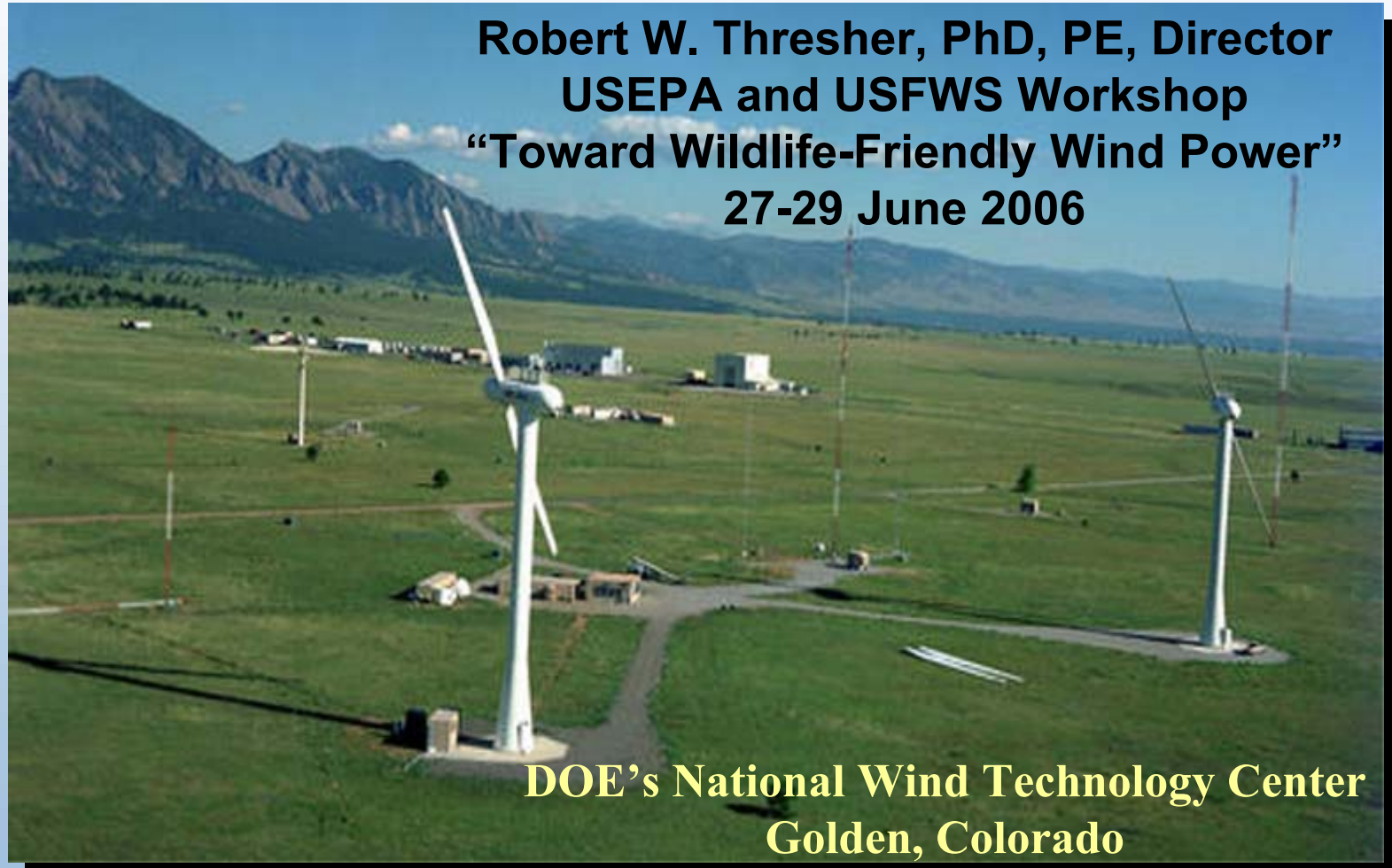
The Status and Future of Wind Energy Development

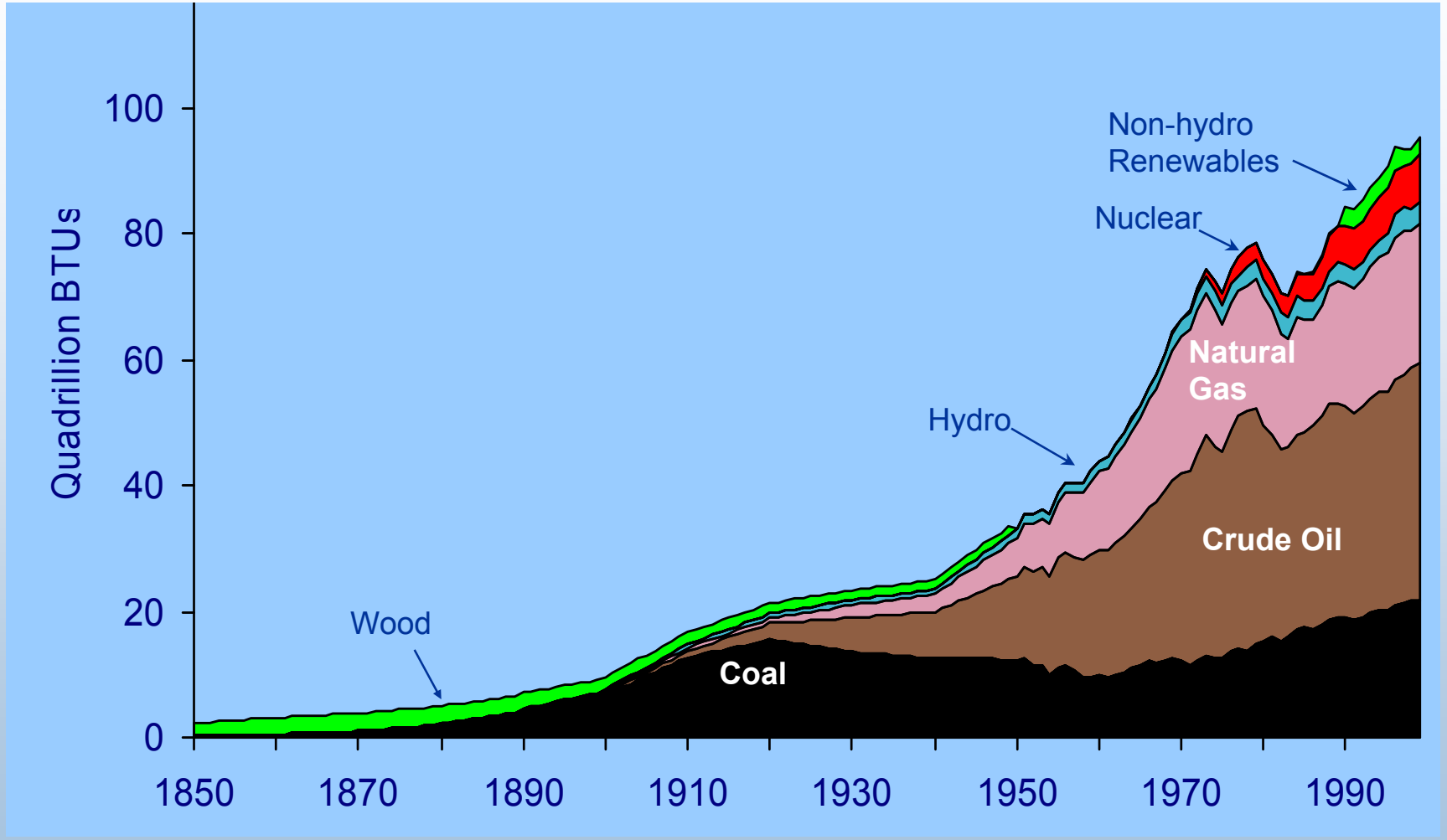


Robert W. Thresher, PhD, PE, Director
USEPA and USFWS Workshop
"Toward Wildlife-Friendly Wind Power"
27-29 June 2006

