Short Course

Renewable Energy Integration

Overview: Wind Energy

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company,
for the United States Department of Energy's National Nuclear Security Administration
under contract DE-AC04-94AL85000.

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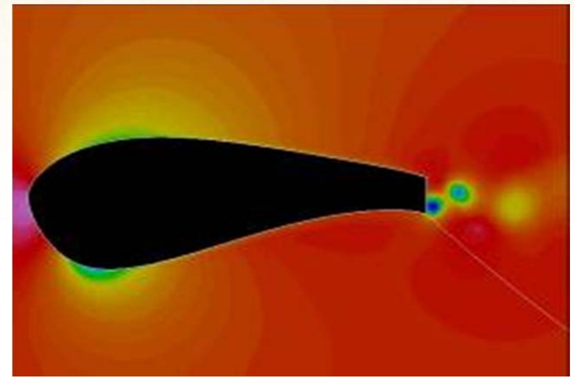
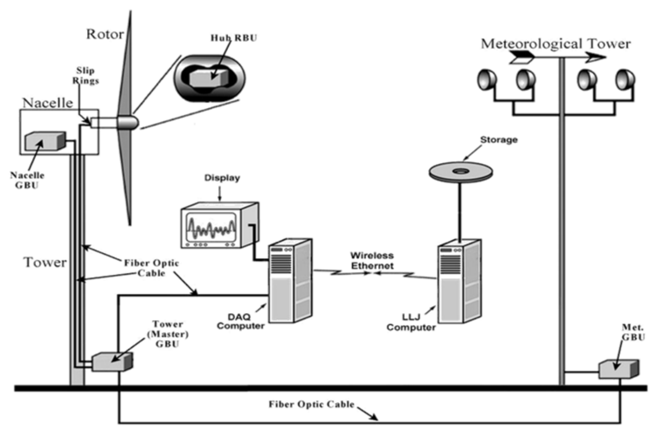
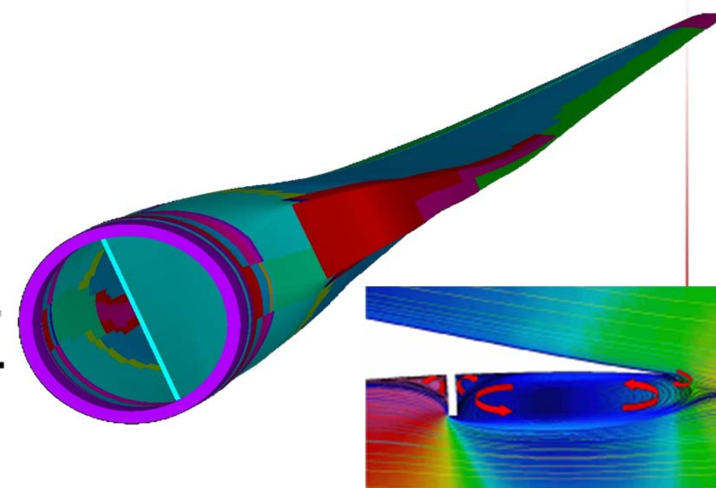
SNL's Wind Energy Program

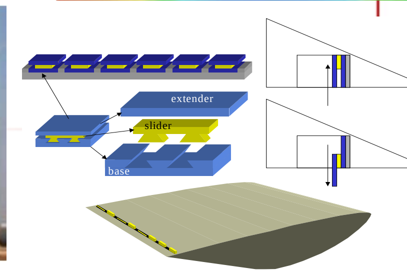
- **Blade Technology**
  - Materials and Manufacturing
  - Structural, Aerodynamic, and Full System Modeling
  - Sensors and Structural Health Monitoring
  - Advanced Blade Concepts
  - Lab - Field Testing and Data Acquisition
- **System Reliability**
  - Industry Data Collection
  - Improve reliability of the existing technology and future designs
- **System Integration & Outreach**
  - Wind/RADAR Interaction
  - DOE/Wind M&O









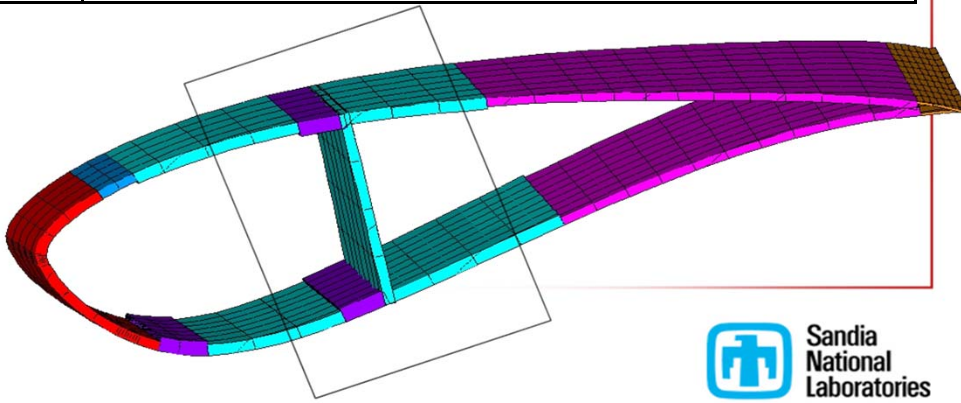
Department Background & Accomplishments

- **Established in Mid 1970's**
  - Primary focus VAWT's
  - Industry partnerships
- **Transitioned to Blades in early 1990's**
- **15 Full-Time Employees**
- **Several Contractors and Students**

