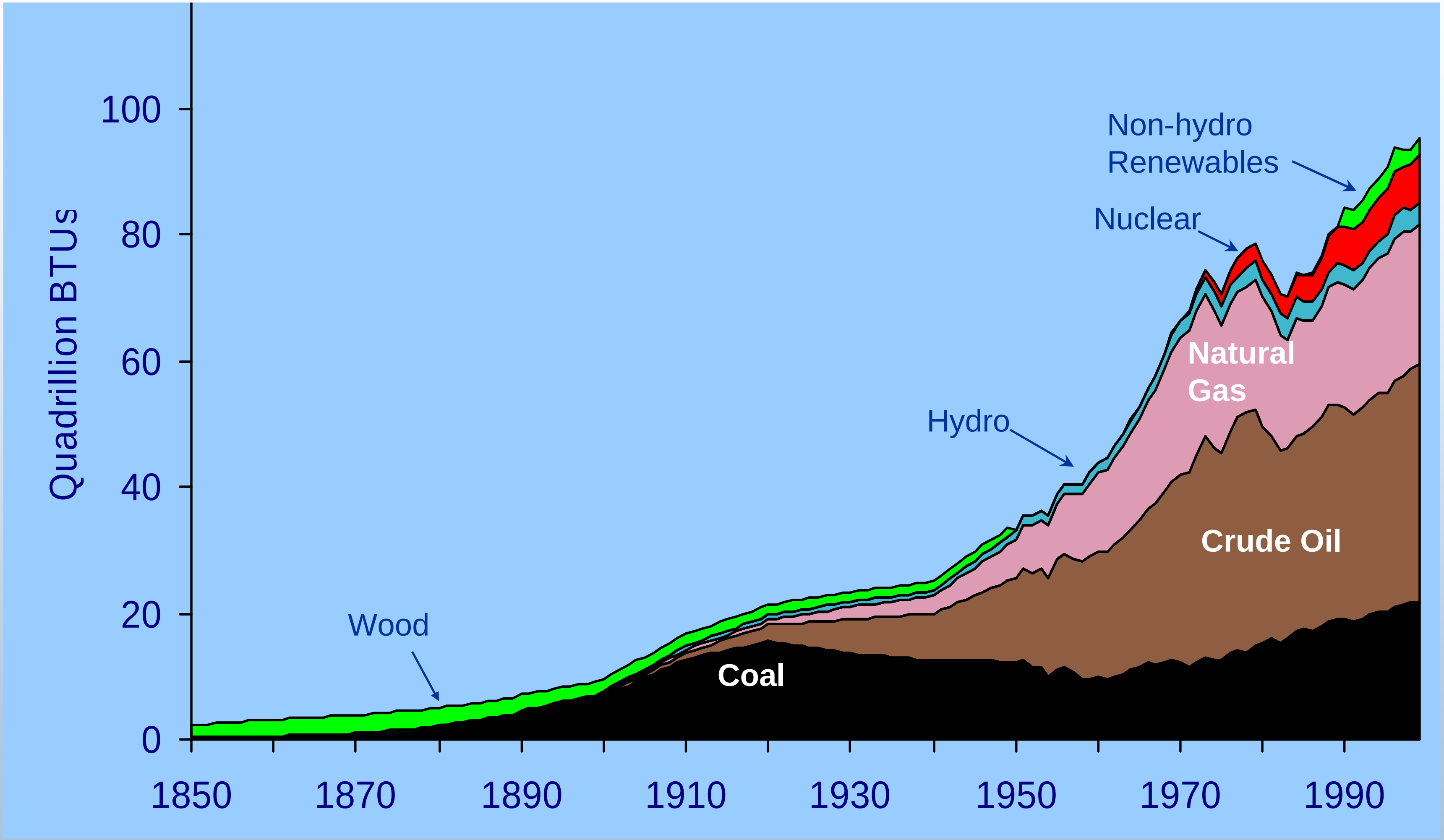
Wind Technology and Wildlife Interactions

Presentation for the California Fish and Game Workshop
By Robert W. Thresher, Director
National Wind Technology Center
4 March 2008

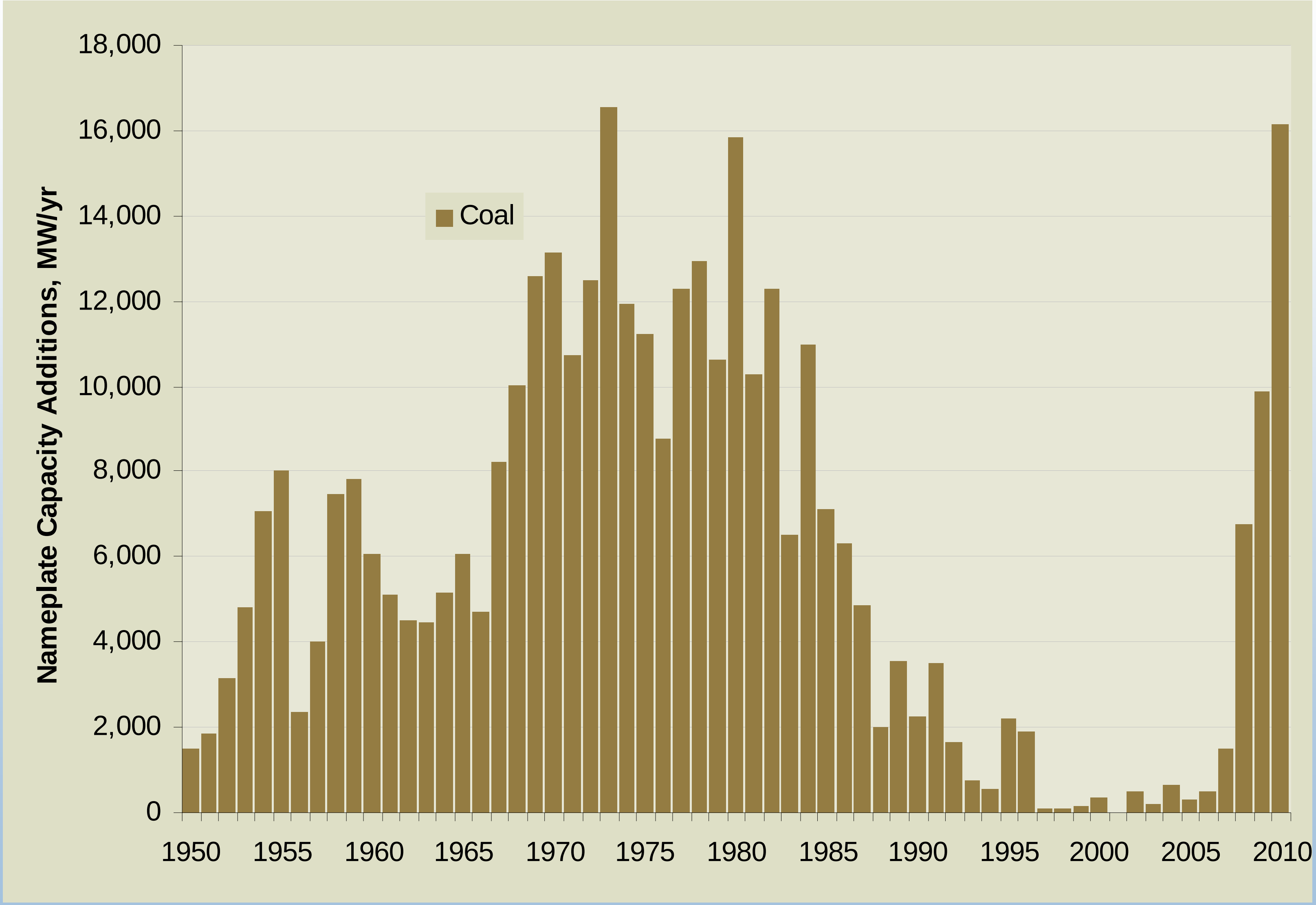
The U.S. Energy Picture

by source - 1850-1999



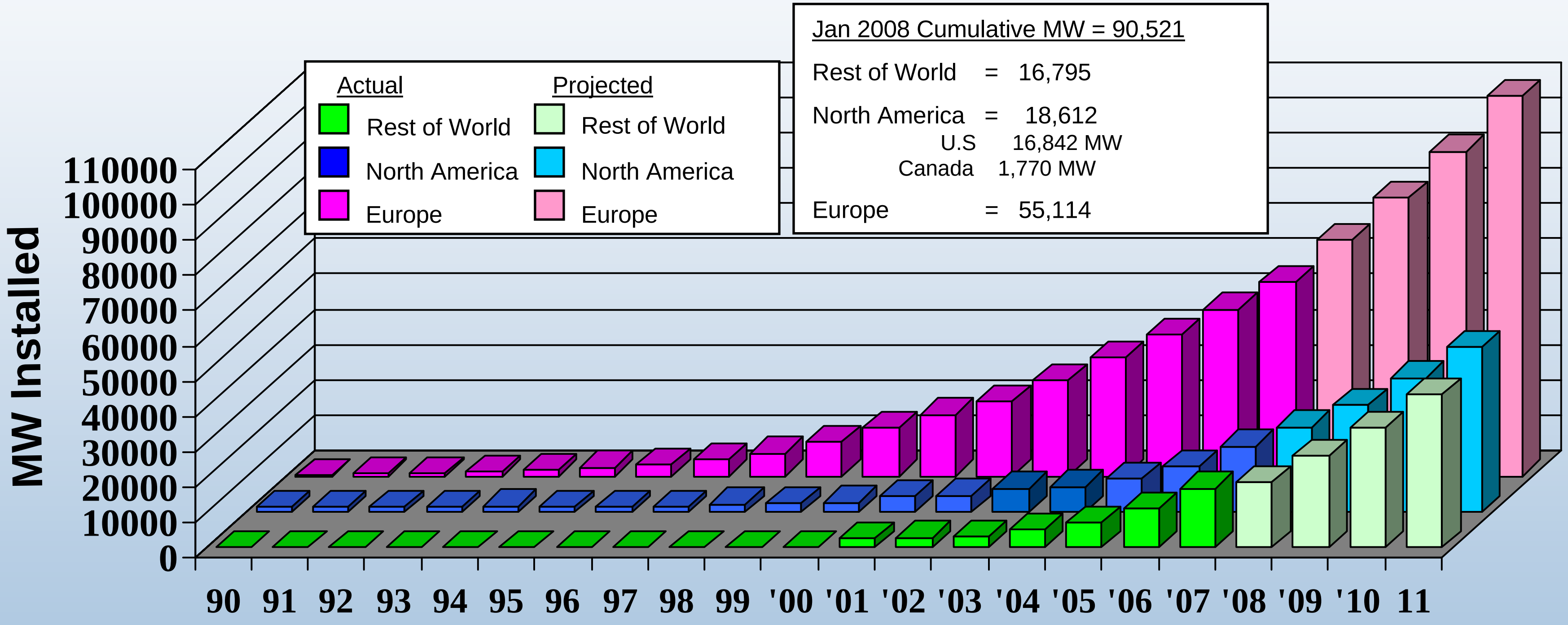
Source: 1850-1949, Energy Perspectives: A Presentation of Major Energy and Energy-Related Data, U.S. Department of the Interior, 1975; 1950-1996, Annual Energy Review 1996, Table 1.3. Note: Between 1950 and 1990, there was no reporting of non-utility use of renewables. 1997-1999, Annual Energy Review 1999, Table F1b.

The US History and Future Planned Additions of Coal Generated Electricity



Source: Black & Veatch Analysis of data from Global Energy Decisions Energy Velocity database

Growth of Wind Energy Capacity Worldwide



Jan 2008 Cumulative MW = 90,521

Rest of World = 16,795

North America = 18,612

U.S 16,842 MW

Canada 1,770 MW

Europe = 55,114

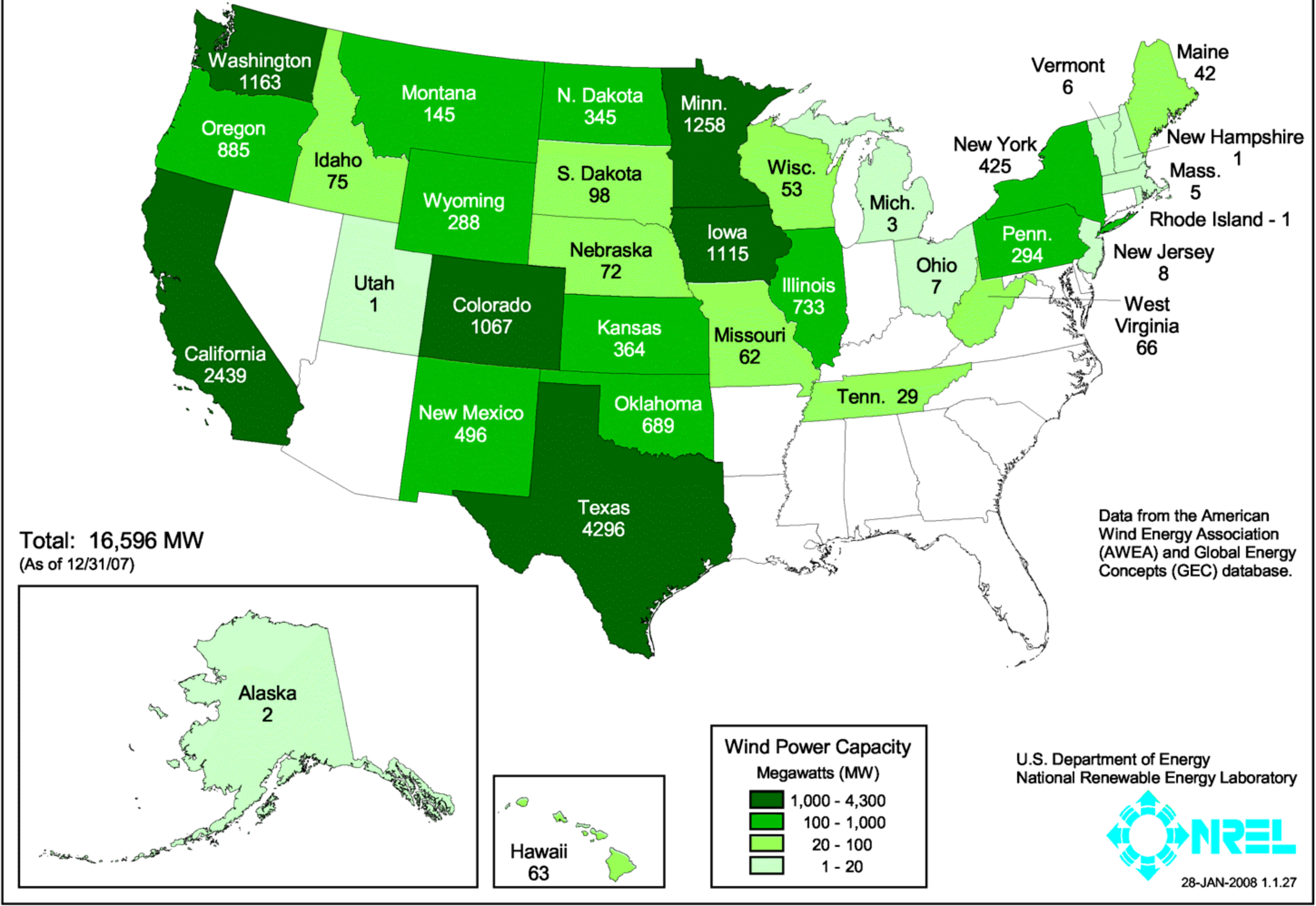
Sources: BTM Consult Aps, March 2007

Windpower Monthly, January 2008

*NREL Estimate for 2008

National Renewable Energy Laboratory

United States - 2007 Year End Wind Power Capacity (MW)



