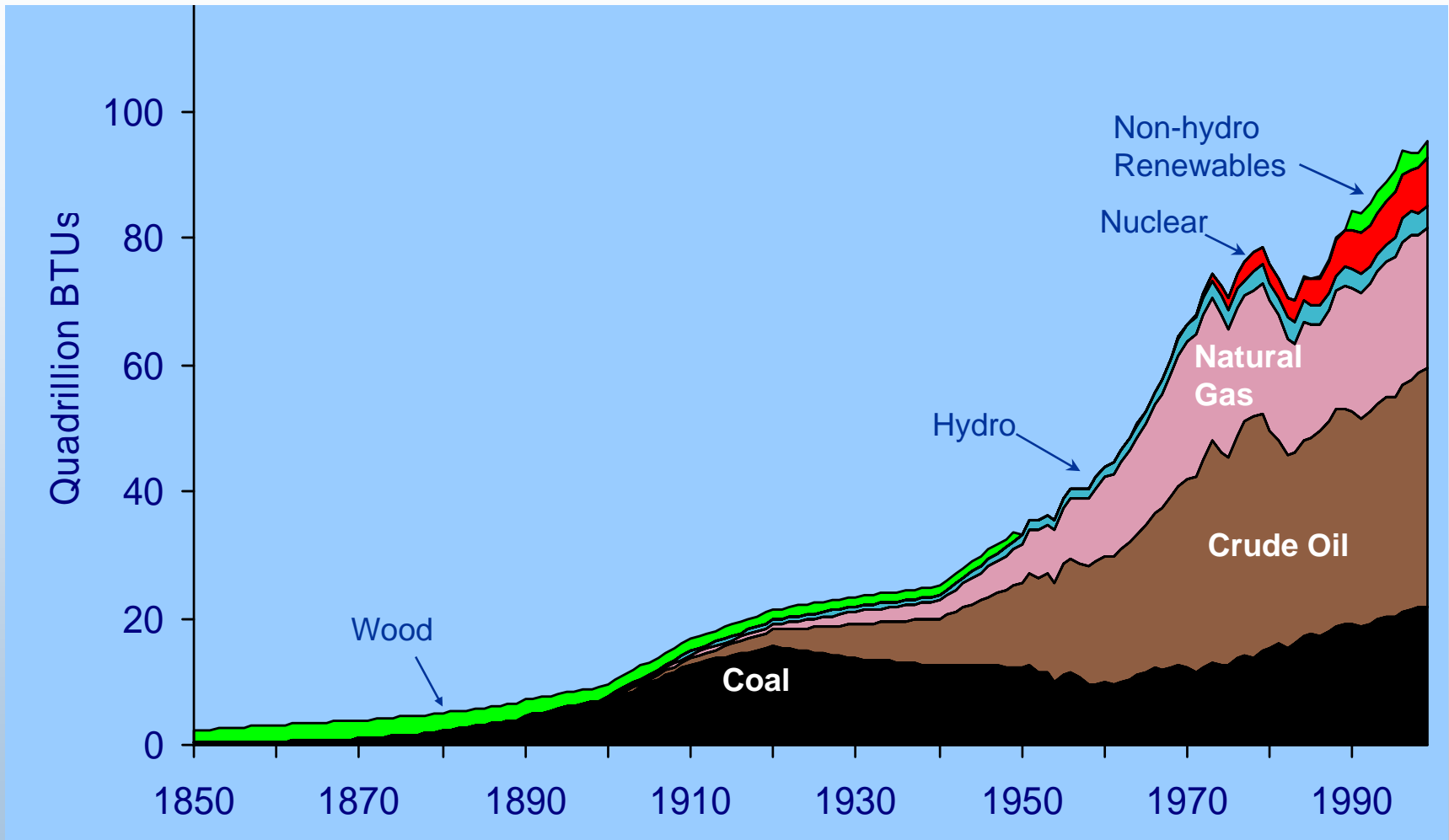


# *Wind Technology and Wildlife Interactions*

An aerial photograph of a wind farm in a valley. Several white wind turbines are visible in the foreground and middle ground. The valley floor is green and grassy, with some buildings and roads scattered throughout. In the background, there are large, rugged mountains under a blue sky with some clouds.

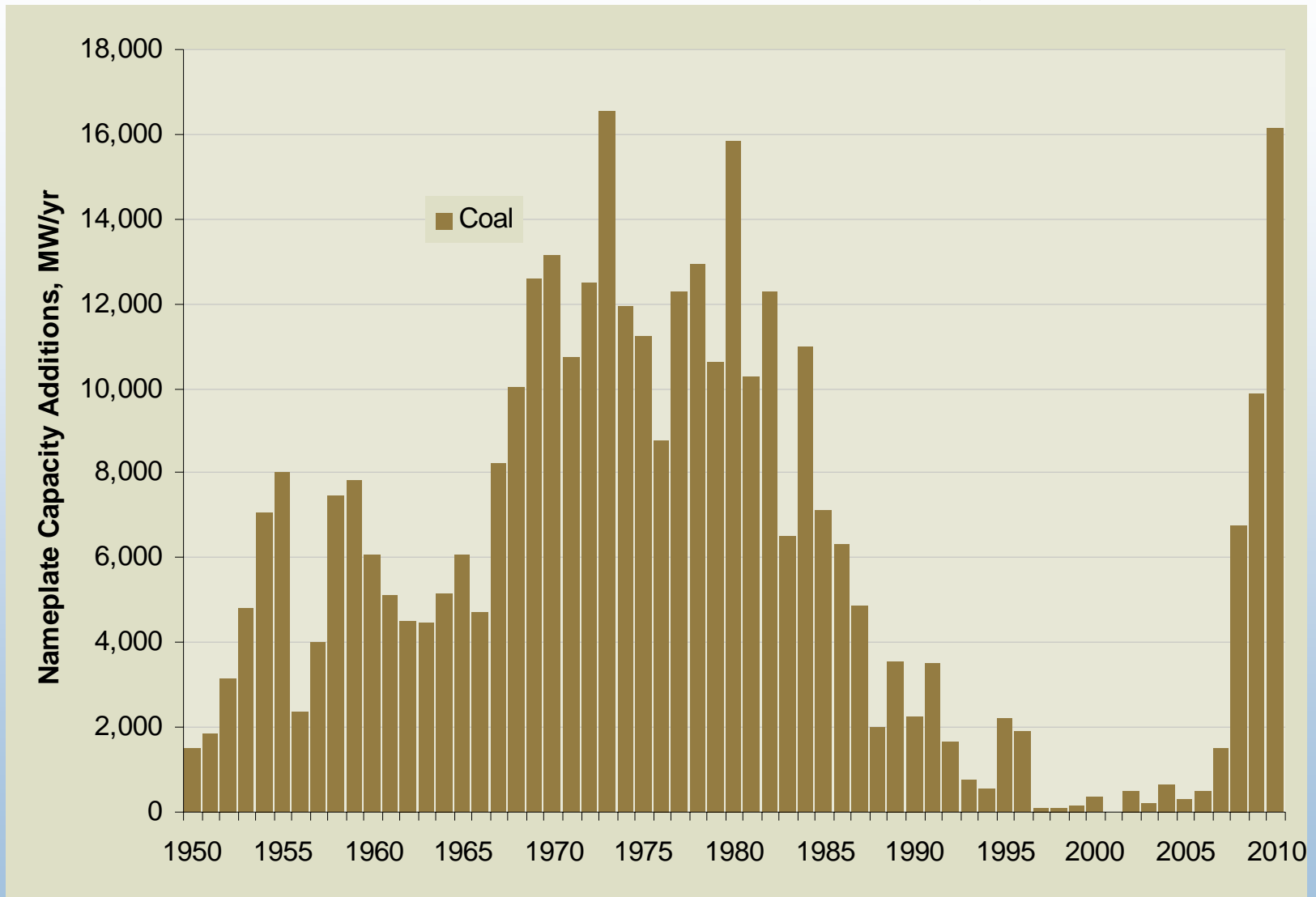
**Presentation for the California Fish and Game Workshop  
By Robert W. Thresher, Director  
National Wind Technology Center  
4 March 2008**

# The U.S. Energy Picture by source - 1850-1999



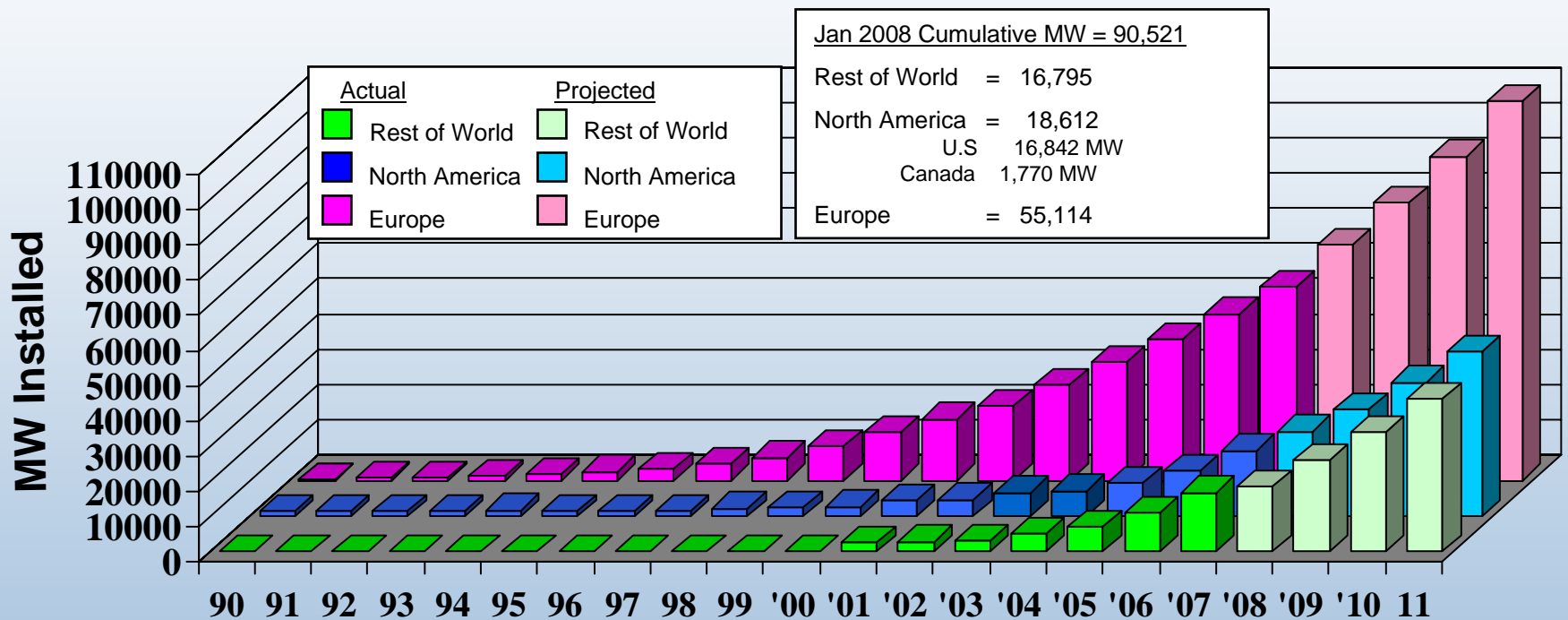
Source: 1850-1949, Energy Perspectives: A Presentation of Major Energy and Energy-Related Data, U.S. Department of the Interior, 1975; 1950-1996, Annual Energy Review 1996, Table 1.3. Note: Between 1950 and 1990, there was no reporting of non-utility use of renewables. 1997-1999, Annual Energy Review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