1975	SNL Wind Program Established
1977	17m VAWT Fabricated
1981	1st Wind-Turbine Specific Airfoils
1982	FloWind Technology Transfer
1984	34m VAWT Test Bed
1988	SNL/MSU Material Dbase Established
1994	SNL Blade Program Started
1998	Blade Manufacturing Initiative
2003	Incorporation of Carbon on Blades
2005	K&C Swept Blade Contract
2006	Reliability Program Started
2007	RSI Program Started

Mission:

To provide a knowledge base expertise in the design and advancements of composite wind turbine blades and turbine reliability, in order to accelerate the penetration of Wind Energy.



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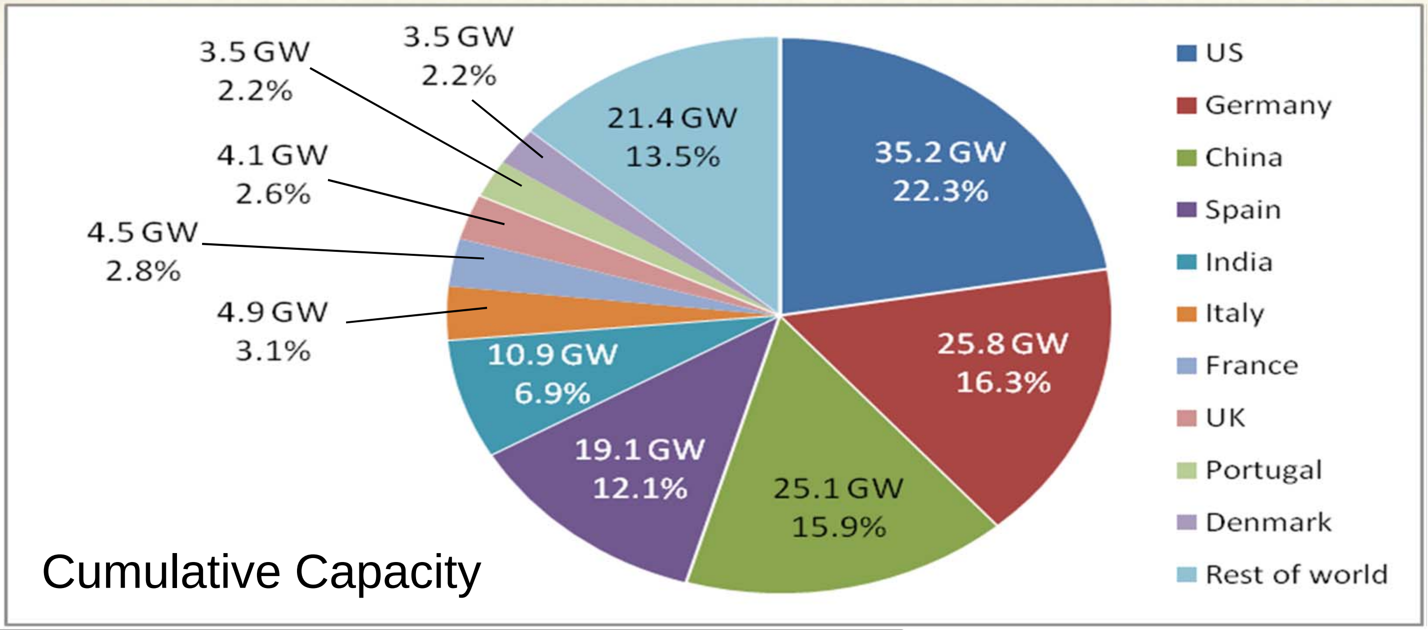
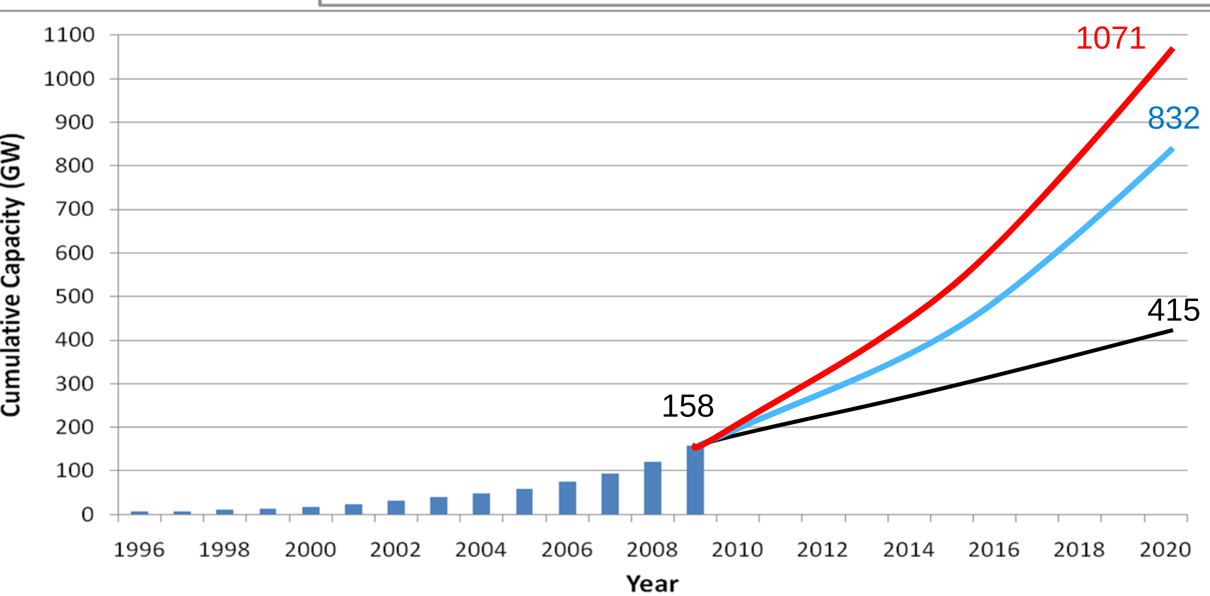
Global Installed Capacity





