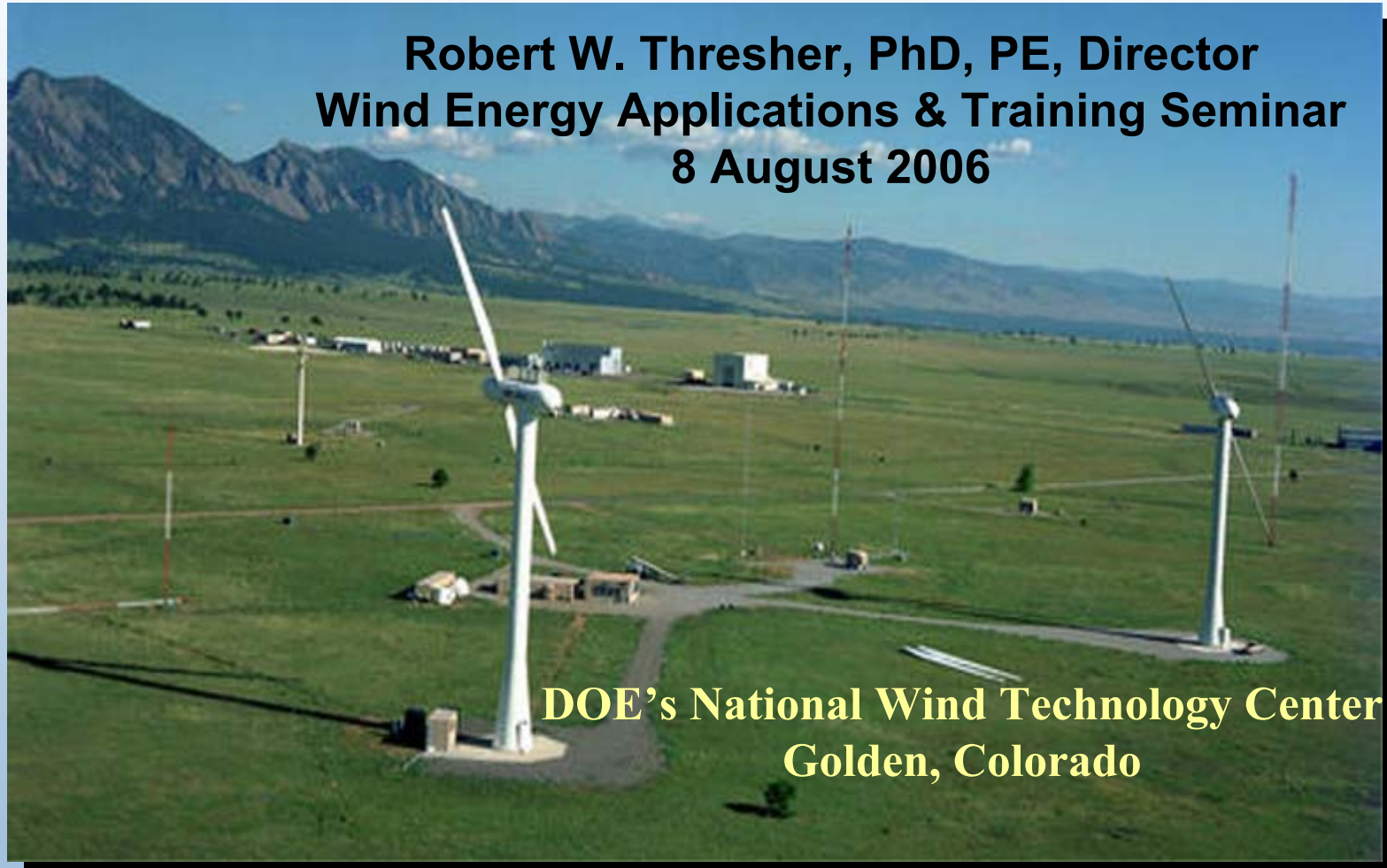
Wind Energy Status and R&D Challenges



Robert W. Thresher, PhD, PE, Director
Wind Energy Applications & Training Seminar
8 August 2006

DOE's National Wind Technology Center
Golden, Colorado

National Wind Technology Center Staff

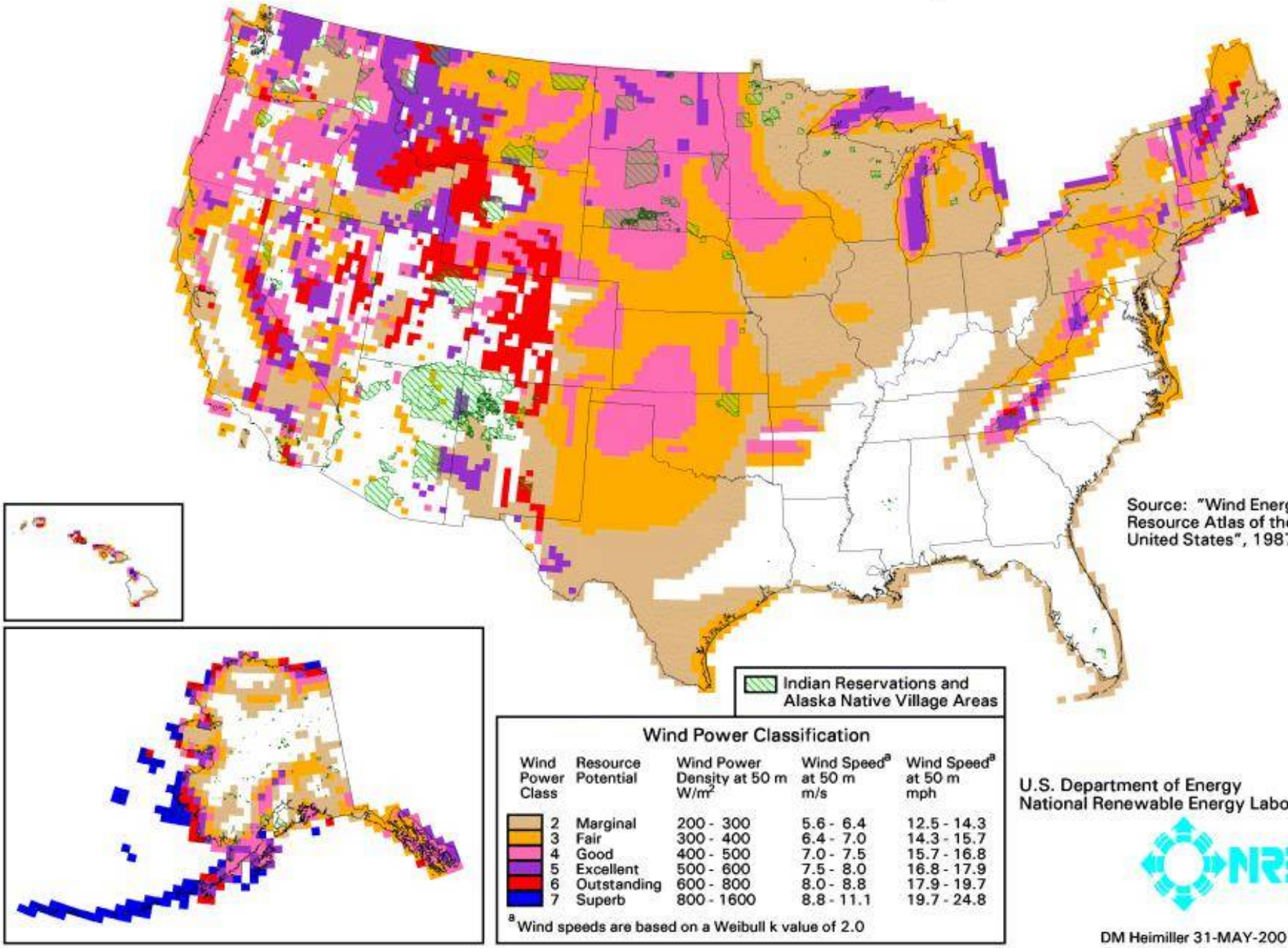
Average Staffing:

- Researchers – 42
- Technicians – 6
- Students – 5
- Post Doctorates – 1 - 3

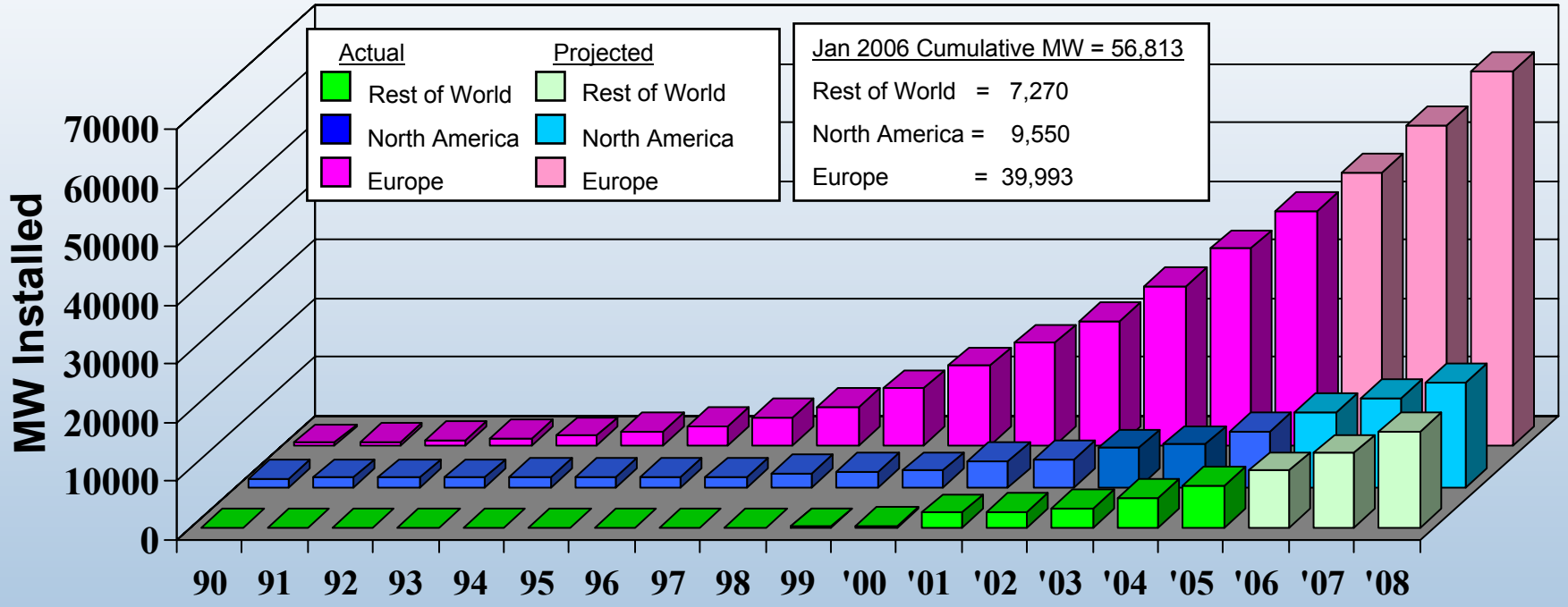
Funding Level:

- DOE Wind Program Funding: $40M/year
- NREL Wind Program Funding: $30M/year
- NREL Industry Funding: $582K/year

