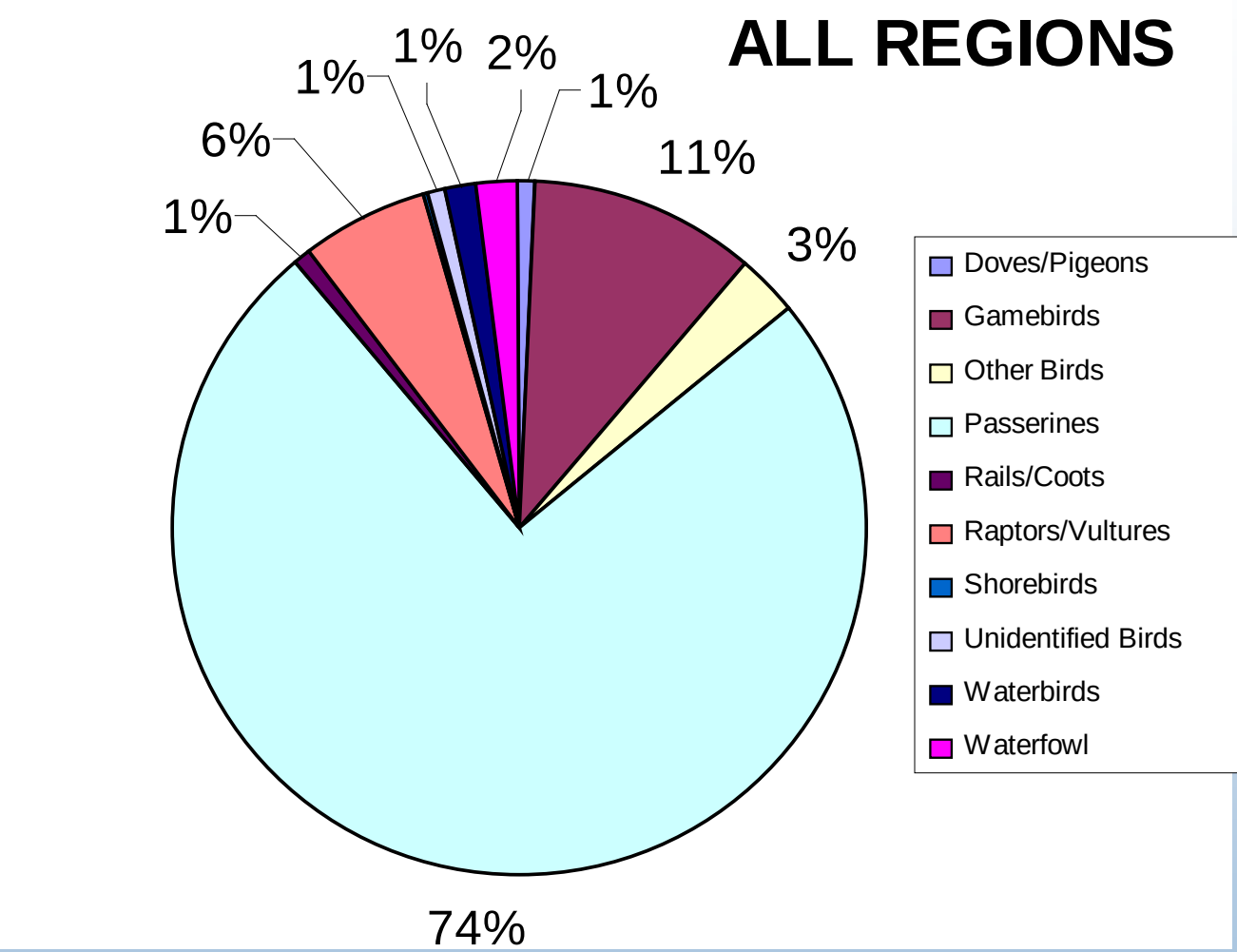
U.S. Wind Resource



Future Research on Offshore Wind Technology