DOE's National Wind Technology Center
Golden, Colorado

The U.S. Energy Picture

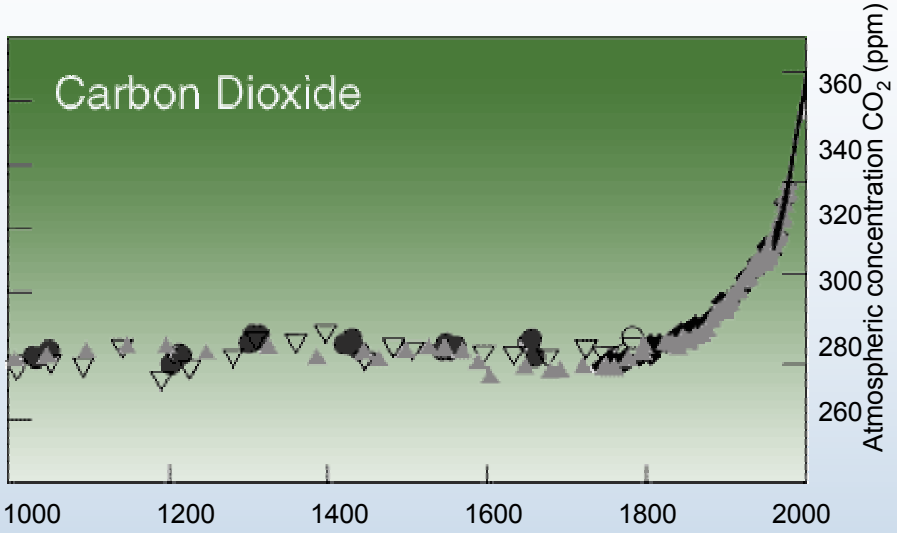
by source - 1850-1999

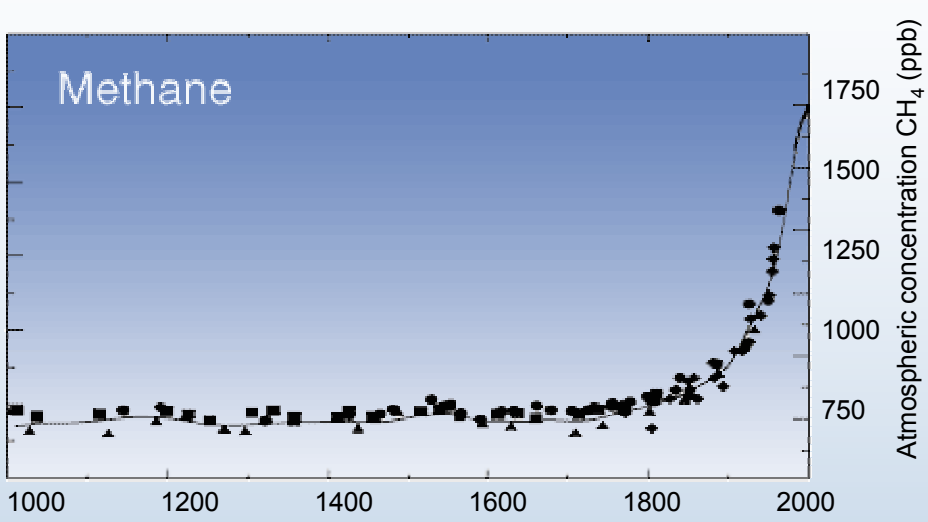


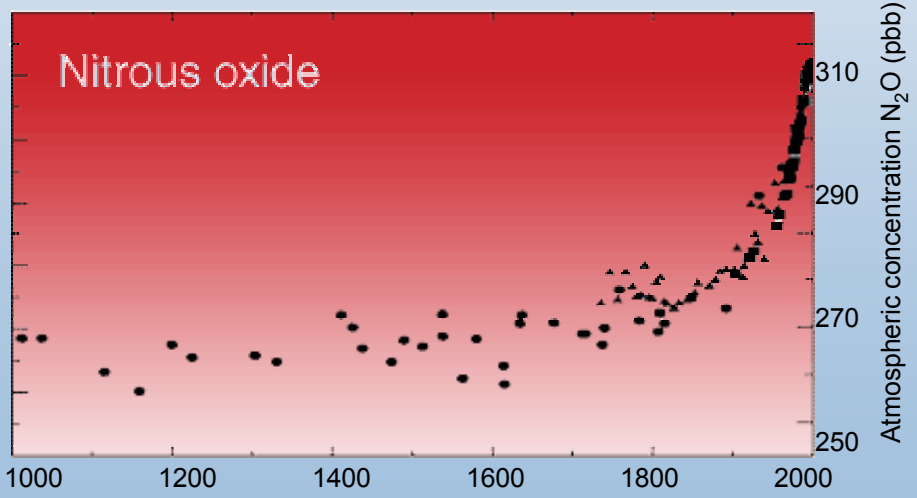
Source: 1850-1949, Energy Perspectives: A Presentation of Major Energy and Energy-Related Data, U.S. Department of the Interior, 1975; 1950-1996, Annual Energy Review 1996, Table 1.3. Note: Between 1950 and 1990, there was no reporting of non-utility use of renewables. 1997-1999, Annual Energy Review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

Changes in Atmospheric Concentration

CO_2, CH_4, and N_20 – A Thousand Year History



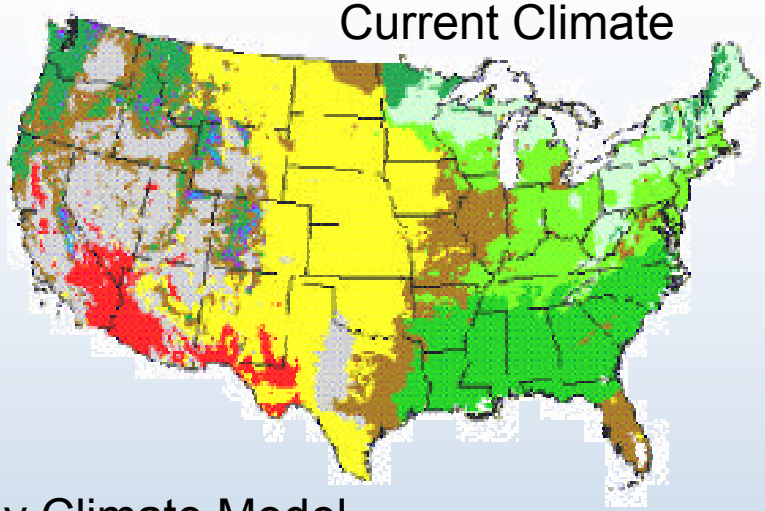




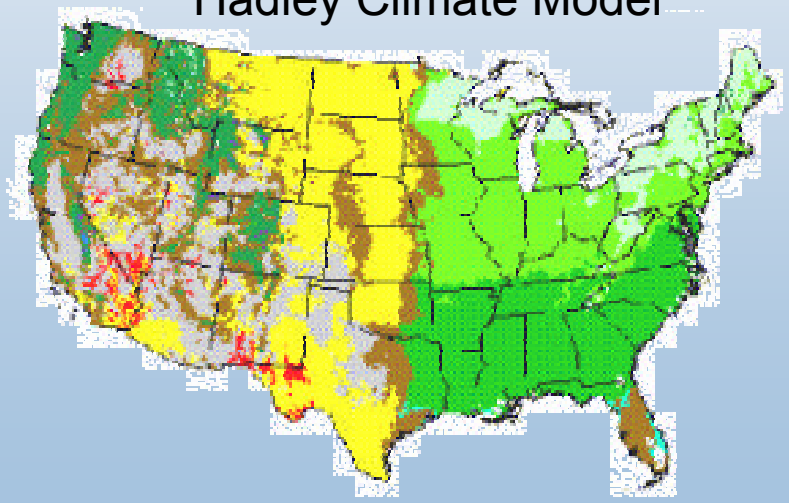
Source: IPCC Third Assessment Report (2001)

Simulations of vegetation response by 2070-2099 to different climate change models (U.S. Forest Service 2004)

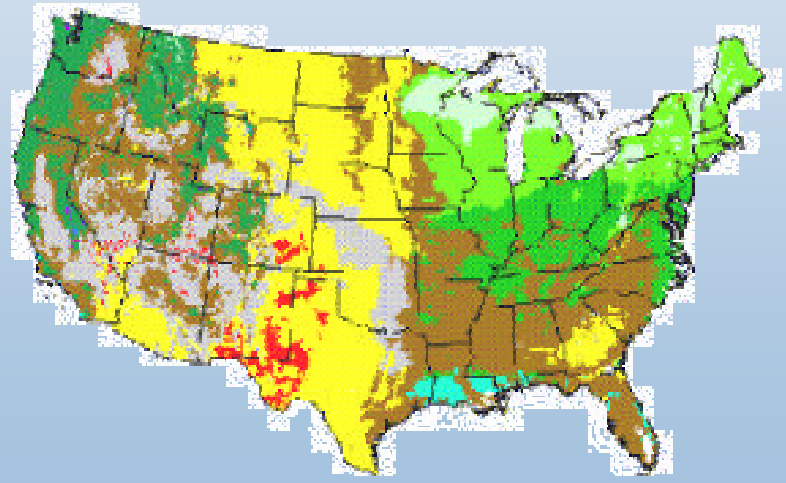
Current Climate



Hadley Climate Model



Canadian Climate Centre Model



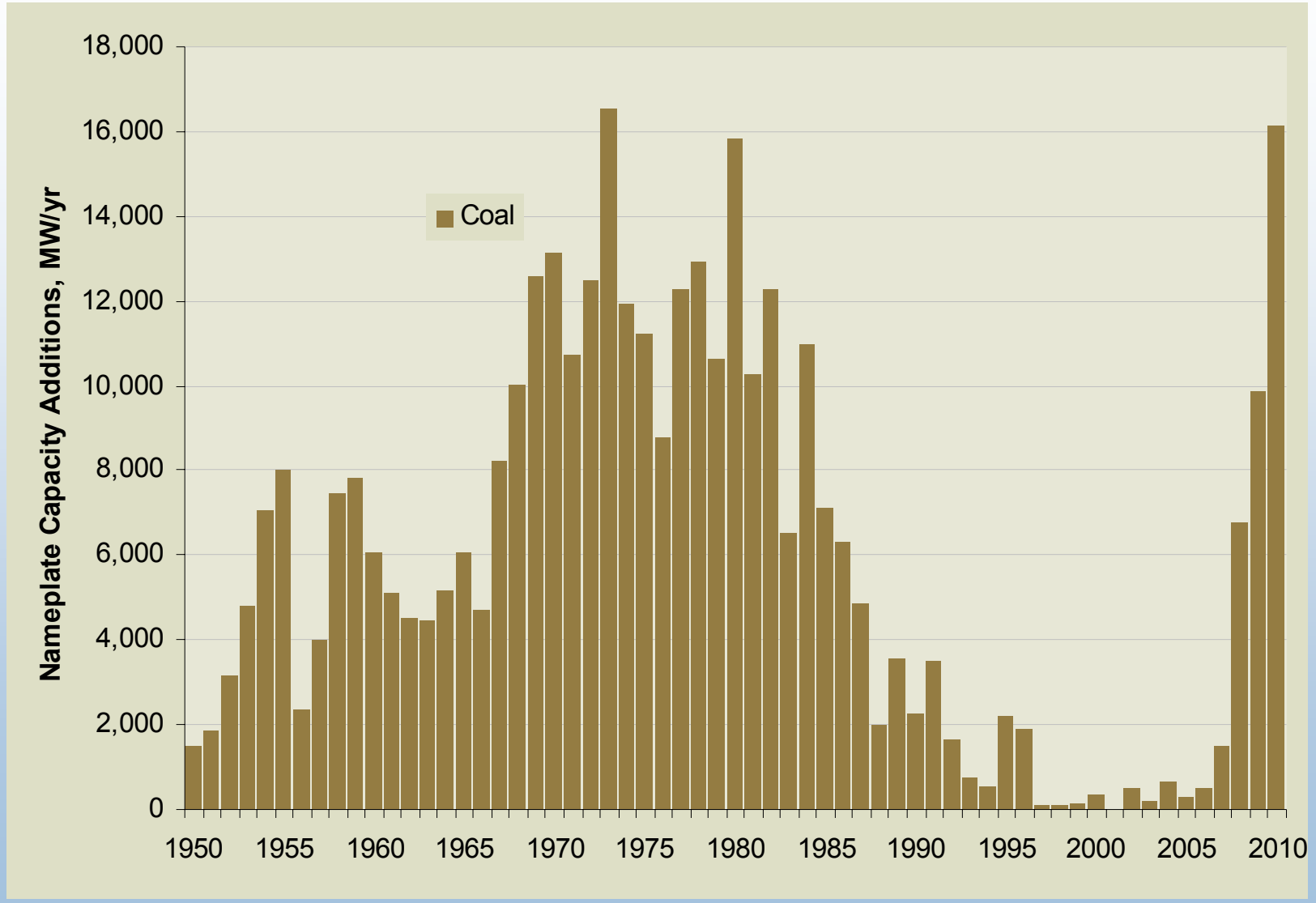
Global Climate Change and Wildlife in North America. The Wildlife Society Technical Review 04-2 2004.