United States - Wind Resource Map

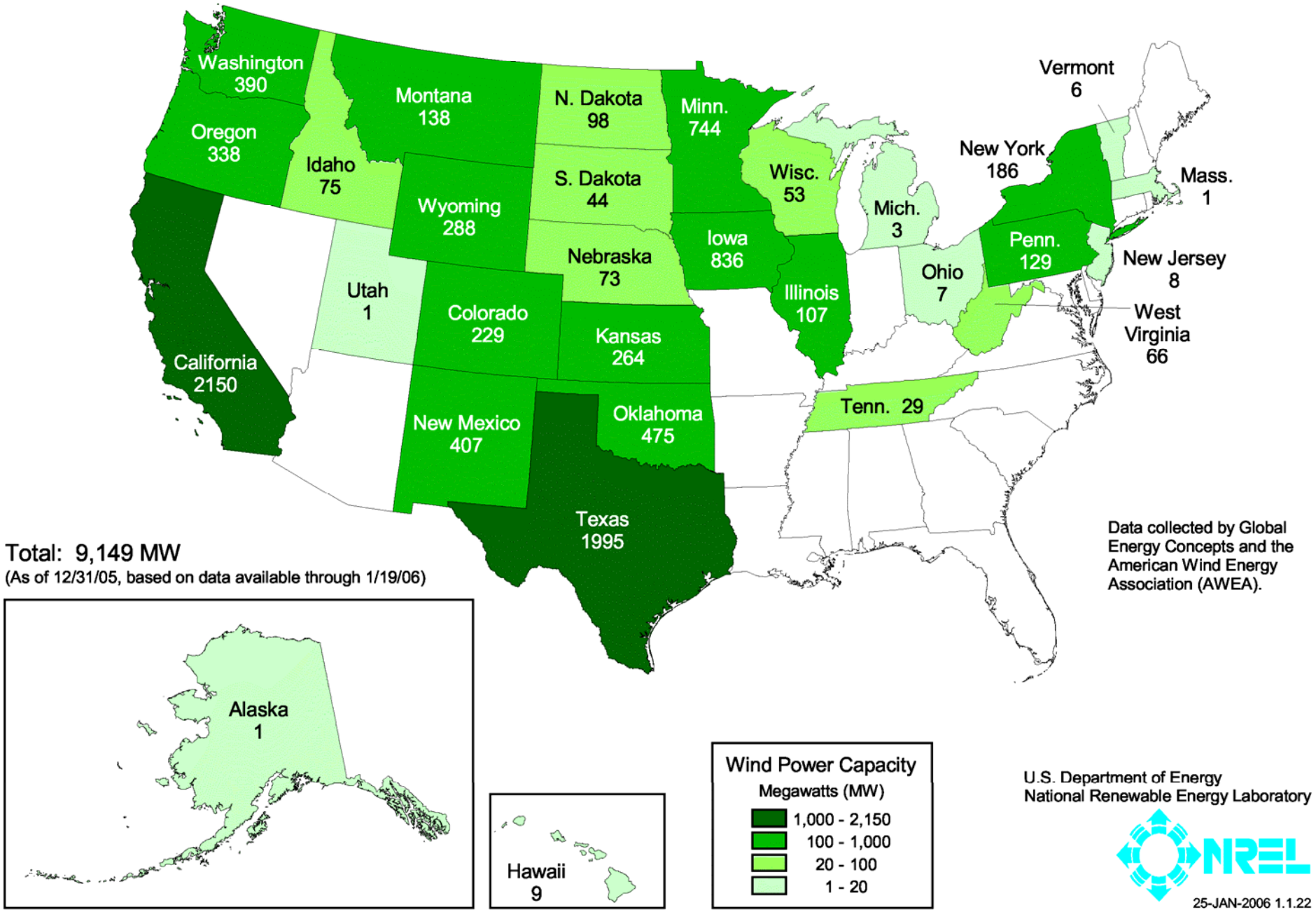


Growth of Wind Energy Capacity Worldwide



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

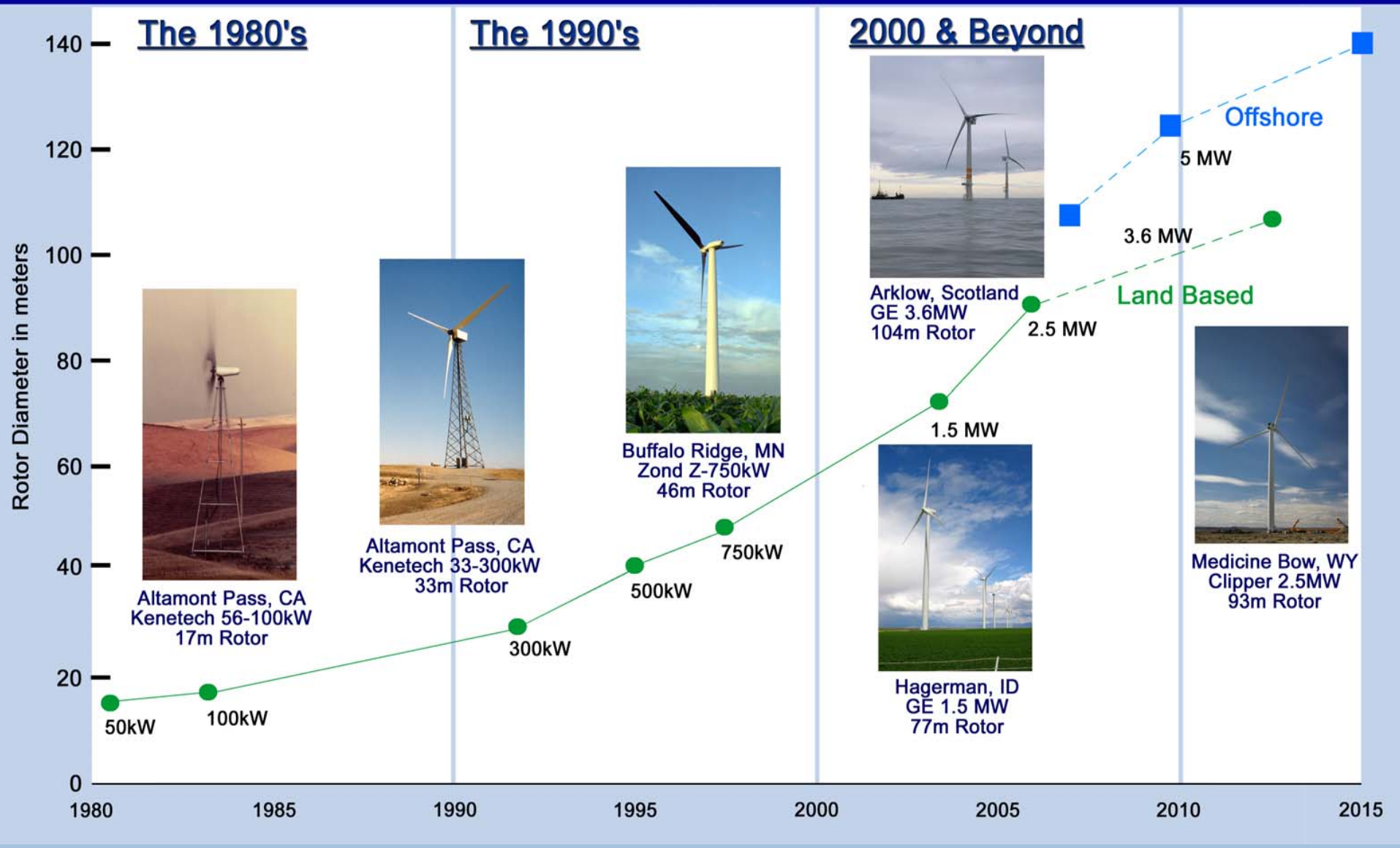
United States - 2005 Year End Wind Power Capacity (MW)



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).

Evolution of U.S. Commercial Wind Technology



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

Sizes and Applications

Small (≤10 kW)

- Homes (Grid connected)
- Farms
- Remote Applications

  (e.g. battery changing, water pumping, telecom sites, icemaking)

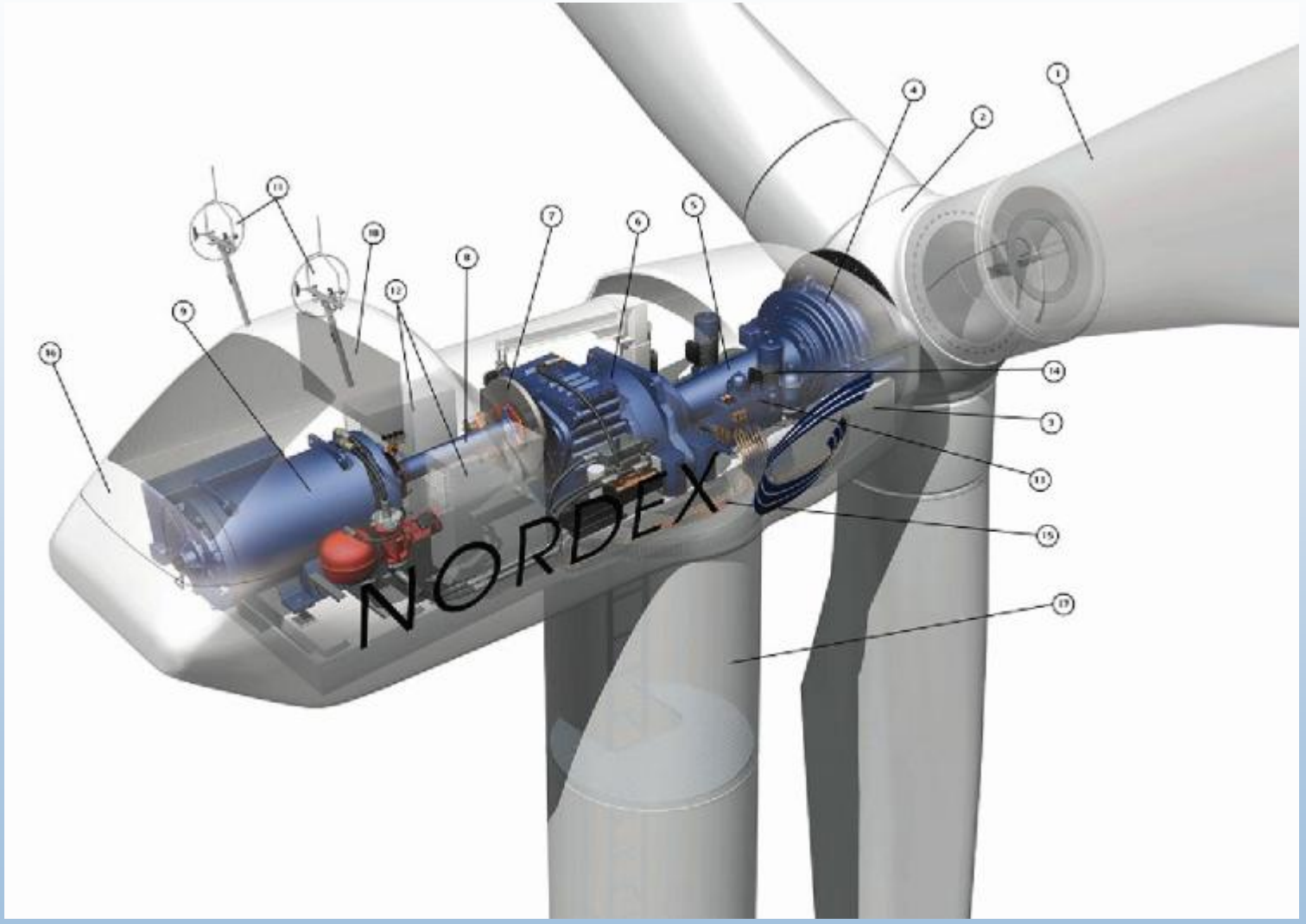
Intermediate (10-500 kW)

- Village Power
- Hybrid Systems
- Distributed Power

Large (500 kW – 6 MW)

- Central Station Wind Farms
- Distributed Power
- Offshore Wind Generation Stations

A Typical Large Turbine has Multiple Subsystems and Controls



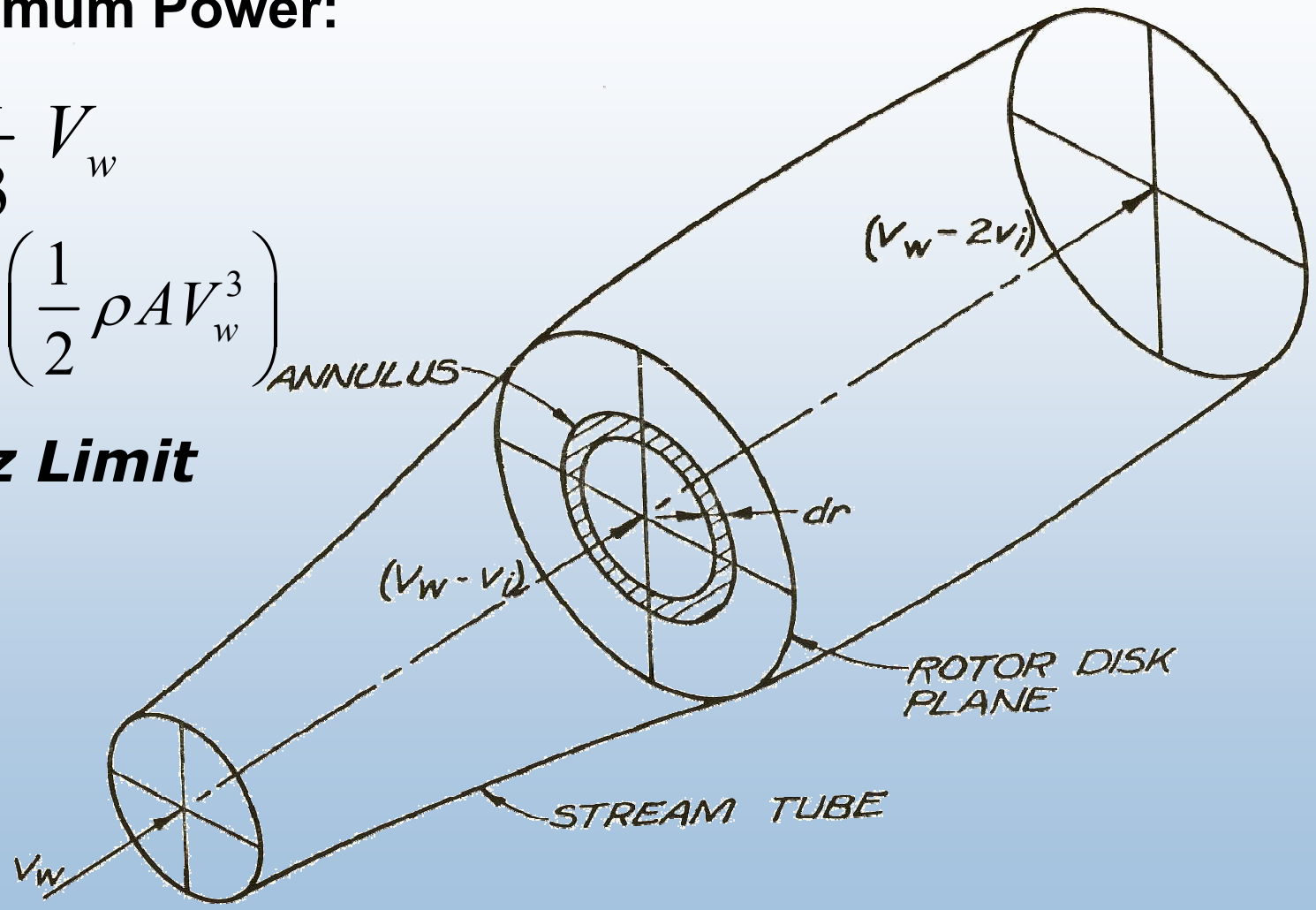
Stream Tube for Momentum Balance

For Maximum Power:

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

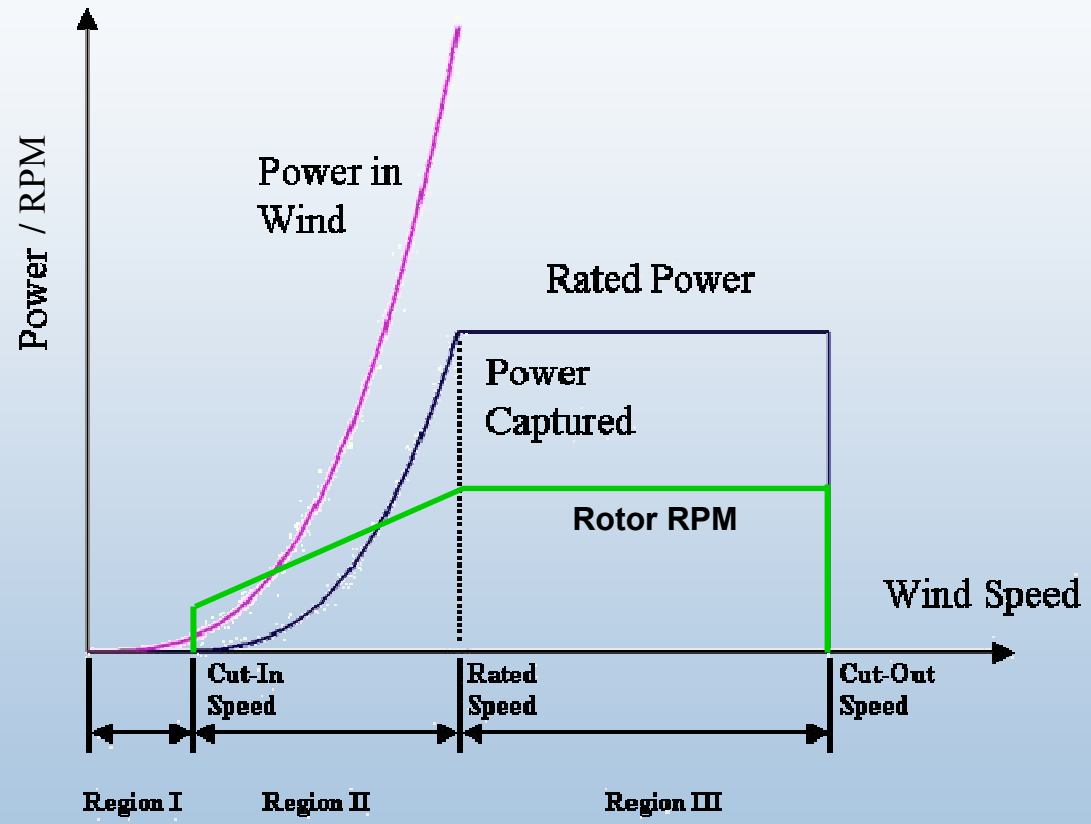
$$P = \frac{16}{27}\left(\frac{1}{2}\rho A V_w^3\right)$$

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

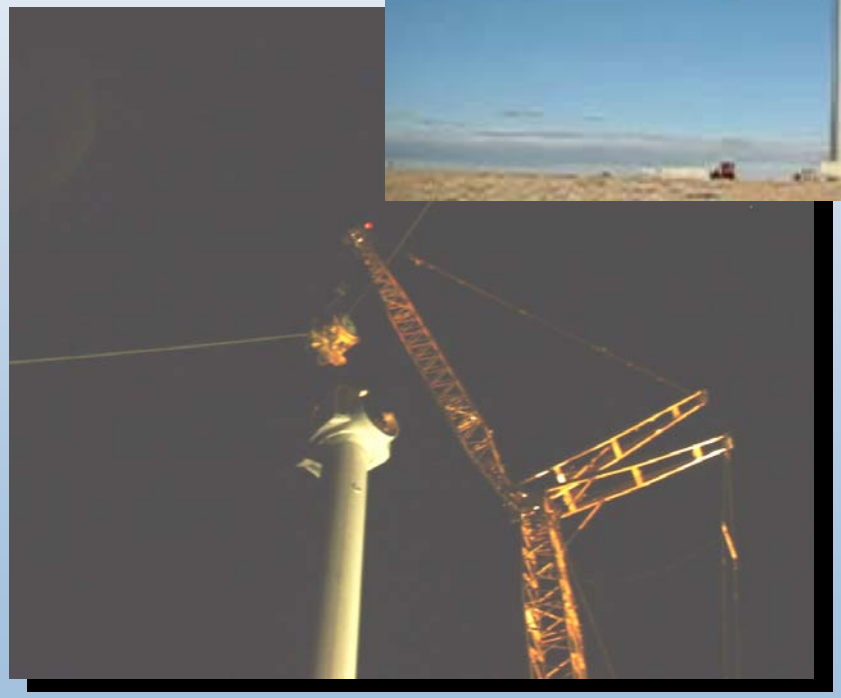


Modern Turbine Power Curve

Wind Energy Research Activities

- Low Wind Speed Technology
- Distributed Wind Technology
- Advanced Rotor Development
- Generator, Drivetrain, and Power Electronics
- Systems and Control
- Technology Acceptance
- Utility Grid Integration
- Certification Testing

Clipper LWST Prototype
2.5 MW with 93 m Rotor



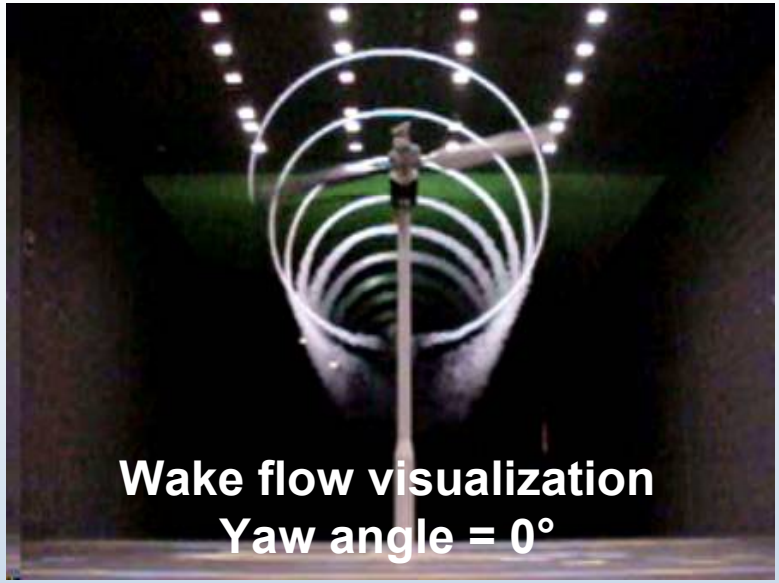
SWWP DWT Prototype 1.8kW under test at the NWTC

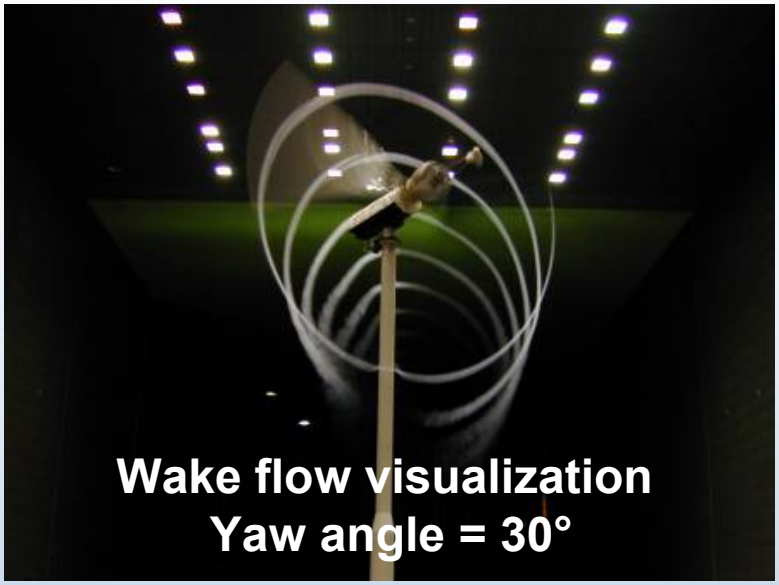
High Wind Operation

Installation

NASA Ames 80 ft x 120 ft Test Section

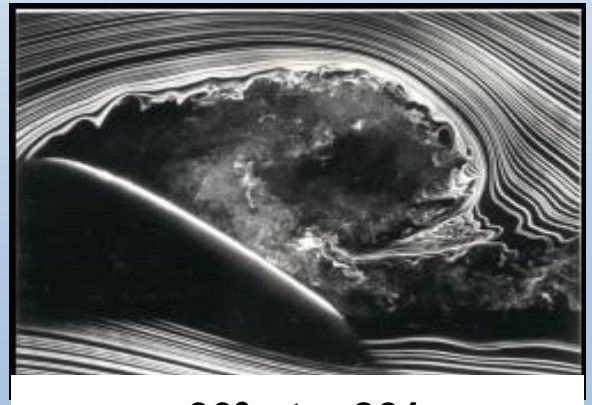
The wind tunnel allows the study of aerodynamic stall in a stable flow





α = 20º ; t = 174 ms
Vortex initiates

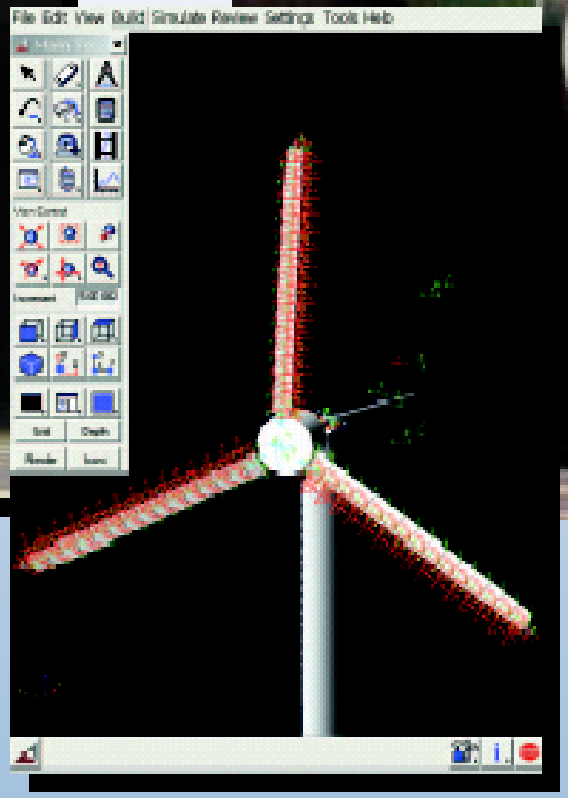
α = 25º ; t = 217 ms
Vortex grows, moves