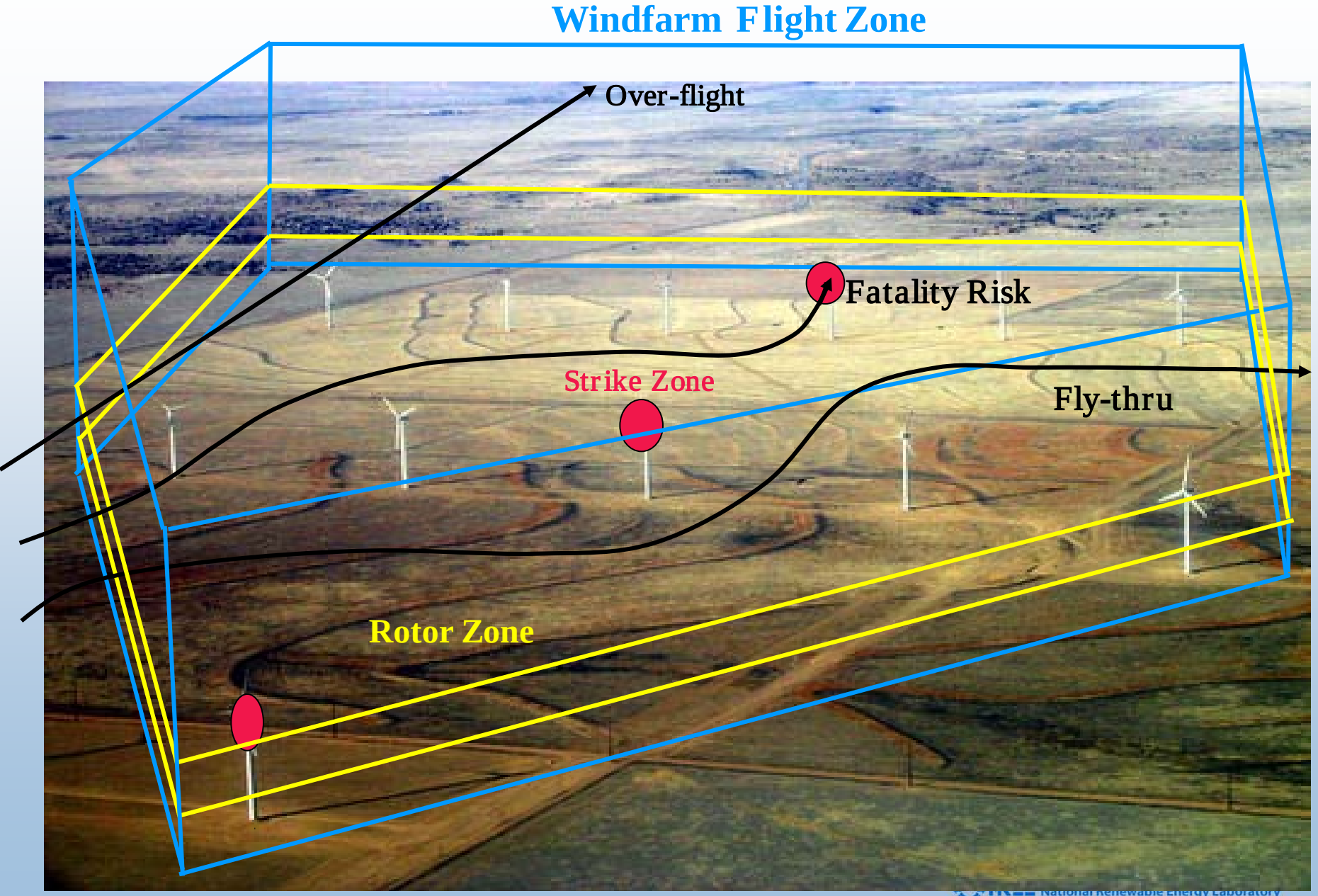
Wind and Wildlife: Wind Turbine Bird Fatalities