Possible Climate Change Impacts by 2100

Possible changes in percentages of breeding Neotroptical migrant species in the next 100 years (Price and Root 2001).	Possible change (%)	
	Gross	Net
California	-29	-6
Eastern Midwest	-57	-30
Great Lakes	-53	-29
Great Plains – Central	-44	-8
Great Plains – Northern	-44	-10
Great Plains – Southern	-32	-14
Mid-Atlantic	-45	-23
New England	-44	-15
Pacific Northwest	-32	-16
Rocky Mountains	-39	-10
Southeast	-37	-22
Southwest	-29	-4

Global Climate Change and Wildlife in North America. The Wildlife Society Technical Review 04-2 2004.

The US History and Future Planned Additions of Coal Generated Electricity



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

A New Vision
For Wind Energy in the U.S.

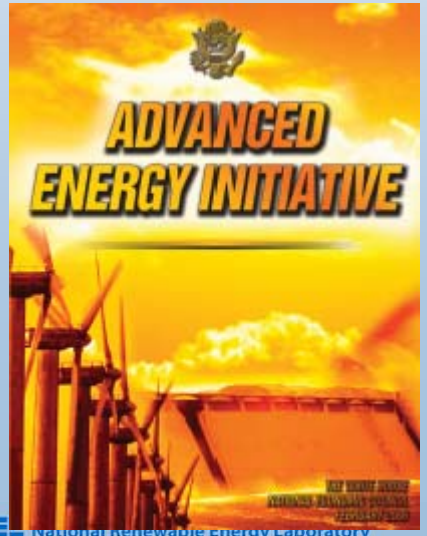

White House photo by Eric Draper

State of the Union Address

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

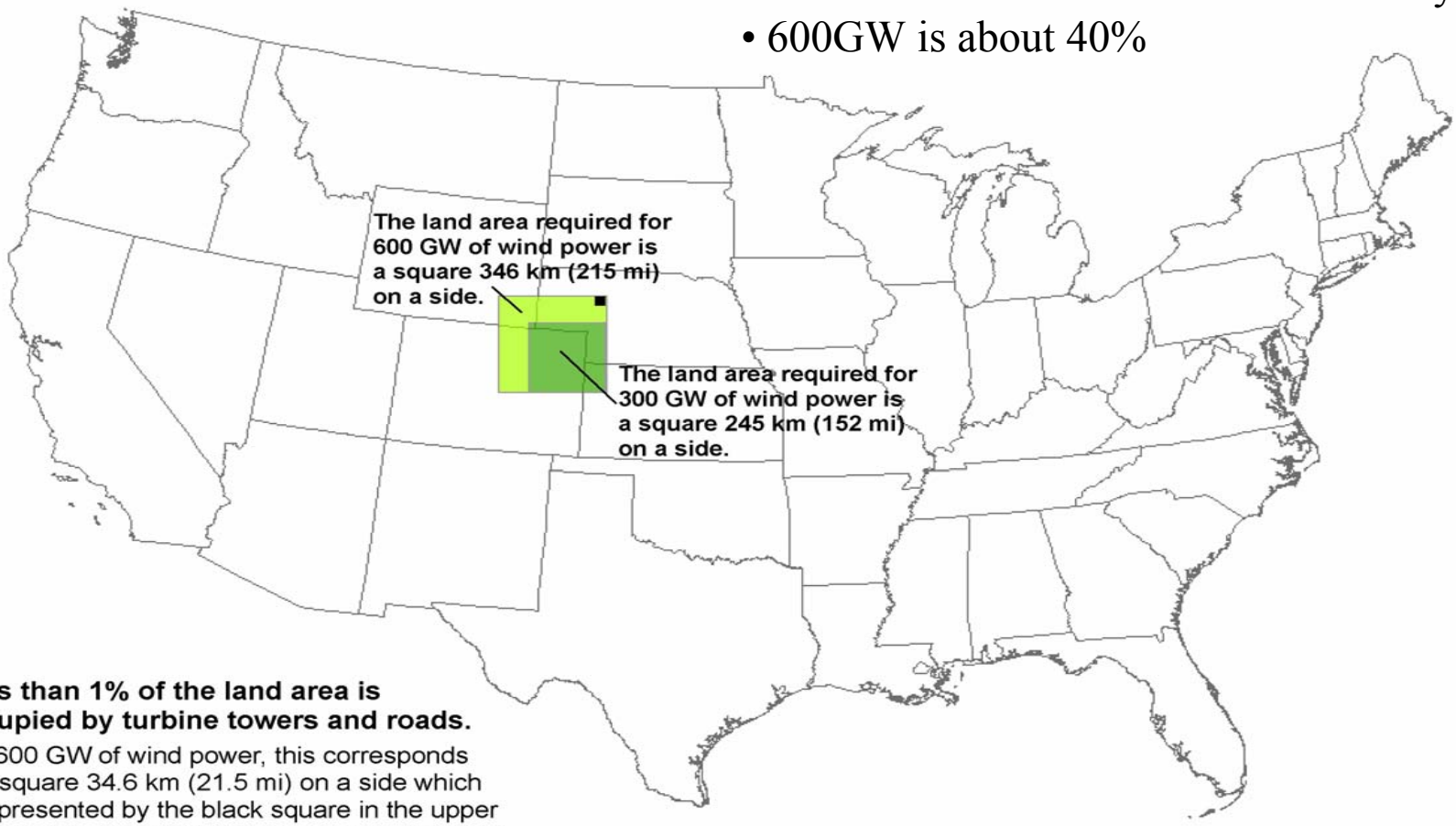
Advanced Energy Initiative

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



Land Requirements for 20% of the Nations Electricity

- 300GW is about 20% of US Electricity
- 600GW is about 40%



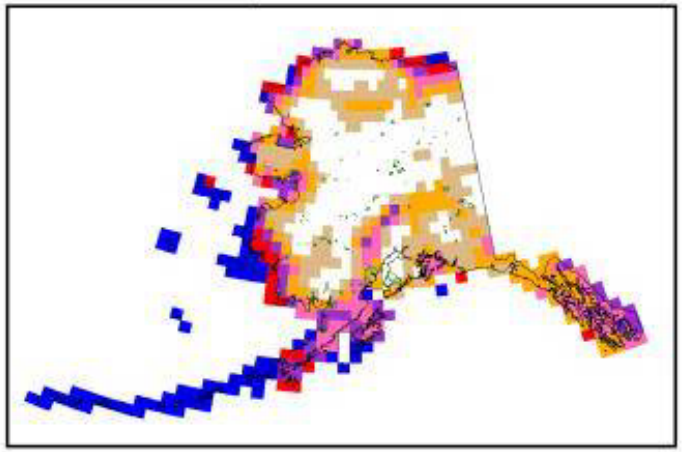
Less than 1% of the land area is occupied by turbine towers and roads.

For 600 GW of wind power, this corresponds to a square 34.6 km (21.5 mi) on a side which is represented by the black square in the upper right corner. The majority of land area in a wind farm remains available for its original use such as ranching or farming.

U.S. Department of Energy
National Renewable Energy Laboratory

NREL
16-MAY-2006

United States - Wind Resource Map



Source: "Wind Energy Resource Atlas of the United States", 1987

Indian Reservations and Alaska Native Village Areas

Wind Power Classification

Wind Power Class	Resource Potential	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	Marginal	200 - 300	5.6 - 6.4	12.5 - 14.3
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

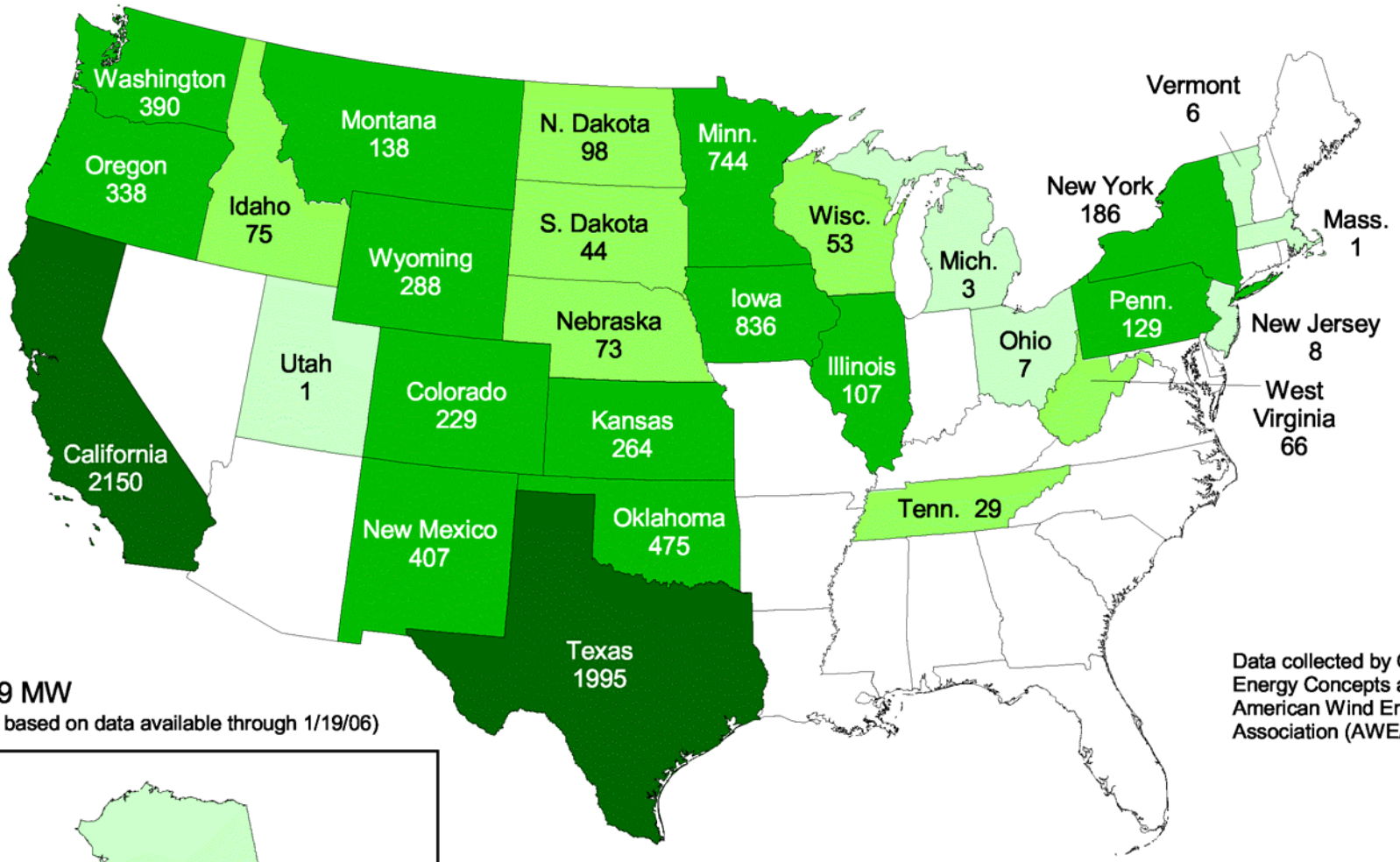
[a] Wind speeds are based on a Weibull k value of 2.0