Total: 16,596 MW
(As of 12/31/07)

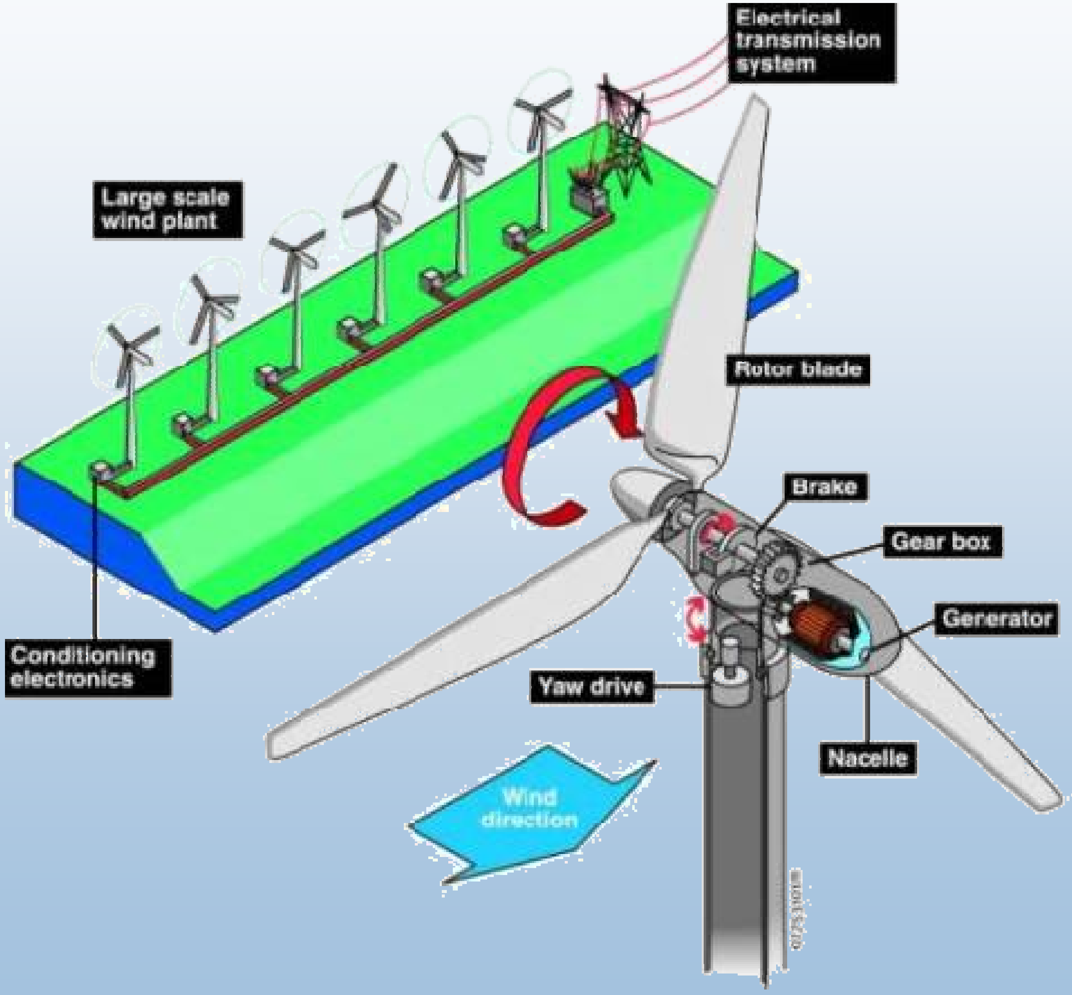
Data from the American Wind Energy Association (AWEA) and Global Energy Concepts (GEC) database.

U.S. Department of Energy
National Renewable Energy Laboratory

28-JAN-2008 1.1.27

Wind Energy Technology

At it’s simplest, the wind turns the turbine’s blades, which spin a shaft connected to a generator that makes electricity. Large turbines can be grouped together to form a wind power plant, which feeds power to the electrical transmission system.



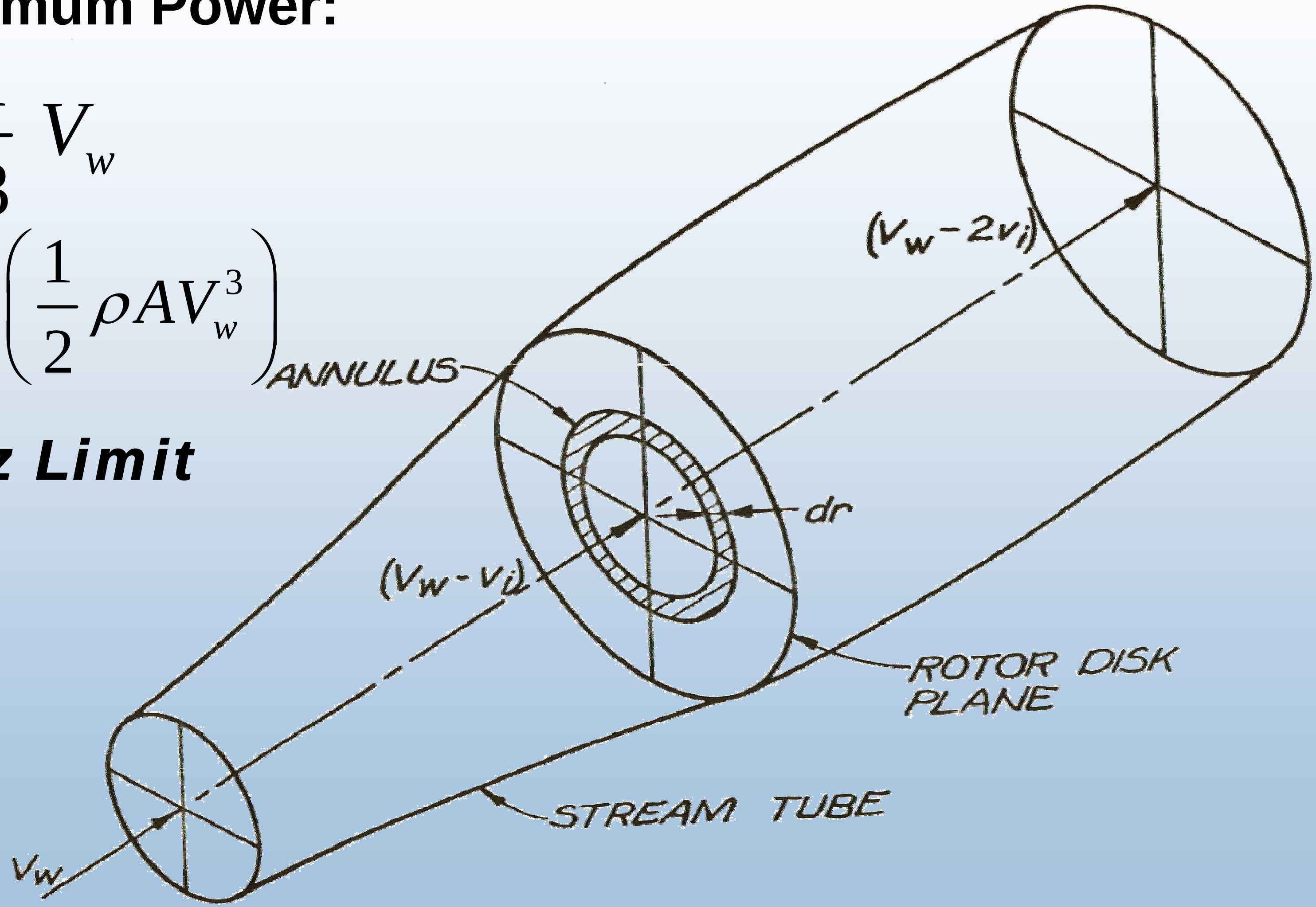
Stream Tube for Momentum Balance

For Maximum Power:

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

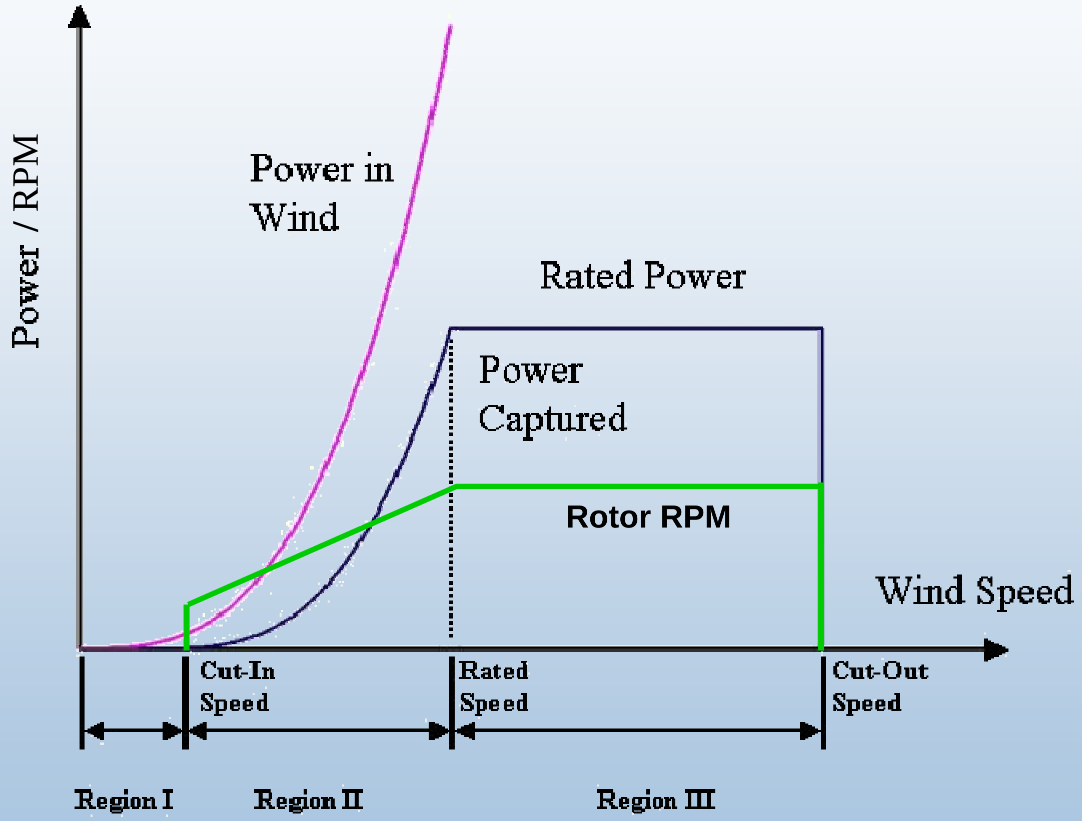
$$P = \frac{16}{27}\left(\frac{1}{2}\rho A V_w^3\right)$$

The Betz Limit



Wind Energy Production Terms

- *Power in the Wind* = $1/2\rho AV^3$
- *Power Coefficient* - C_p
- *Betz Limit* - 59% Max
- Efficiency – about 80%
- *Rated Power* – Maximum power generator can produce
- *Capacity factor* - Annual energy capture / Generator max output X 8760
- *Cut-in* wind speed where energy `production begins
- *Cut-out* wind speed where energy production ends



Modern Turbine Power Curve

A New Vision

For Wind Energy in the U.S.