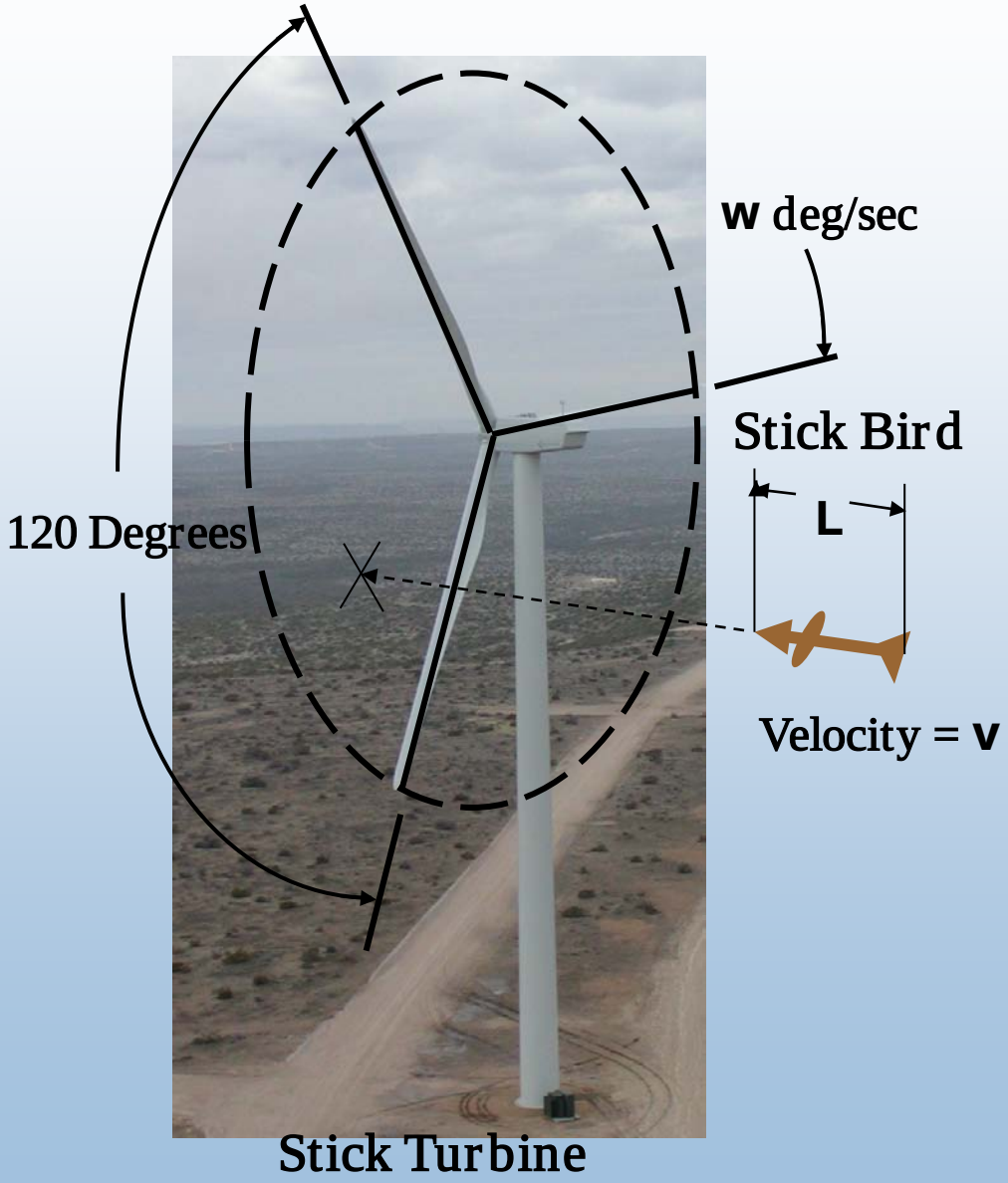
Proportion of fatalities at sites reporting fatalities by species, summarized for all regions where studies have been conducted (Pacific Northwest, Mid-West, Rocky Mountains, and East).