U.S. Department of Energy
National Renewable Energy Laboratory

NREL

DM Heimiller 31-MAY-2001 1.2.8

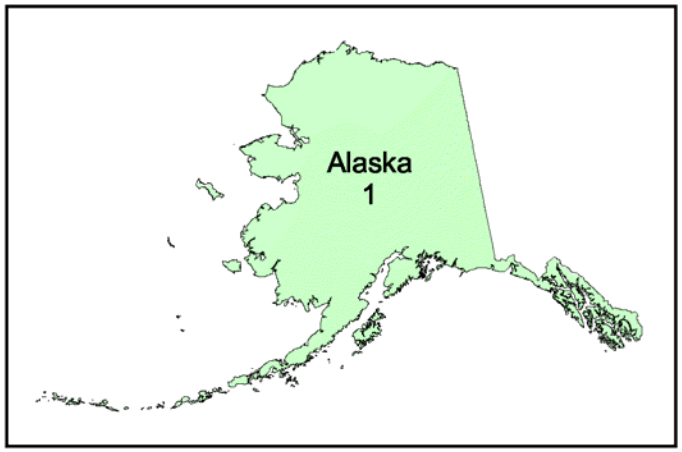
United States - 2005 Year End Wind Power Capacity (MW)

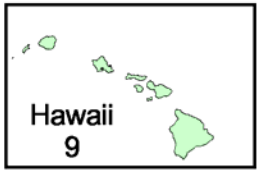


Total: 9,149 MW

(As of 12/31/05, based on data available through 1/19/06)

Data collected by Global Energy Concepts and the American Wind Energy Association (AWEA).





Wind Power Capacity

Megawatts (MW)

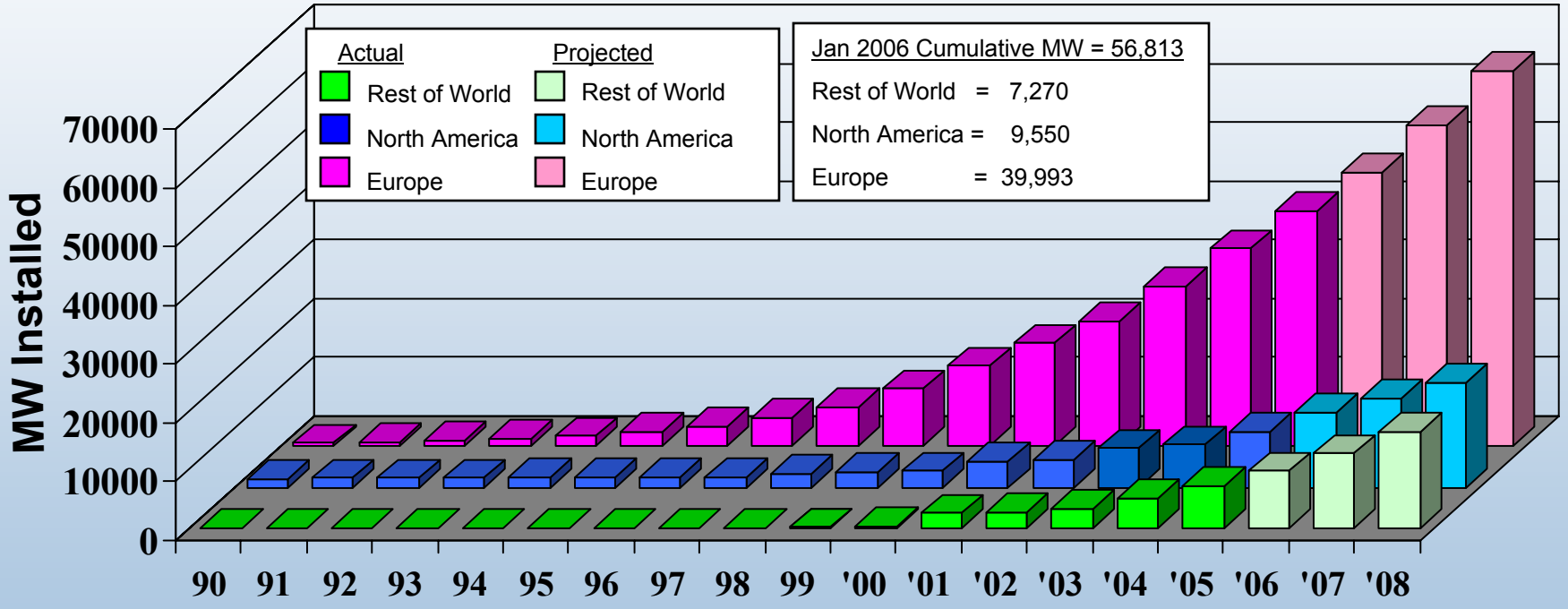
- 1,000 - 2,150
- 100 - 1,000
- 20 - 100
- 1 - 20

U.S. Department of Energy
National Renewable Energy Laboratory

NREL

25-JAN-2006 1.1.22

Growth of Wind Energy Capacity Worldwide



Sources: BTM Consult Aps, Sept 2005
Windpower Monthly, January 2006

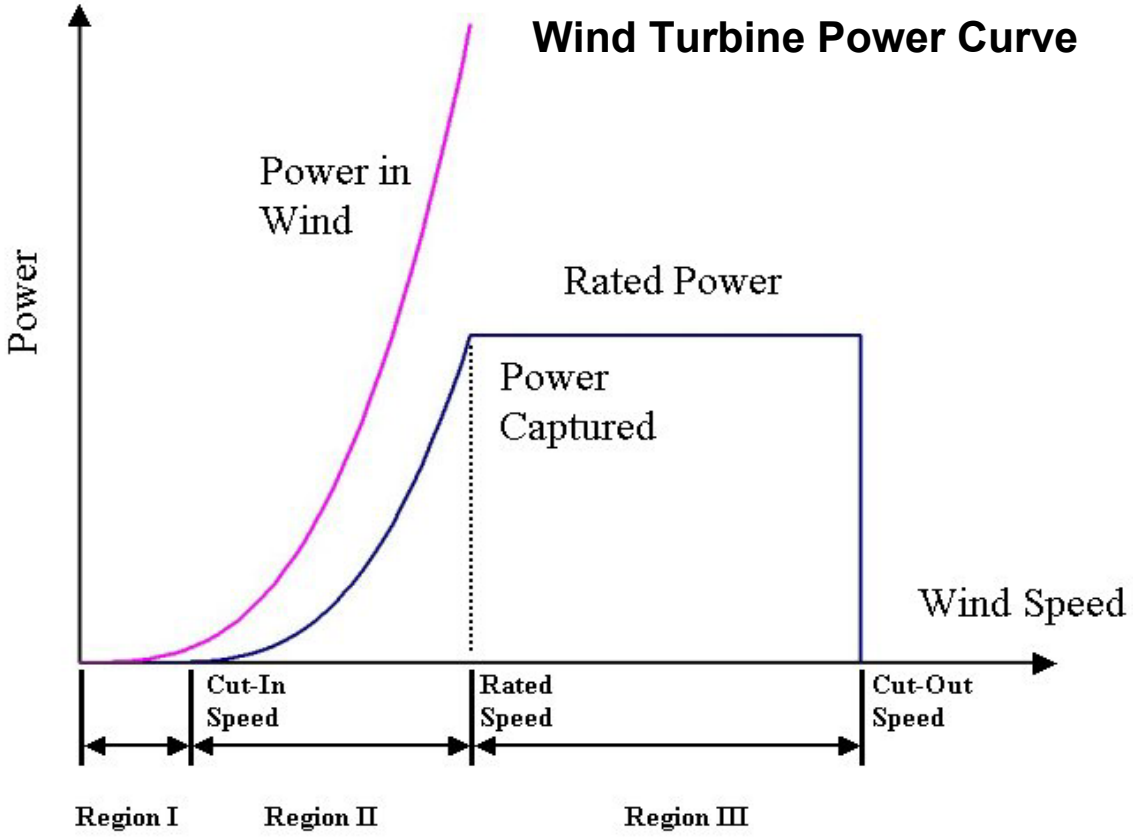
Wind Turbine Power Basics

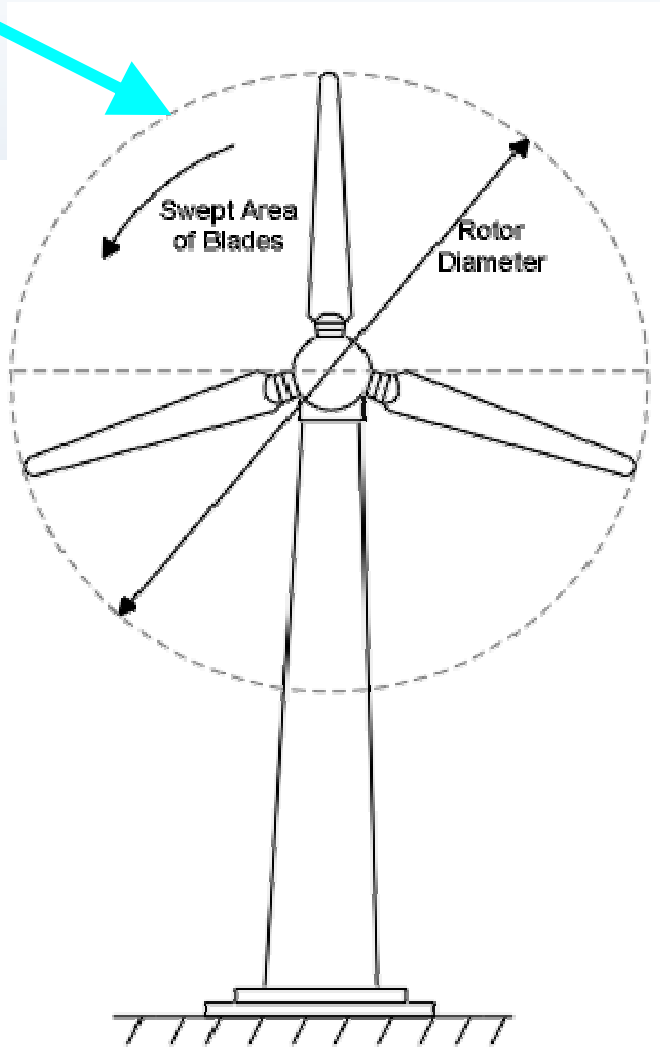
Power in the Wind = $\frac{1}{2}\rho A V^3$