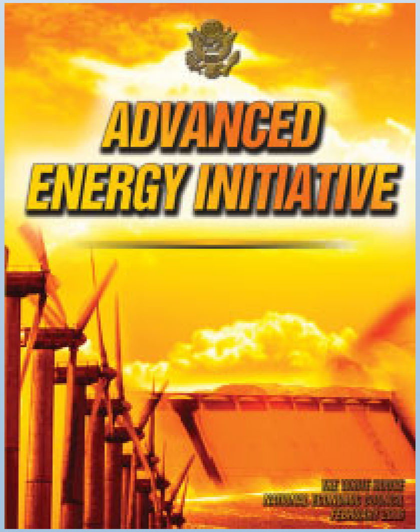

White House photo by Eric Draper

State of the Union Address

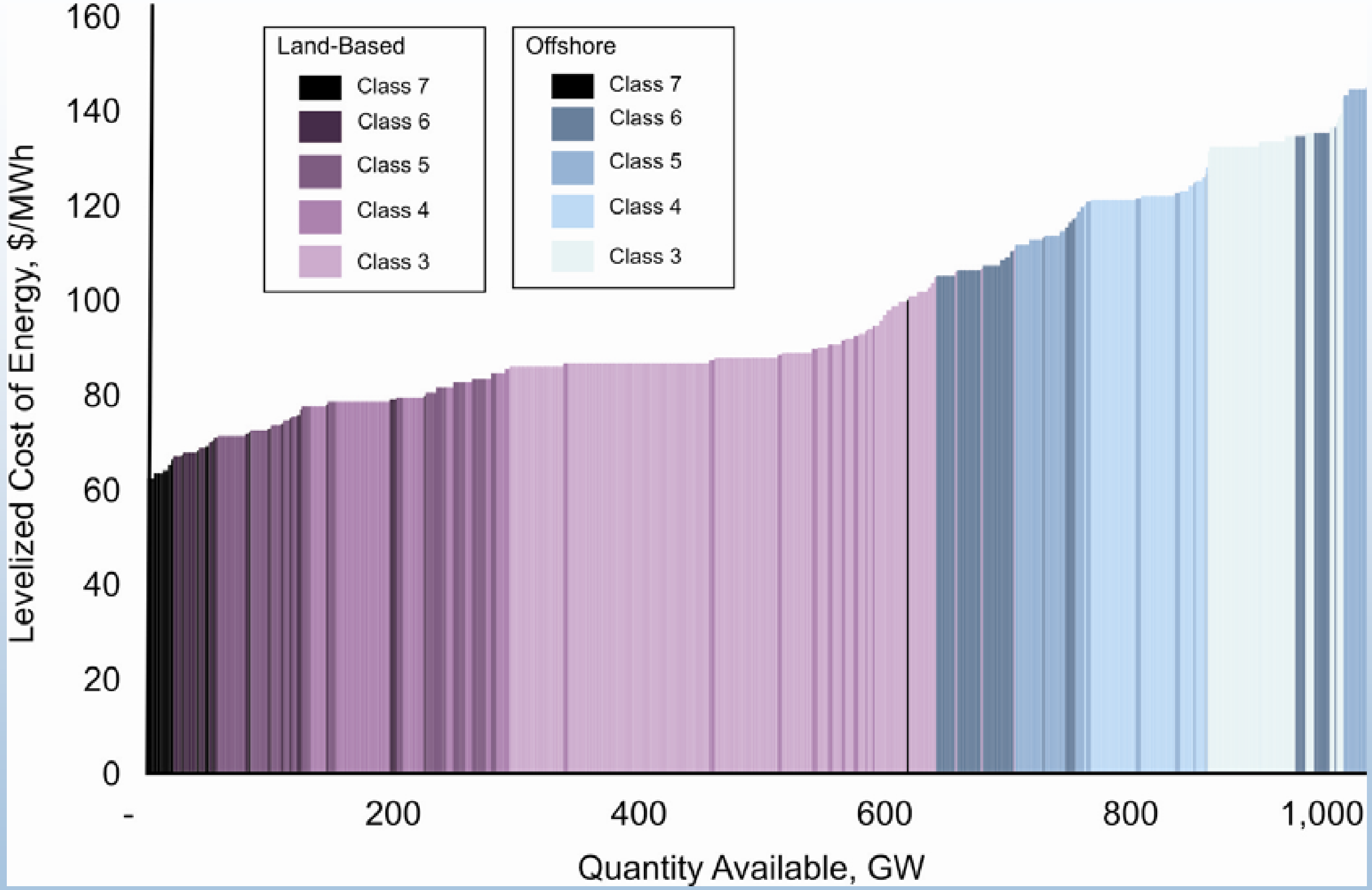
"…We will invest more in … **revolutionary** and solar **wind technologies**"

Advanced Energy Initiative

"Areas with good wind resources have the potential to **supply up to 20% of the electricity** consumption of the United States."

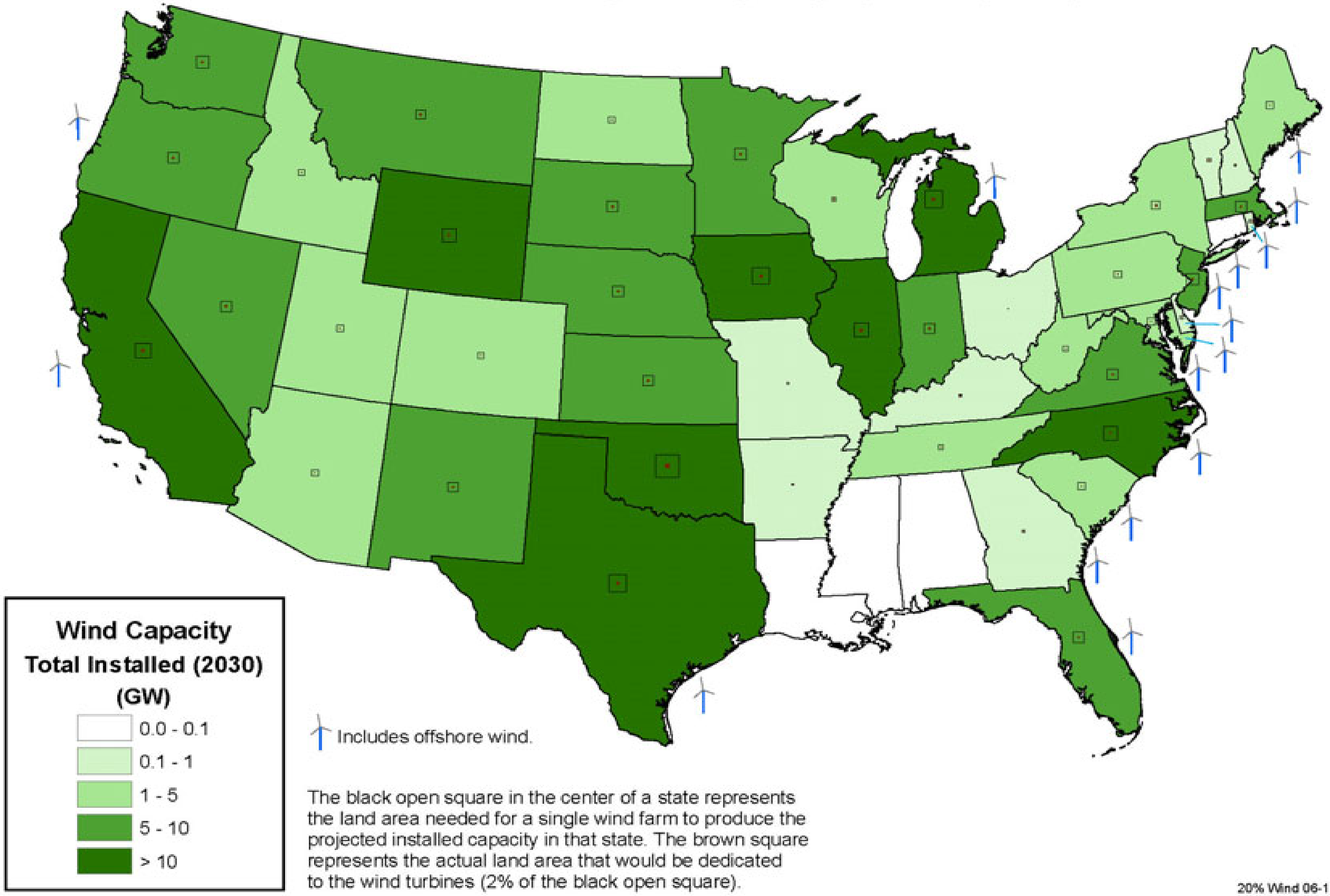

ADVANCED ENERGY INITIATIVE

Wind Energy Supply Curve



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

Installed Wind Nameplate Capacity by State (2030)



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

U.S. Wind Industry Challenge

- Rising costs driven by inconsistent policies and increased competition
  - PTC inconsistency
  - Copper and Steel prices
  - Transportation
  - Permitting and siting costs
- Poor performance and reliability
  - Drivetrains
  - Other components
- Understanding and acceptance by financial sector, regulators, utilities, public
  - A disruptive technology
  - A new technology with limited experience
  - Different operating characteristics
  - Highly visible generating a NIMBY reaction
  - Wildlife and environmental concerns
- Integrating wind onto the grid at a large scale
  - Fluctuating output
  - Not Dispatchable
  - Transmission access

Cost of Energy Trend

1981: 40 cents/kWh

Decreasing Cost Due to:

- **Increased Turbine Size**
- **R&D Advances**
- **Manufacturing improvements**

NSP 107 MW Lake Benton, MN wind farm

2007: 6-9 cents/kWh with no PTC for a 13mph wind speed at 10m (18mph at 100m hub)

Recent cost increases are due to:

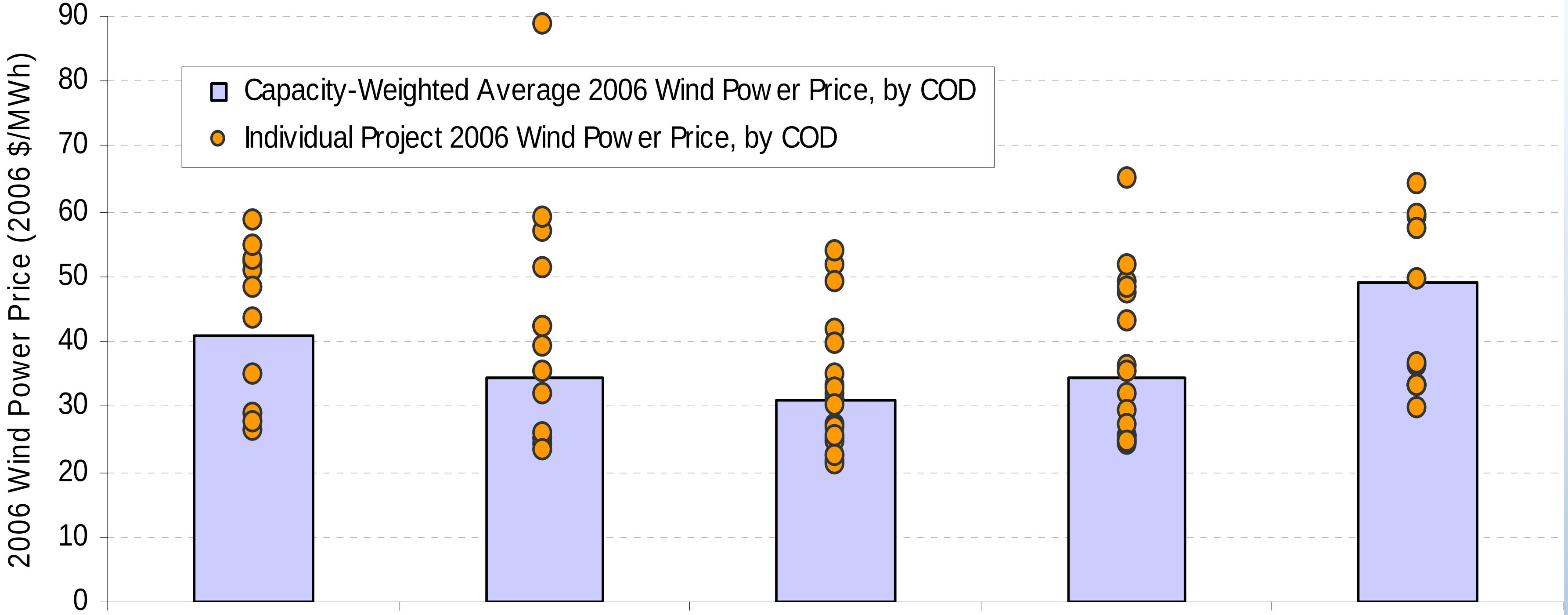
- **Price increases in steel & copper**
- **Turbines sold out for 2 years**

Note: These energy costs are average for the US and costs in many locations with lower winds at hub height, higher insurance, permitting, and land cost, such as in California can increase energy cost by up to 20%.

Goal : To make wind competitive with no subsidies

Wind Energy Price to Utilities

(Includes PTC & Other State Incentives)



COD:	1998-99	2000-01	2002-03	2004-05	2006
# Projects:	11	14	21	17	9
# MW:	591	857	1,765	1,666	723

Source: Berkeley Lab database

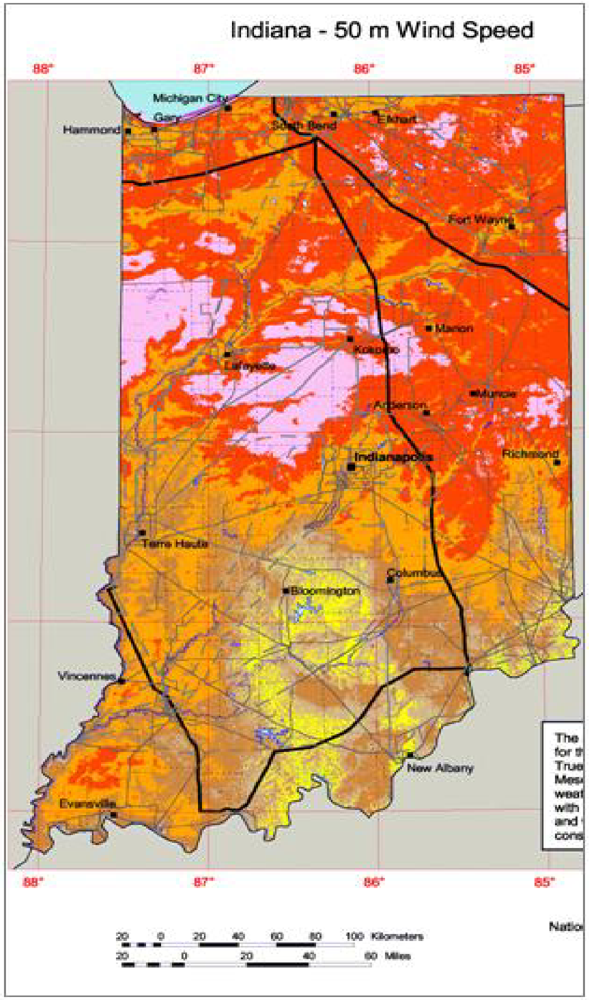
Considerations for Siting a Wind Farm

- 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

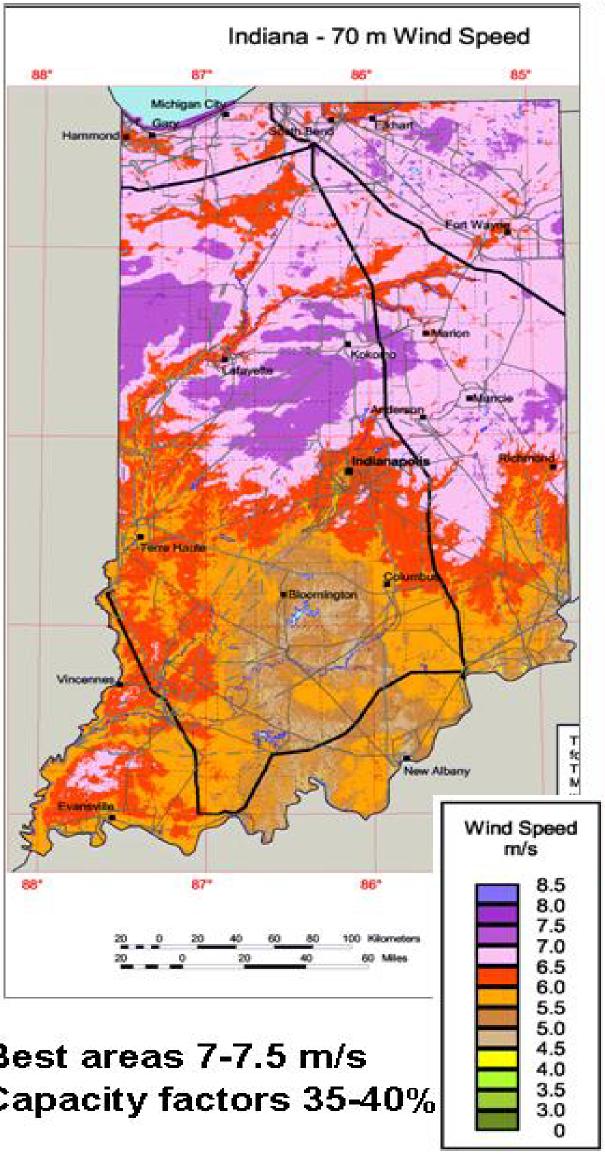
Rotor Blades 37m:
- Shown Feathered
- 37m length