# The US History and Future Planned Additions of Coal Generated Electricity



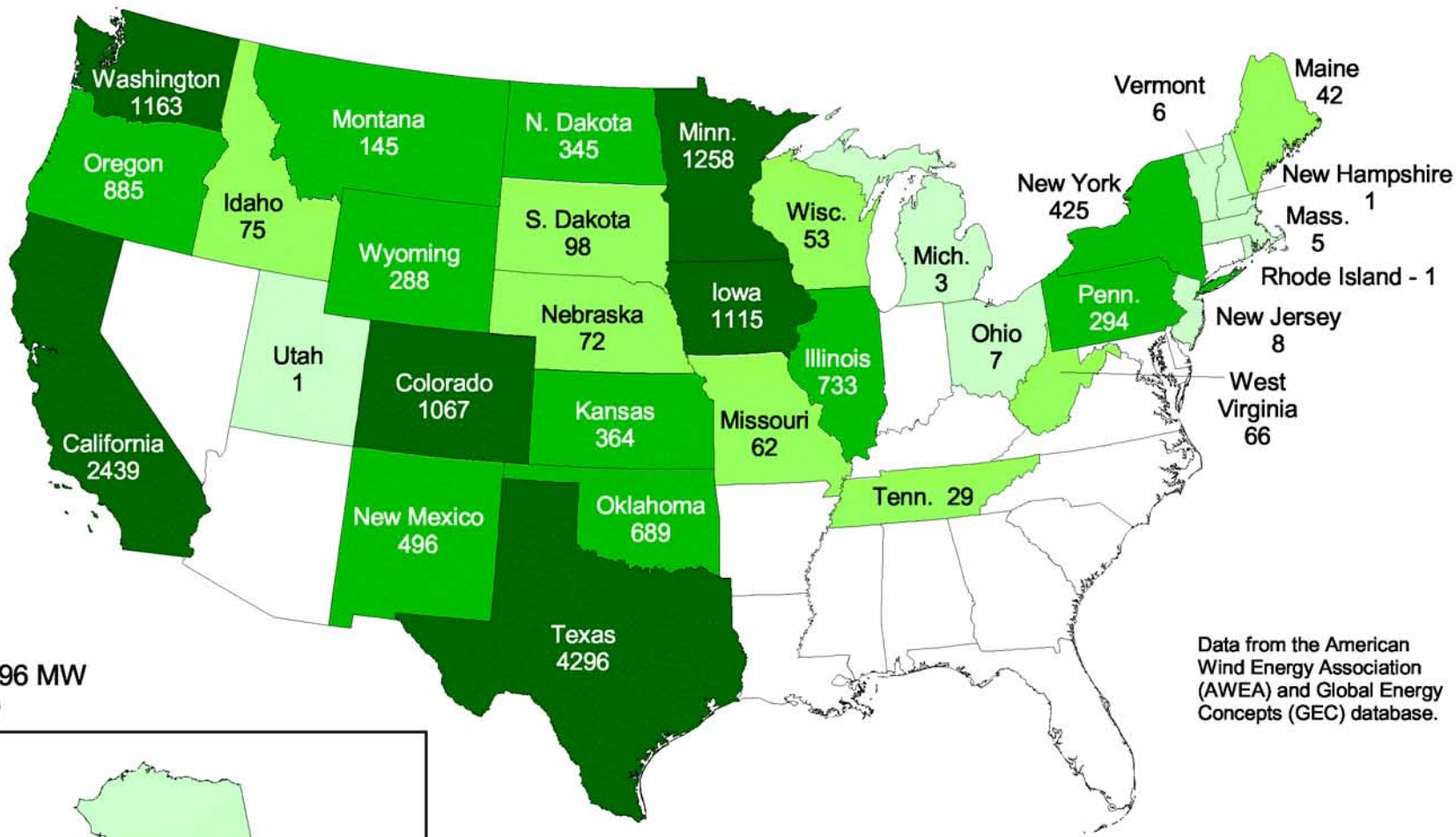
Source: Black & Veatch Analysis of data from Global Energy Decisions Energy Velocity database

# Growth of Wind Energy Capacity Worldwide



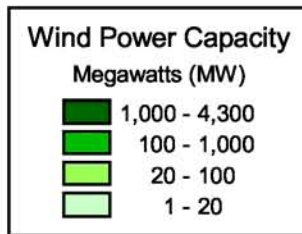
Sources: BTM Consult Aps, March 2007  
 Windpower Monthly, January 2008  
 \*NREL Estimate for 2008

# 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.

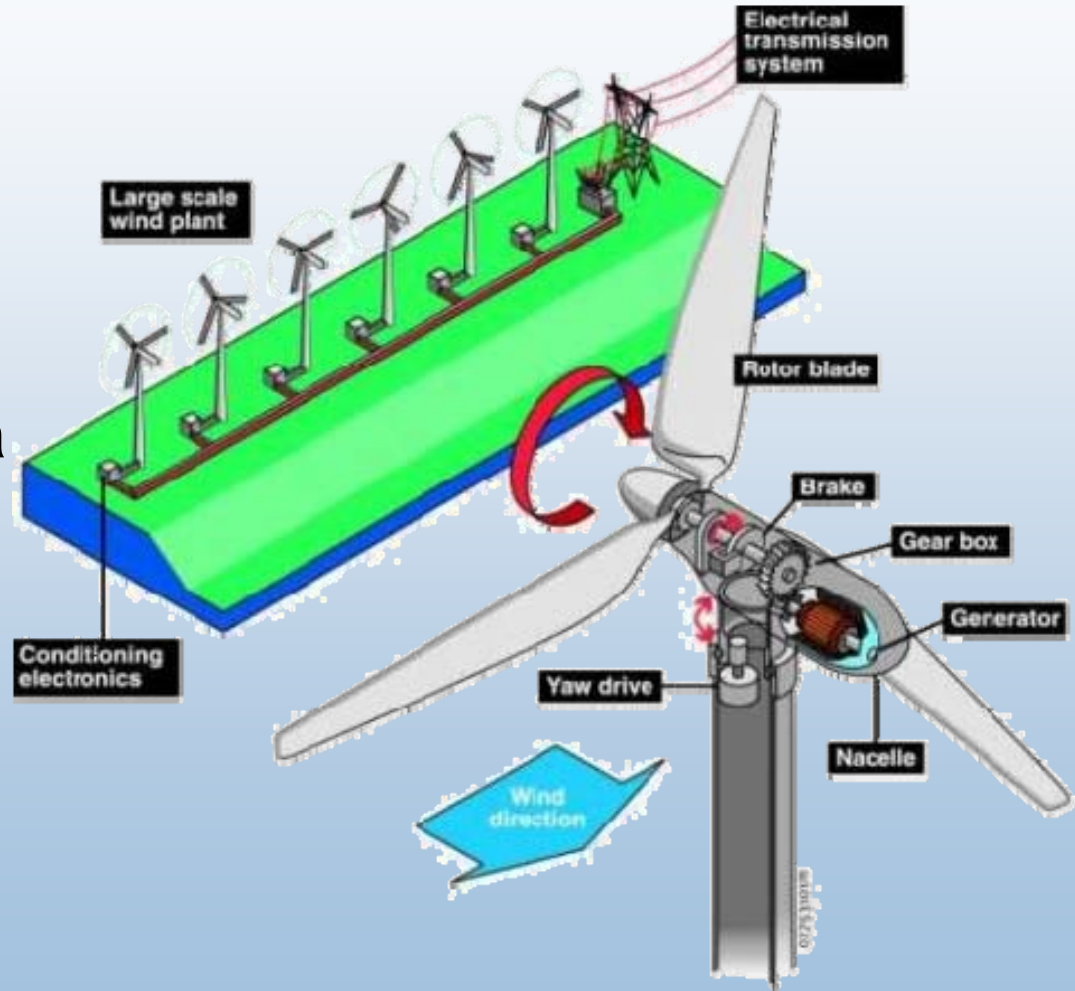


U.S. Department of Energy  
National Renewable Energy Laboratory



# 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.



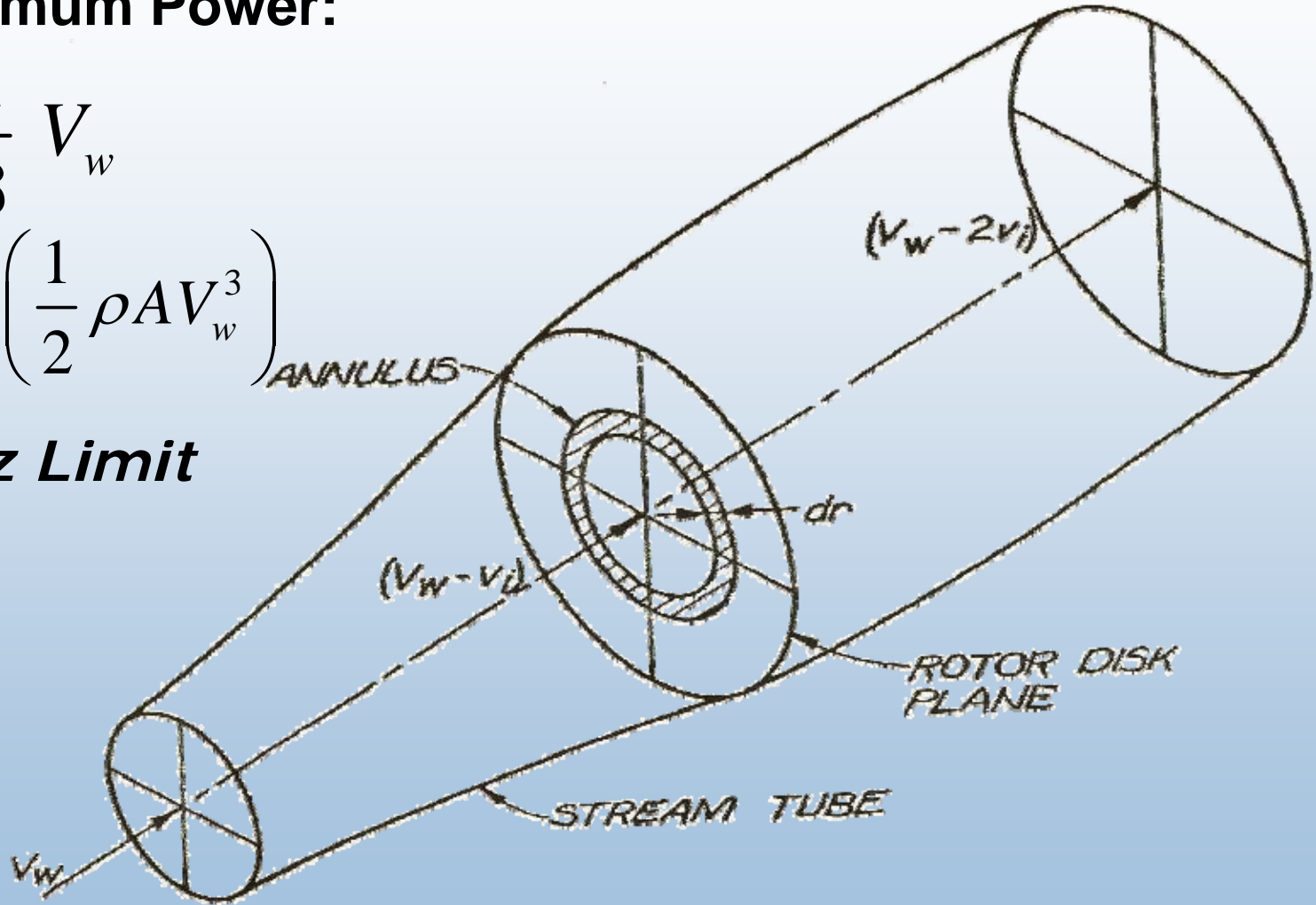
# Stream Tube for Momentum Balance

For Maximum Power:

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

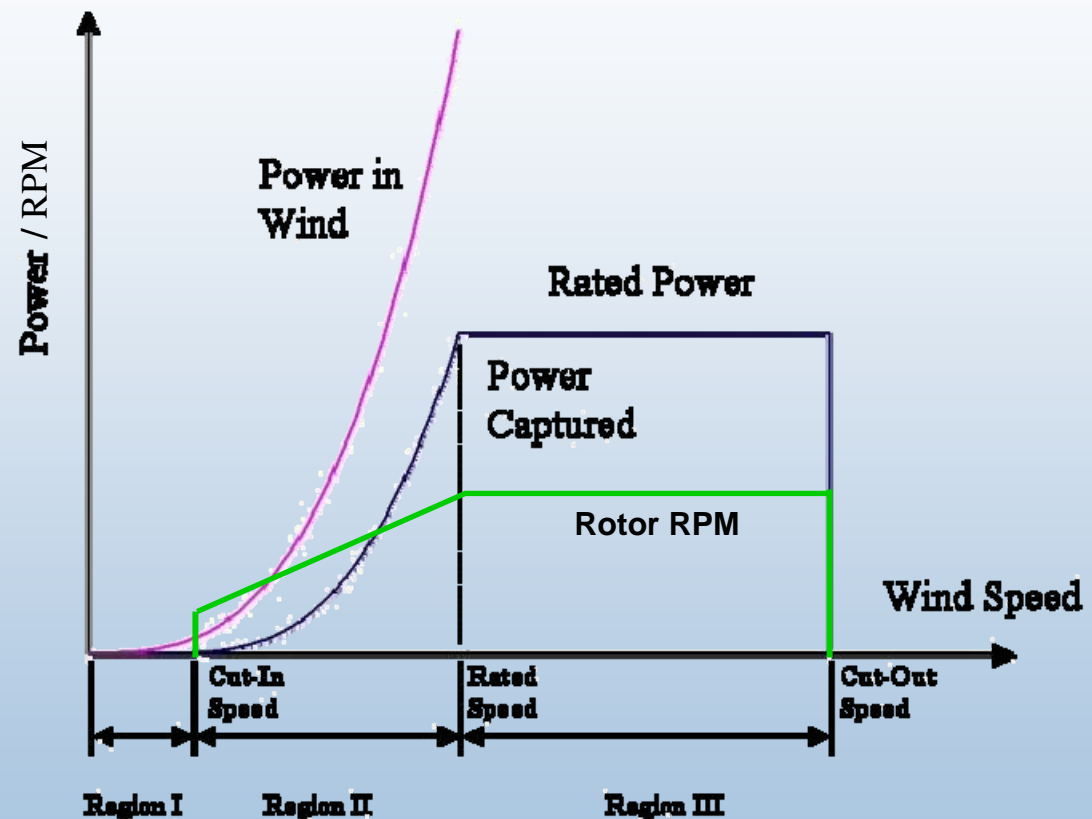
$$P = \frac{16}{27} \left( \frac{1}{2} \rho A V_w^3 \right)$$