A - Area of the circle swept by the rotor

ρ = Air density

V = Wind Velocity

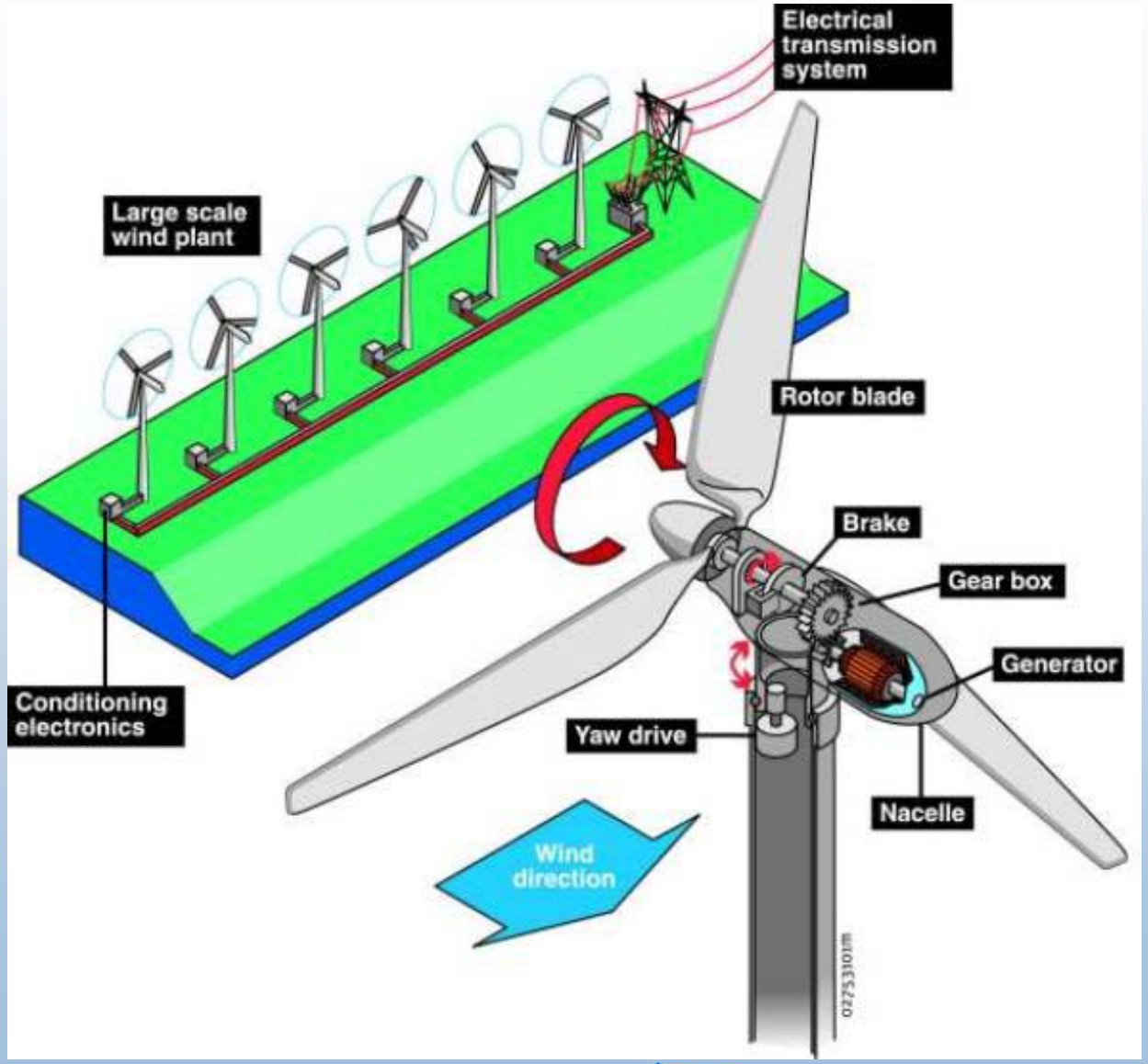




Schematic of Wind Plant

At it's simplest, the wind turns the turbine's blades, which spin a shaft connected to a generator that makes electricity.

Large turbines are grouped together in an array of about 5 Diameters by 10 Diameters to form a wind power farm, which feeds electricity to the grid.



Consideration 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

A Utility Scale 1.5 MW Wind Turbine

Cost of Energy Trend

1981: 40 cents/kWh

Decreasing Cost Due to:
- **Increased Turbine Size**
- **R&D Advances**
- **Manufacturing improvements**

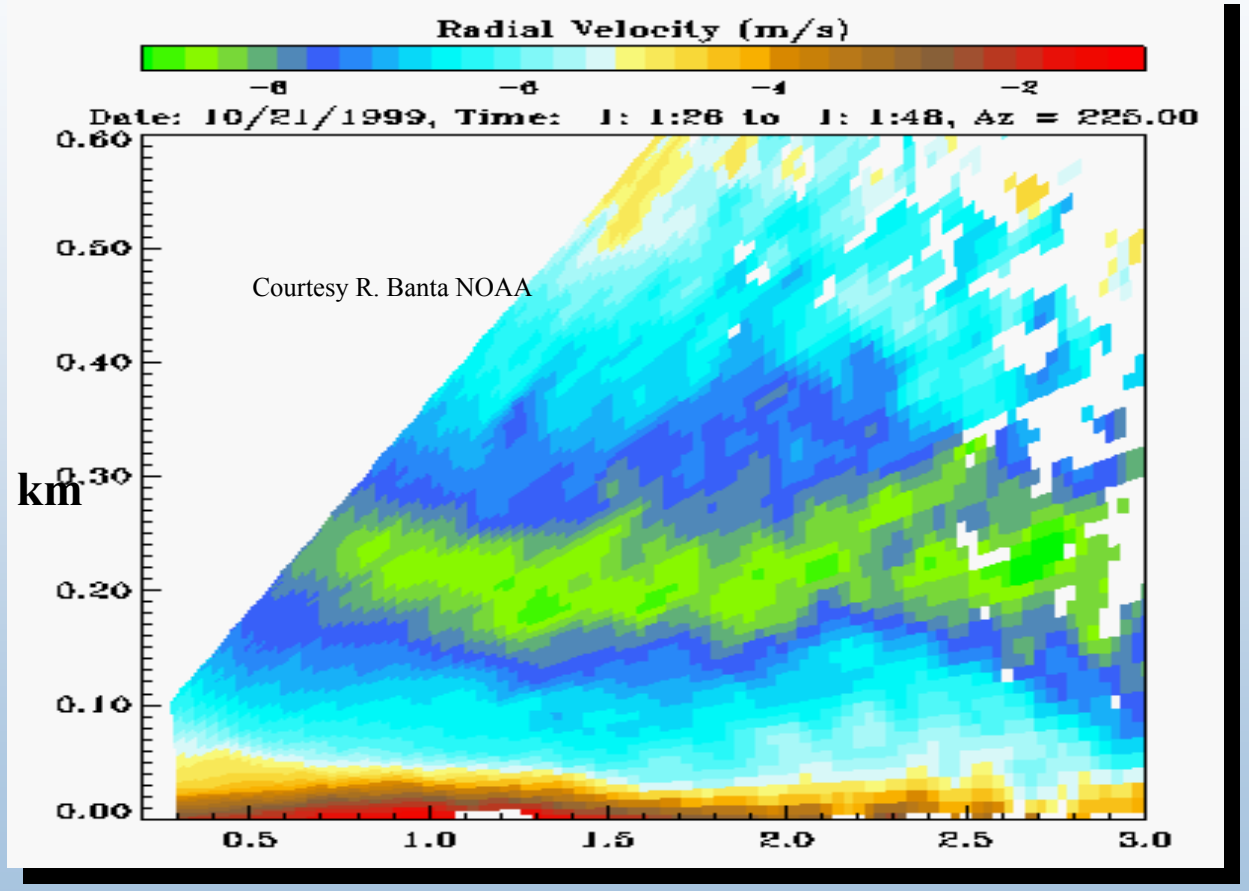
NSP 107 MW Lake Benton, MN wind farm

2006: 5-8 cents/kWh with no PTC

Cost Increases Due to:
- **Price increases in Steel & Copper**
- **Turbines Sold Out for 2 Years**