A Utility Scale 1.5 MW Wind Turbine

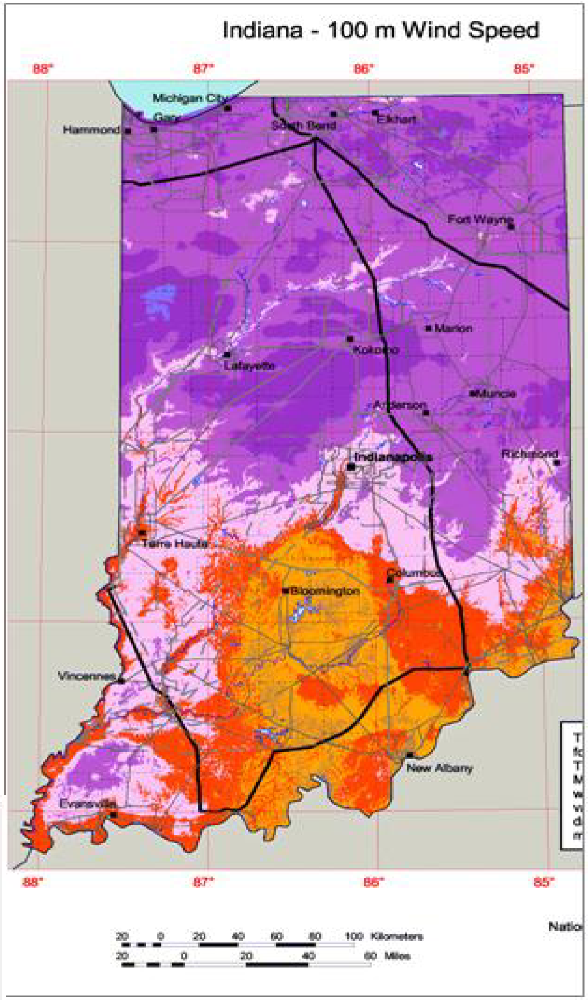
Wind Energy Increases with Height



Best areas 6.5-7 m/s
Capacity factors 30-35%

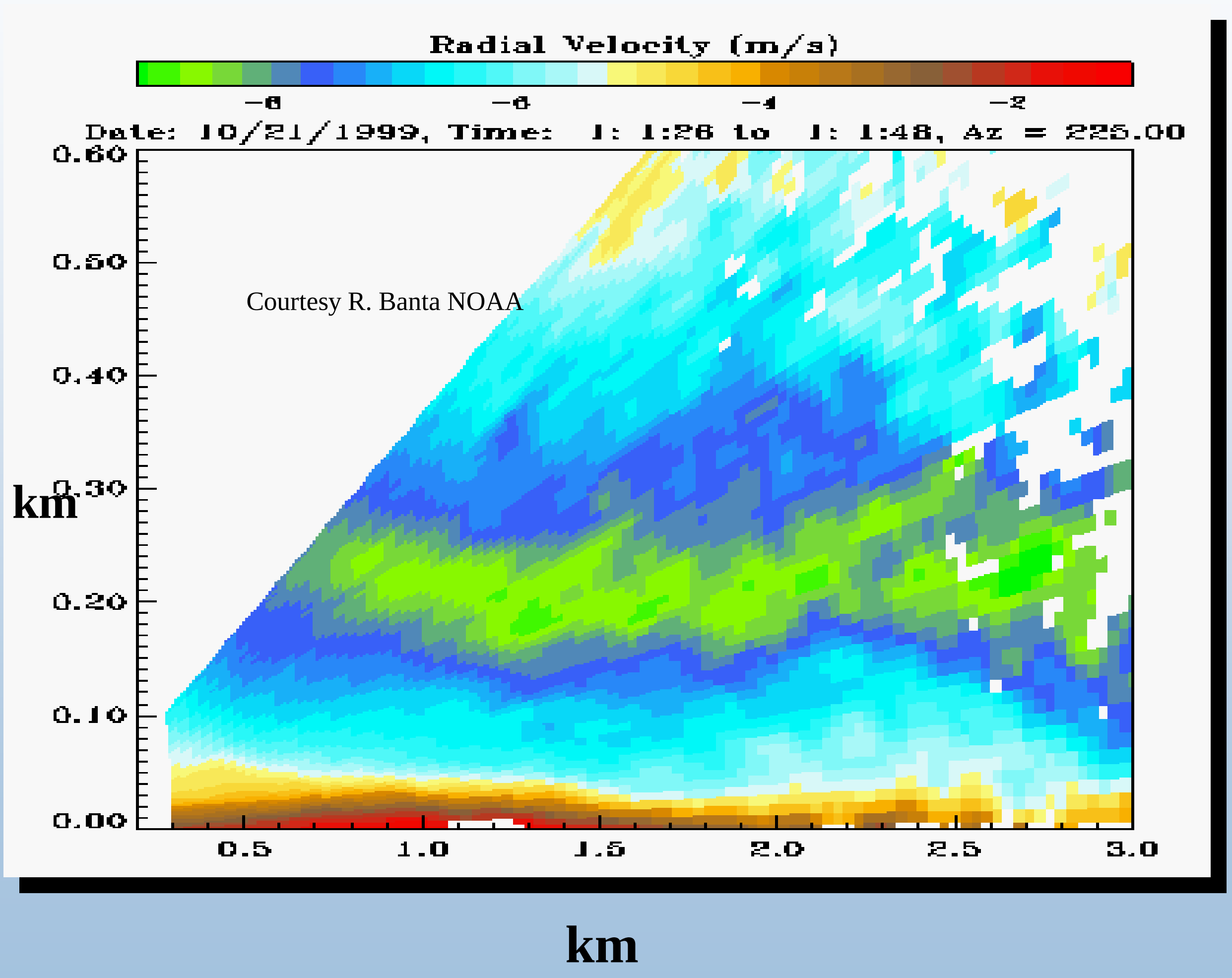


Best areas 7-7.5 m/s
Capacity factors 35-40%



Best areas 7.5-8.2 m/s
Capacity factors 40-45%

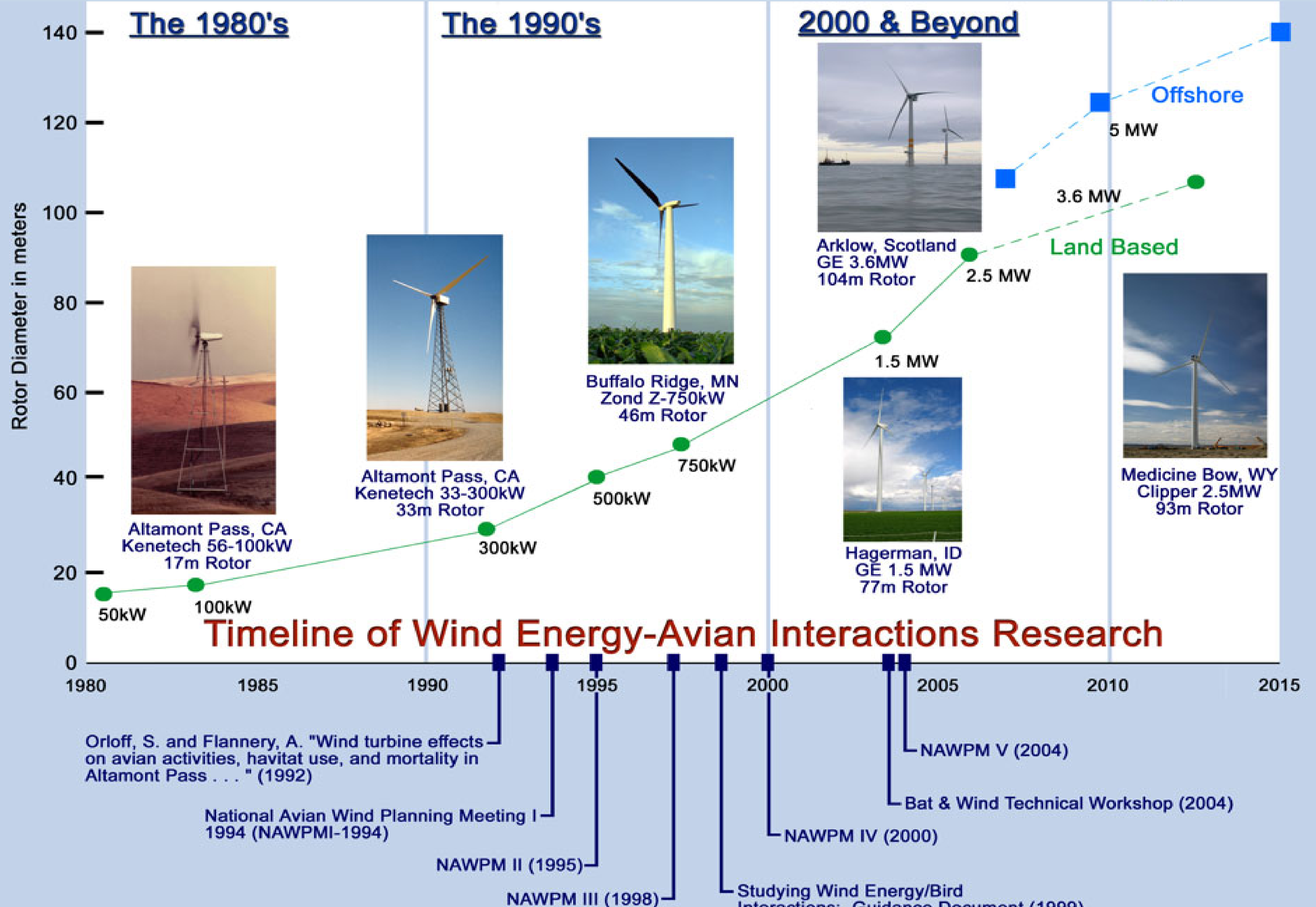
Measuring and Modeling the Wind: Lidar Picture of Low-Level Nocturnal Jet



Courtesy R. Banta NOAA

Met tower and SODAR at Lamar, Colorado

Evolution of U.S. Commercial Wind Technology



Timeline of Wind Energy-Avian Interactions Research

Orloff, S. and Flannery, A. "Wind turbine effects on avian activities, havitat use, and mortality in Altamont Pass . . . " (1992)

National Avian Wind Planning Meeting I 1994 (NAWPMI-1994)

NAWPM II (1995)

NAWPM III (1998)

Studying Wind Energy/Bird Interactions: Guidance Document (1999)

NAWPM IV (2000)

Bat & Wind Technical Workshop (2004)

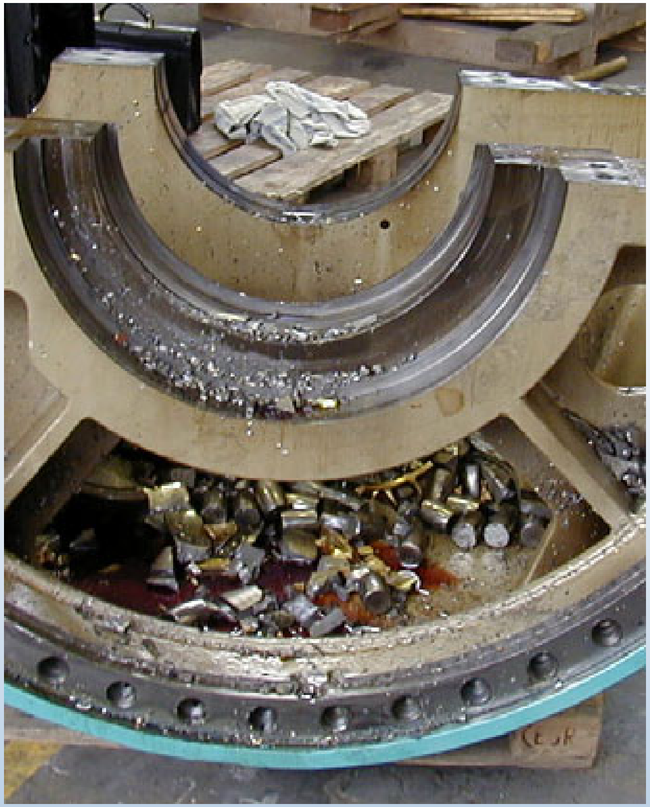
NAWPM V (2004)

Industry's Growing Needs

A new 45-meter wind turbine blade was shipped to the NWTC for testing in July 2004.

Clipper LWST Prototype
2.5 MW with 93 m Rotor

Engineering Challenges



The Problems:

- Capital cost to high
- Gearbox reliability poor
- Transportation costs to high
- Crane capacity & availability limited
- Operational expenses to high
- Rotor expansion reaching limits
- Innovation risk is high

Modern turbines represent a complex & highly integrated structure and technology improvements must be evaluated as a system, because of the coupled interactions between components can greatly affect the optimum configuration and resulting cost.