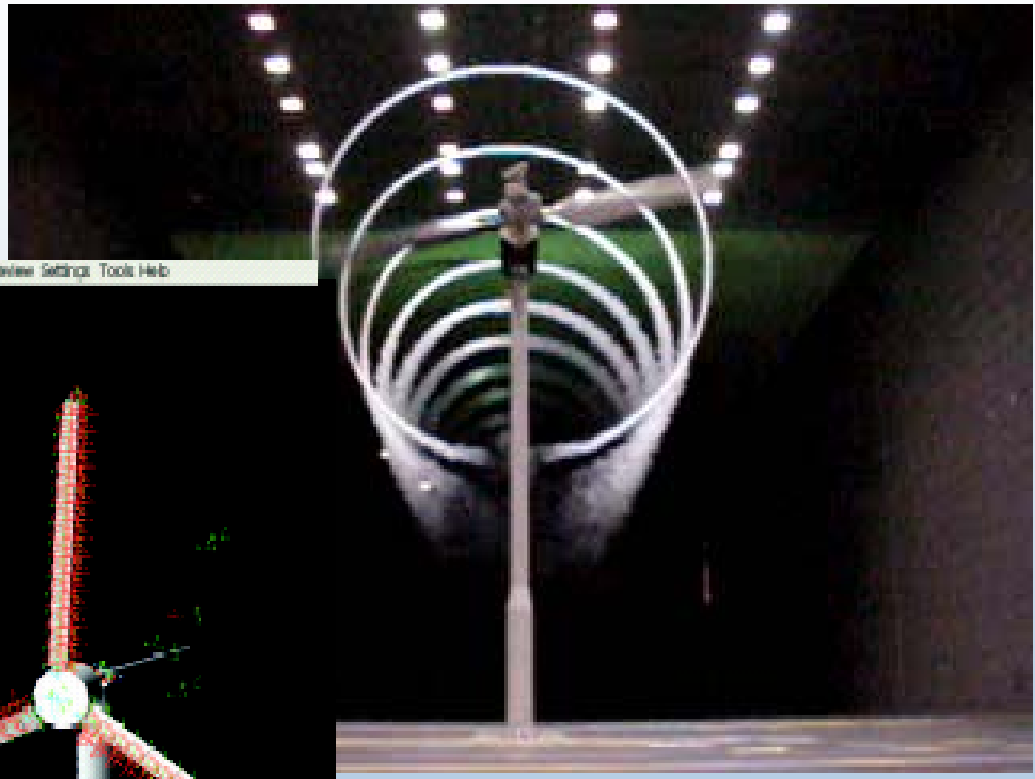
α = 30º ; t = 261 ms
Vortex sheds

Measuring and Modeling Dynamic Stall and Unsteady Aerodynamics

NASA Ames 80’ by 120’
Wind Tunnel Test

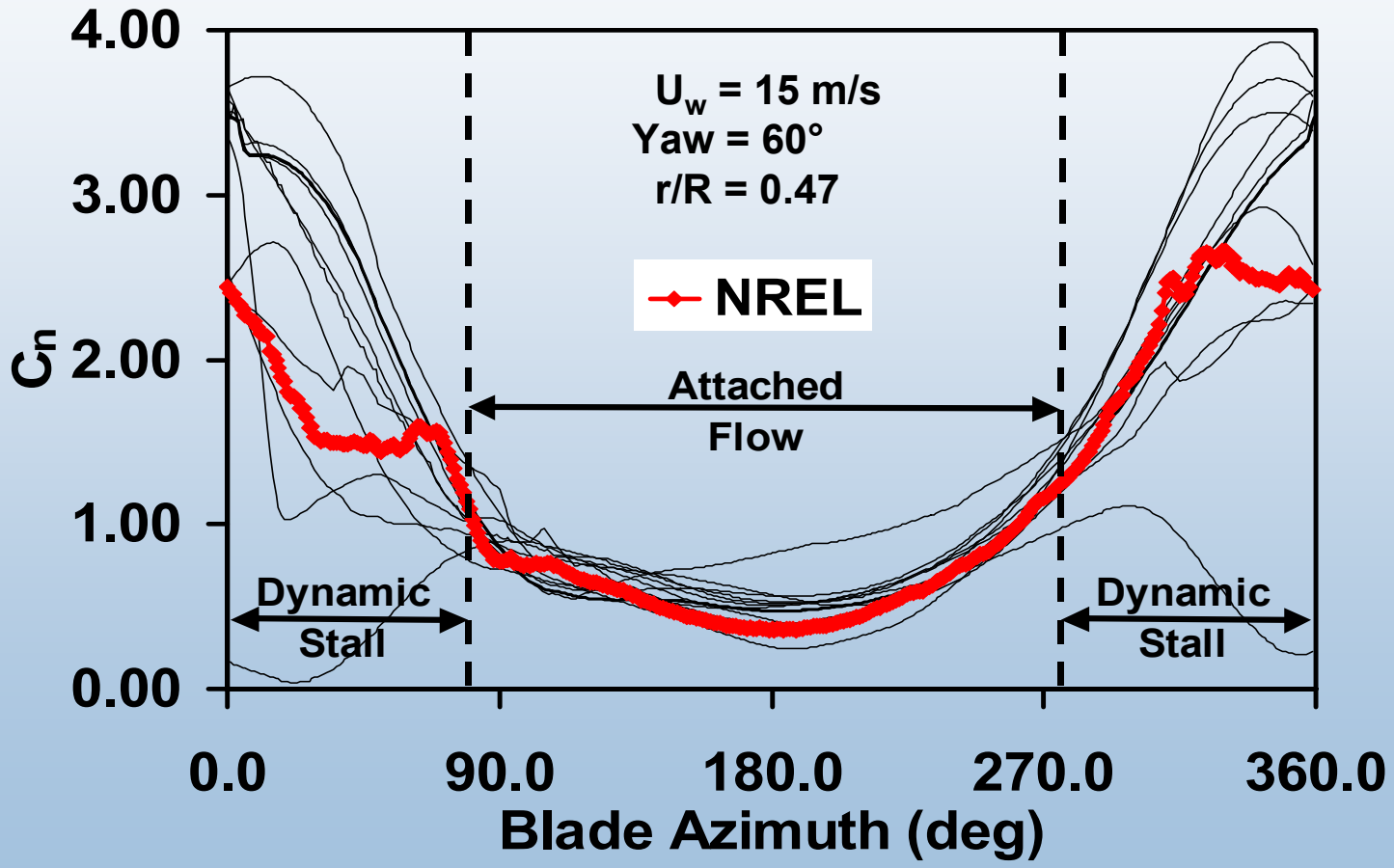


ADAMS Model

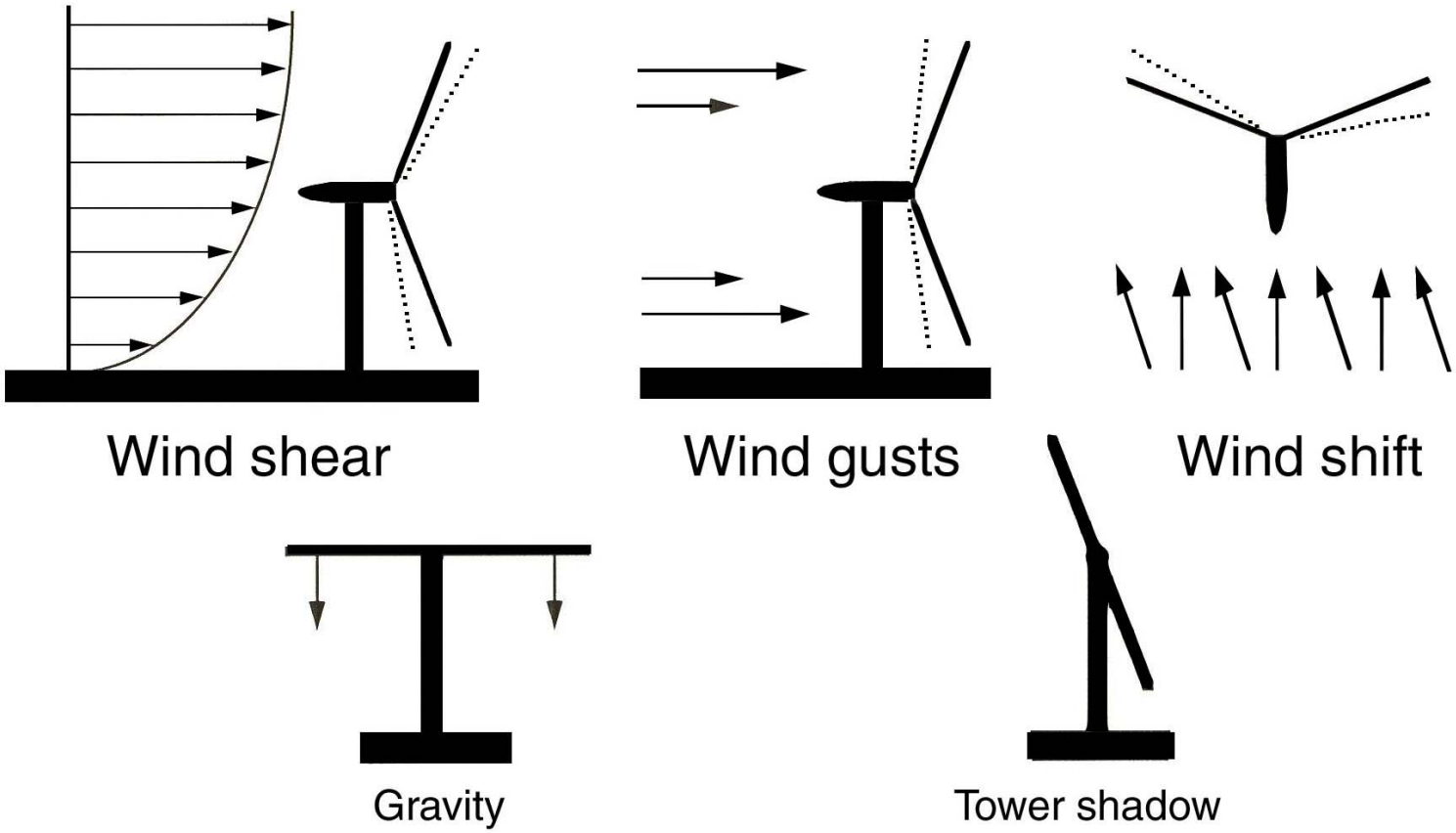


Smoke Test

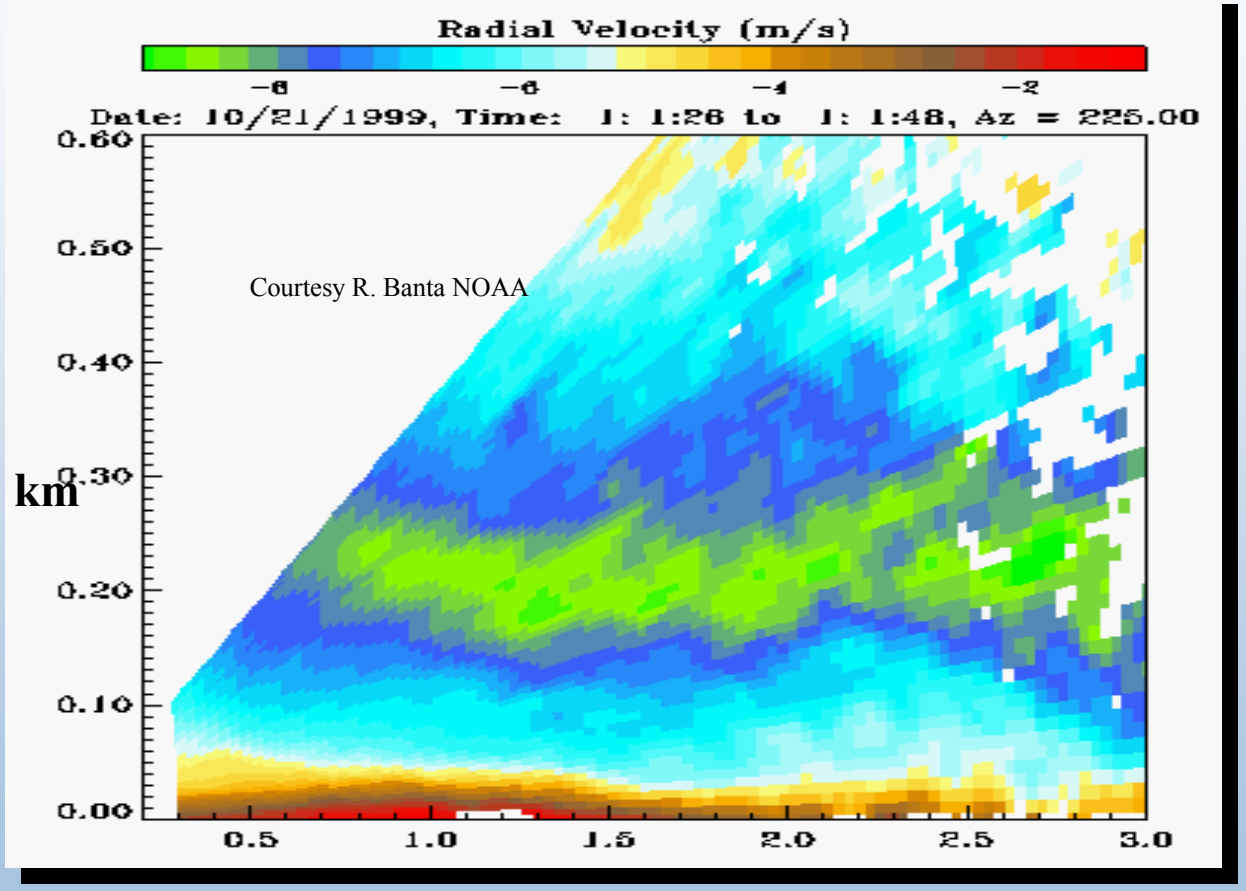
International Blind Comparison Benchmarking