Source: Strickland and Morrison

Visualization of Avian Interaction Zones



Avian Impact Probability: Stick Collision Model



Bird passage time through the rotor:

$t_p = L/V =$ **Length speed ratio** (sec)

Blocked Sector of Turbine Rotor:

$B = t_p\, w$ (deg)

Probability of collision:

$P_c =$ **Blocked Area / Disk Area**

$P_c = 3B/(360\text{deg})$

$P_c = 3(L/V)\{w(\text{deg/sec})/360\text{deg}\}$

To account for avoidance:

$P_c = 3\,A\,(L/V)\{w(\text{deg/sec})/360\text{deg}\}$

$$\text{where } A = \left\{\begin{array}{l} <1 \text{ for avoidance} \\ 1 \text{ for no behavior} \\ >1 \text{ for attraction} \end{array}\right\}$$

Avian Strike Probability Versus Turbine Size

Altamont Scale

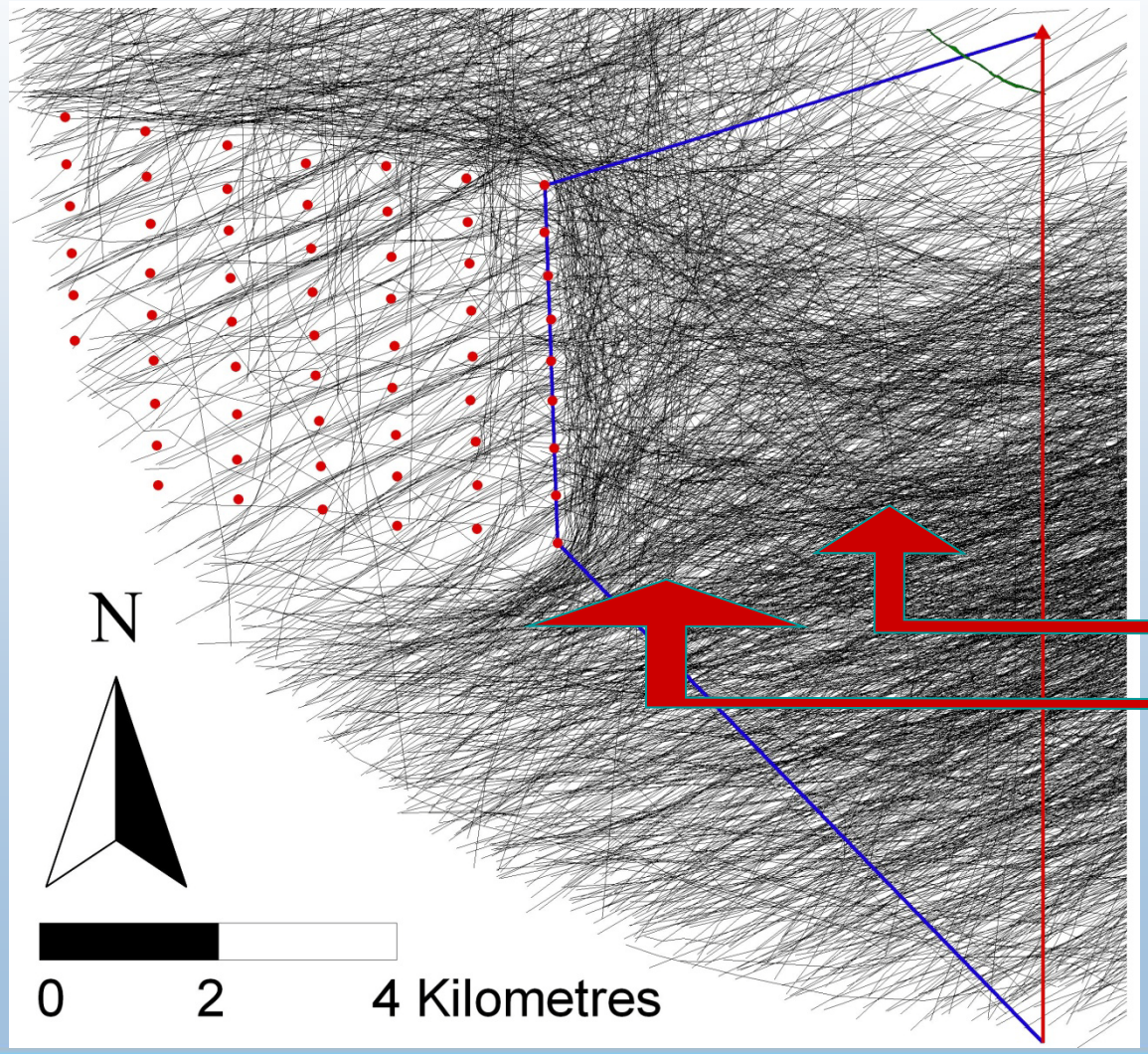
15 Meter Diameter and 100 kW

Next Generation Scale

93 Meter Diameter and 2.5MW

Avoidance Behavior is Significant

Radar Tracks of Migrating Birds through Nysted Offshore Windfarm for Operation in 2003



Response distance:

day = c. 3000m

night = c. 1000m

Candidate Avian Risk Metrics

Hypothesis: "Mortality risk increases with flight time in the rotor zone (yellow zone), if the turbine is operating"

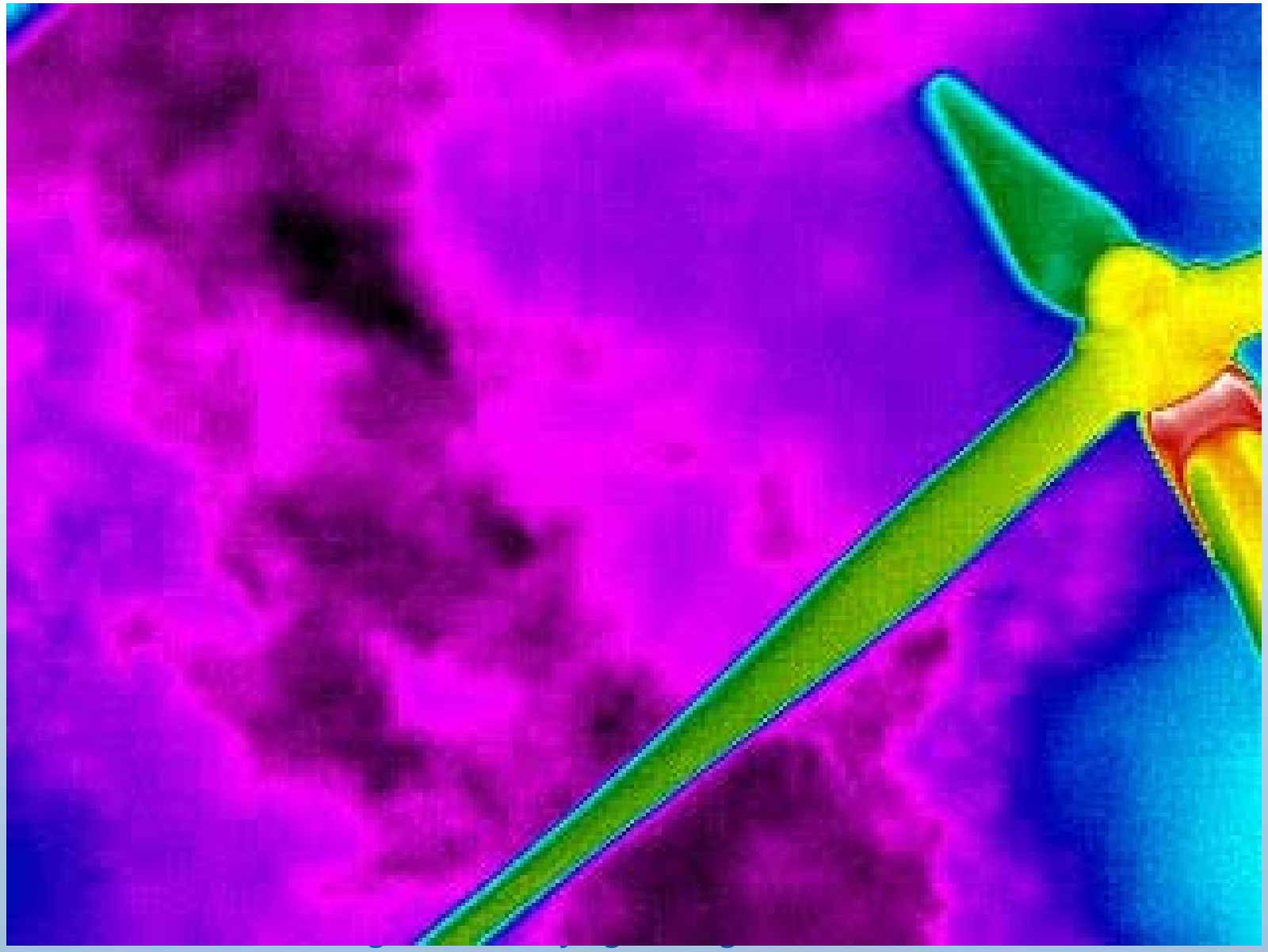
- **A Candidate Post-construction Fatality Metric:**