2012 Goal : 3.6 cents/kWh with no PTC

Measuring and Modeling the Low-Level Nocturnal Jet

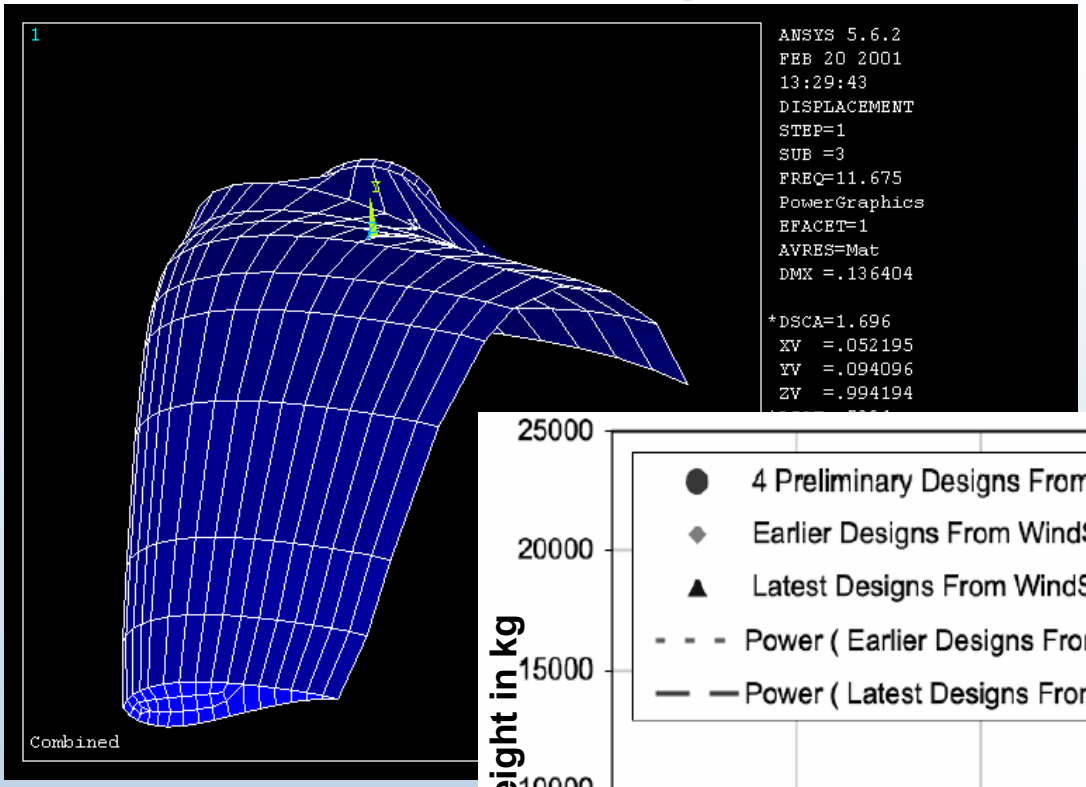


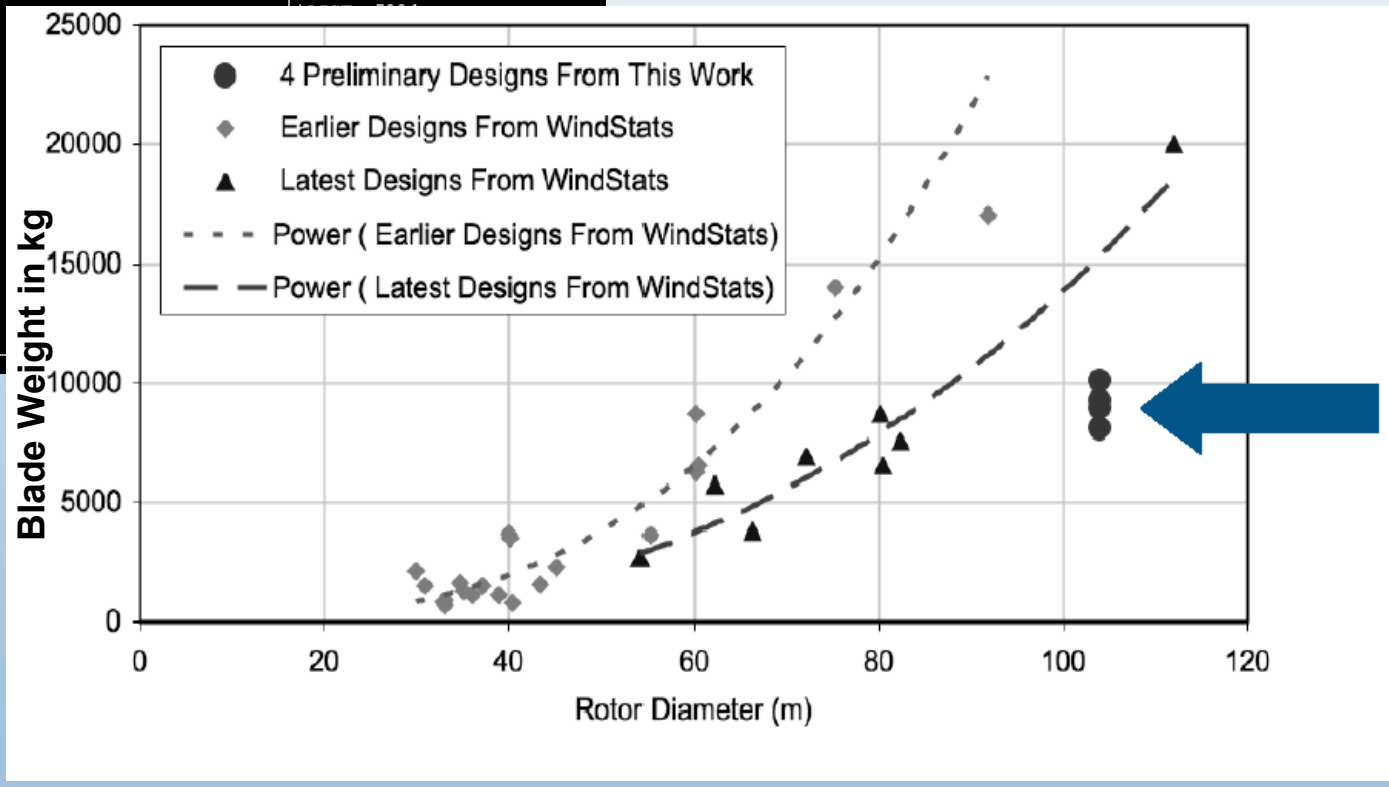
Met tower and SODAR at Lamar, Colorado

Blade Fatigue Testing at NREL

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

Blade Scaling for Multi-megawatt Rotors





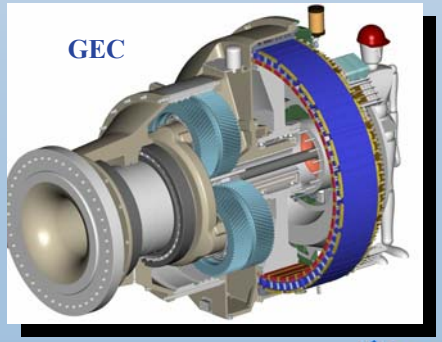
NREL Advanced Drivetrain R&D

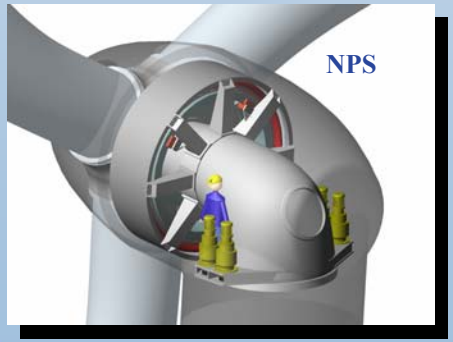
Today

1.5MW Commercial Technology

Tomorrow

Prototype Technology



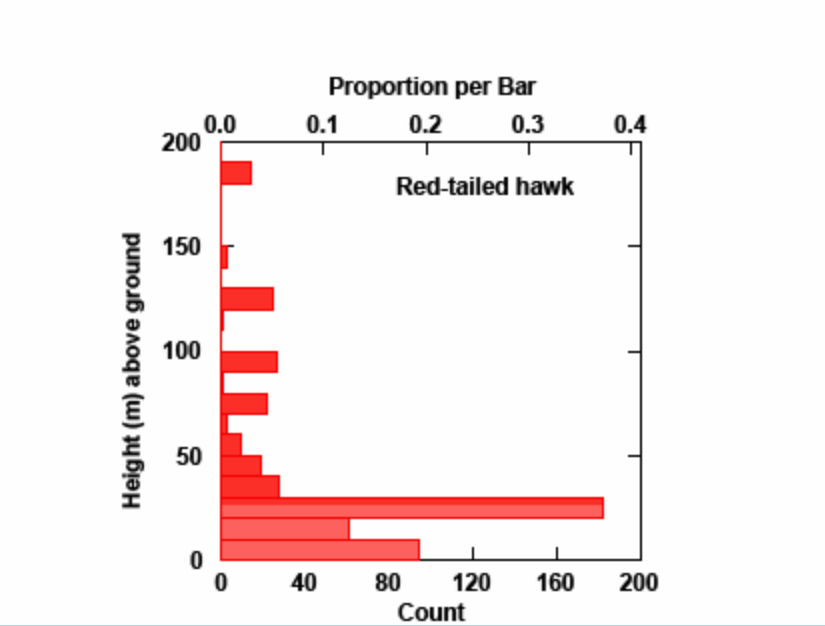


Highlights of One Interaction Study in Altamont Pass

- **Topographical features, turbine location and prey appear to play roles**
- **Not all turbines appear to contribute to fatalities**

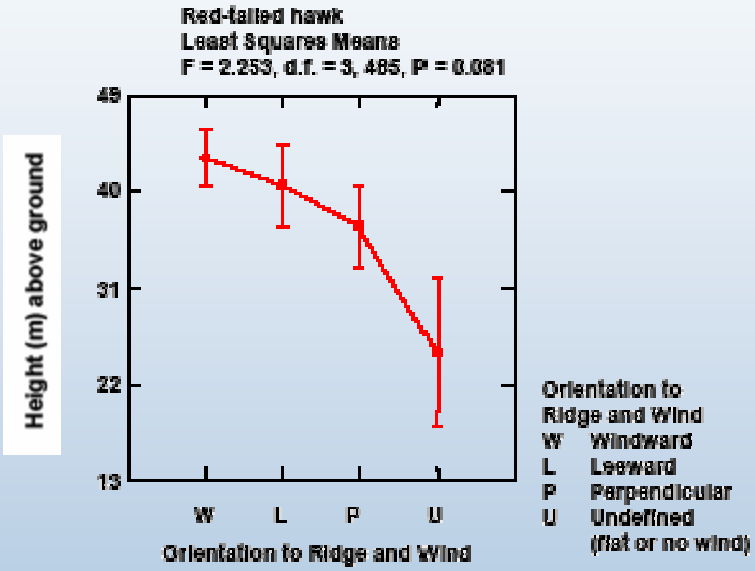
Red Tailed Hawk Flight Observations
Histogram for Altamont Pass

Height Histogram



Distribution of flight heights above ground level amount red-tailed hawks observed during behavioral observations sessions during 2003 and 2004 in the APWRA.

Height versus Orientation



Mean flight heights of red-tailed hawk over aspect of ridge relative to oncoming winds.