Wind Turbine Load Sources



Measuring and Modeling the Low-Level Nocturnal Jet



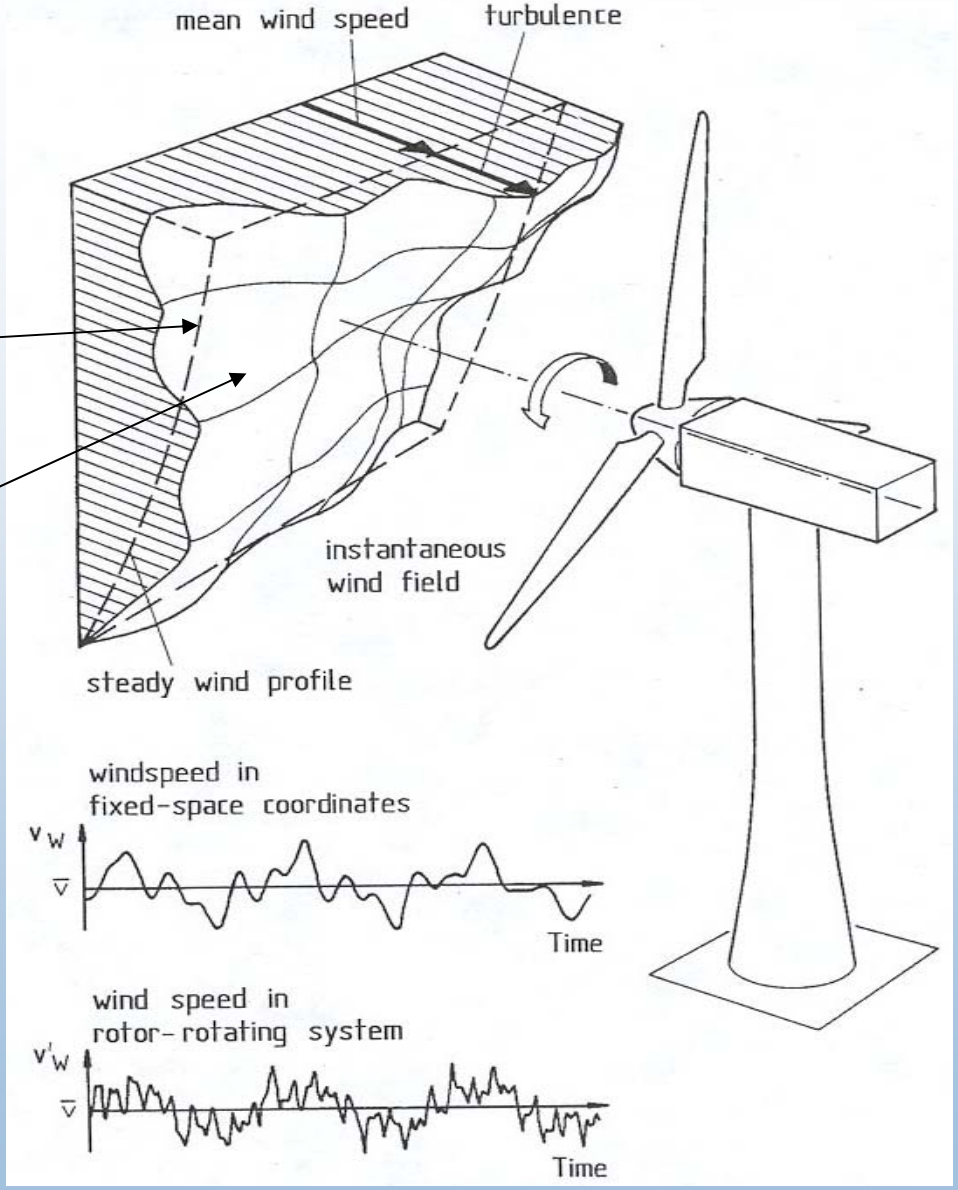
Courtesy R. Banta NOAA

Met tower and SODAR at Lamar, Colorado

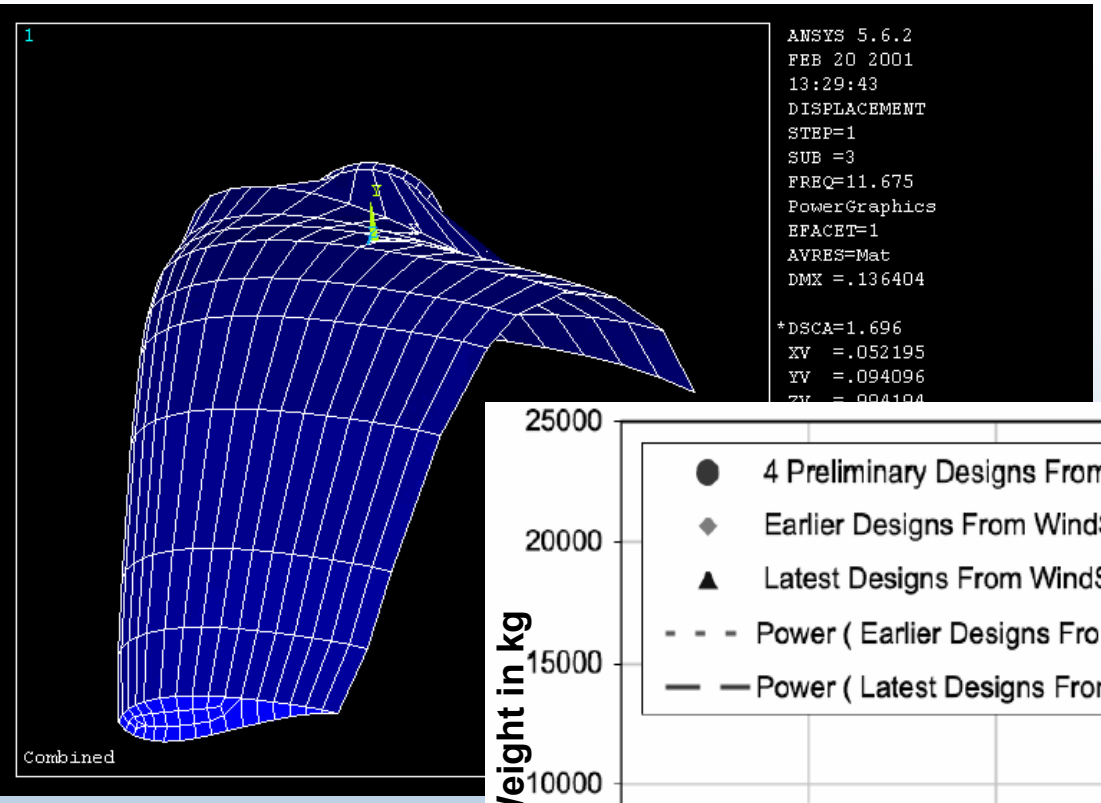
Dynamic Loading Environment

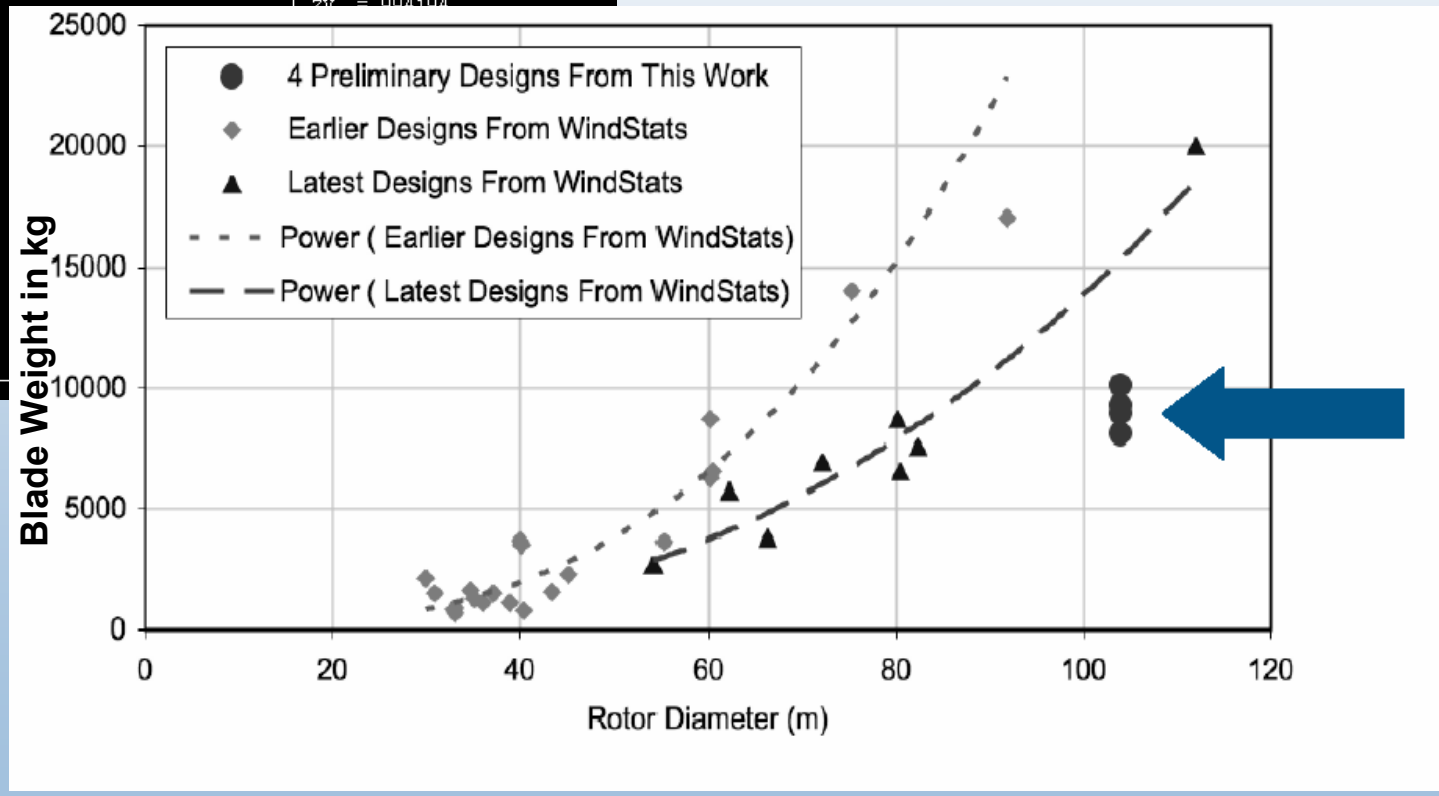
- **Wind field = U (y,z,t)**
- **Steady wind shear superimposed**

Rotational sampling effect increases effective wind fluctuations



Blade Scaling for Multi-megawatt Rotors





Industry's Growing Needs

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

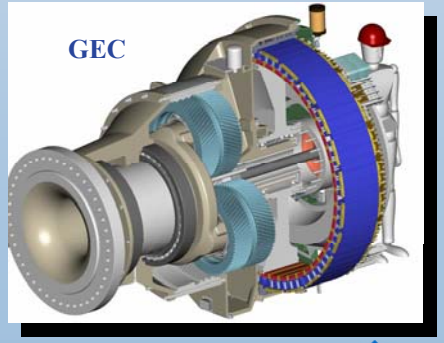
Advanced Drivetrain R&D

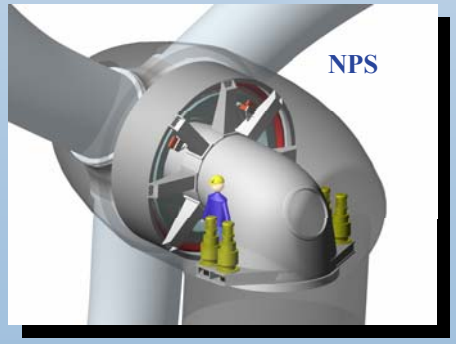
Tomorrow

Prototype Technology

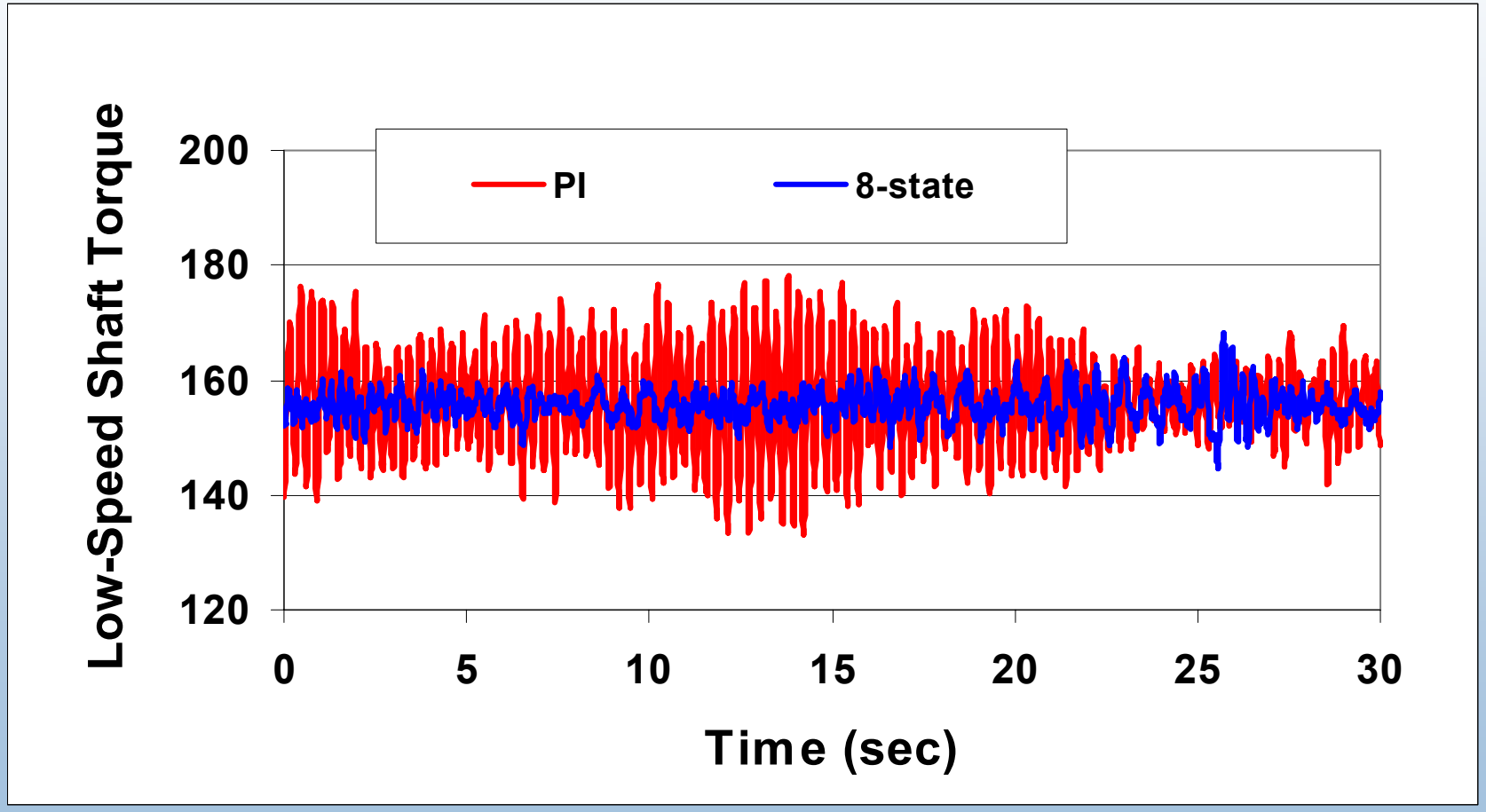
Today

1.5MW Commercial Technology



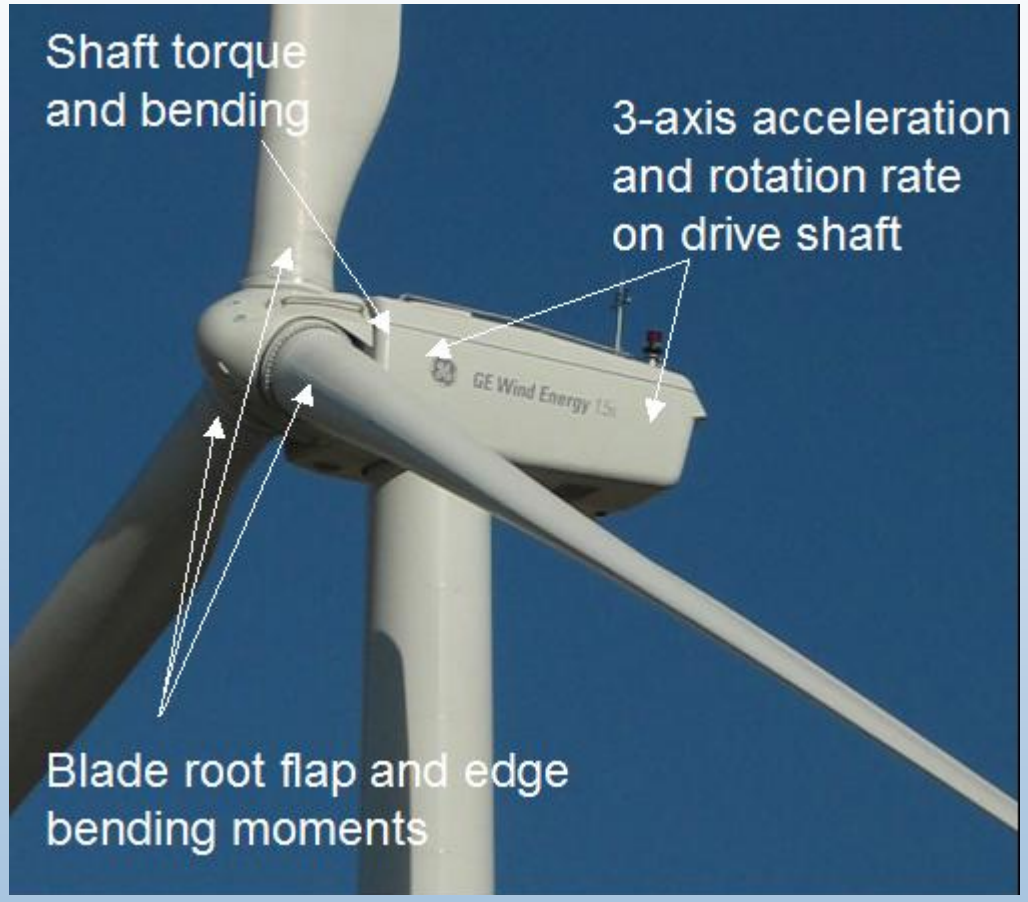


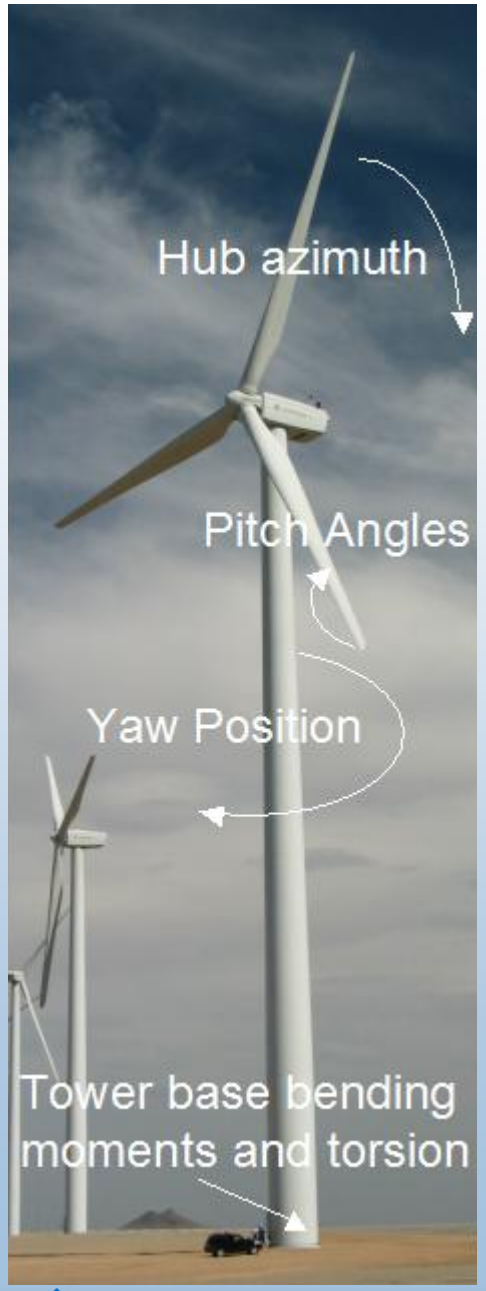
Comparison of Classical (PI) and Advanced Controls (8-state)