**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.



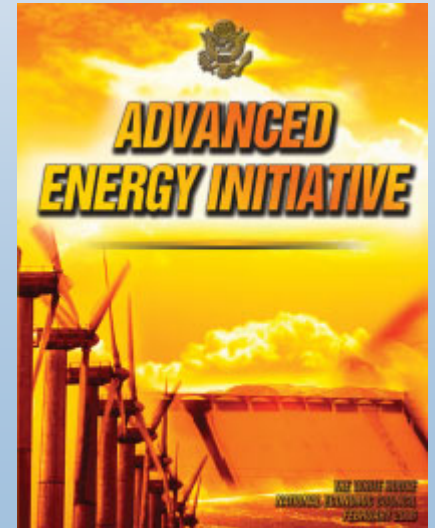
White House photo by Eric Draper

## State of the Union Address

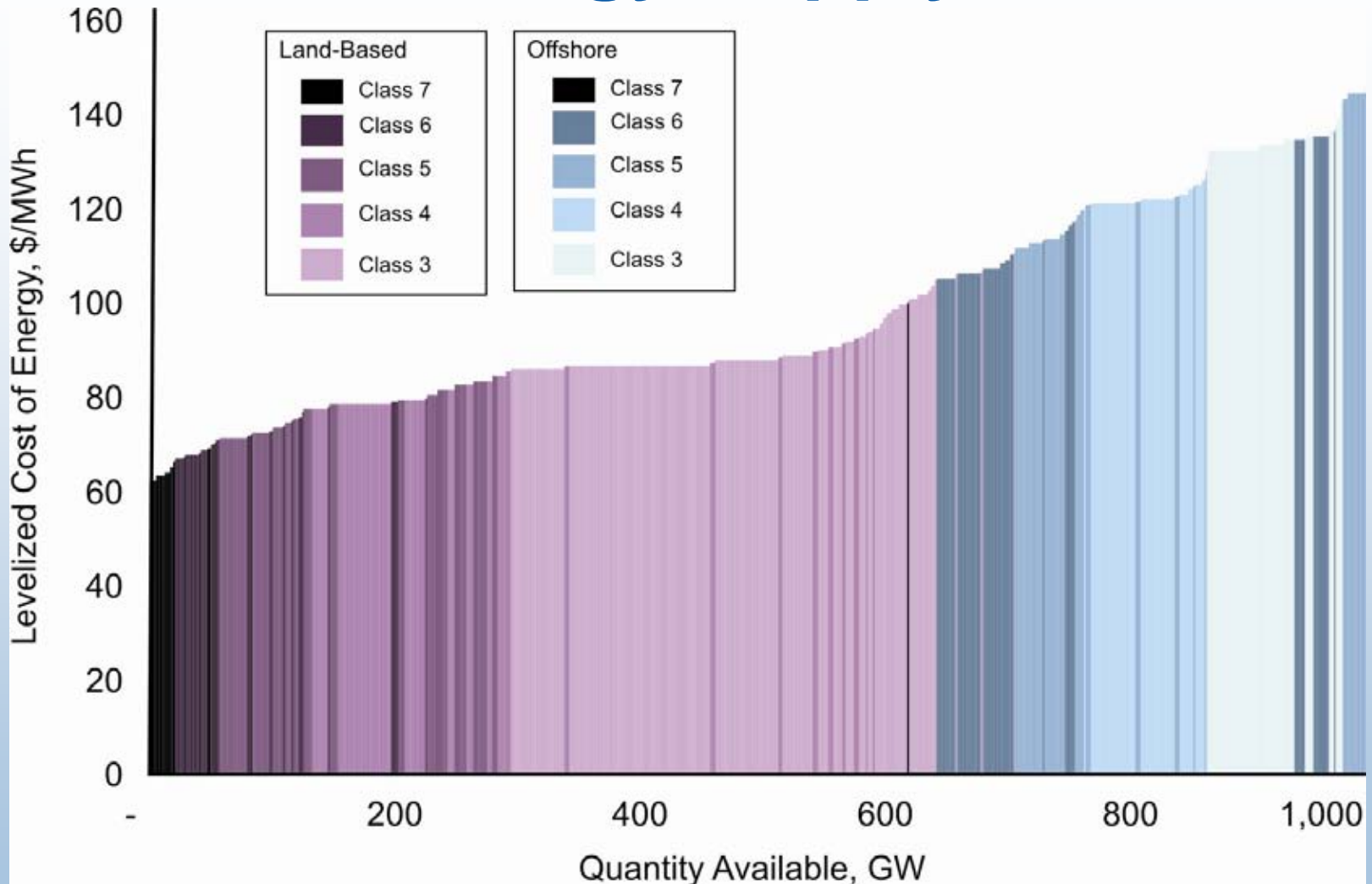
“...We will invest more in ...  
**revolutionary** and solar **wind**  
**technologies**”

## Advanced Energy Initiative

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

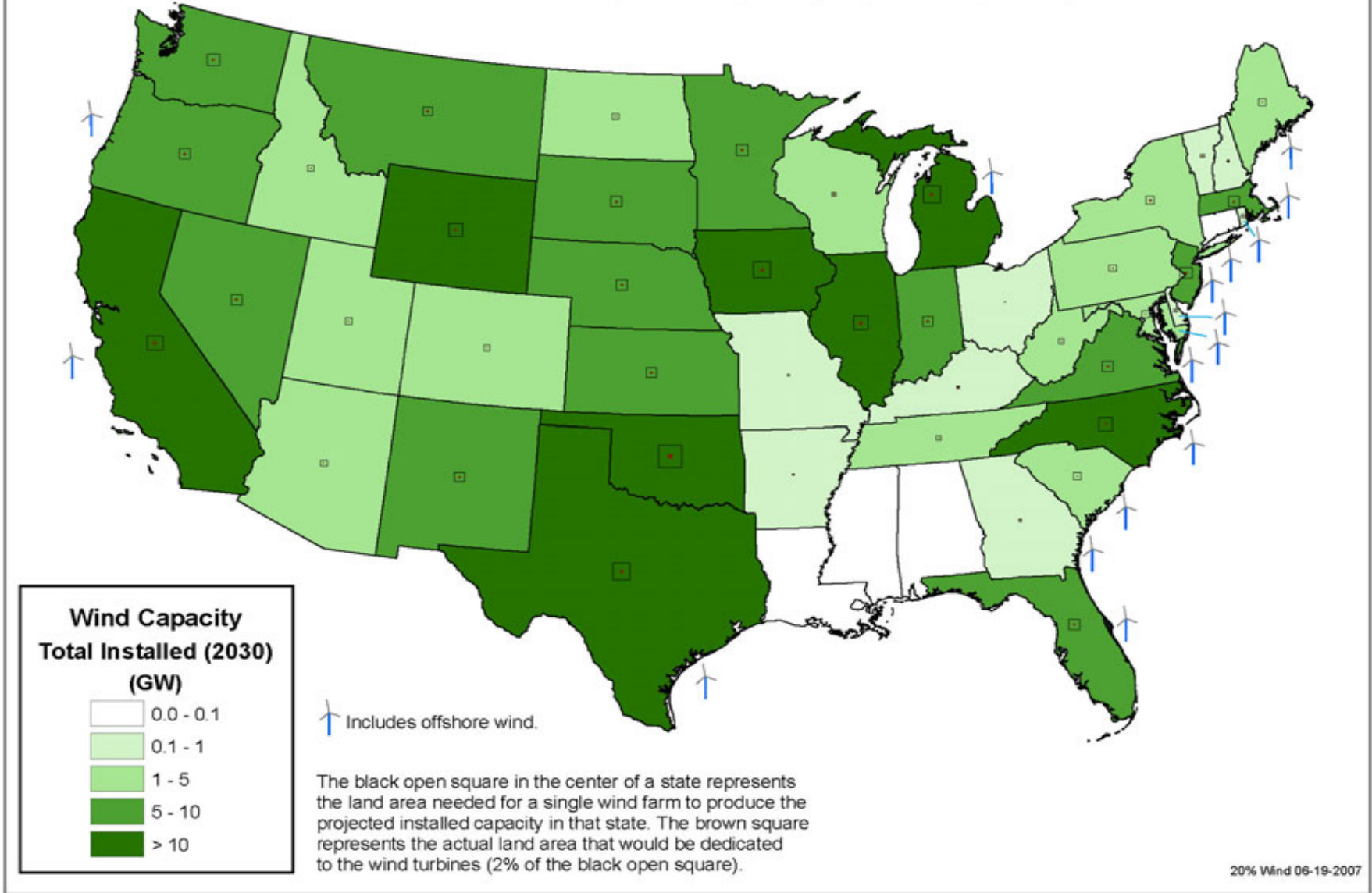


# Wind Energy Supply Curve



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)



# 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:**

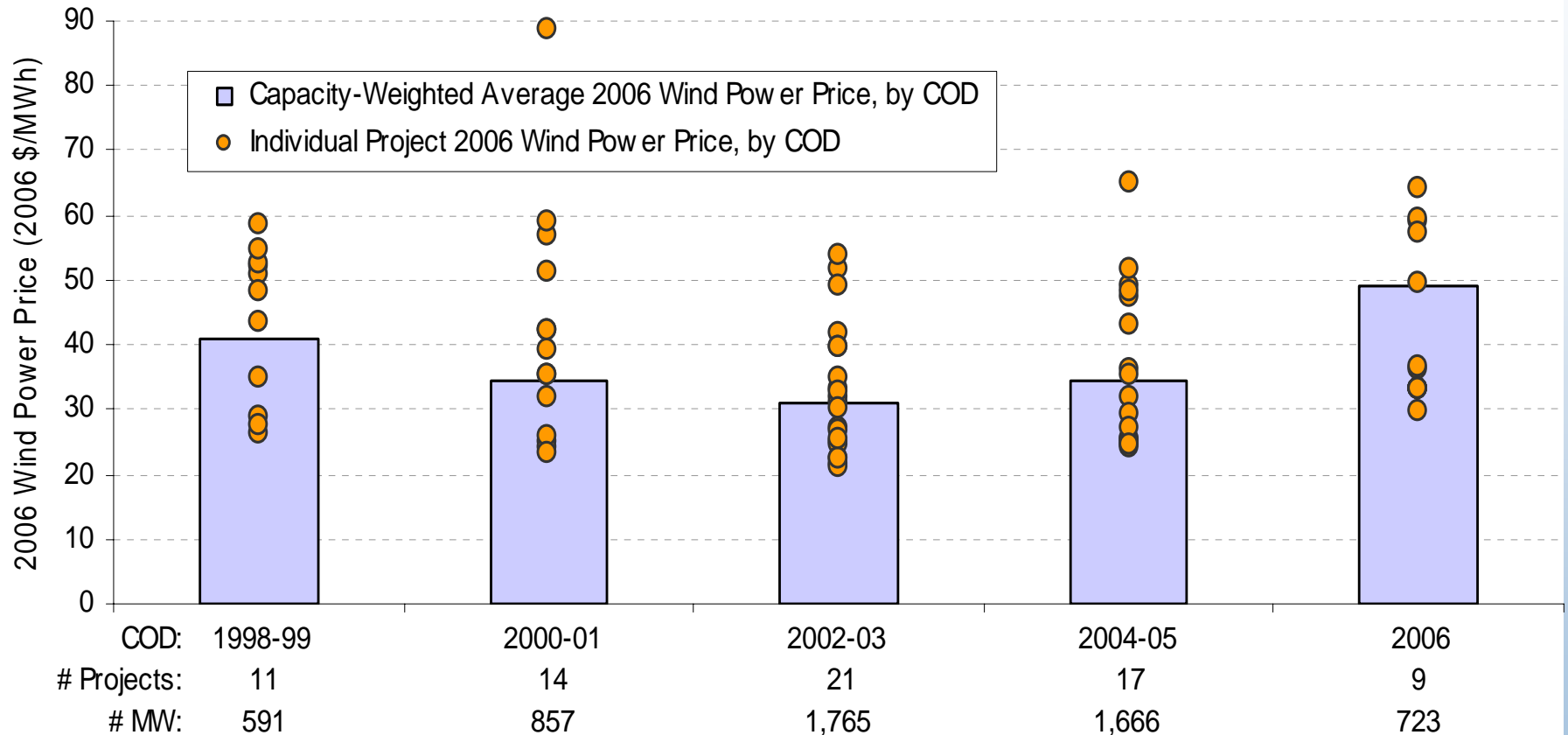
- **Price increases in steel & copper**
- **Turbines sold out for 2 years**