  Species Risk = Fatalities/(Swept Area x Turbine Operation Hours)

- **A Candidate Preconstruction Relative Risk Metric:**

  Species Relative Risk = (Flight Hours in Rotor Zone with Wind in Operating Range)/(Plant Swept Area x Hours with Wind in Operating Range)

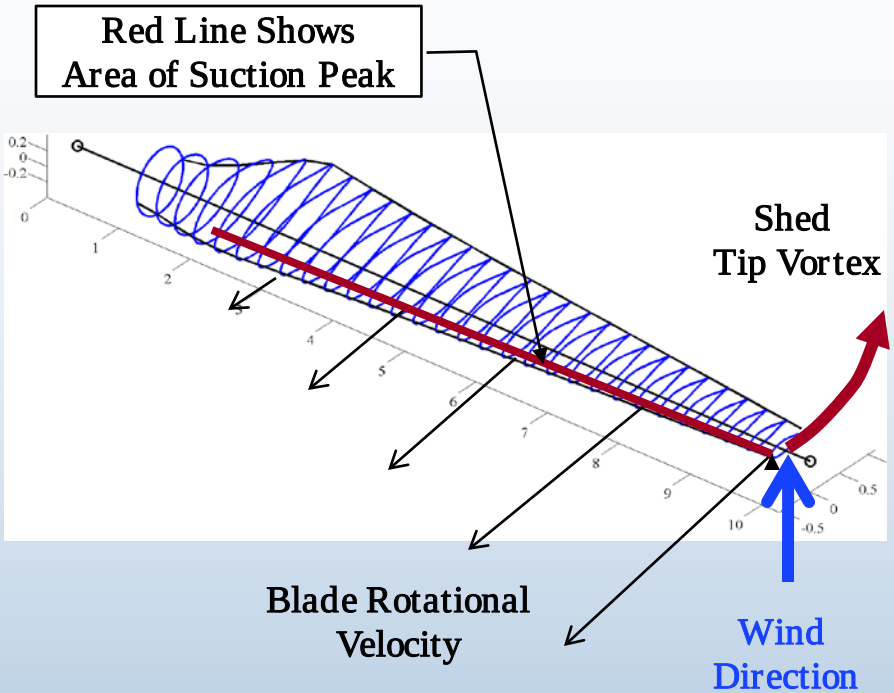
Bats and Wind Energy Cooperative Studies