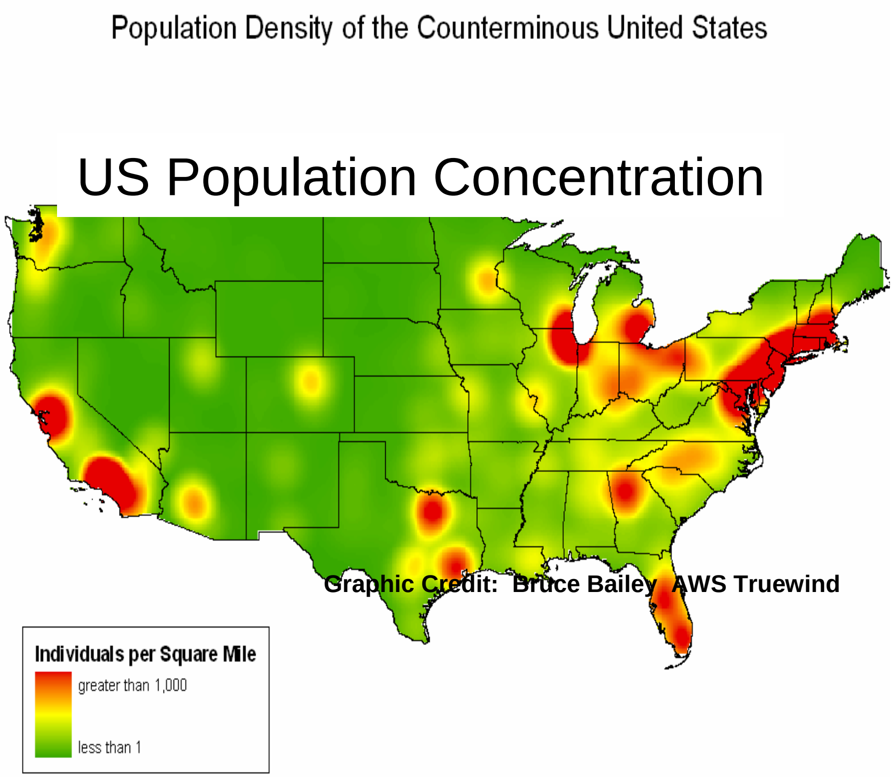
Offshore Wind: Why?

Land-based sites are not close to coastal load centers

Load centers are close to offshore wind sites

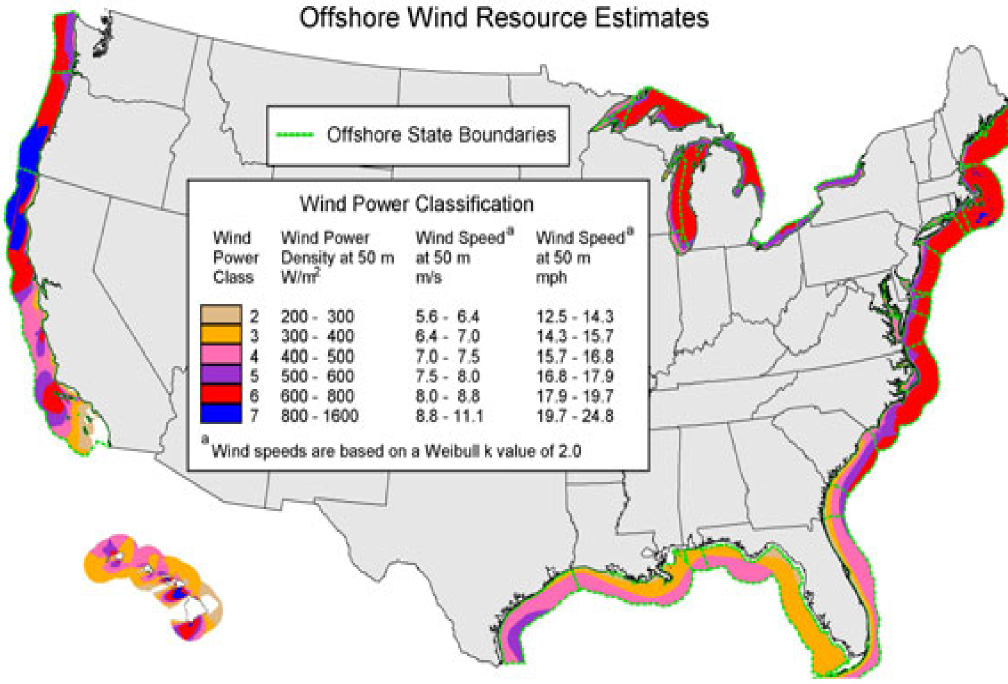
28 Coastal States Use 78% of Electricity

US Population Concentration



Graphic Credit: Bruce Bailey AWS Truewind

U.S. Wind Resource



Wind Power Classification

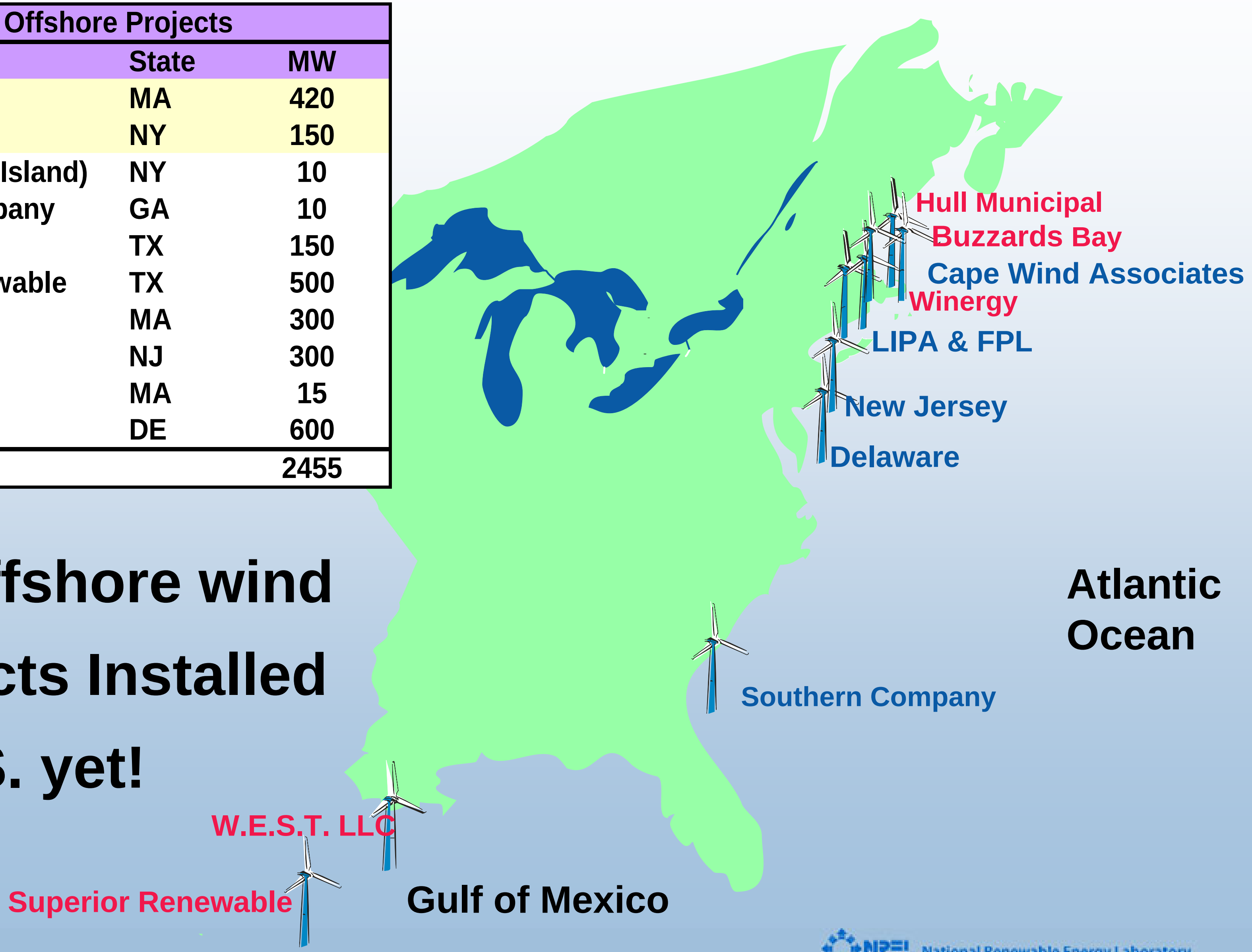
	Wind Power Class	Wind Power Density at 50 m W/m^2	Wind Speed[a] at 50 m m/s	Wind Speed[a] at 50 m mph
🟫	2	200 - 300	5.6 - 6.4	12.5 - 14.3
🟧	3	300 - 400	6.4 - 7.0	14.3 - 15.7
▨	4	400 - 500	7.0 - 7.5	15.7 - 16.8
🟪	5	500 - 600	7.5 - 8.0	16.8 - 17.9
🟥	6	600 - 800	8.0 - 8.8	17.9 - 19.7
🟦	7	800 - 1600	8.8 - 11.1	19.7 - 24.8

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

Proposed U.S. Offshore Projects

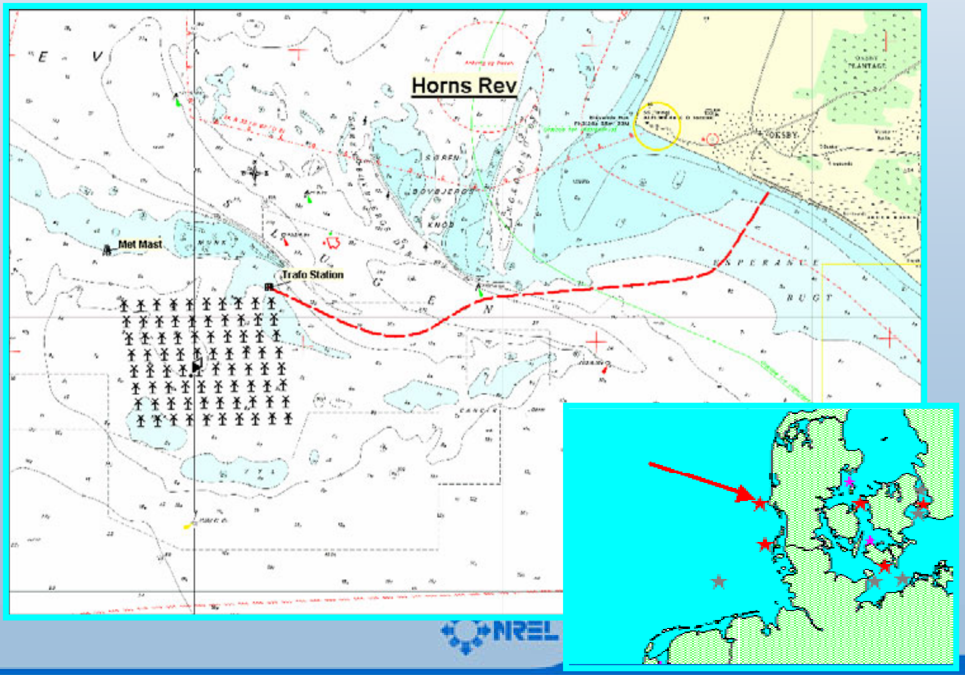
US Offshore Projects		
Project	**State**	**MW**
Capewind	MA	420
LIPA	NY	150
Winergy (plum Island)	NY	10
Southern Company	GA	10
W.E.S.T.	TX	150
Superior Renewable	TX	500
Buzzards Bay	MA	300
New Jersey	NJ	300
Hull Municipal	MA	15
Delaware	DE	600
Total		2455

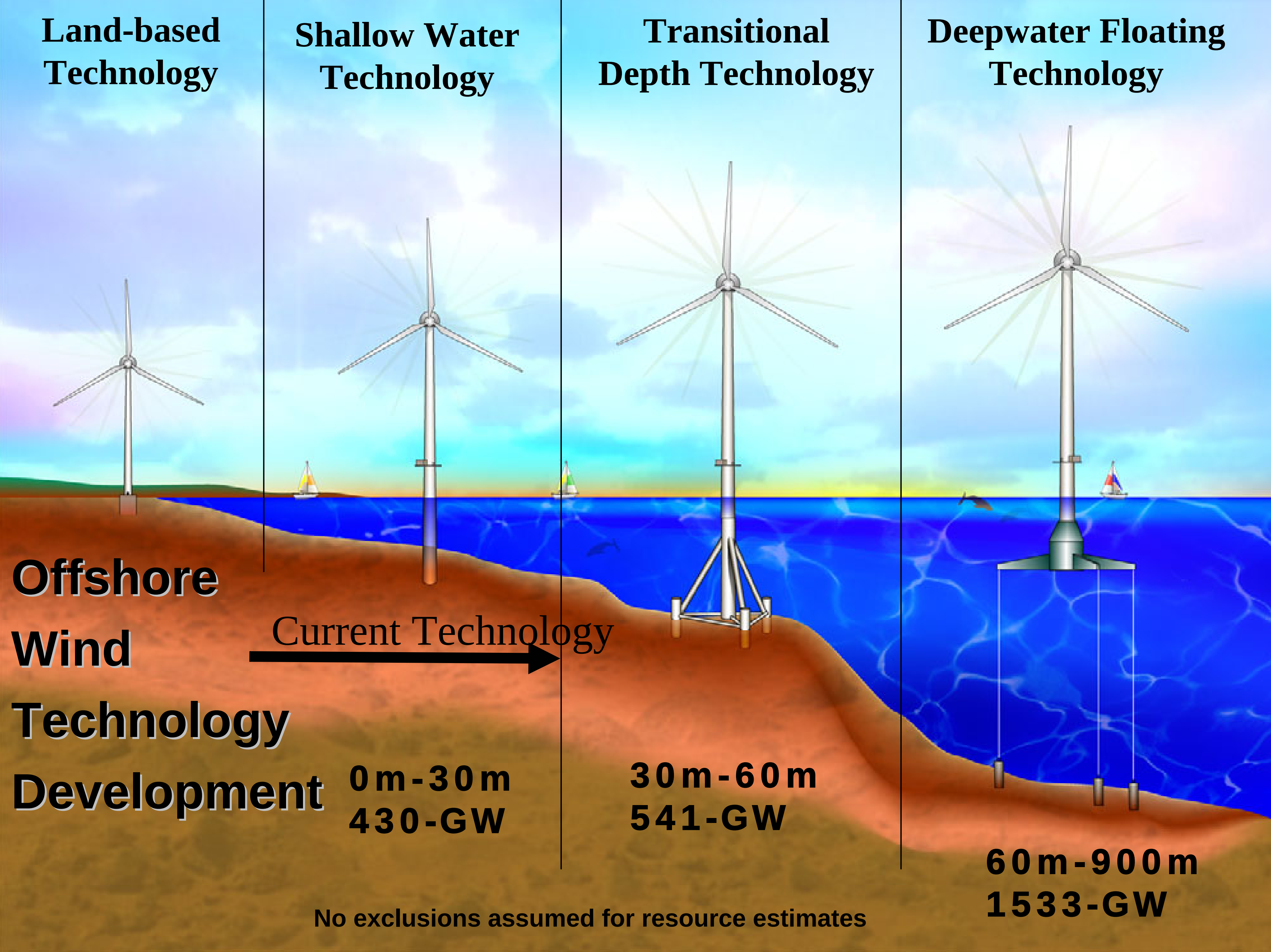
No Offshore wind projects Installed in U.S. yet!