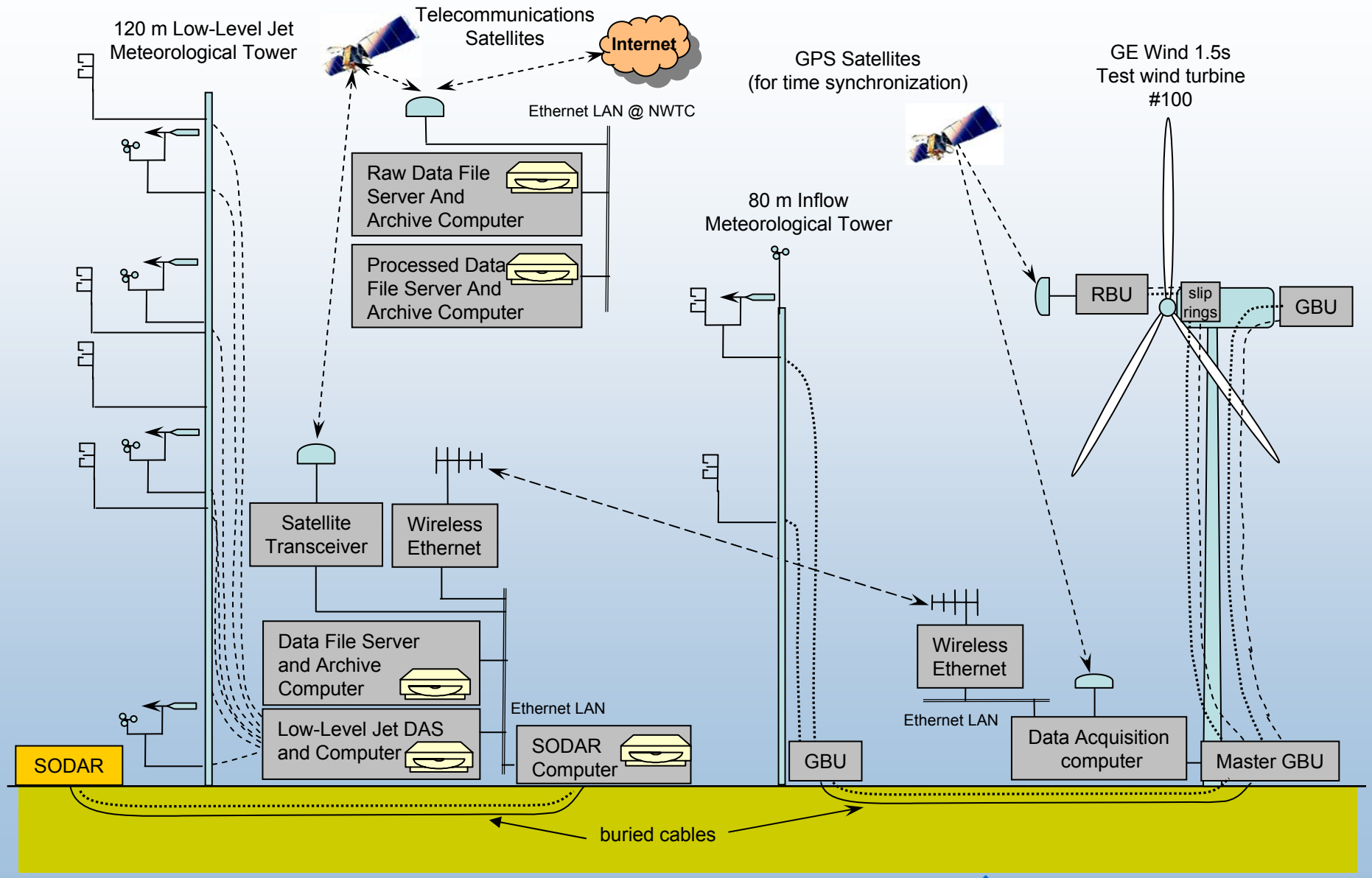
Field Testing of Wind Turbines

Turbine Instrumentation





Data Flow from Lamar, CO to NWTC to SNL and GE Wind for Field Test

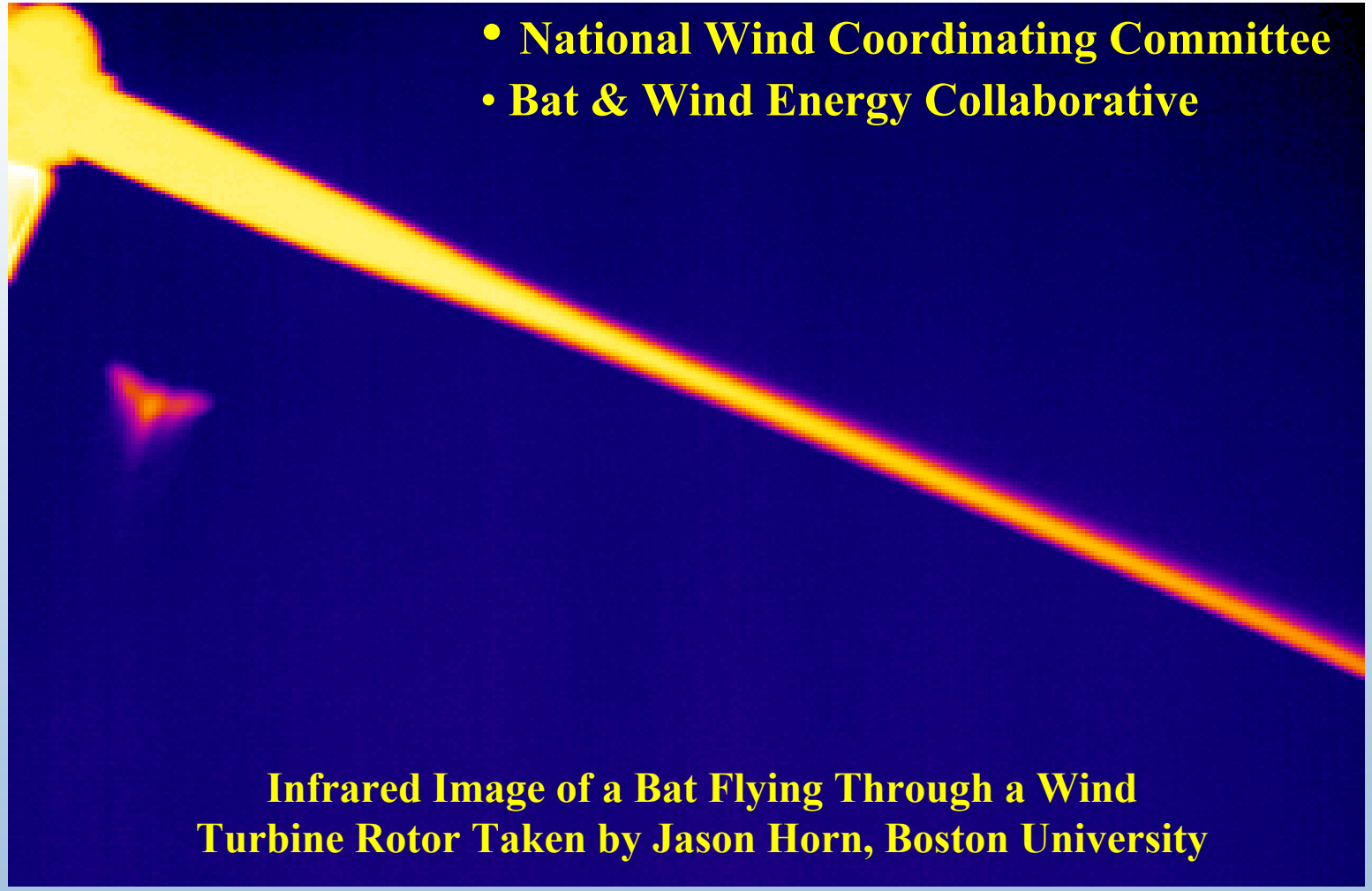


Avian Interactions Research

- Data suggest the most significant avian wind-turbine interaction problem in the U.S. is in the Altamont WRA.
- There is no reason that avian issues should be a concern for future wind farm development; any potential problem should be identified and dealt with before micrositing occurs.
- Two guidance documents have been adopted by the NWCC: (1) *Permitting of Wind Energy Facilities,* and (2) *Metrics and Methods for Avian Studies.* These two documents serve as guidance for siting and development of new wind farms in the U.S.
- Facilities developed following these guidelines have not experienced significant avian impact issues.

NREL Avian Library Available at: www.nrel.gov/wind/avian_lit.html

Collaborative Wildlife Research



Infrared Image of a Bat Flying Through a Wind Turbine Rotor Taken by Jason Horn, Boston University

Offshore Wind – U.S. Rationale

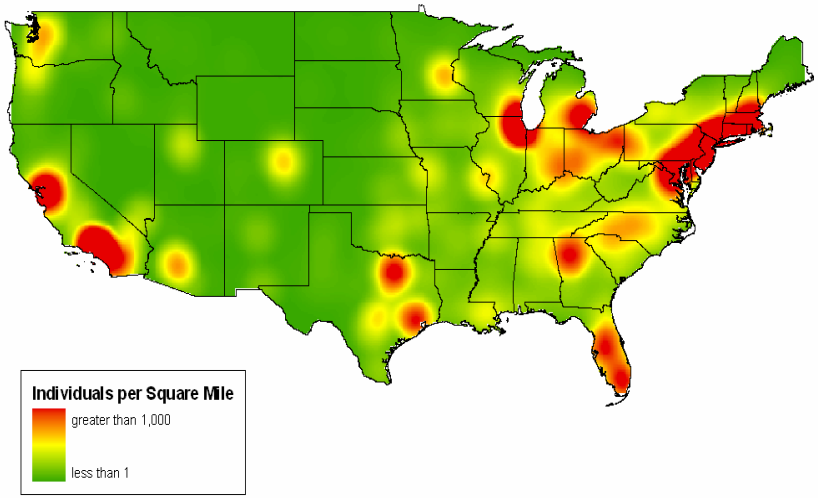
Why Go Offshore?

Windy onshore sites are not close to coastal load centers

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

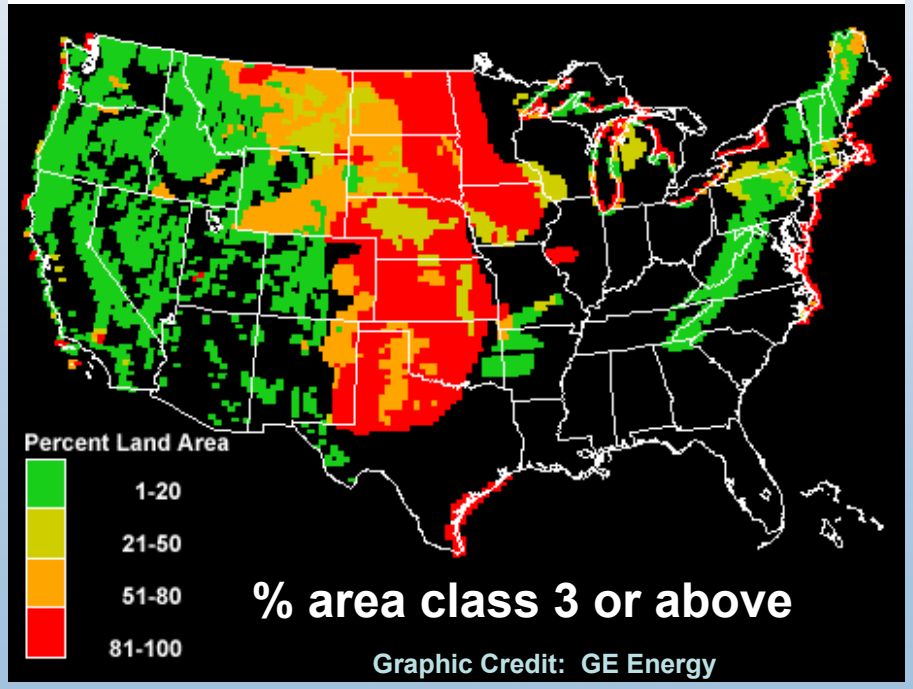
Load centers are close to the offshore wind sites