**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)



Source: Berkeley Lab database

# Considerations for Siting a Wind Farm

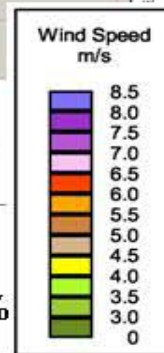
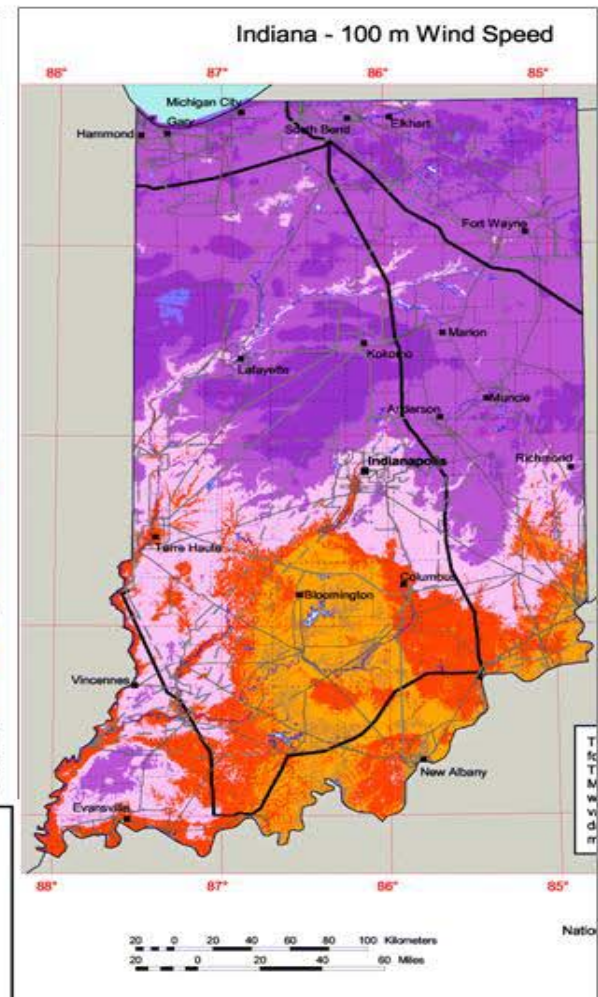
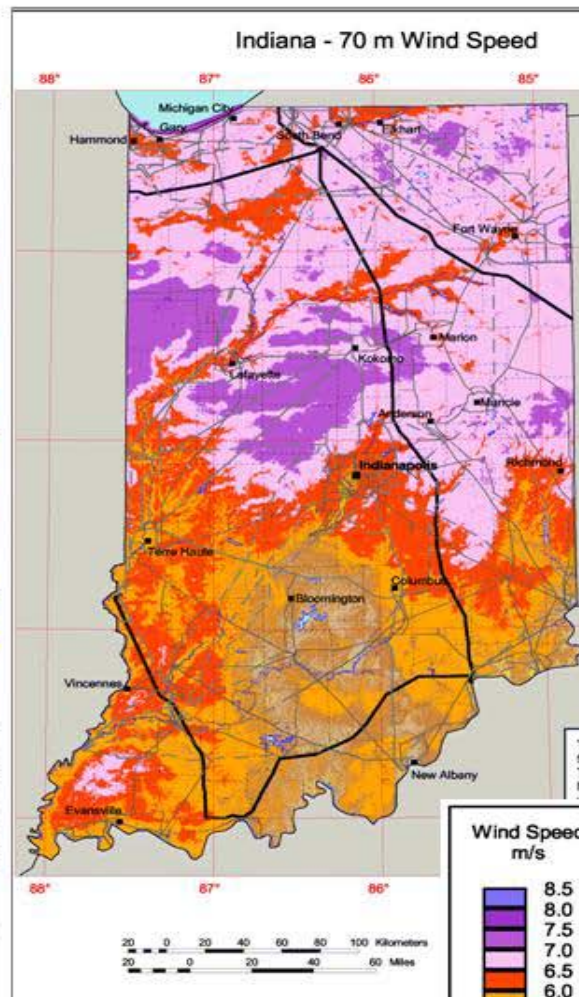
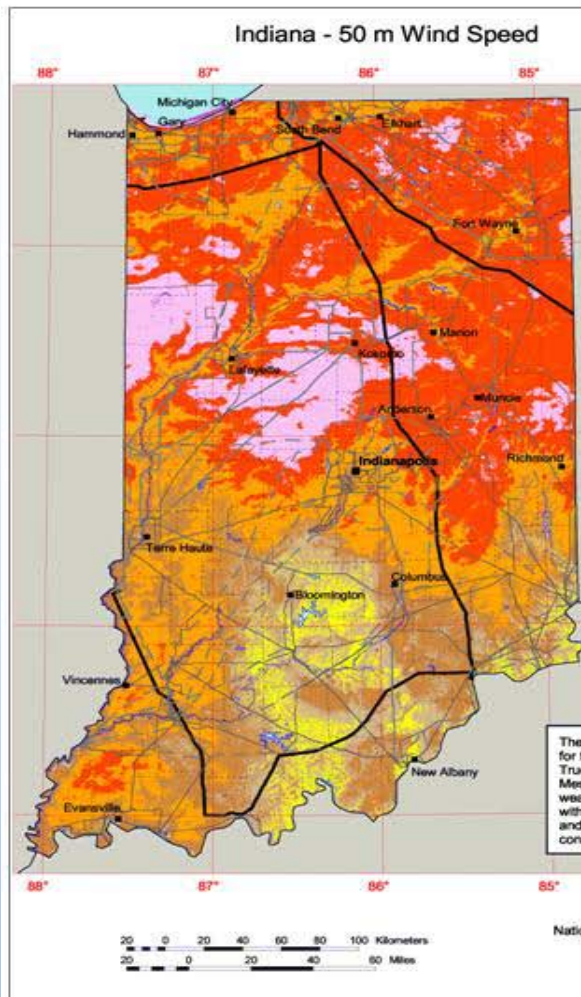
- **Income = Energy Output  $\sim$  (Wind Speed)<sup>3</sup>**
- **Transmission Access**
- **Power Purchase Agreement with Utility**
- **Land with landowner willing to lease**
- **Permits: Minimal Wildlife & NIMBY**
- **Turbines at a Competitive Price**
- **Financing**



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

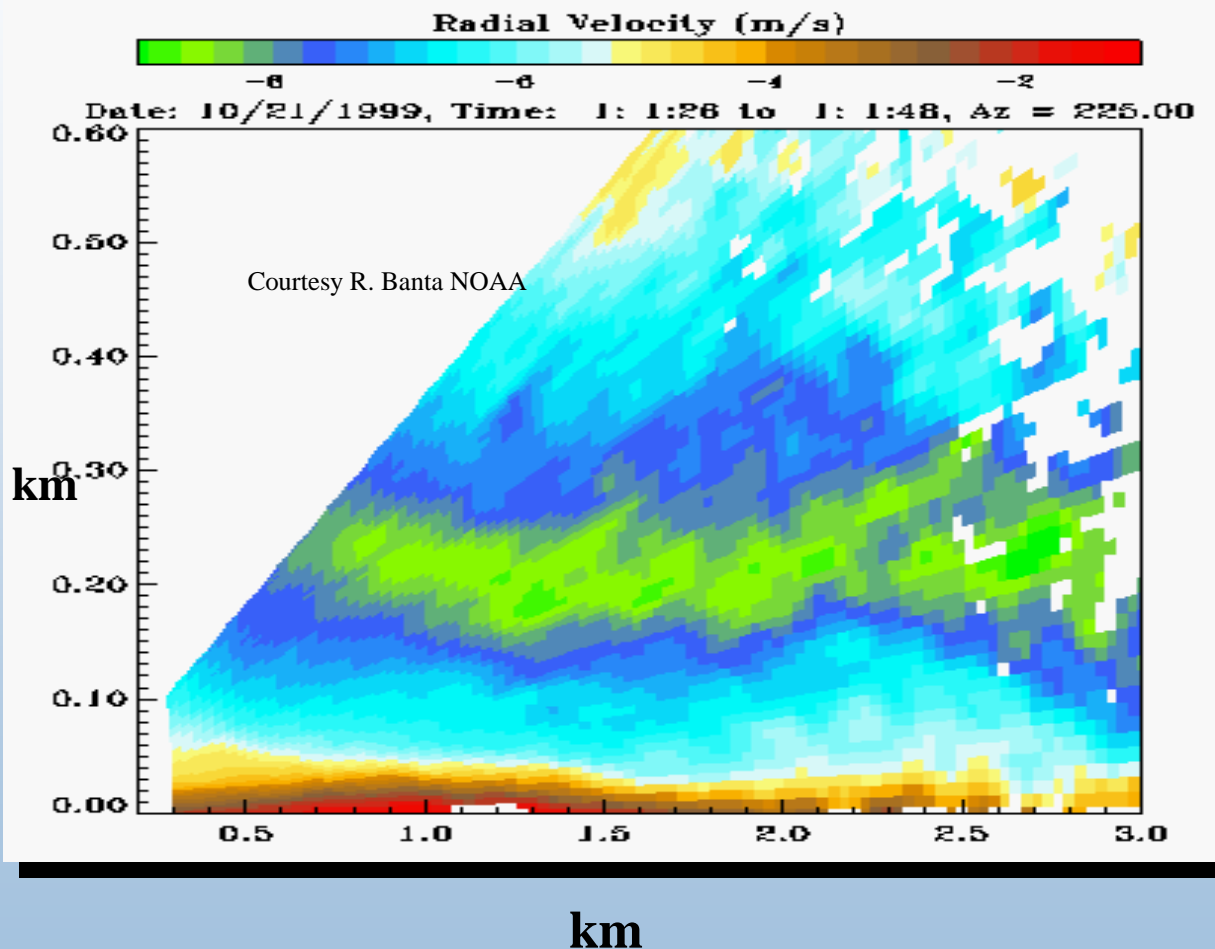
**A Utility Scale 1.5 MW Wind Turbine**

# Wind Energy Increases with Height

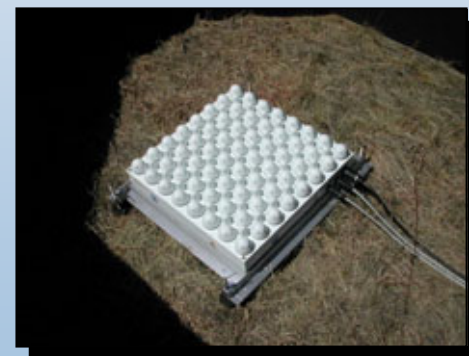




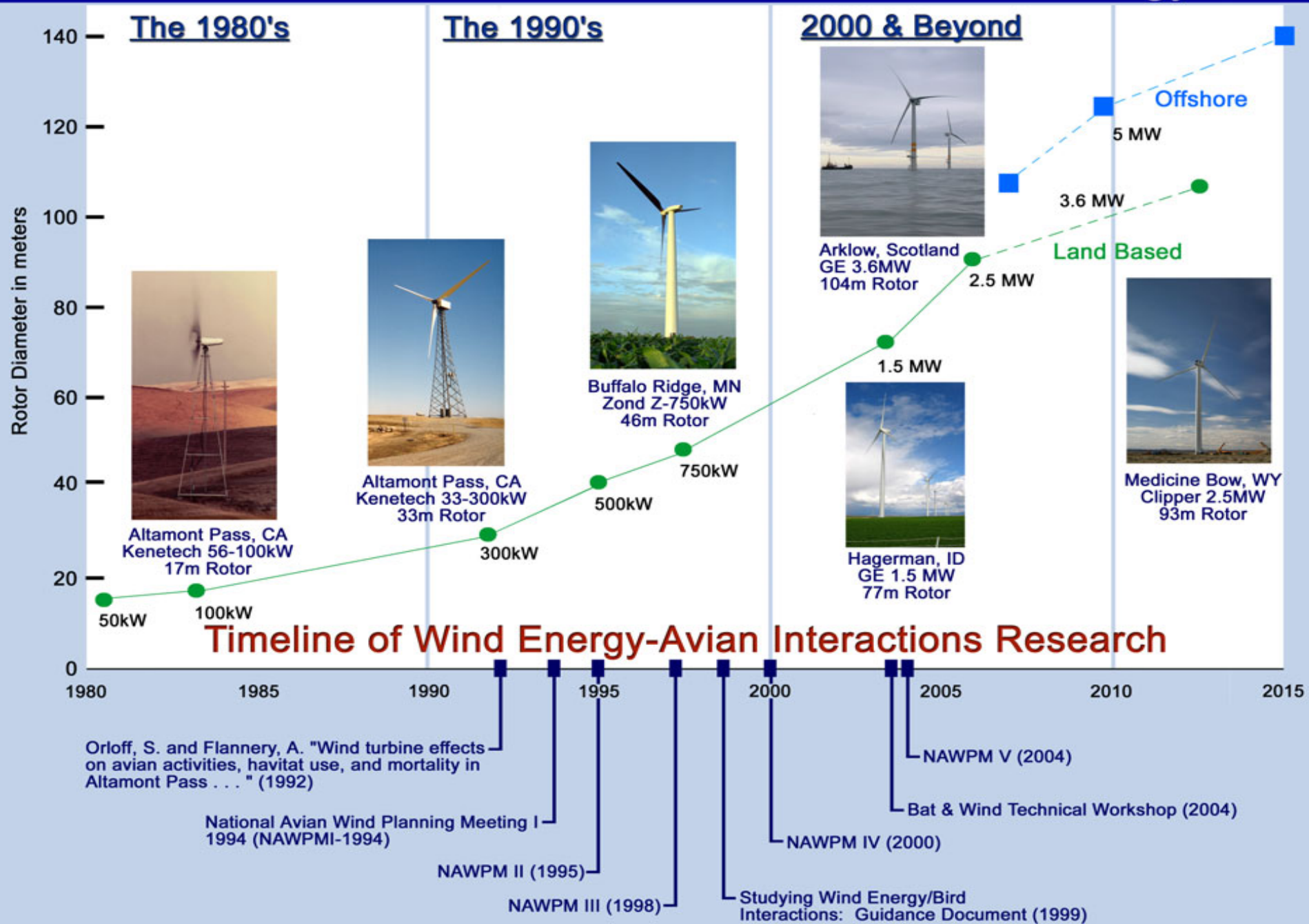
# Measuring and Modeling the Wind: Lidar Picture of Low-Level Nocturnal Jet