Horns Rev Wind Farm Installation

Country: Denmark
Location: West Coast
Total Capacity: 160 MW
Number of Turbines: 80
Distance to Shore: 14-20 km
Depth: 6-12 m
Capital Costs: 270 million Euro
Manufacturer: Vestas
Total Capacity: 2 MW
Turbine-type: V80 - 80m diameter
Hub-height: 70-m
Mean Windspeed: 9.7 m/s
Annual Energy output: 600 GWh





Land-based Technology

Shallow Water Technology

Transitional Depth Technology

Deepwater Floating Technology

Offshore Wind Technology Development

Current Technology

0m-30m
430-GW

30m-60m
541-GW

60m-900m
1533-GW

No exclusions assumed for resource estimates

Small Wind Power Applications in the U.S.


Farm


Industry


Business


Residential


Schools

SWWP DWT Prototype
1.8kW under test at the NWTC

High Wind Operation

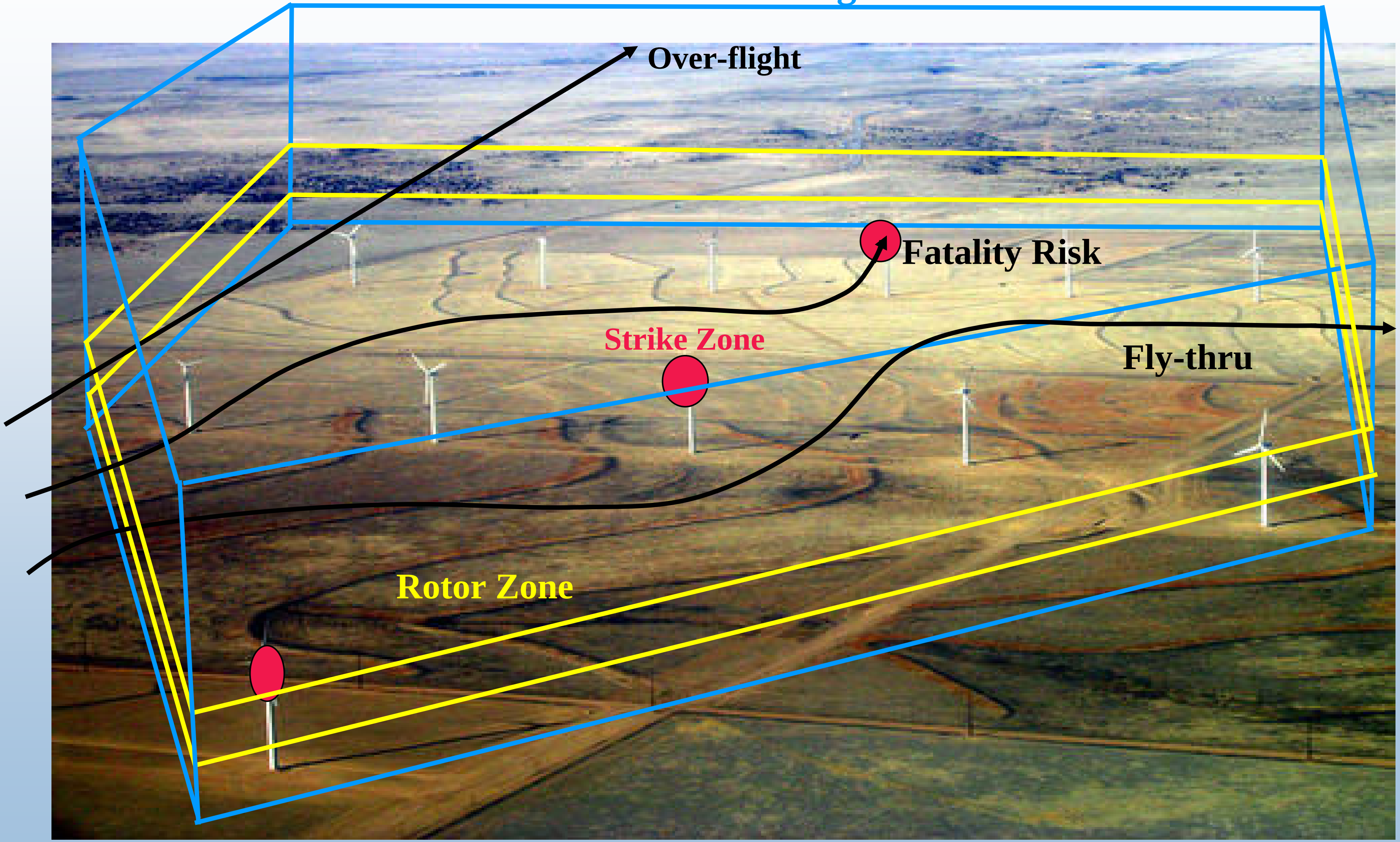
Installation

National Avian – Wind Power Planning Meeting I July 1994

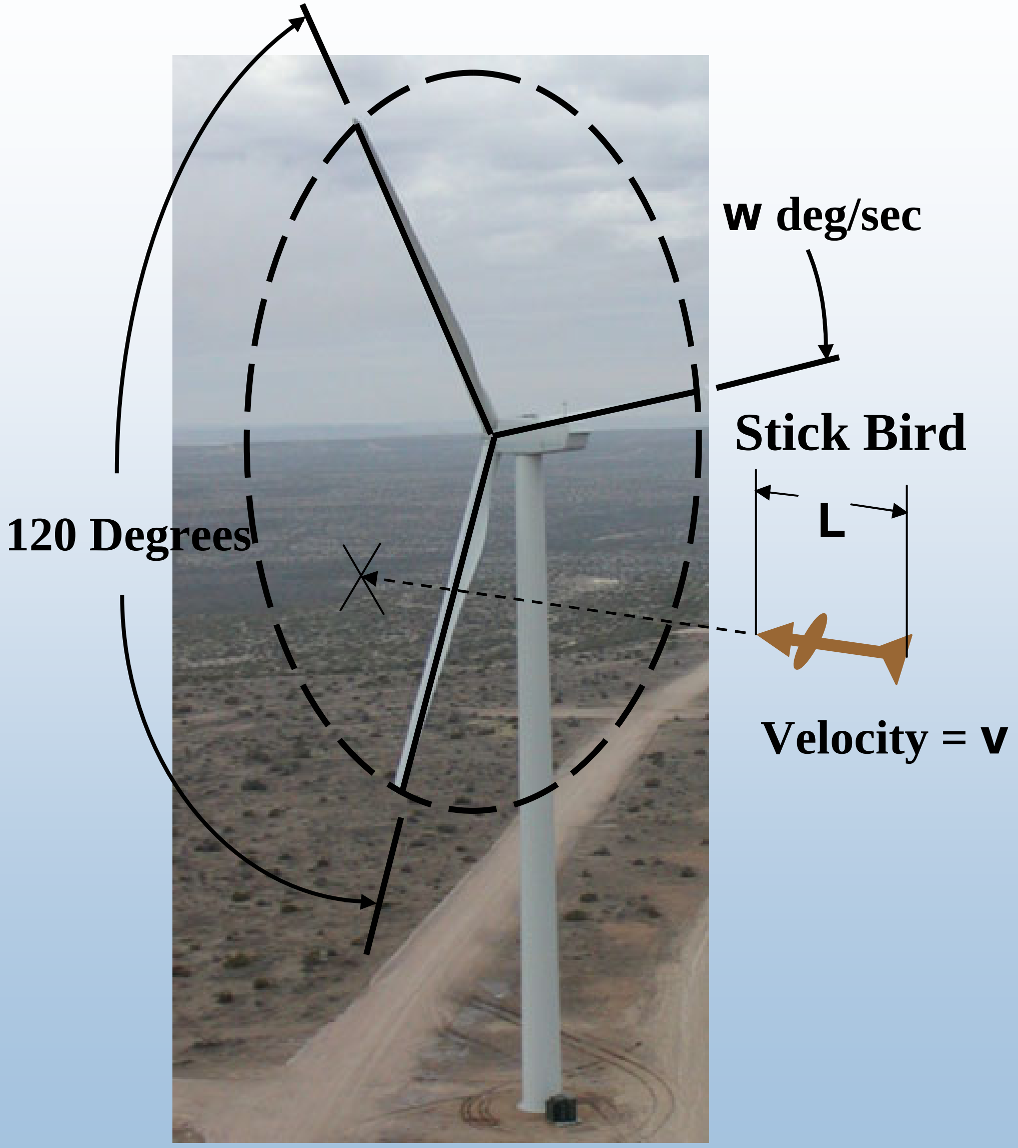
Meeting Outcome: Five Major Research Areas

- Assess mortality attributable to wind turbines at existing sites (including control data from “no turbine” sites)
- Predict mortality at planned wind power sites, based in part on previous bullet
- Predict population consequences
- Identify ways to reduce bird kills at wind plants
- Set values for off-site mitigation

Visualization of Avian Interaction Zones



A Simple Stick Collision Model



Stick Turbine

Bird passage time through the rotor:

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

Blocked Sector of Turbine Rotor:

$$B = t_p\, w \ (\text{deg})$$

Probability of collision:

$$P_c = \text{Blocked Area} / \text{Disk Area}$$

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

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

To account for avoidance:

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

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

Avian Strike Probability Versus Turbine Size

Altamont Scale

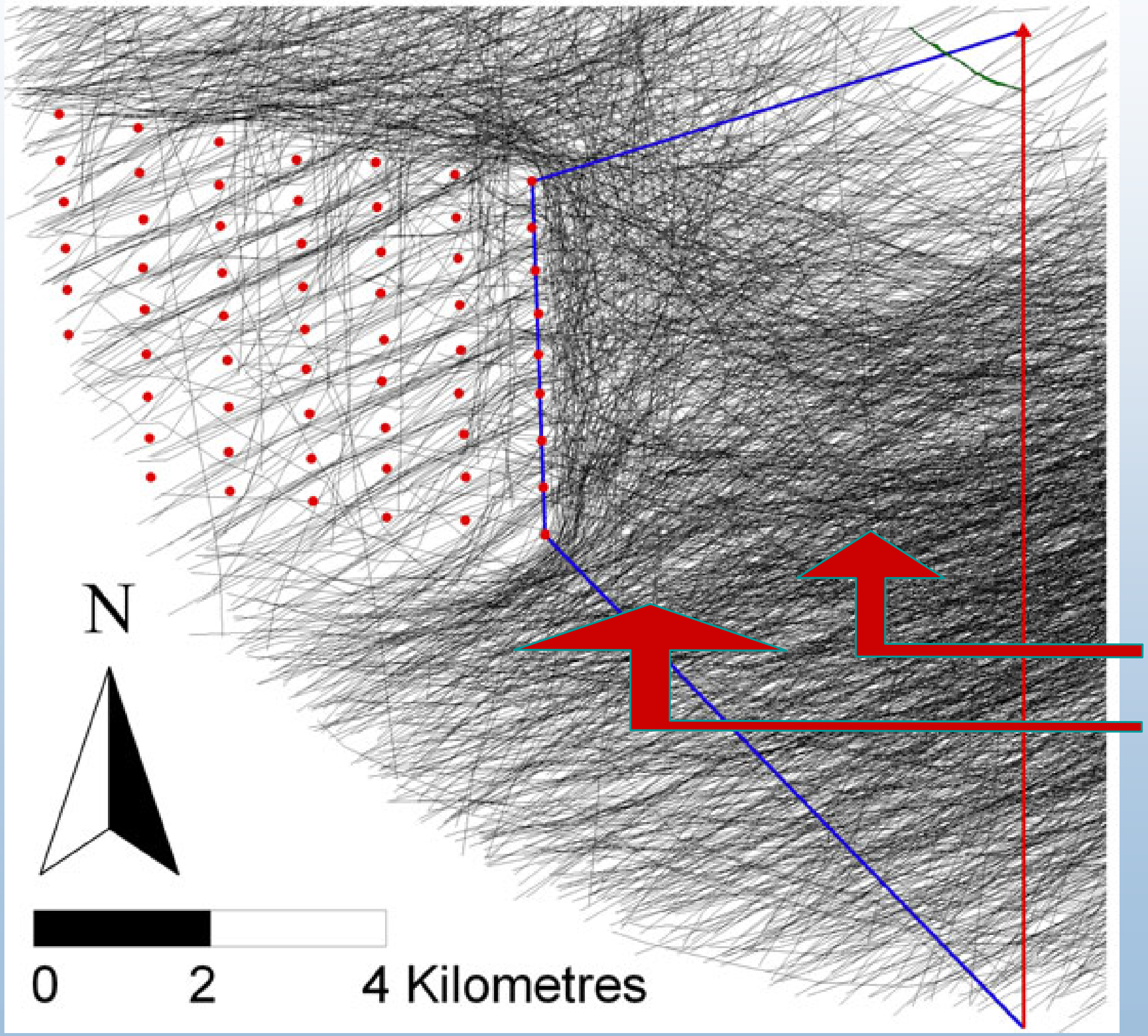
15 Meter Diameter and 100 kW

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

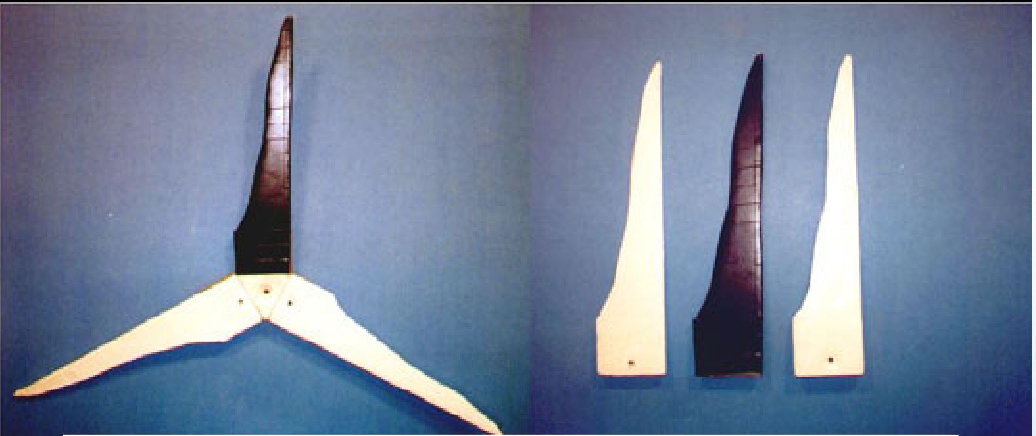


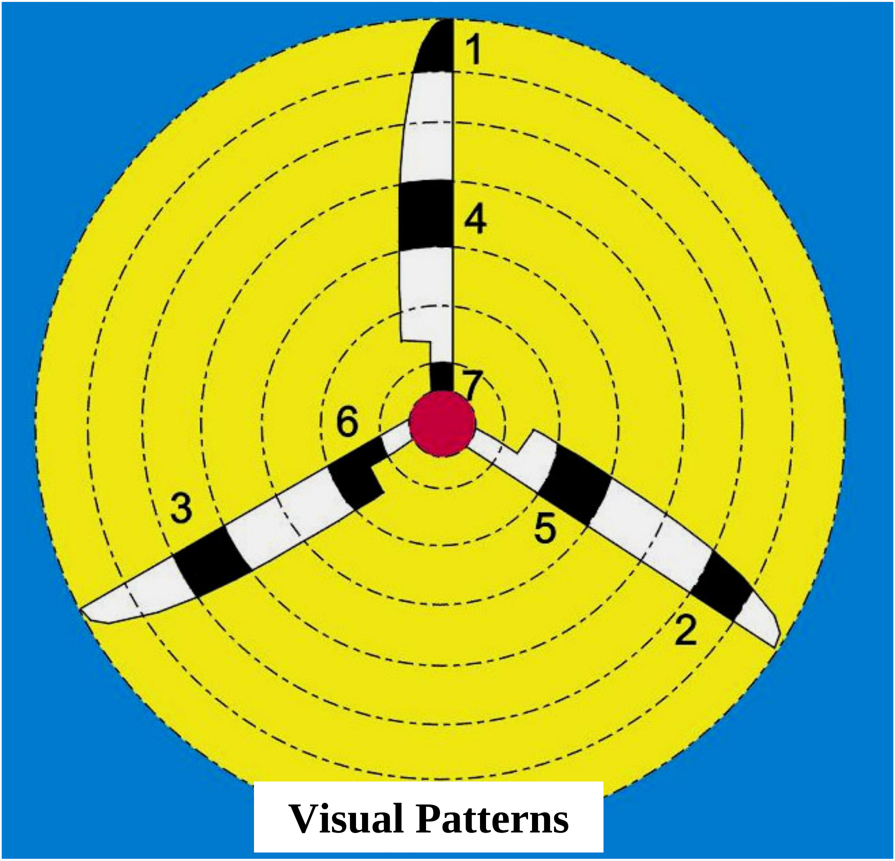
Response distance:

day = c. 3000m

night = c. 1000m

Avian Risk Reduction: Visual Enhancement to Increase Avoidance





Visual Patterns

American Kestrel

Source: ***The Role of Visual Deterrents in Reducing Avian Collisions;*** **William Hodos, University of Maryland**

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)

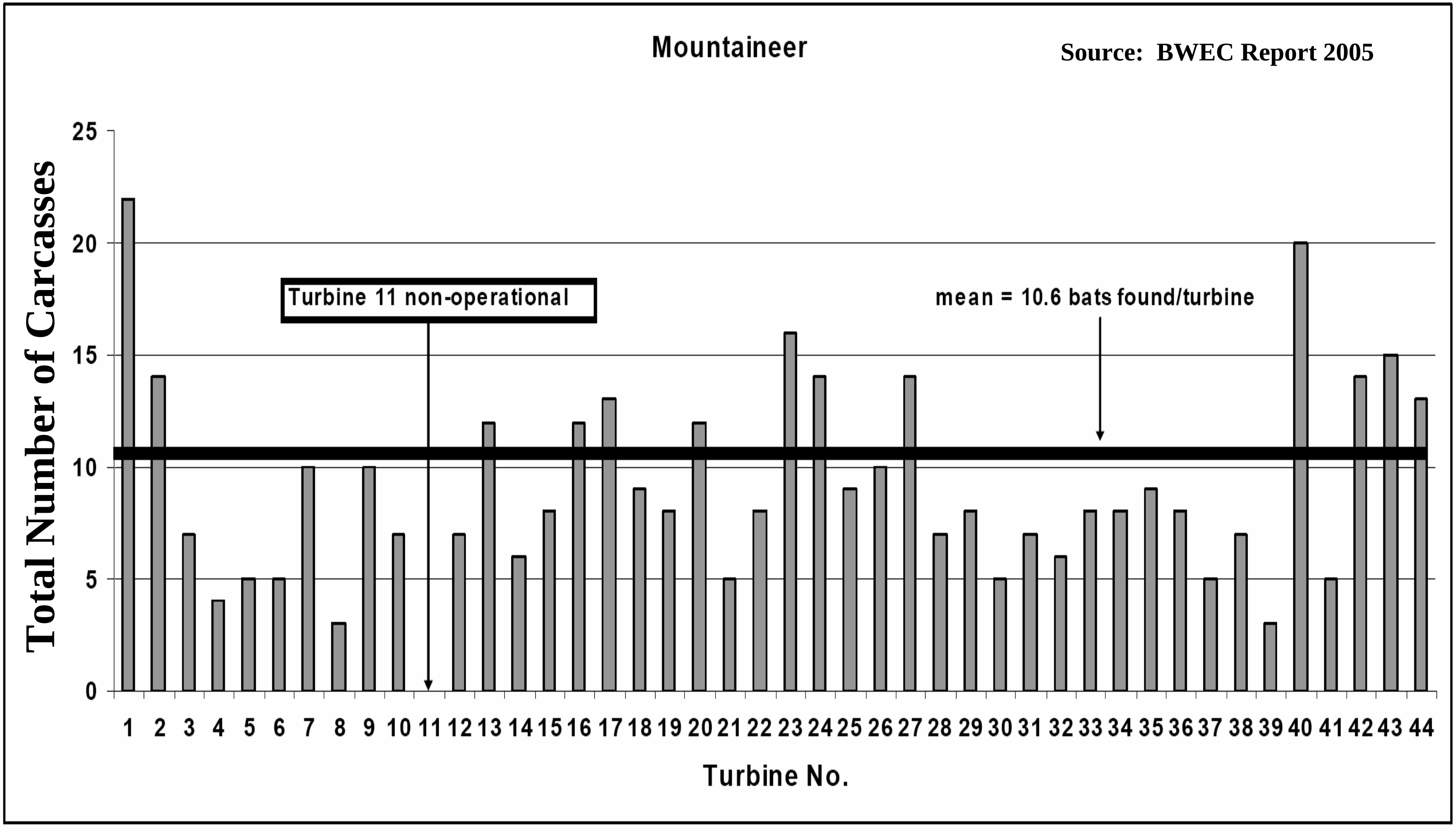
Infrared Image of a Bat Flying Through a Wind Turbine Rotor

Photo by Jason Horn, Boston University

Multi-Stakeholder Wildlife Research

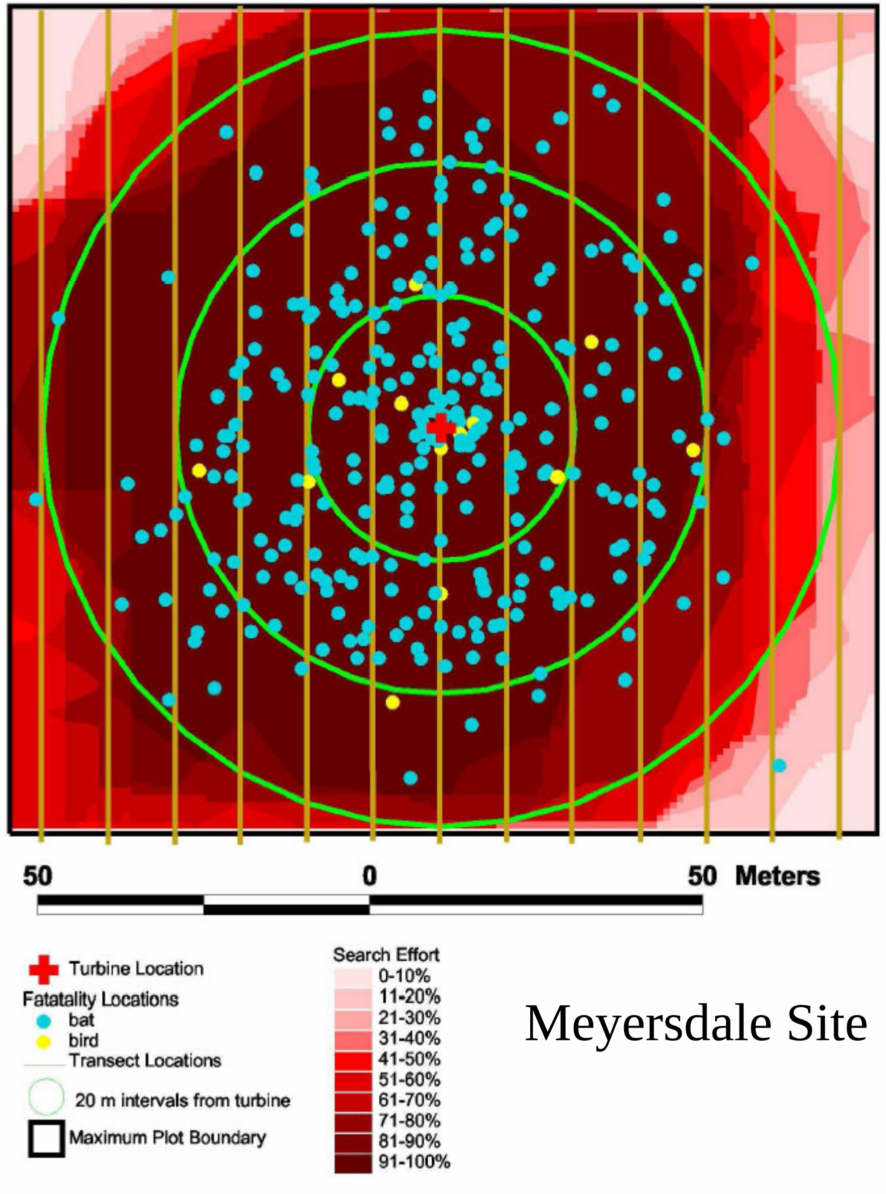
- **National Wind Coordinating Committee**
  - **Federal, State, Utilities, NGOs, Wind Industry**
- **Bat & Wind Energy Cooperative (BWEC)**
  - **AWEA, Wind Industry, USFWS, DOE, NGOs**
- **Grassland Shrub Steppe Species Collaborative**
  - **AWEA, Wind Industry, States, DOE, USFWS**

BWEC Study Results



Number of bat fatalities found at each turbine during the study period.

BWEC Study Results



Meyersdale Site

Source: BWEC Report 2005

Meyersdale Wind farm:

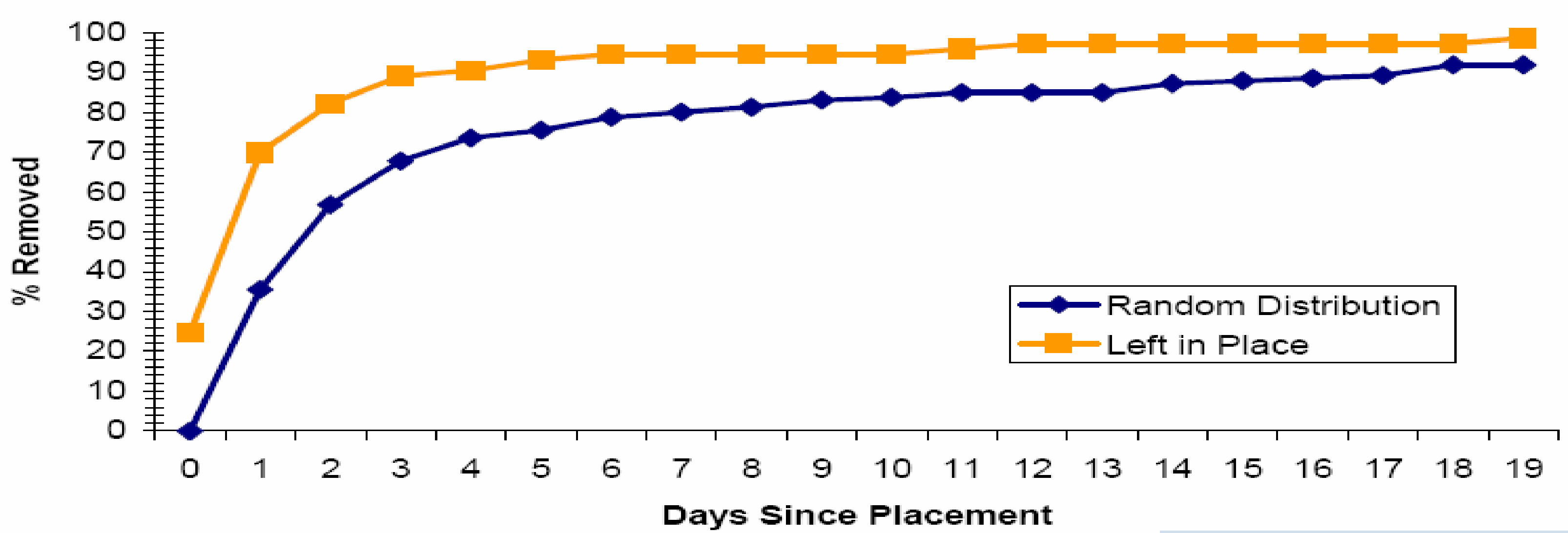
- NEG – Micon 1.5 MW Turbine
- 72 meter rotor Diameter
- 17 revs/min = 102 deg/sec
- Constant rotor rpm
- Green dots are bat carcasses
- Yellow dots are birds
- Bird and bat fatalities for all 20 turbines are overlaid