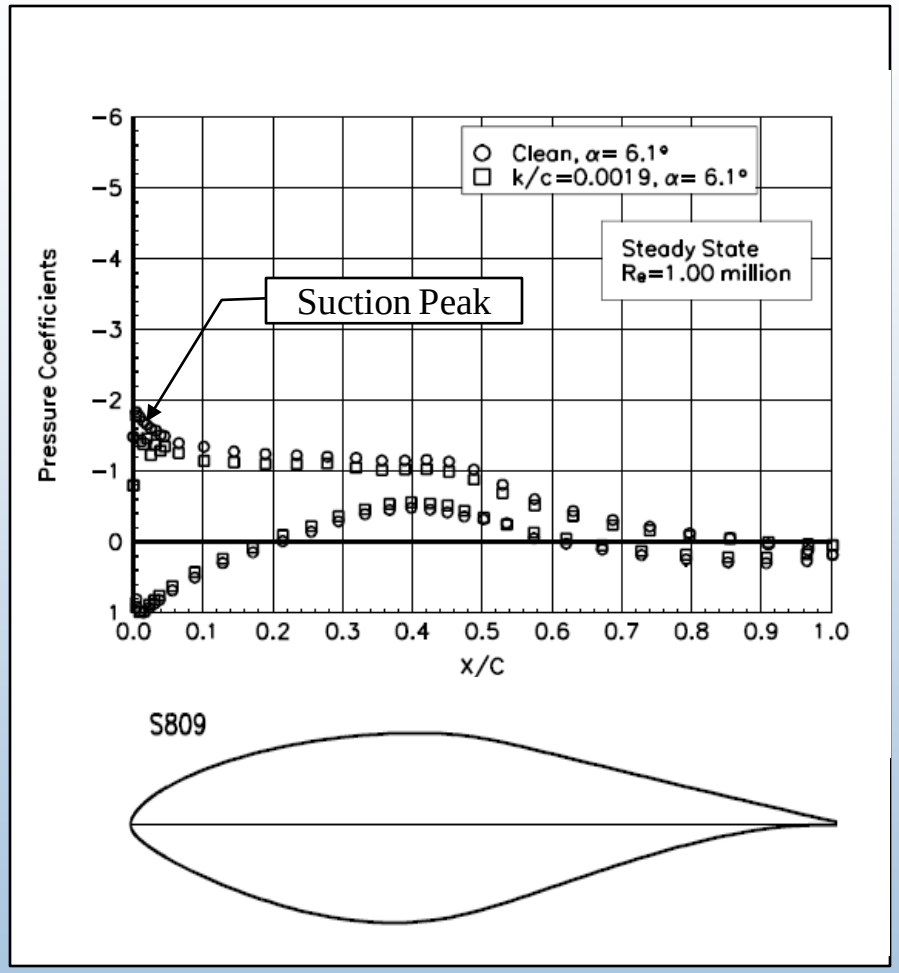
Video by Jason Horn, Boston University

Bat Barotrauma: Low Pressure Trauma

Low Pressure Areas on a Wind Turbine Blade



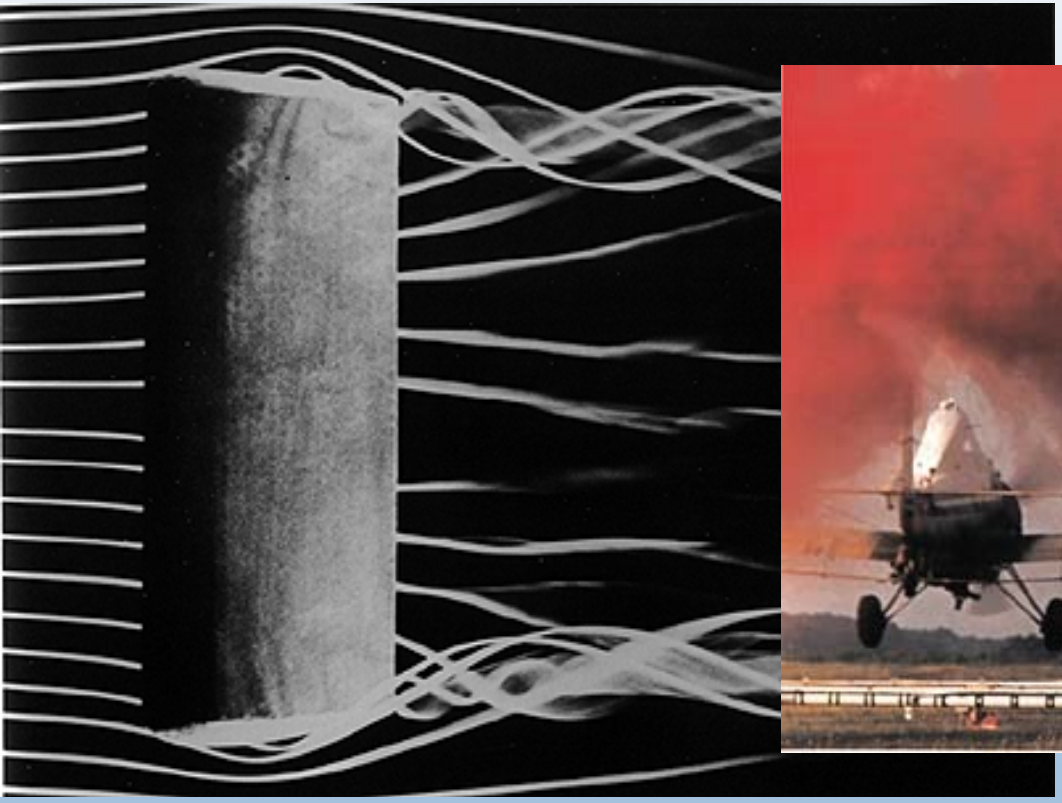
Airfoils Suction Peak Location



The Pressure Distribution on an Airfoil

The Tip Vortex has a Low Pressure Core

- Near blade tips the flow is highly three-dimensional with flow from the higher pressure side of the blade to the suction side of the blade



Closing Thoughts: Where we are and where we need to go in wind and wildlife research

National Avian-Wind Power Planning Meeting I, July 1994

Where we started in 1994:

Meeting Outcome - Five Major Research Areas:

1. Assess mortality attributable to wind turbines at existing sites (including control data from "no turbine" sites)
2. Predict mortality at planned wind power sites, based in part on previous bullet
3. Predict population consequences
4. Identify ways to reduce bird kills at wind plants
5. Set values for off-site mitigation
6. High Bat Fatalities in Mid-Atlantic Highlands (New Issue in 2004)
7. Habitat impacts (New Issue in 2006)

Current Status of Issues:

1. Mortality estimates made post construction (Limited distribution of study results)
2. No pre-construction predictor of post-construction mortality. (Increases risk)
3. No population impact predictor
4. In process at Altamont Pass
5. No standard mitigation values set
6. Under study through Public-Partnership
7. Prairie chickens & other prairie songbirds study underway (Sage Grouse study forming)

The Siting and Permitting Challenge

To reach 20% wind energy by 2030 will require minimizing the barriers to siting and permitting by "understanding, minimizing and, mitigating environmental impacts to wildlife." The issues that must be addressed through further research are:

- Understanding, minimize, avoiding, and mitigating specific species impacts:
  - Birds
  - Bats
  - Other species using the windfarm habitat
- Habitat modification and fragmentation effects
- Individual animal versus cumulative population impacts
- The influence of variables such as weather, lighting, turbine height, turbine rotation speed
- Effective mitigation measures and methods, both onsite and offsite

Source: Adapted from 20% Wind Energy by 2030