US Population Concentration



Graphic Credit: Bruce Bailey AWS Truewind

US Wind Resource



Graphic Credit: GE Energy

U.S. Offshore Wind Energy Resource

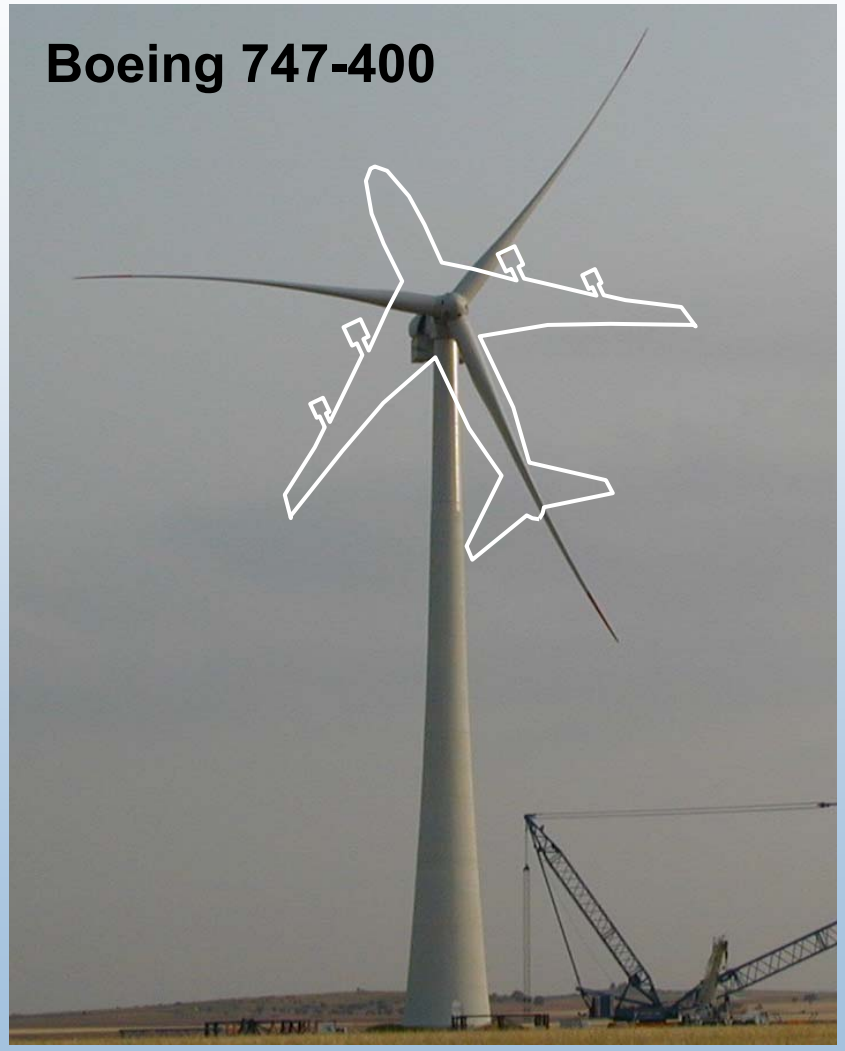
	GW by Depth (m)			
Region	0 - 30	30 - 60	60 - 900	> 900
New England	10.3	43.5	130.6	0.0
Mid-Atlantic	64.3	126.2	45.3	30.0
Great Lakes	15.5	11.6	193.6	0.0
California	0.0	0.3	47.8	168.0
Pacific Northwest	0.0	1.6	100.4	68.2
Total	90.1	183.2	517.7	266.2

Resource Not Yet Assessed

Offshore GE Wind Energy 3.6 MW Prototype

- Offshore GE 3.6 MW
  104 meter rotor diameter

- Offshore design requirements considered from the outset:
  - Crane system for all components
  - Simplified installation
  - Helicopter platform



Arklow Banks Windfarm
The Irish Sea

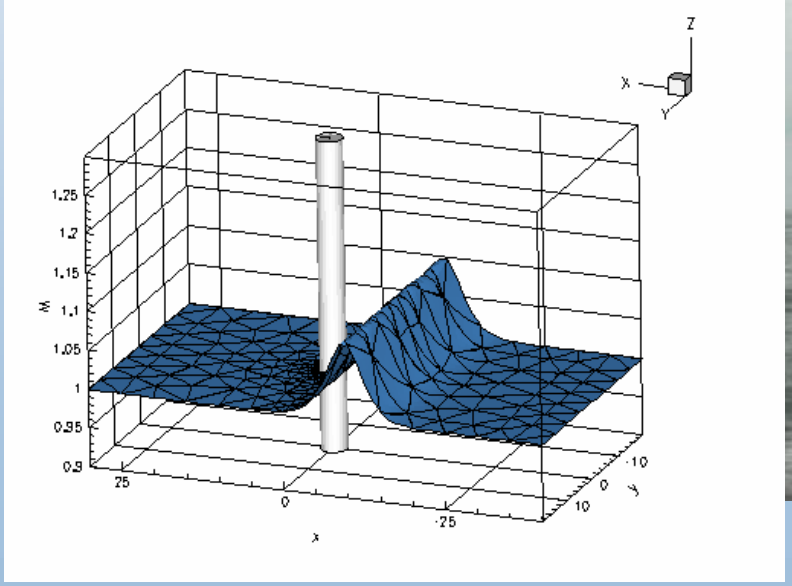


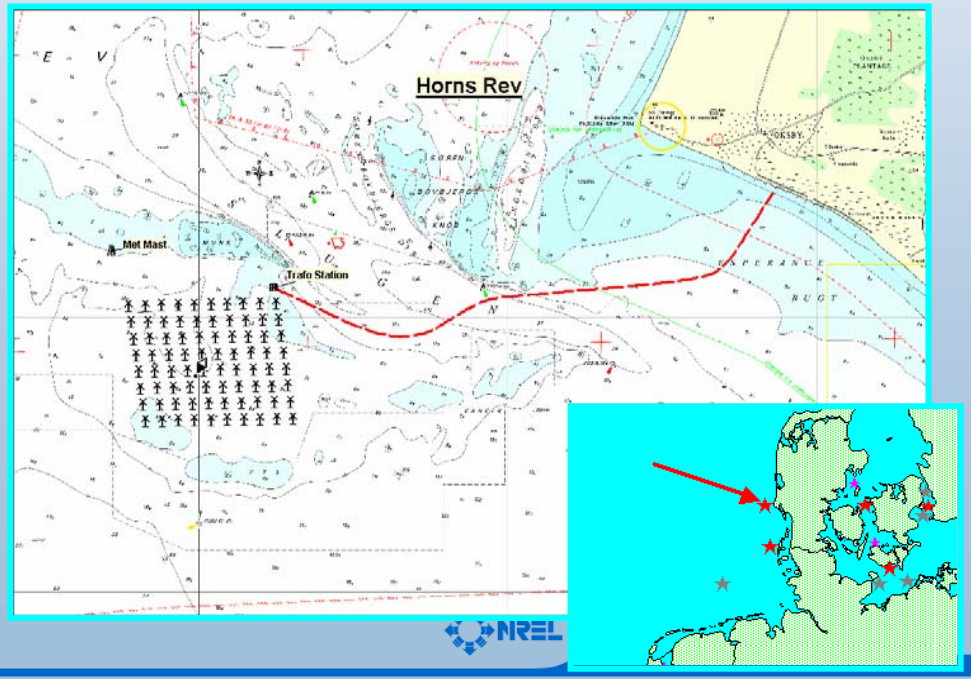
Photo: R. Thresher

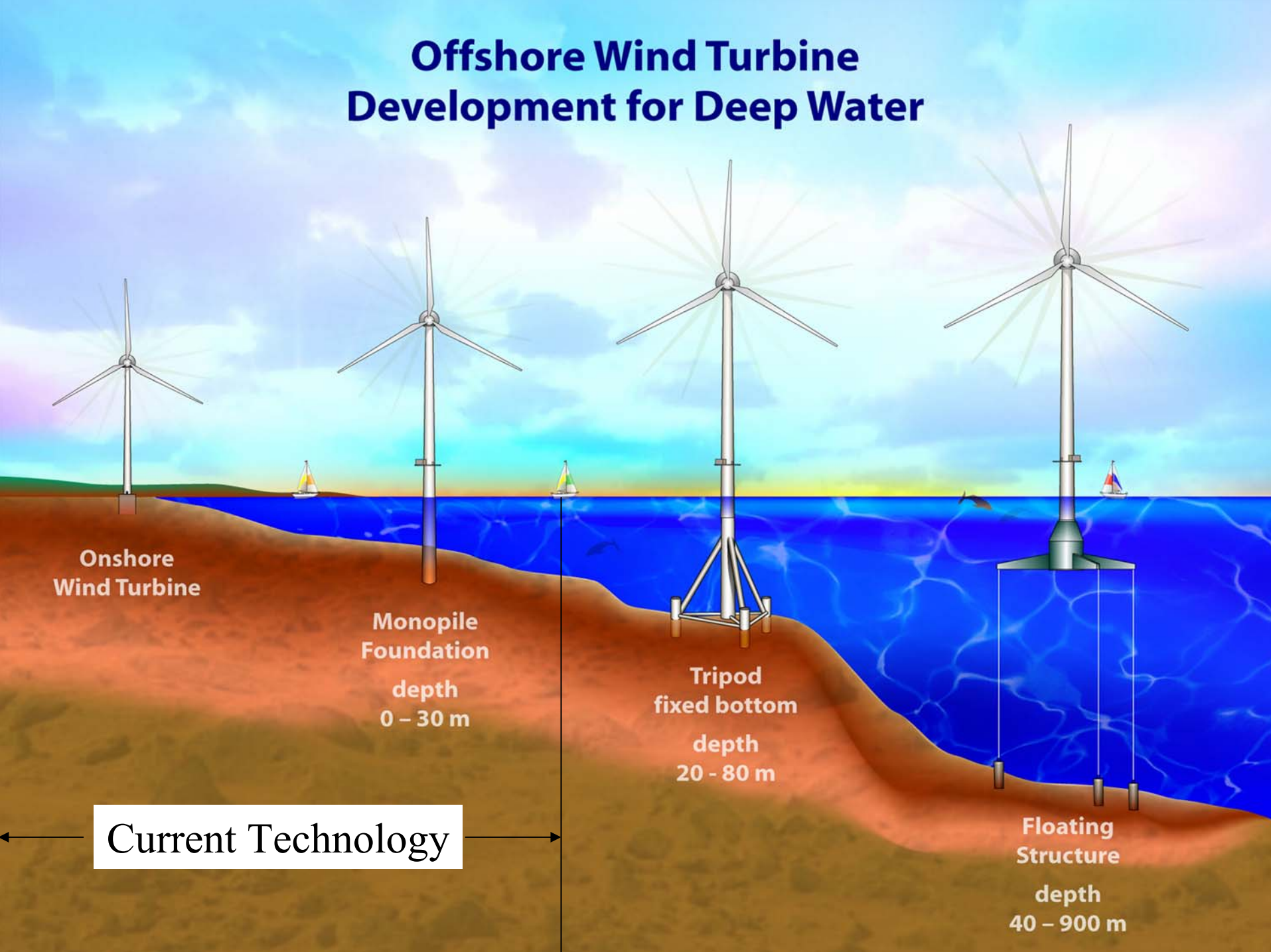
Location of Existing Offshore Installations Worldwide

Source: Wind Directions, September 2004

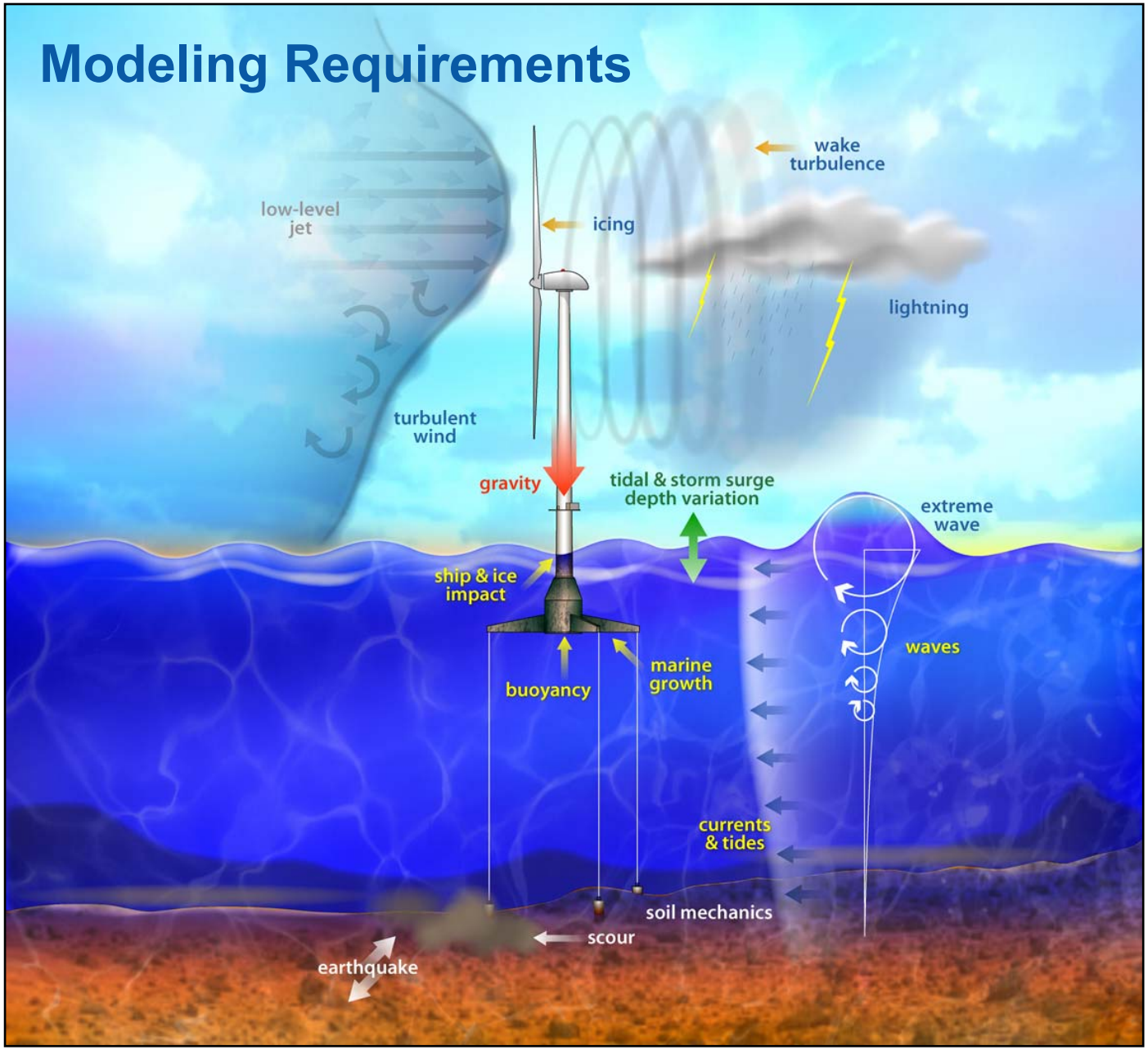
Horns Rev Wind Farm Installation

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

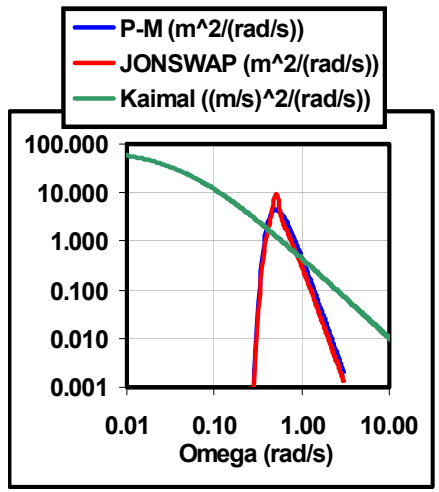



Offshore Wind Turbine
Development for Deep Water
Onshore
Wind Turbine
Monopile
Foundation
depth
0 – 30 m
Tripod
fixed bottom
depth
20 - 80 m
Floating
Structure
depth
40 – 900 m
Current Technology