Met tower and  
SODAR at Lamar,  
Colorado



# Evolution of U.S. Commercial Wind Technology



# 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 too high
- Gearbox reliability poor
- Transportation costs too high
- Crane capacity & availability limited
- Operational expenses too 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?

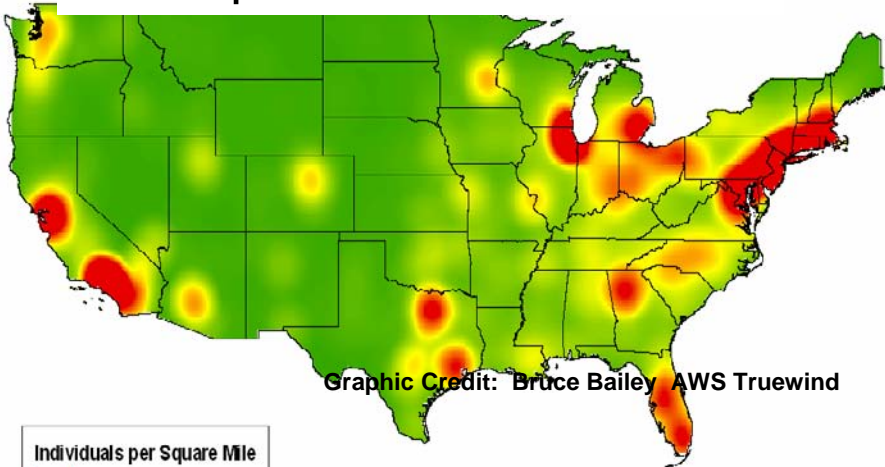
*Land-based sites are not close to coastal load centers*

*Load centers are close to offshore wind sites*

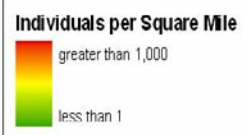
## 28 Coastal States Use 78% of Electricity