Source: K. Smallwood and L. Neher, CEC-500-2005-005, December 2004

Avian Strike Probability Versus Turbine Size

Altamont Scale

15 Meter Diameter and 100 kW

Next Generation Scale

93 Meter Diameter and 2.5MW

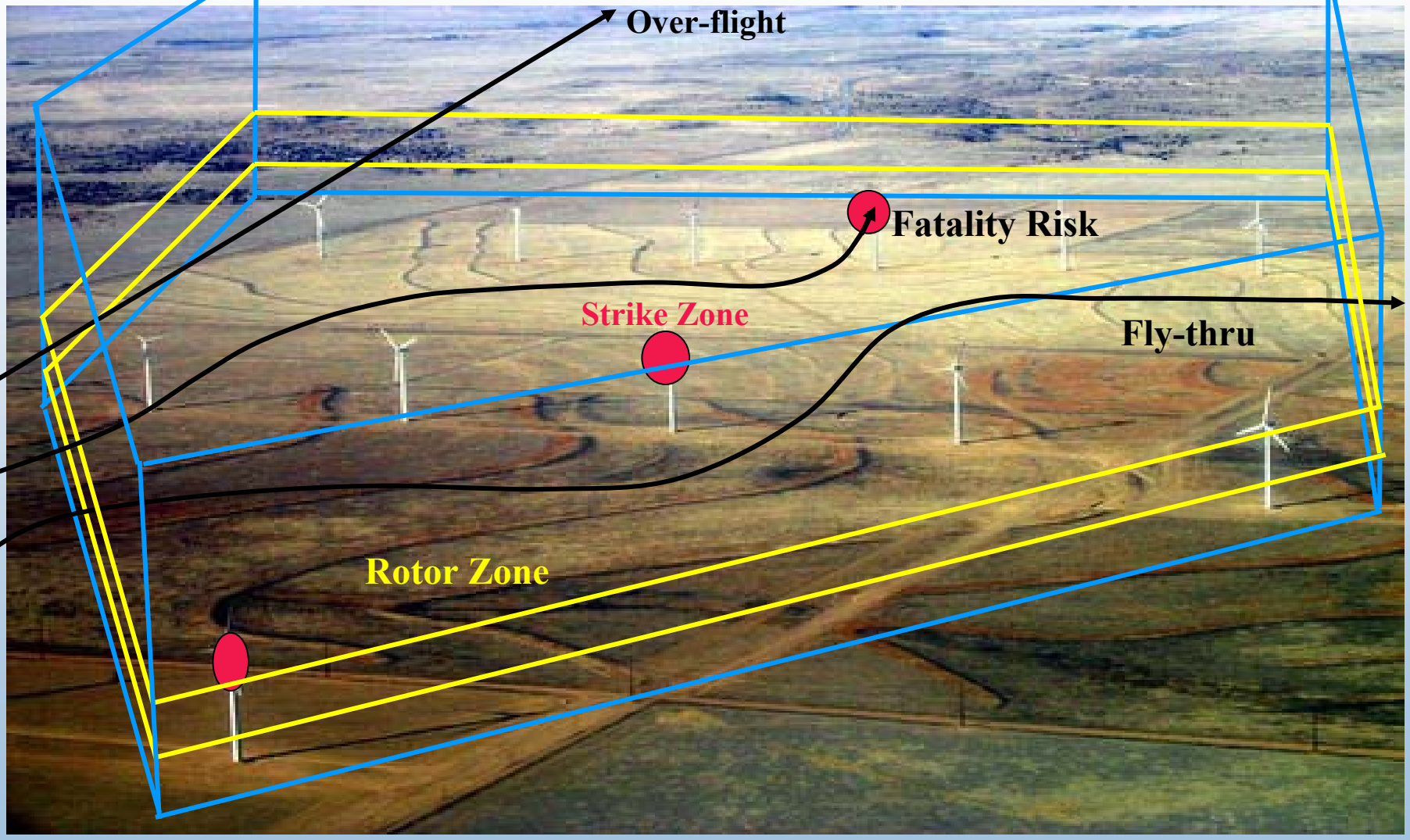
NREL Avian Studies Available at:

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

Visualization of Avian Interaction Zones

Windfarm Flight Zone



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)

Offshore Wind – U.S. Rationale

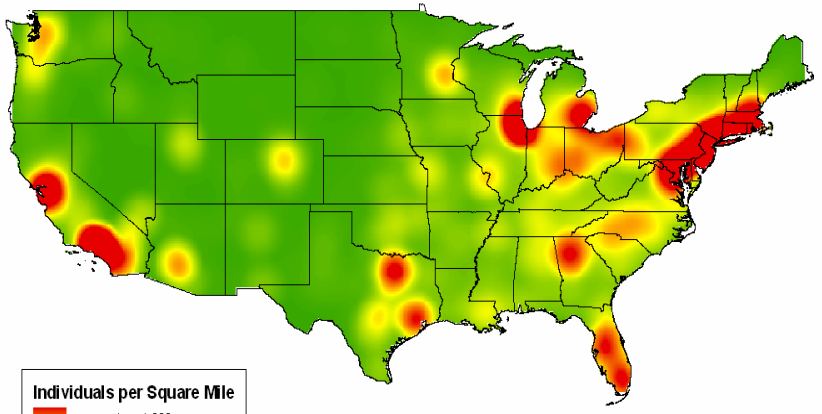
Why Go Offshore?

Windy onshore sites are not close to coastal load centers

The electric utility grid cannot be easily set up for interstate electric transmission

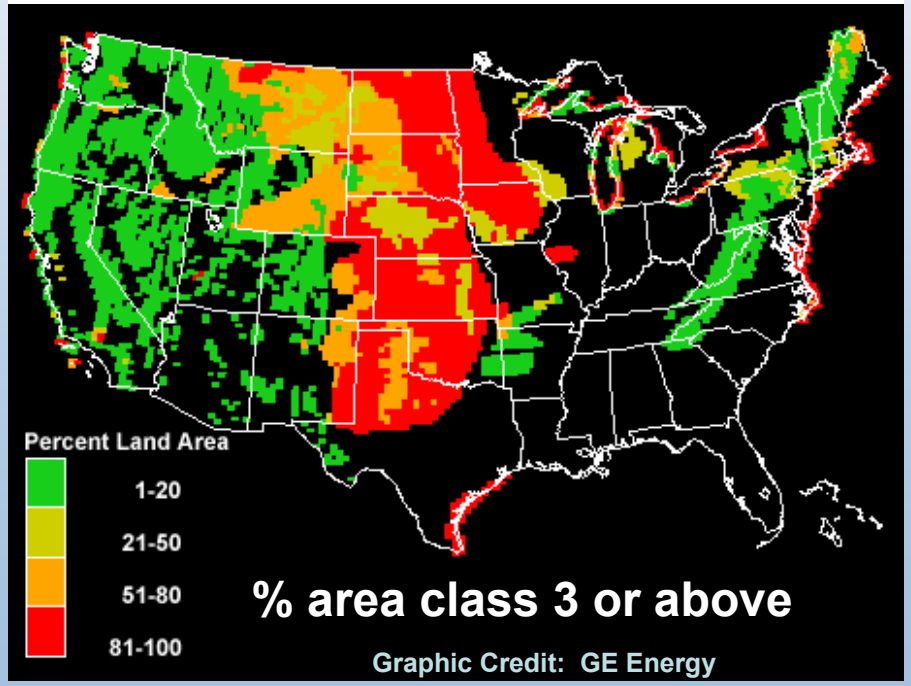
Load centers are close to the offshore wind sites

US Population Concentration



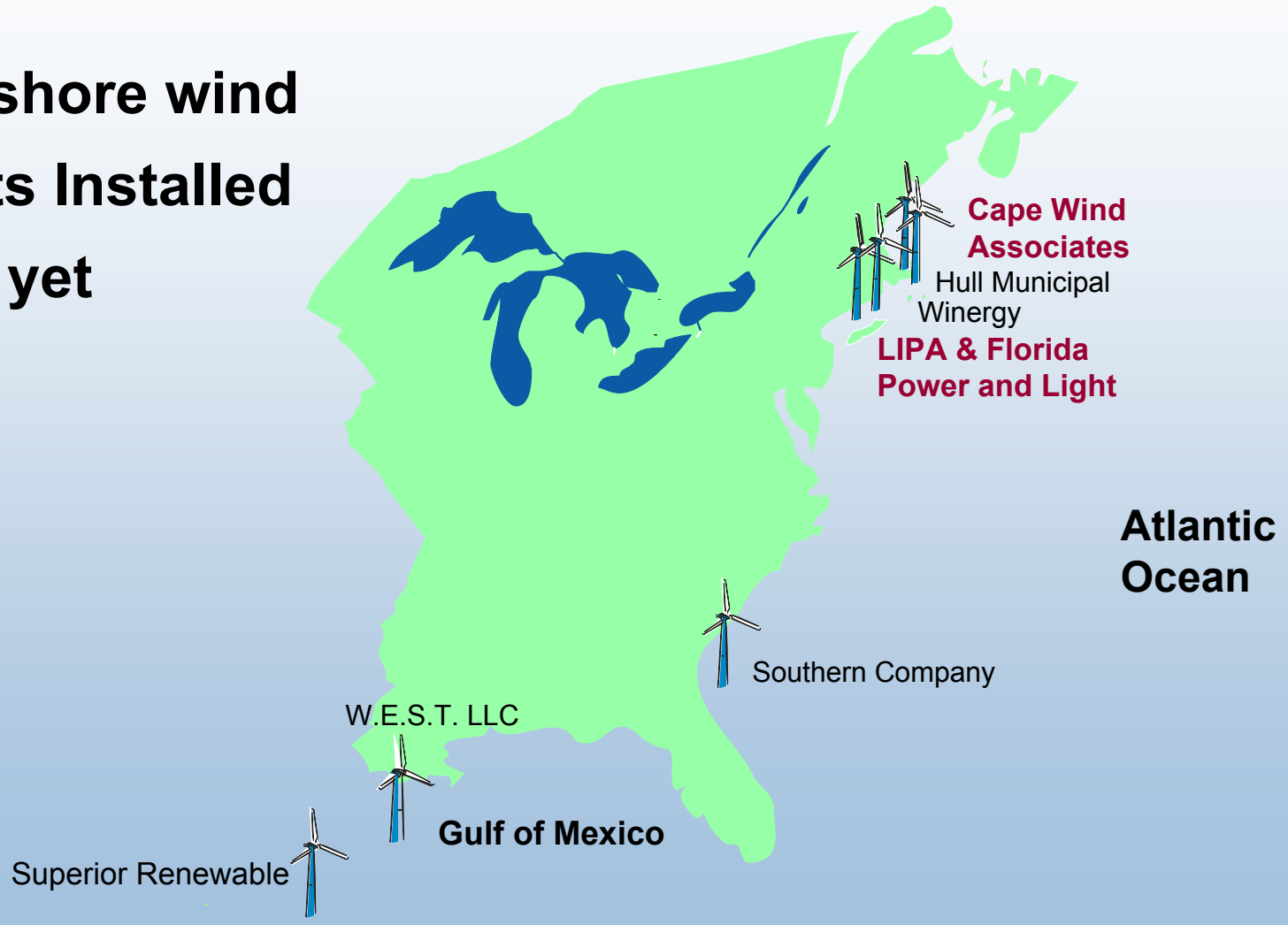
Graphic Credit: Bruce Bailey AWS Truewind