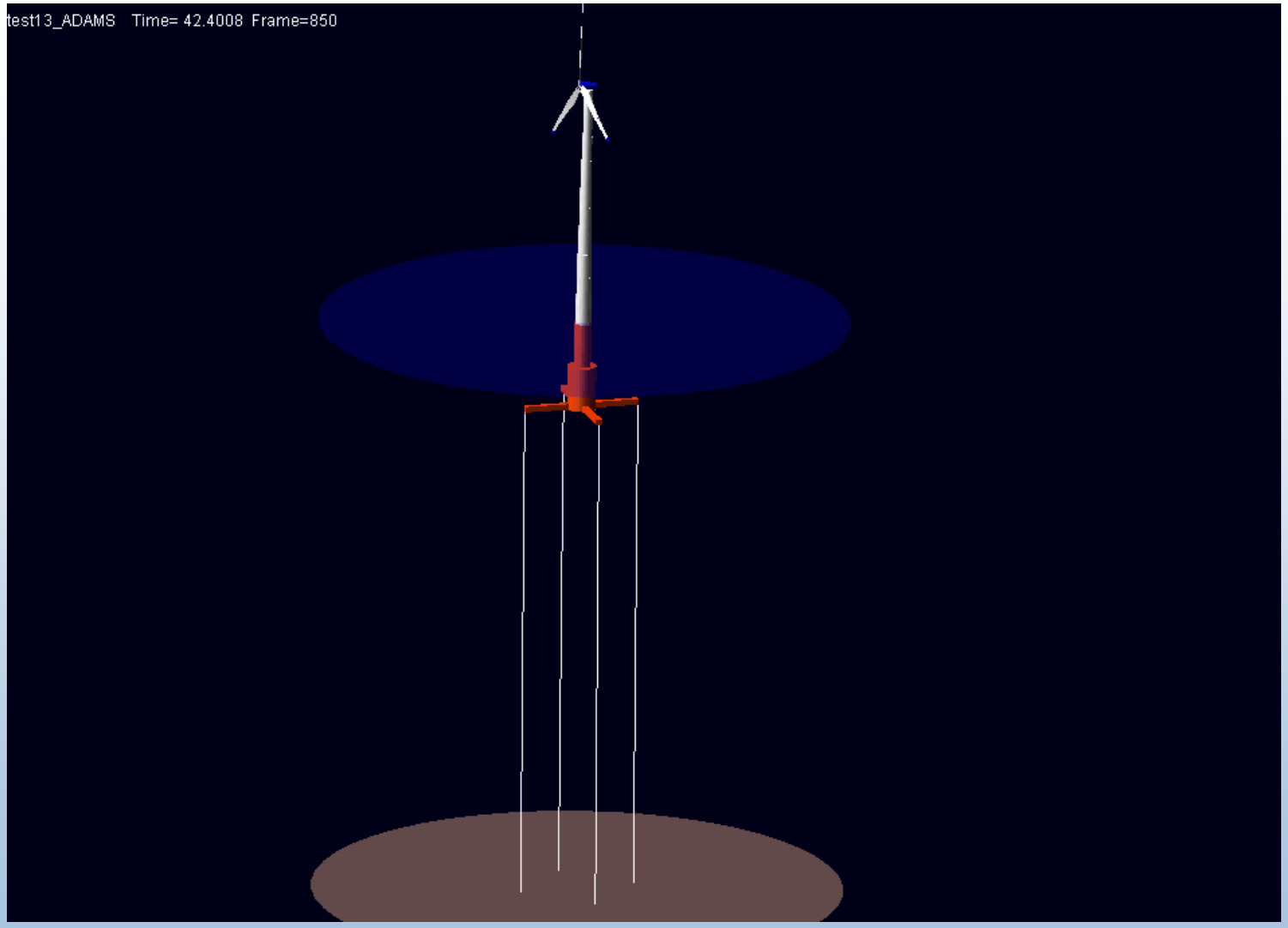
Modeling Requirements



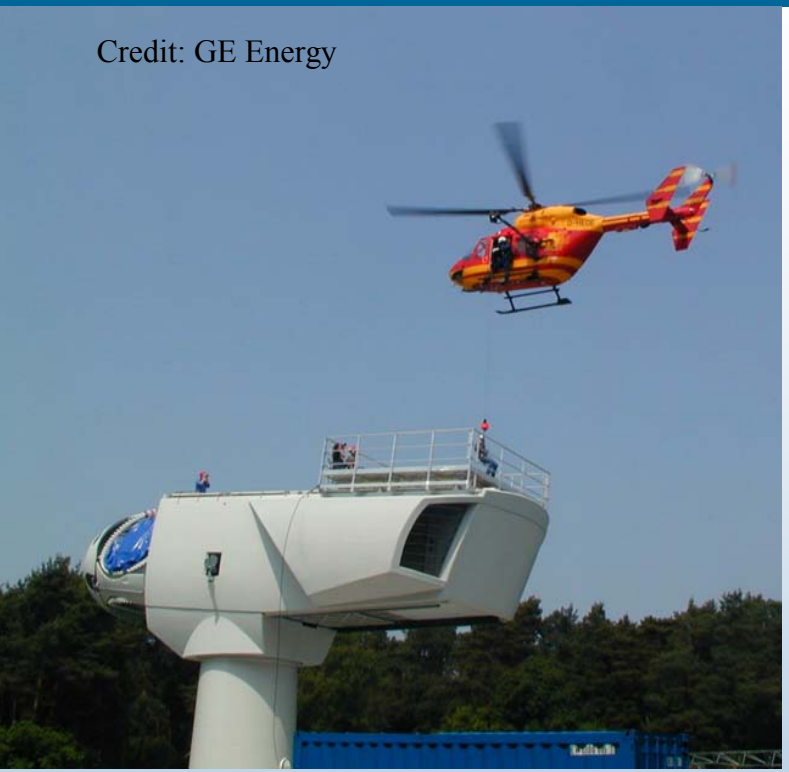
- Turbulent winds
- Irregular waves
- Gravity / inertia
- Aerodynamics:
  - induction
  - skewed wake
  - dynamic stall
- Hydrodynamics:
  - scattering
  - radiation
  - hydrostatics
- Elasticity
- Mooring dynamics
- Control system
- Fully coupled

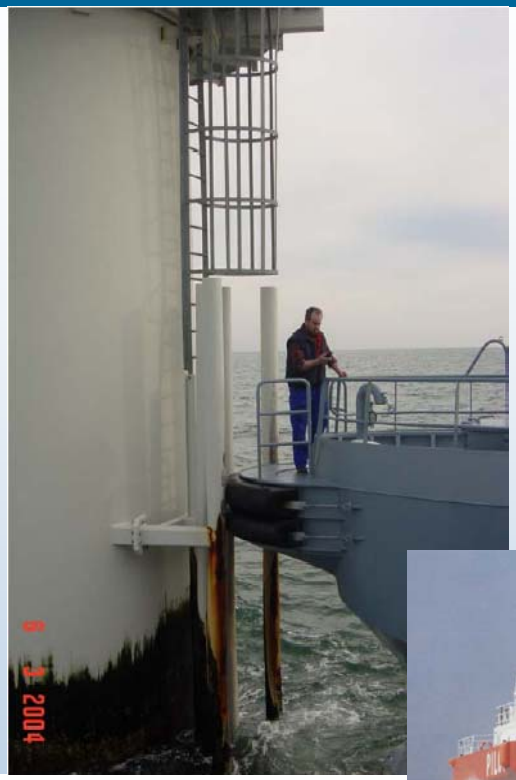


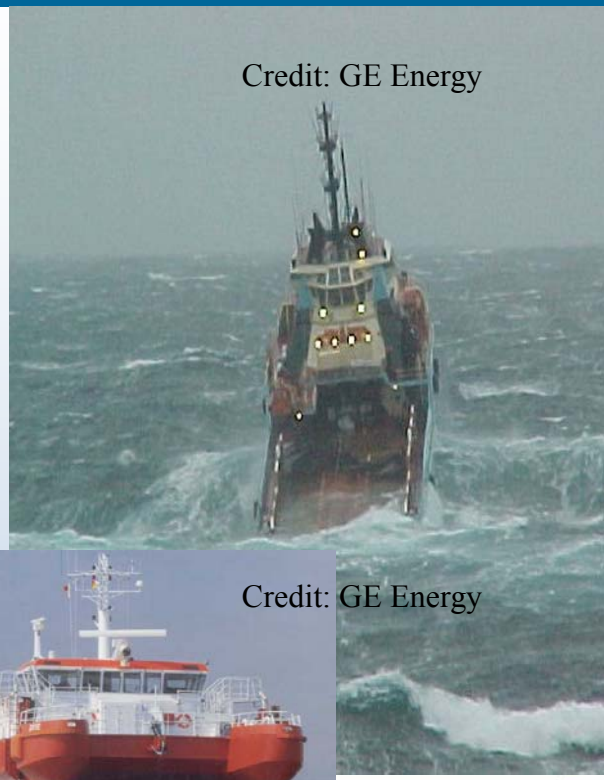
Wind and Wave Spectra


test13_ADAMS Time= 42.4008 Frame=850

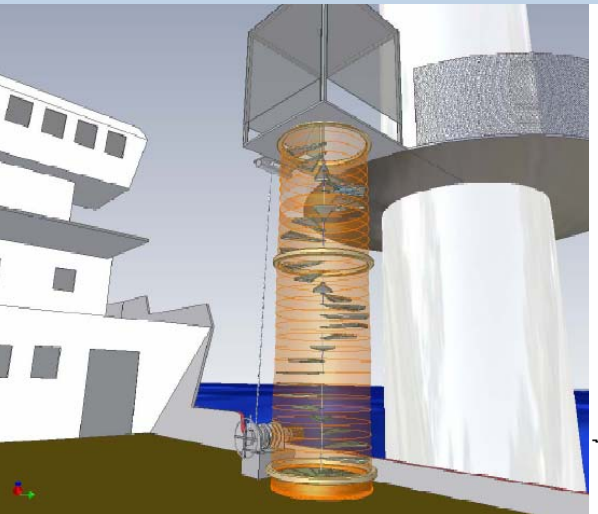
Offshore Turbine Access

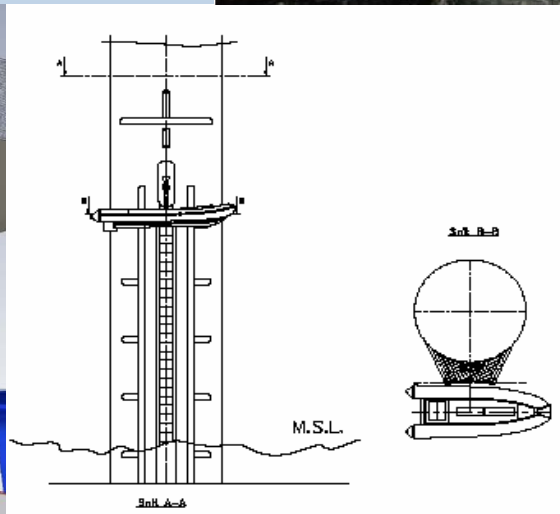

Credit: GE Energy

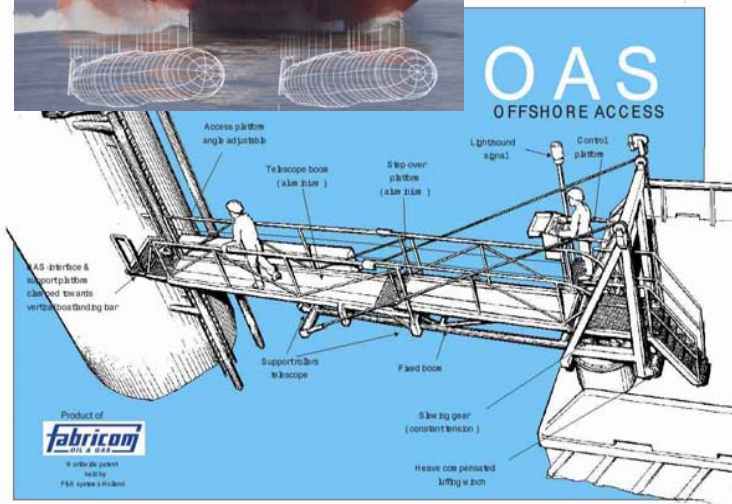



Credit: GE Energy

Credit: GE Energy







A Future Vision for Wind Energy Markets

Today 2006

Bulk Power Generator
5-8¢ at 13mph
With No PTC

- Land Based
- Bulk Electricity
- Wind Farms

Less than 1% of Electricity Market

Tomorrow

Land Based Electricity Path

Land Based LWST Large-Scale 2–5 MW

Transmission Barriers

LWST Turbines:
- 3.6¢/kWh at 13mph
- Electricity Market

2012

Offshore Electricity Path

Offshore Turbines 5 MW and Larger

Cost & Regulatory Barriers

Offshore LWST Turbine:
- 5 cents/kWh
- Shallow/***Deep*** *water*
- Electricity Market
- Higher wind Sites

2014 and Beyond

Advanced Applications Path

- **Hydrogen**
- **Clean Water**
- **Plug Hybrids**

Cost & Infrastructure Barriers

Custom Turbines for Multi-markets:
- Electricity
- H2 production
- Desalinate water
- Transport & Storage

2020 and Beyond