Population Density of the Conterminous United States

US Population Concentration

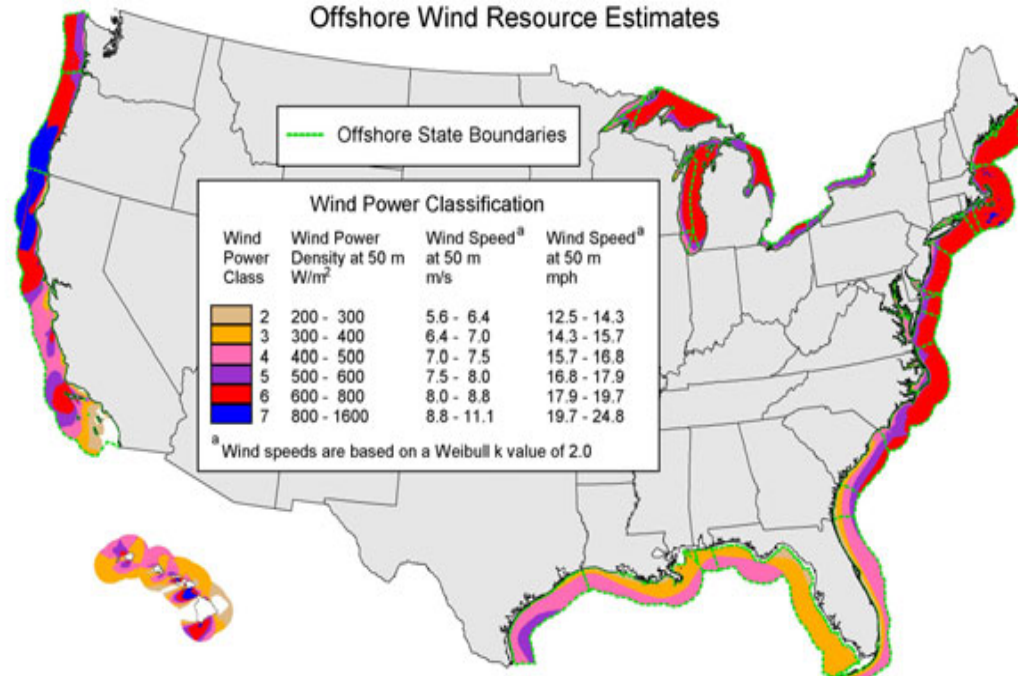


Graphic Credit: Bruce Bailey, AWS Truewind



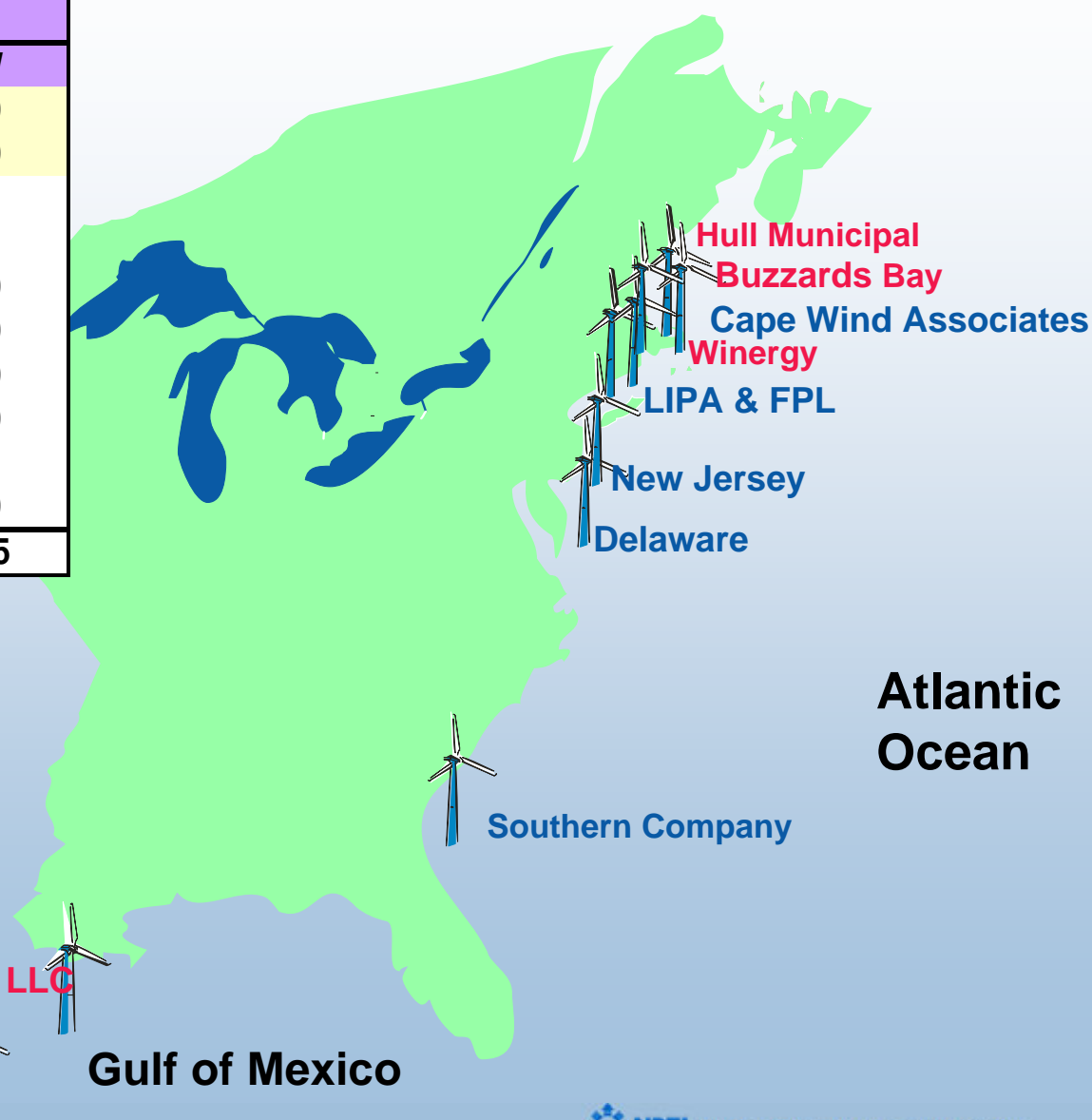
U.S. Wind Resource

Offshore Wind Resource Estimates



# 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
<b>Total</b>		<b>2455</b>



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

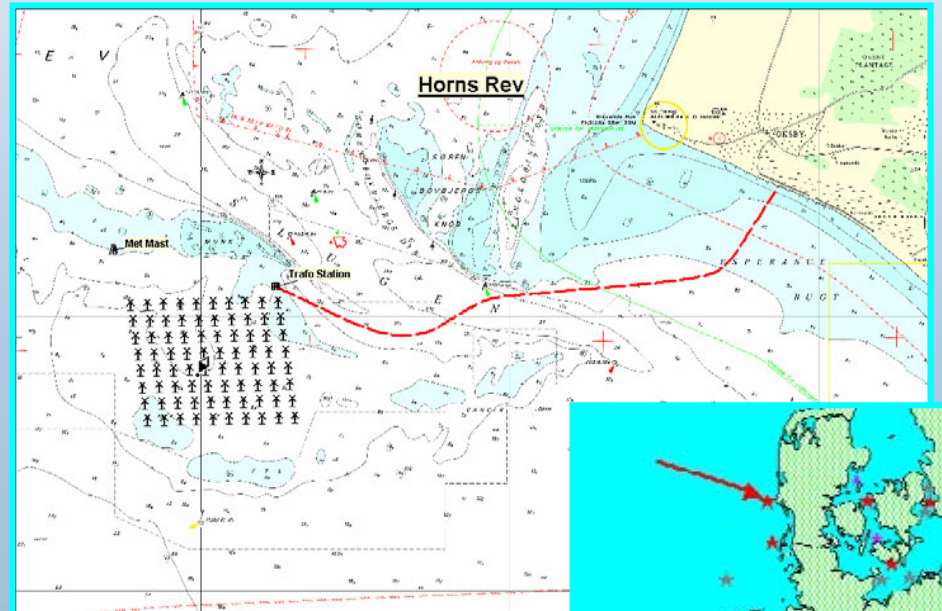
**Atlantic Ocean**

**Gulf of Mexico**

# 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

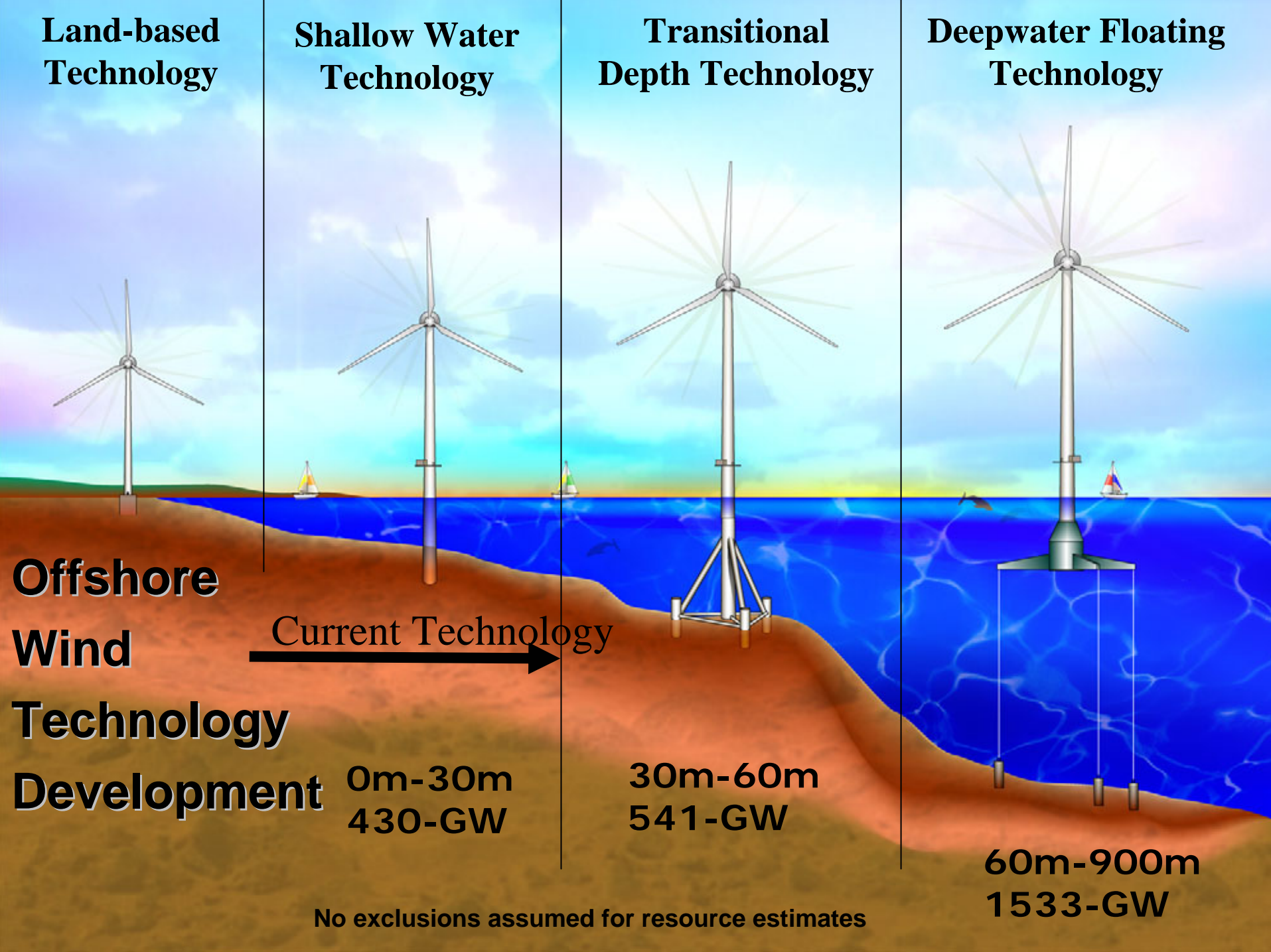
Current Technology →

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.



# SWWP DWT Prototype 1.8kW under test at the NWTC



**High Wind Operation**



**Installation**

# **National Avian – Wind Power Planning Meeting I**

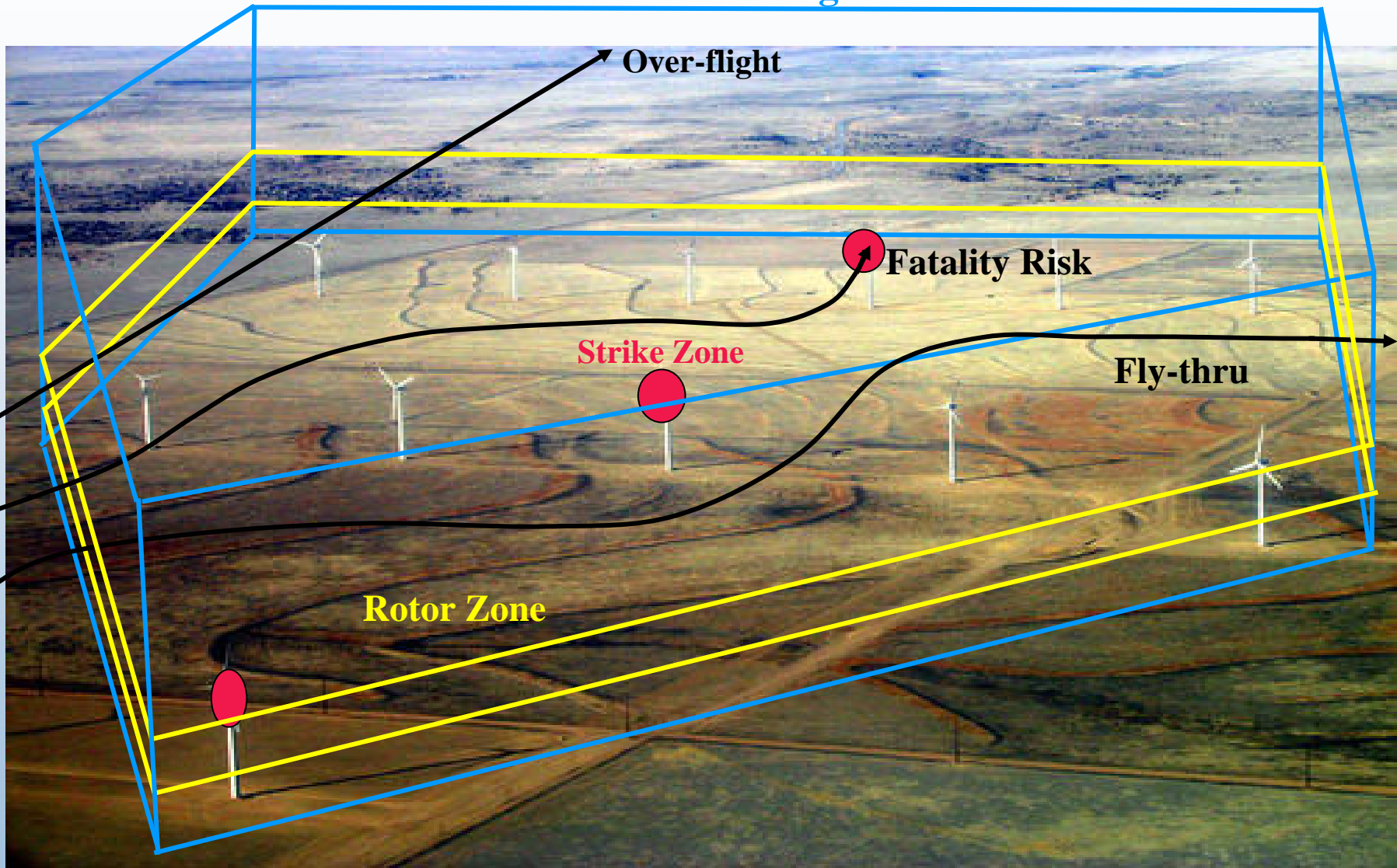
## **July 1994**

### **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

## Windfarm Flight Zone



# A Simple Stick Collision Model

Bird passage time through the rotor:

$$t_p = L/V = \text{Length speed ratio (sec)}$$

Blocked Sector of Turbine Rotor:

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

Probability of collision:

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

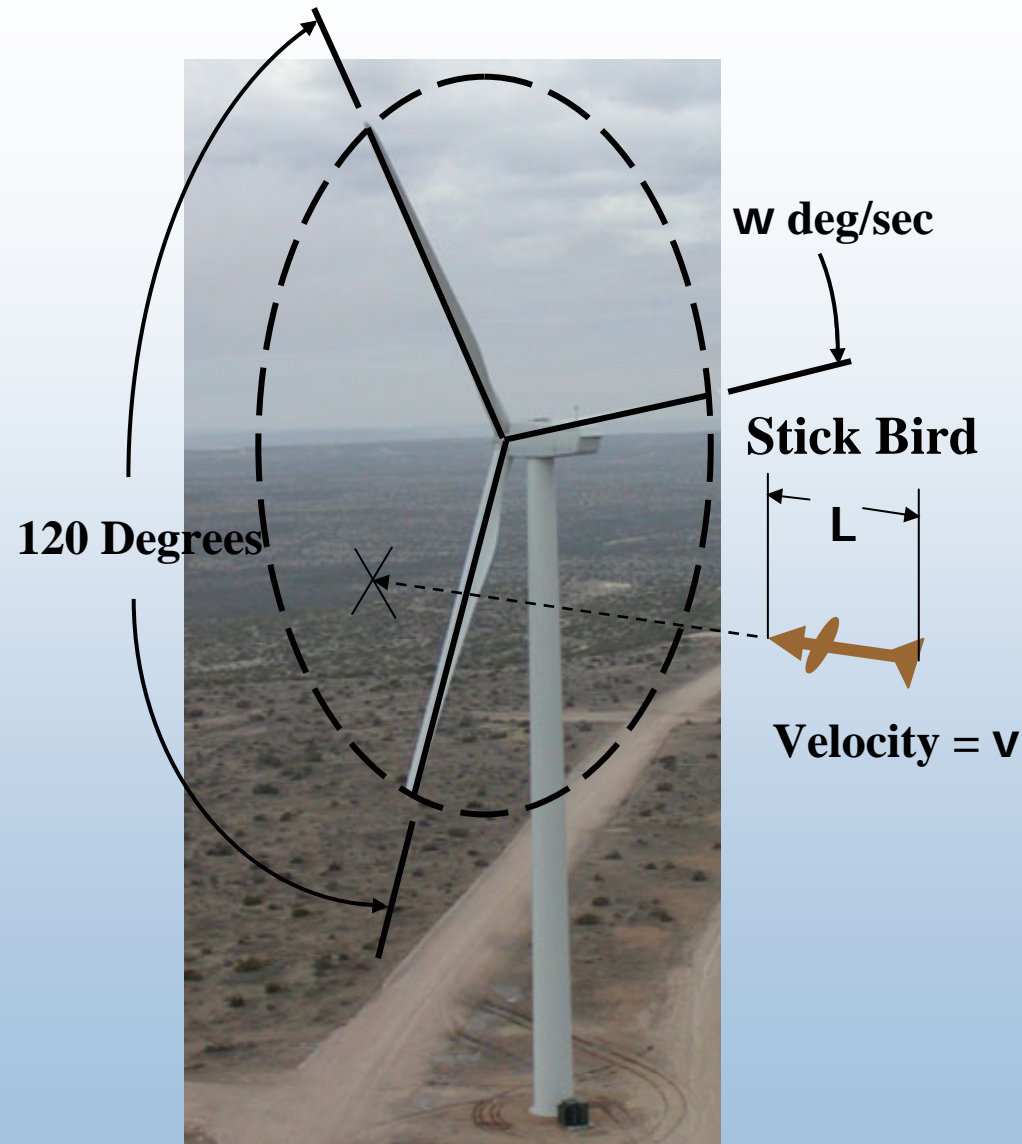
$$P_c = 3B/(360\text{deg})$$

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

To account for avoidance:

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

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



Stick Turbine

# Avian Strike Probability Versus Turbine Size

## Altamont Scale



**15 Meter Diameter and 100 kW**

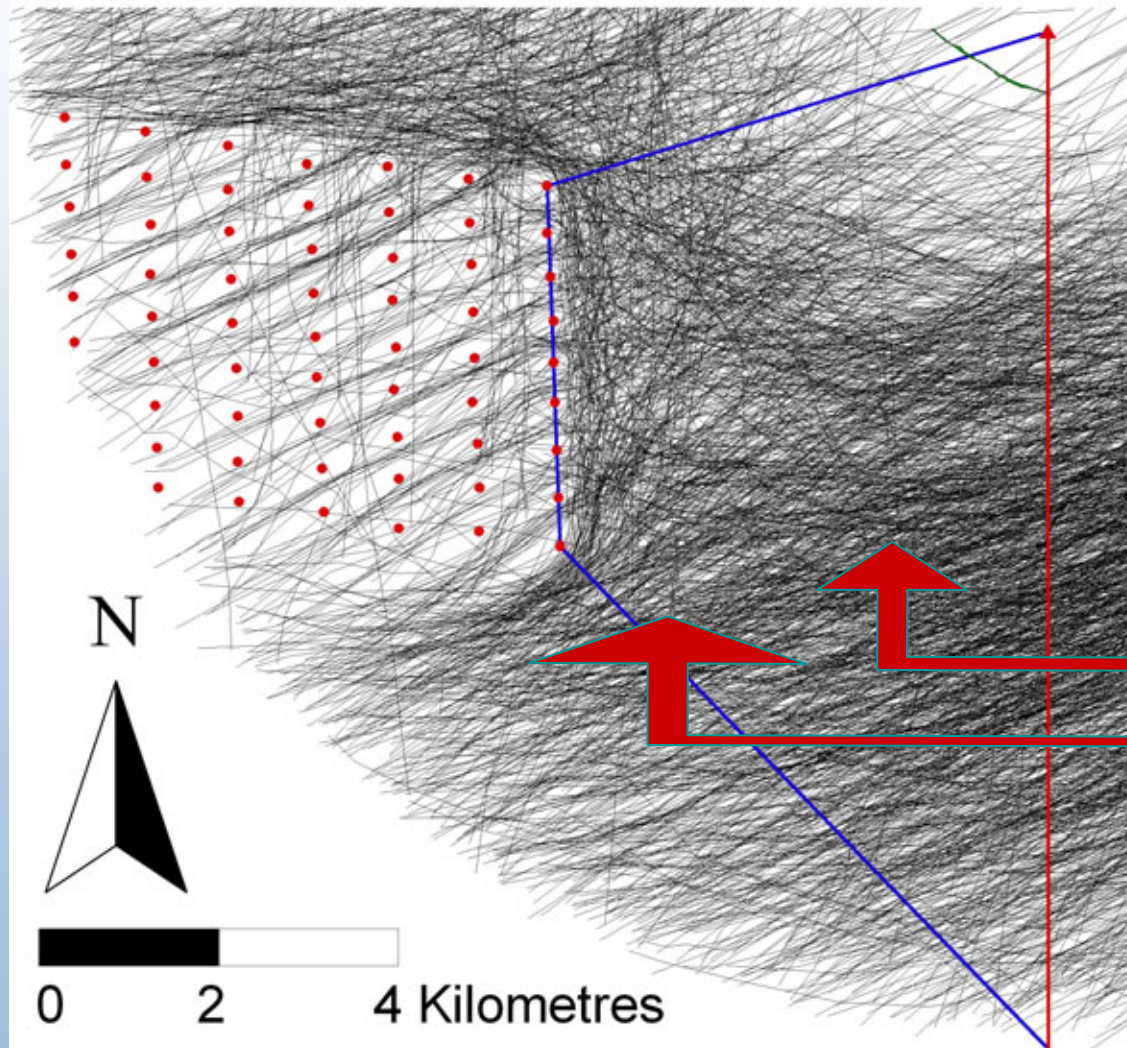
## Next Generation Scale



**93 Meter Diameter and 2.5MW**

# Avoidance Behavior is Significant

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



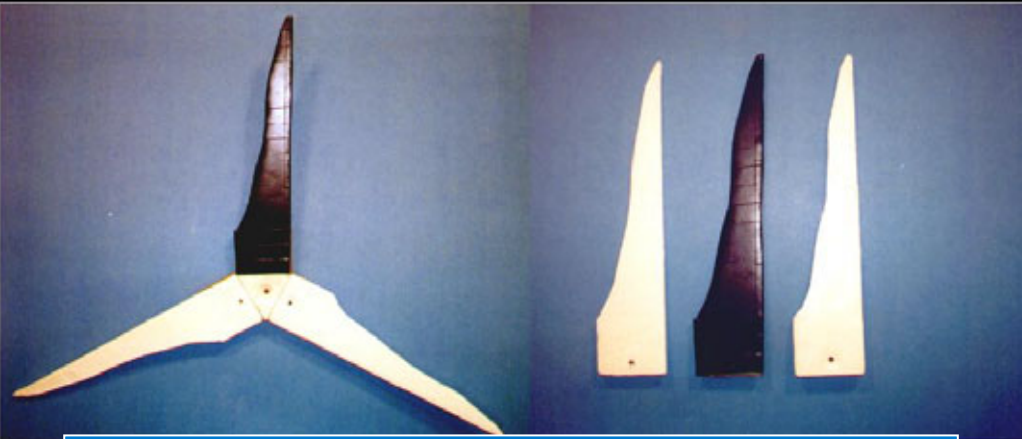
Response distance:

day = c. 3000m

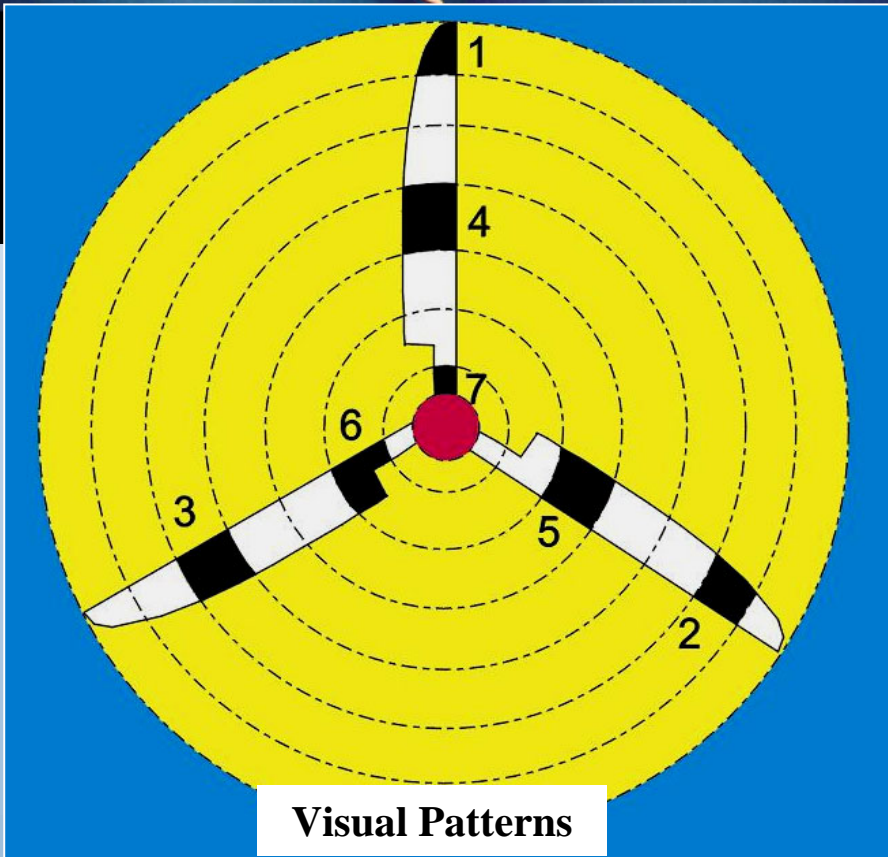
night = c. 1000m



# Avian Risk Reduction: Visual Enhancement to Increase Avoidance



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)

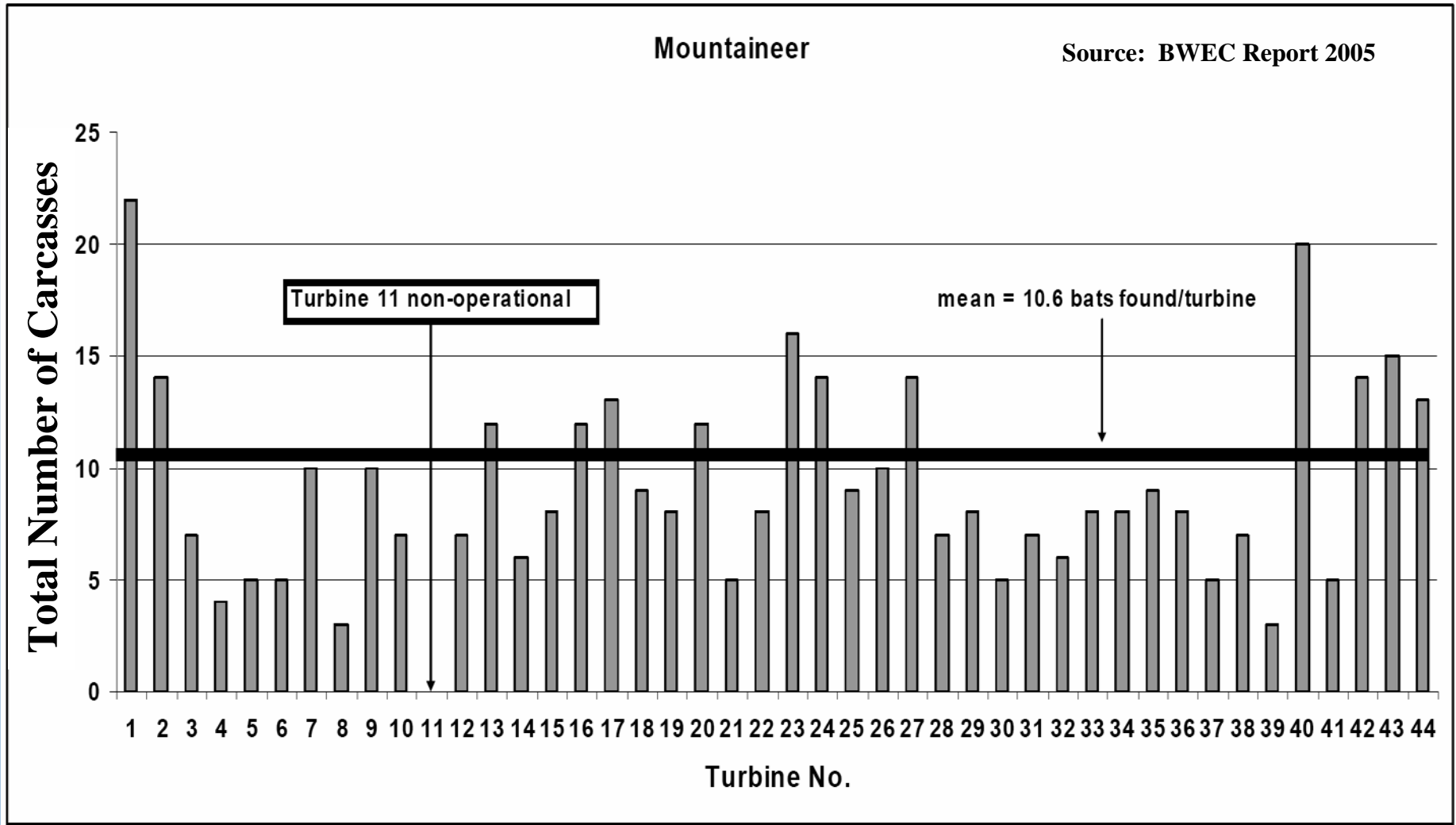
# Infrared Image of a Bat Flying Through a Wind Turbine Rotor

Photo by Jason Horn, Boston University

## Multi-Stakeholder Wildlife Research

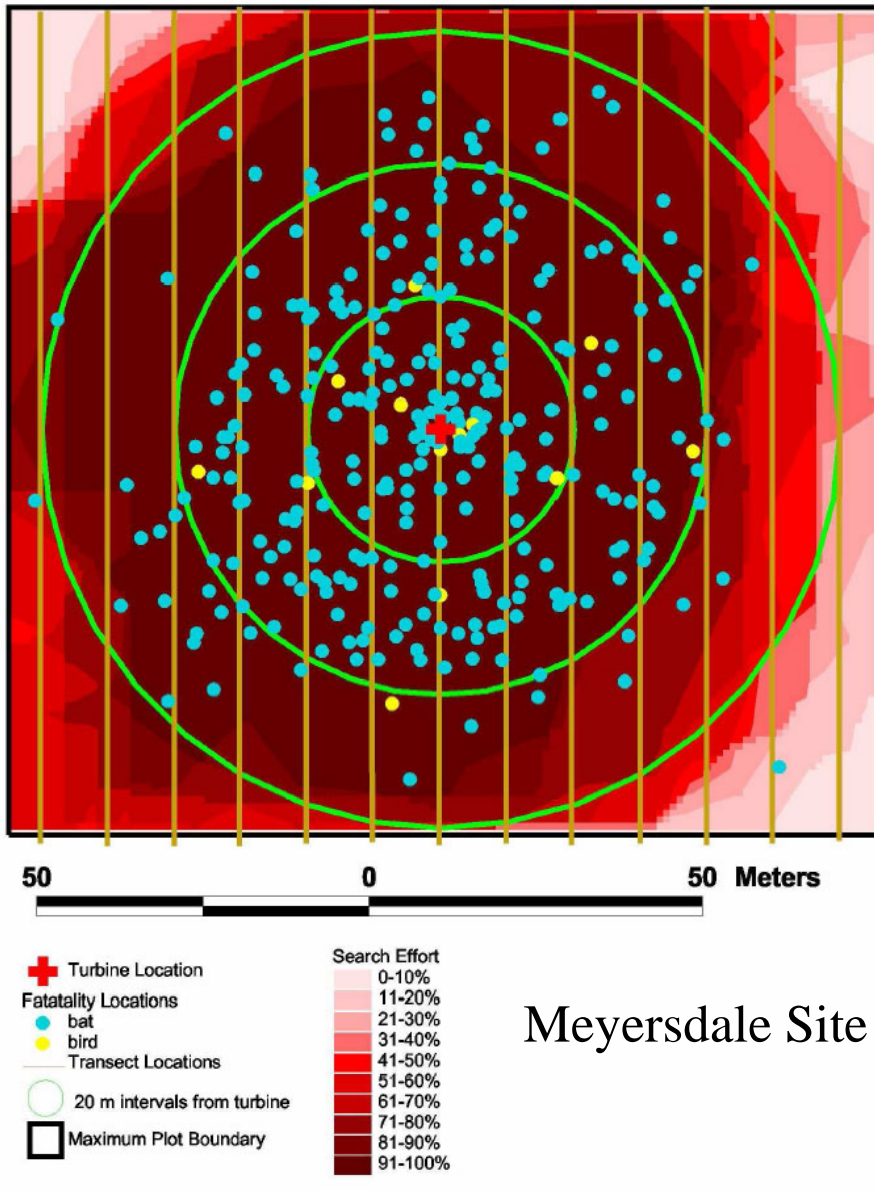
- **National Wind Coordinating Committee**
  - Federal, State, Utilities, NGOs, Wind Industry
- **Bat & Wind Energy Cooperative (BWEC)**
  - AWEA, Wind Industry, USFWS, DOE, NGOs
- **Grassland Shrub Steppe Species Collaborative**
  - AWEA, Wind Industry, States, DOE, USFWS