US Wind Resource



US Offshore Projects Proposed

No Offshore wind projects Installed in U.S. yet

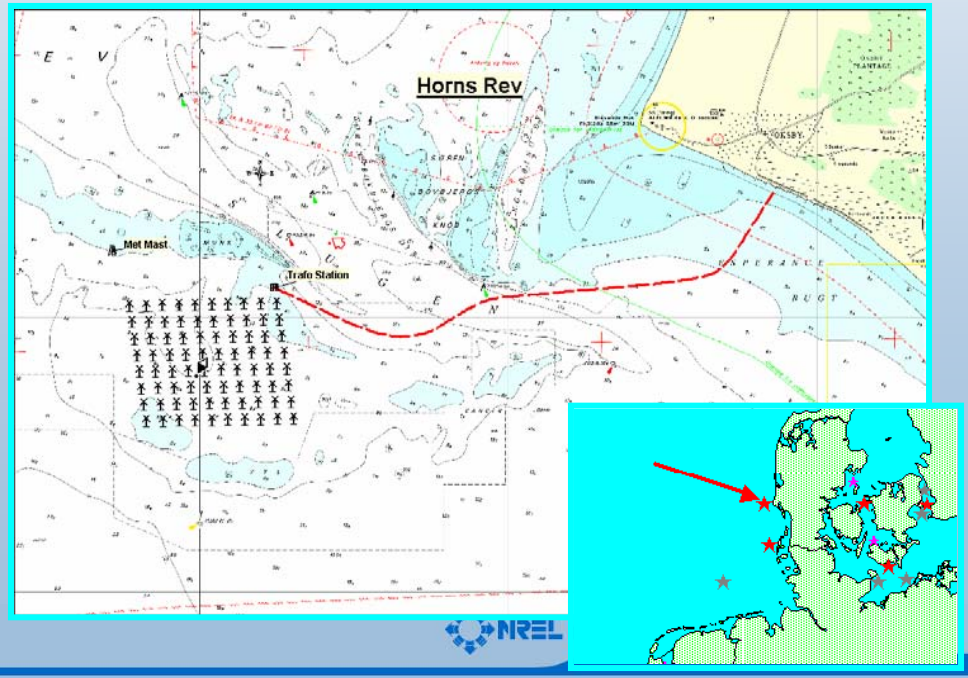


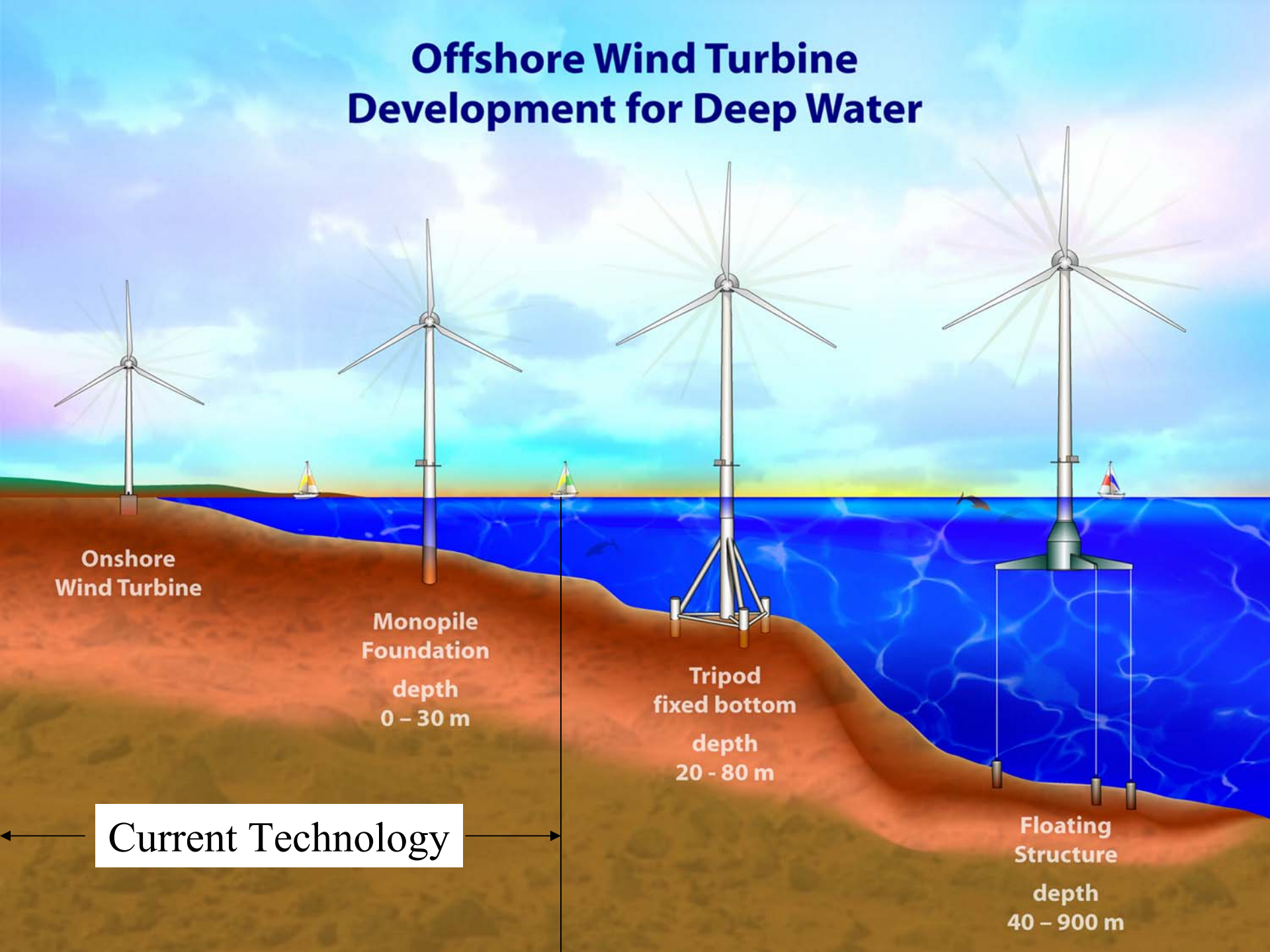
Arklow Banks Windfarm
The Irish Sea

Photo: R. Thresher

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

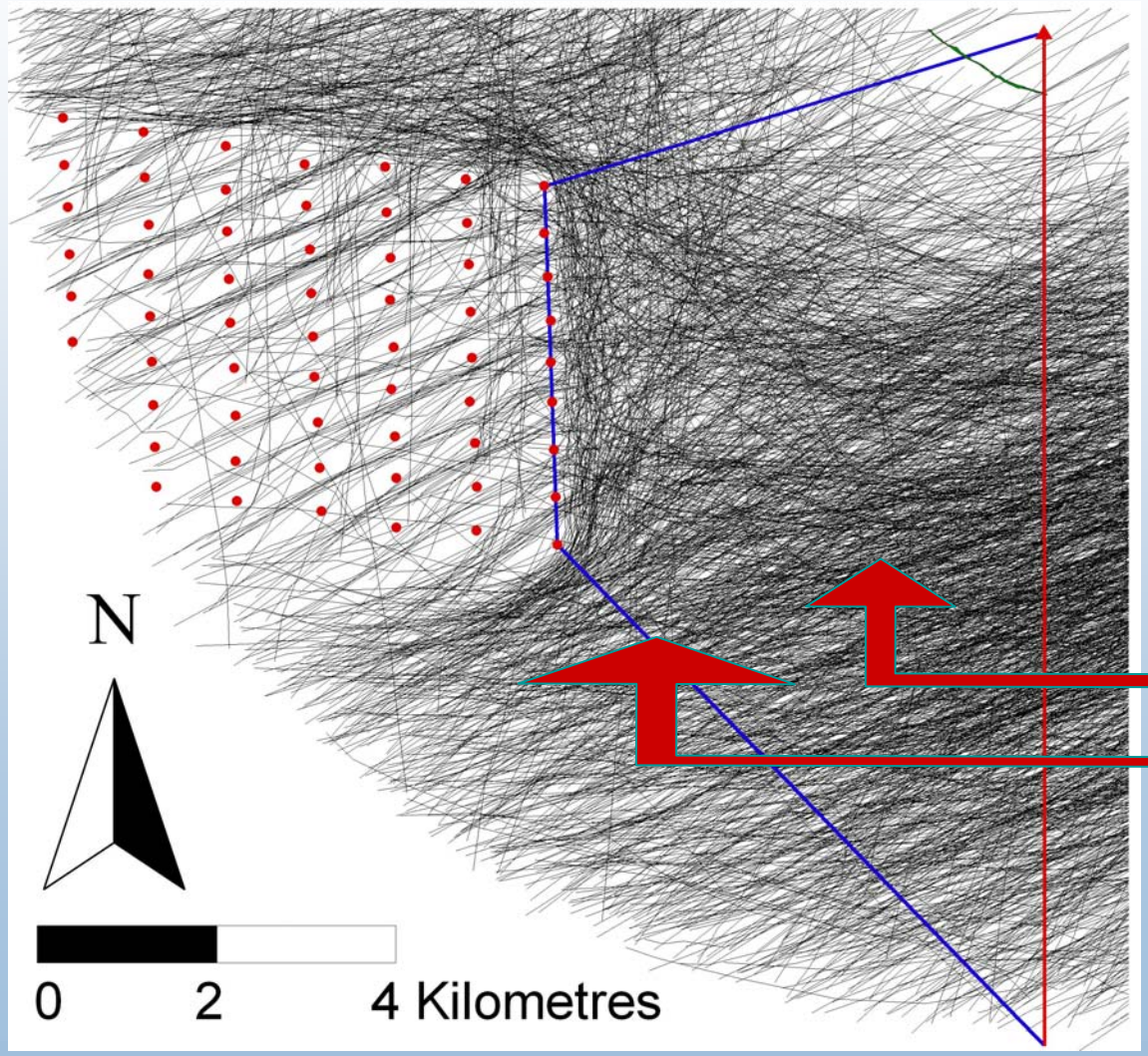



Offshore Wind Turbine
Development for Deep Water
Onshore
Wind Turbine
Monopile
Foundation
depth
0 – 30 m
Tripod
fixed bottom
depth
20 - 80 m
Floating
Structure
depth
40 – 900 m
Current Technology

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

Nysted Migrating Birds



Operation (2003):

Response distance:

day = c. 3000m

night = c. 1000m

GE Wind 1.5 MW – Windfarm Projects

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.

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