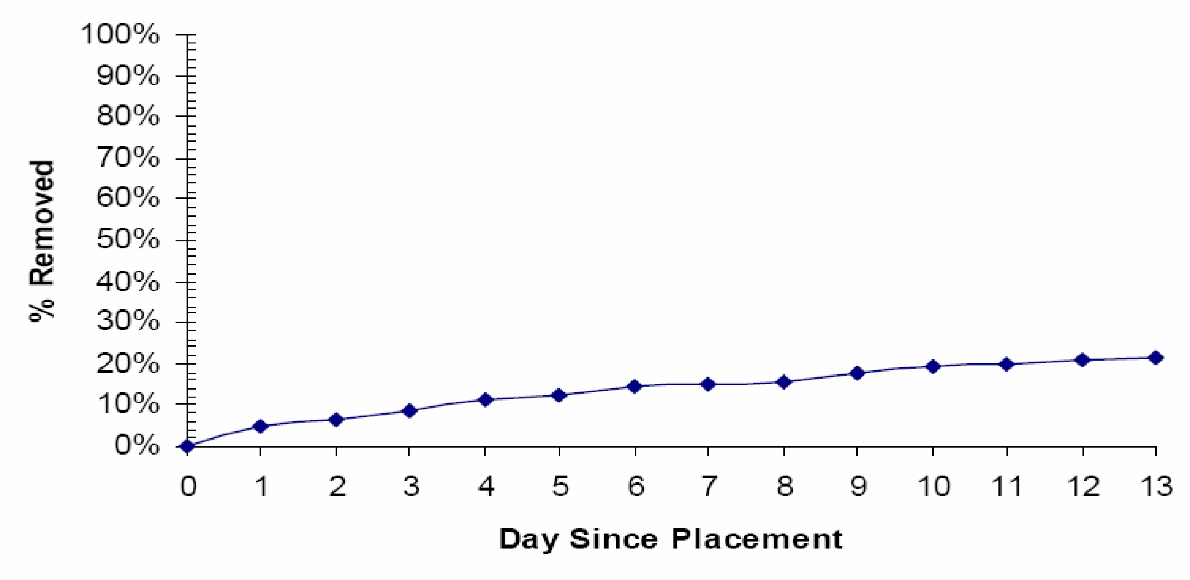
Observations:

- Bird and bat fatalities appear to be fairly uniformly distributed out to 40m
- Beyond a radius of about 40m fatalities drop off rapidly indicating carcasses are not thrown far outside of the blades span
- The higher velocity tip regions of the blade do not seem to be more dangerous than the root near the tower
- Bats are much more vulnerable than birds

BWEC Savaging Study Results

Removal by scavengers

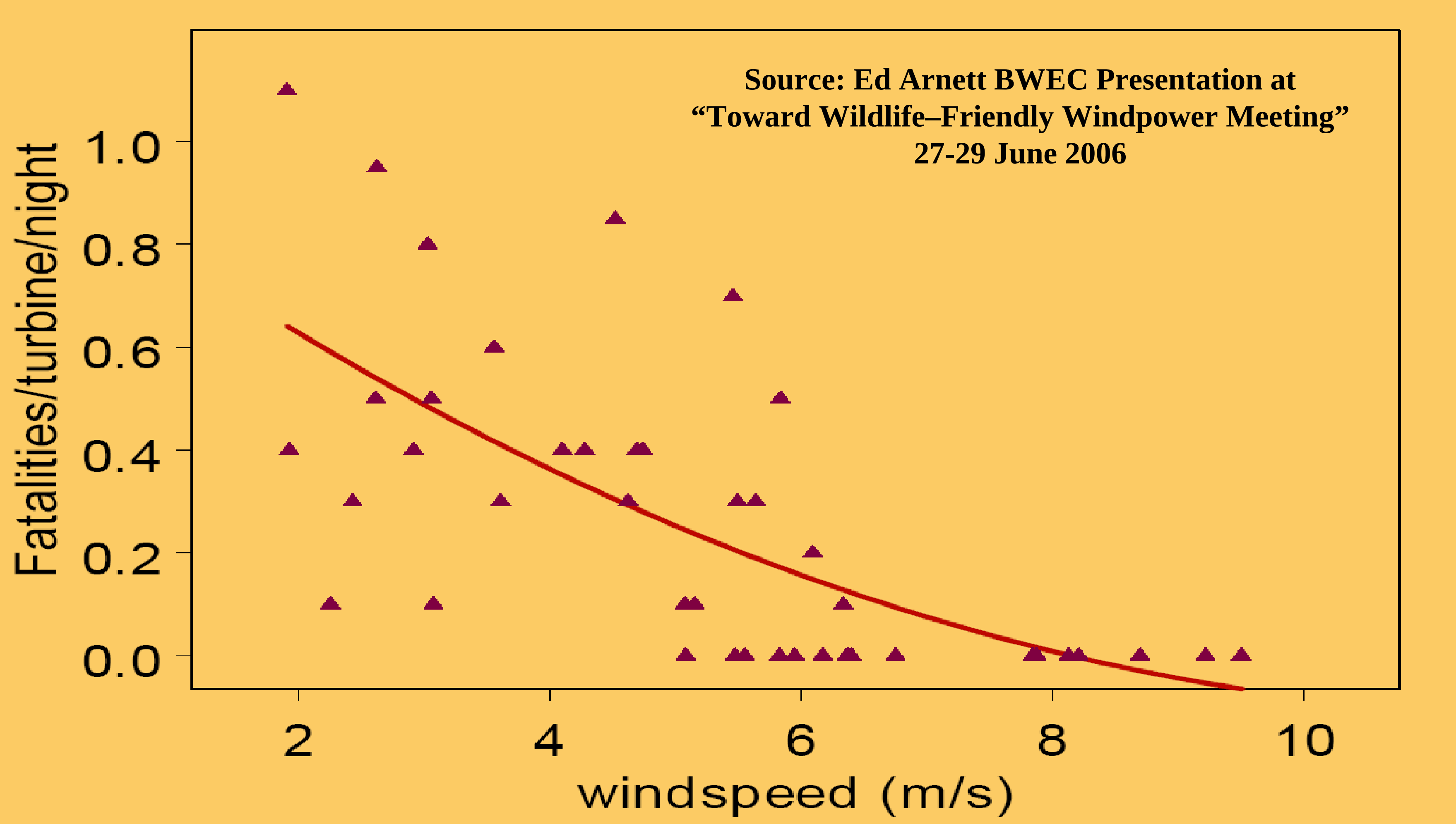




Source: BWEC Report 2005

BWEC Study Results

Fatalities decrease with increasing wind speed

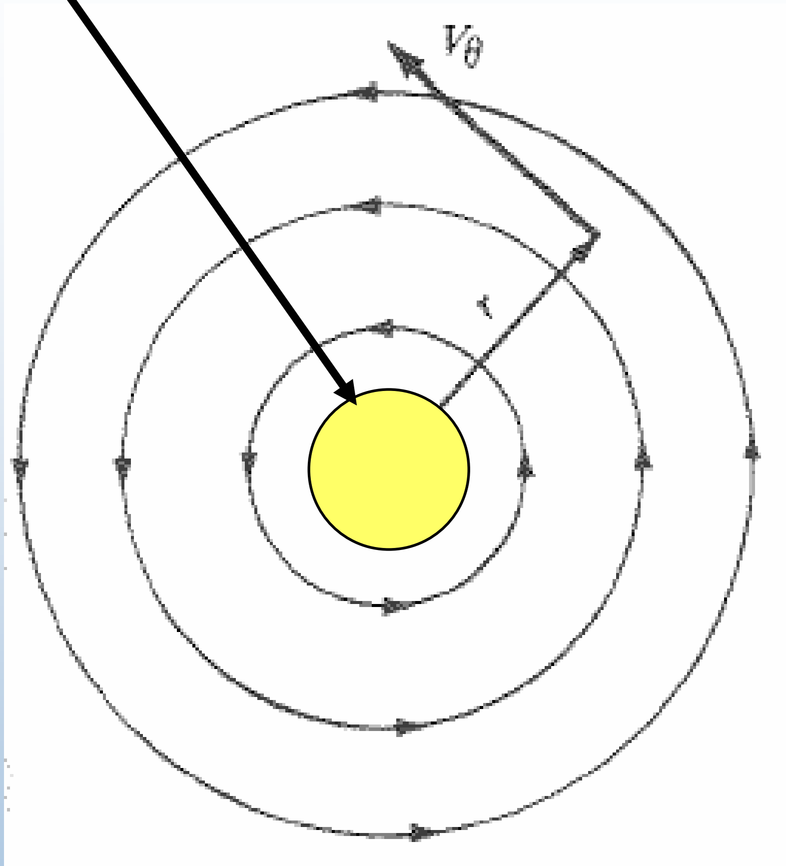


Source: Ed Arnett BWEC Presentation at
“Toward Wildlife–Friendly Windpower Meeting”
27-29 June 2006

Could the Tip Vortex Attract Bats and the Low Pressure Core Cause Trama?

- 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

The Tip Vortex and the Wake

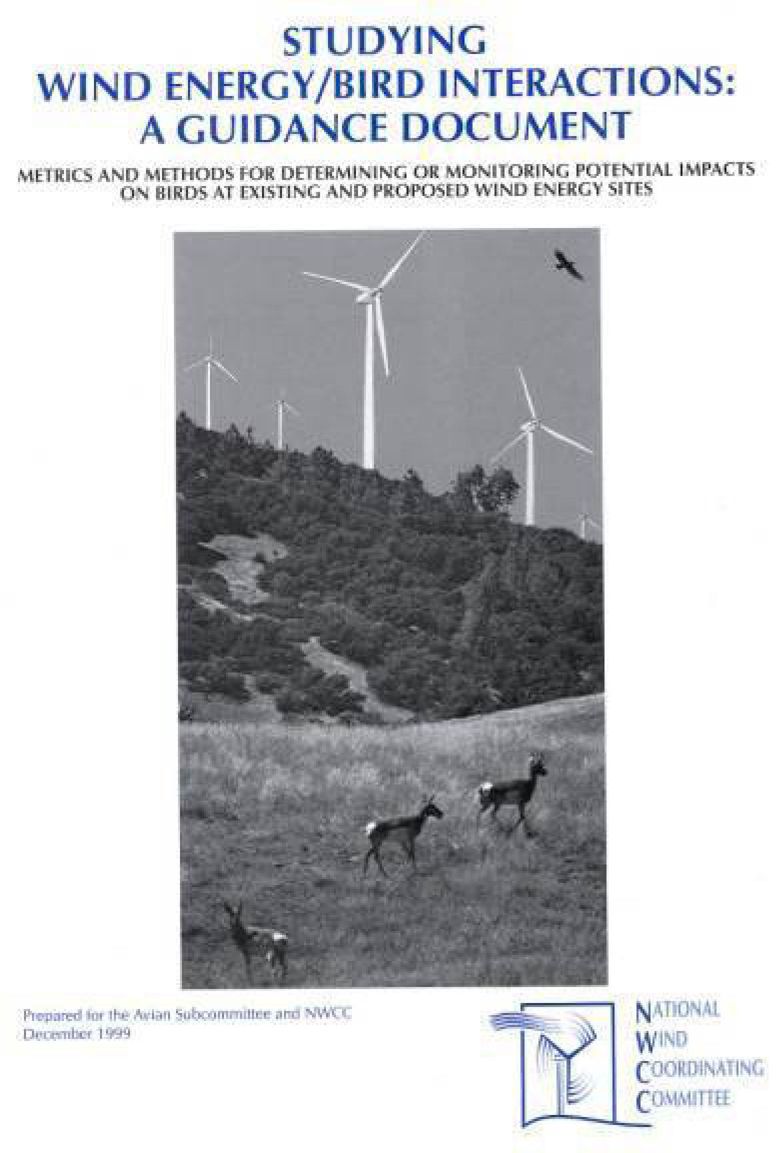

Low Pressure Core

Biot Savart Law

$$V_\theta = \frac{\Gamma}{2\pi r}$$

V_θ = tangential velocity
Γ = vortex strength
r = distance from
vortex center

NWCC Avian Guidance Document



STUDYING
WIND ENERGY/BIRD INTERACTIONS:
A GUIDANCE DOCUMENT

METRICS AND METHODS FOR DETERMINING OR MONITORING POTENTIAL IMPACTS ON BIRDS AT EXISTING AND PROPOSED WIND ENERGY SITES

Prepared for the Avian Subcommittee and NWCC
December 1999

NATIONAL
WIND
COORDINATING
COMMITTEE

Assessing the suitability of a proposed wind farm site with regard to avian concerns is an important component of overall site evaluation. This NWCC document provides guidelines for conducting avian assessments.

- **Published December 1999**
- **Now Being Updated 2008**

Concluding Remark

World-wide electrical energy consumption is projected to grow by about 75% over the next 20 years. All energy technologies have some environmental impacts. Wind Technology is developing rapidly, and a modest investment in environmental R&D now could make the impacts negligible. This would give us a carbon free electricity generating choice that could meet at least 20% of the world’s energy needs.

NREL Avian Studies Available at:

http://www.nrel.gov/wind/avian_lit.html

- Permitting of Wind Energy Facilities: A Handbook
- A Pilot Golden Eagle Population Study in the Altamont Pass Wind Resource Area, California
- A Population Study of Golden Eagles in the Altamont Pass Wind Resource Area, Second-Year Progress Report
- Ponnequin Wind Energy Project – Reference Site Avian Study
- A Population Study of Golden Eagles in the Altamont Pass Wind Resource Area: Population Trend Analysis 1994-1997
- Predicting the Response of Bird Populations to Wind Energy-Related Deaths
- The Response of Red-Tailed Hawks and Golden Eagles to Topographical Features, Weather, and Abundance of a Dominant Prey Species at the Altamont Pass Wind Resource Area, California, April 1999-December 2000
- Searcher Bias and Scavenging Rates in Bird/Wind Energy Studies
- Status of Avian Research at the National Renewable Energy Laboratory (2001)
- Status of the US Dept. of Energy/NREL Avian Research Program (1999)
- Studying Wind Energy/Bird Interactions: A Guidance Document

Offshore Wind
European Environmental References

- **European Union, COD, Principal Findings 2003-2005, prepared by SenterNovem, Netherlands,** **www.offshorewindenergy.org**
- **Offshore Wind: Implementing a New Powerhouse for Europe, Greenpeace International, March 2005** **http://www.greenpeace.org/international/press/reports/offshore-wind-implementing-a**
- **Danish (Horns Rev and Nysted) Ecological Studies** **http://www.hornsrev.dk/Engelk/default_ie.htm and http://uk.nystedhavmoellepark.dk/frames.asp?Page_ID=44&Page_Ref=44&Templates_ID=1**
- **U.K.'s Strategic Environmental Assessment** **http://www.og.dti.gov.uk/offshore-wind-sea/process/envreport.htm**