# BWEC Study Results



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

# BWEC Study Results



Meyersdale Wind farm:

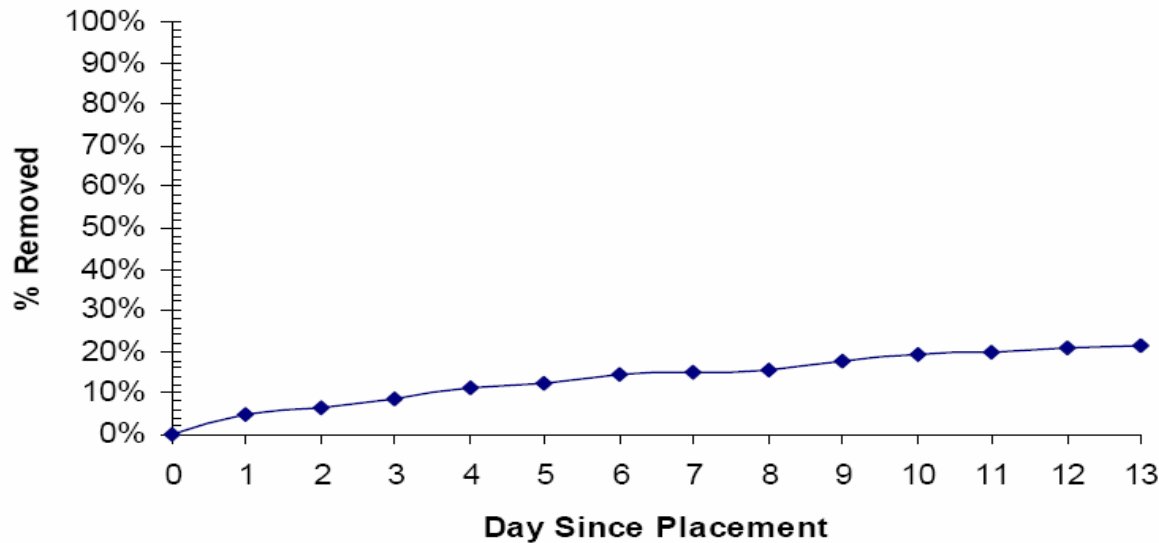
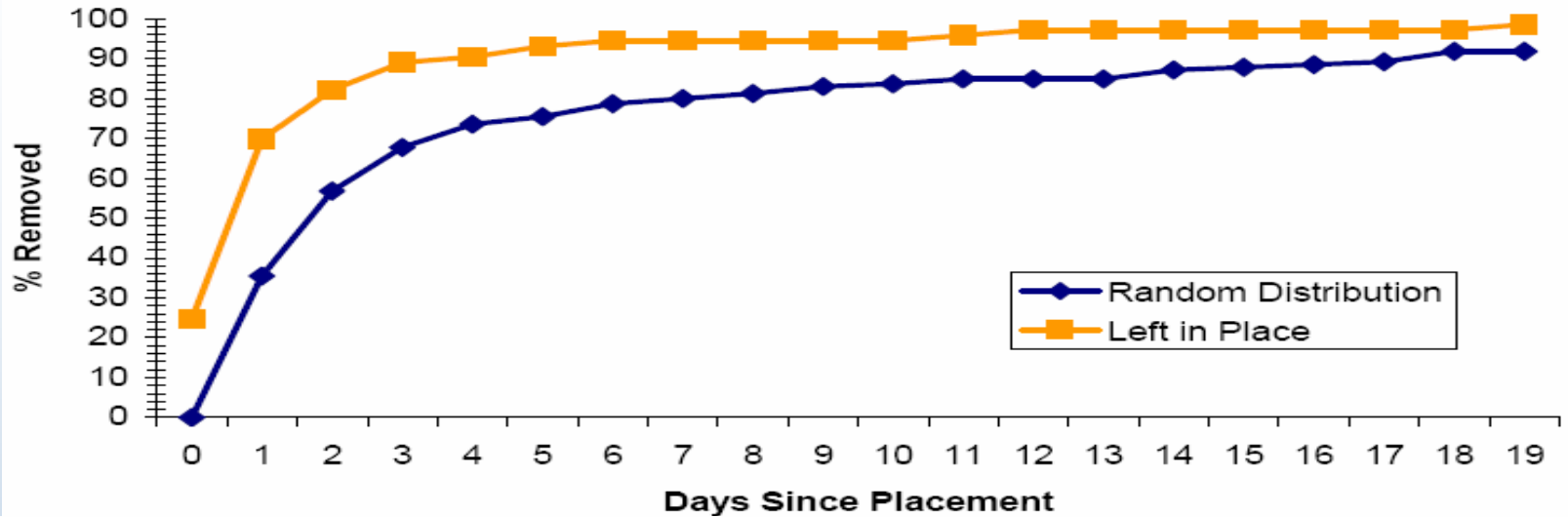
- NEG – Micon 1.5 MW Turbine
- 72 meter rotor Diameter
- 17 revs/min = 102 deg/sec
- Constant rotor rpm
- Green dots are bat carcasses
- Yellow dots are birds
- Bird and bat fatalities for all 20 turbines are overlaid

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

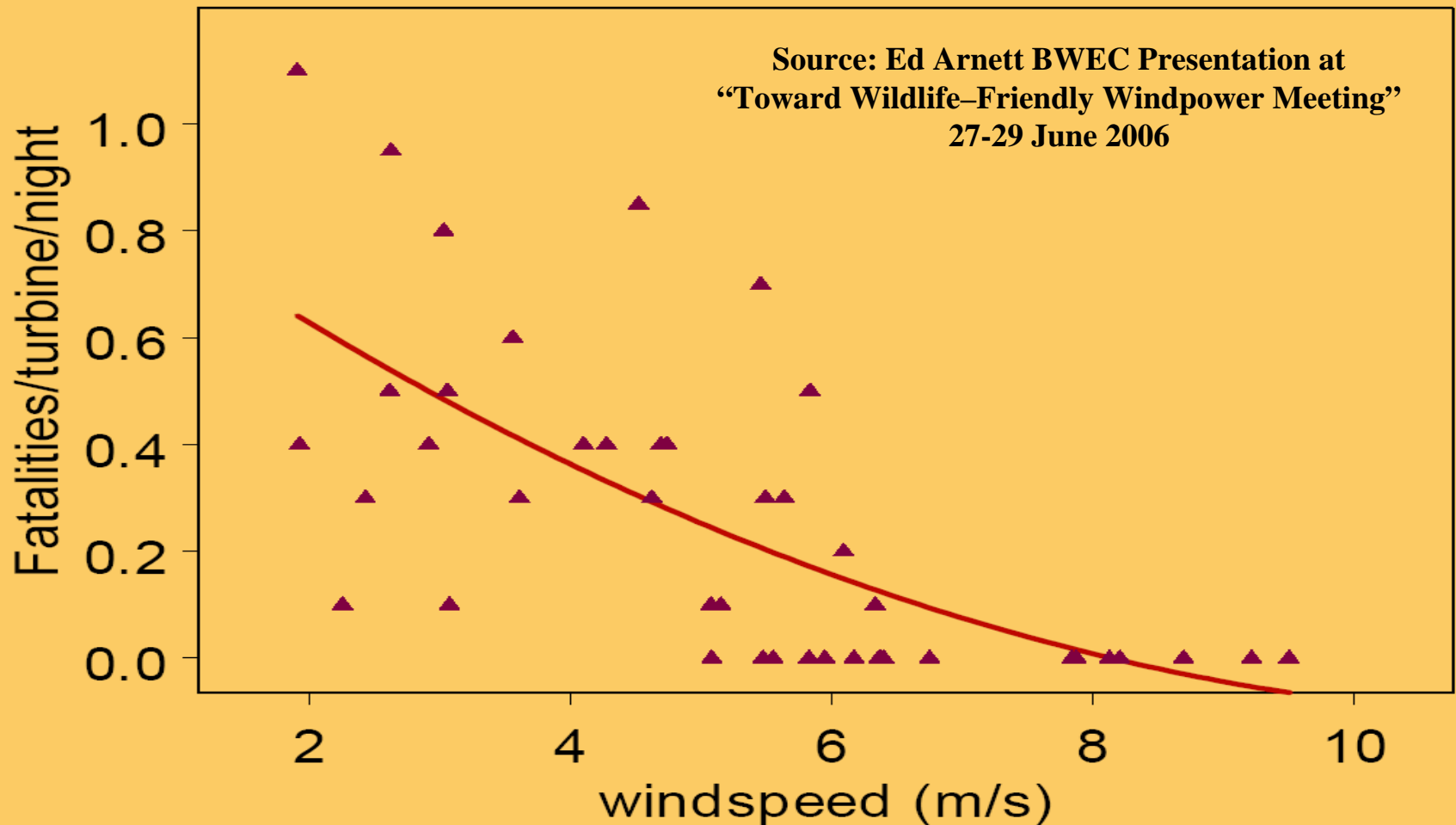
Removal by scavengers



Source: BWEC Report 2005

# BWEC Study Results

Fatalities decrease with increasing wind speed



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

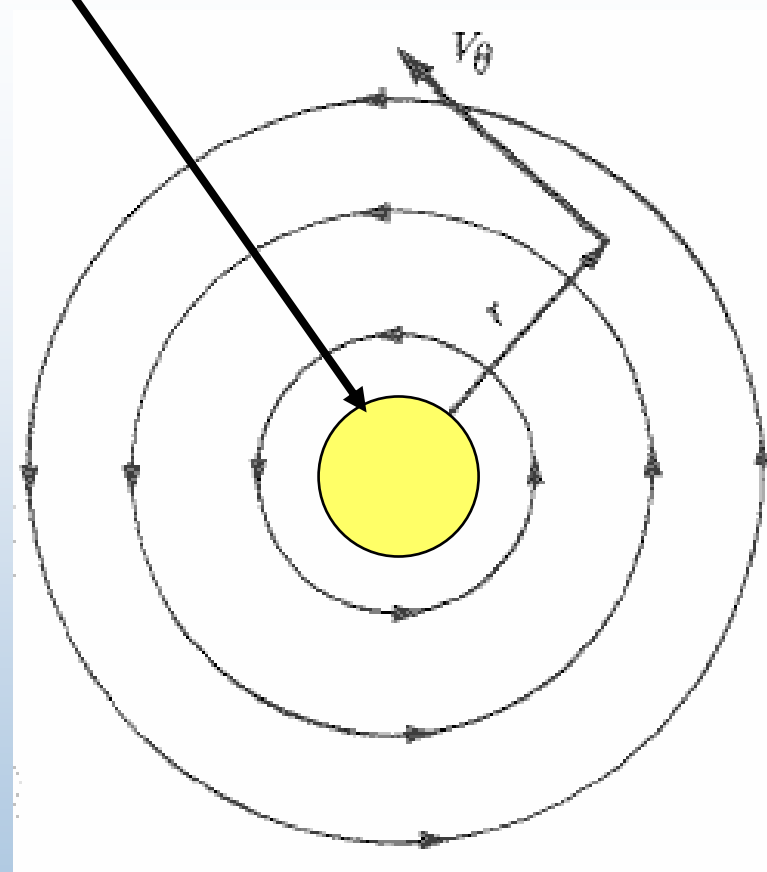
- Near blade tips the flow is highly three-dimensional with flow from the higher pressure side of the blade to the suction side of the blade





# The Tip Vortex and the Wake

Low Pressure Core



**Biot Savart Law**

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

$V_\theta$  = tangential velocity  
 $\Gamma$  = 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



**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](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](http://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](http://www.hornsrev.dk/Engelk/default_ie.htm) and  
[http://uk.nystedhavmoellepark.dk/frames.asp?Page\\_ID=44&Page\\_Ref=44&Templates\\_ID=1](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>