Advanced: Best wind case scenario for policy and market

Moderate: Supportive policy measures enacted & emissions reductions implemented

Reference: Based on IEA 2009 World Energy Outlook w/existing policies

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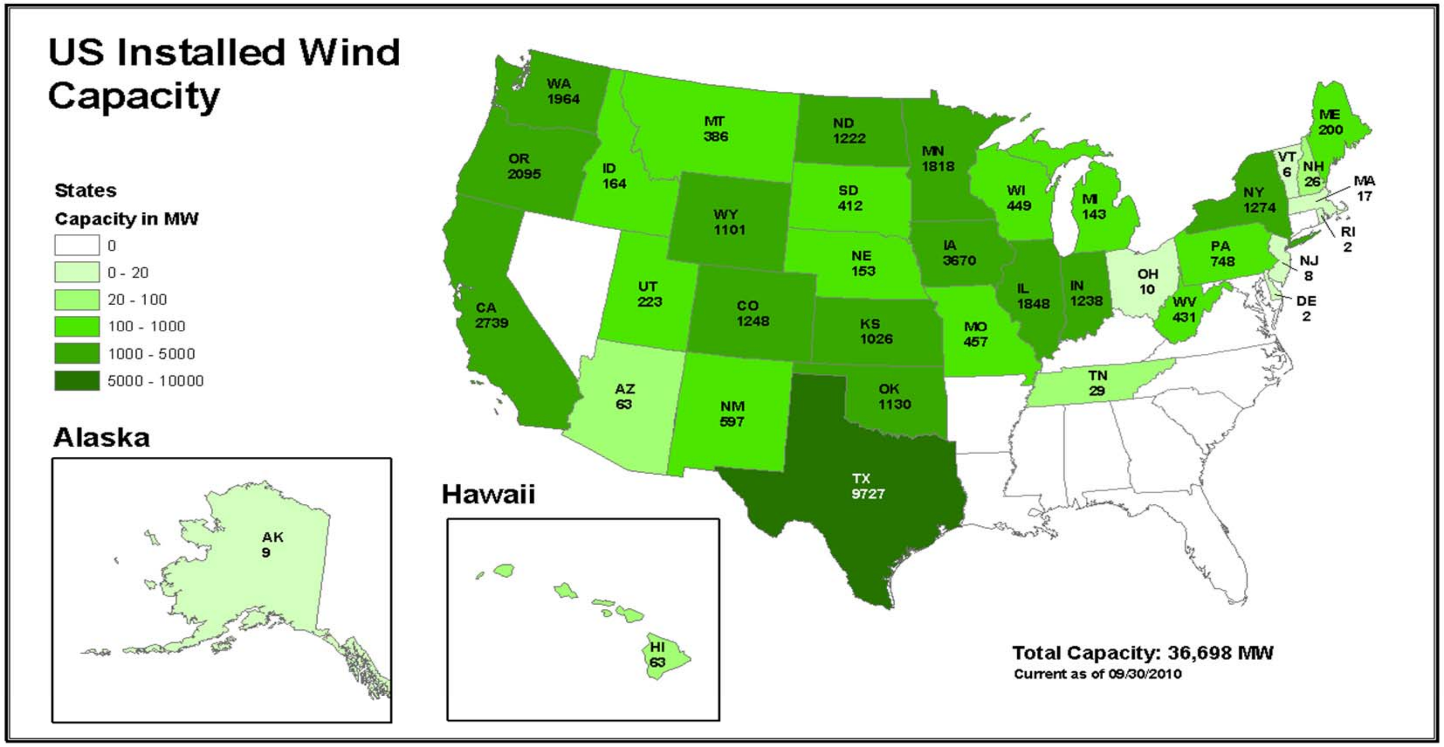
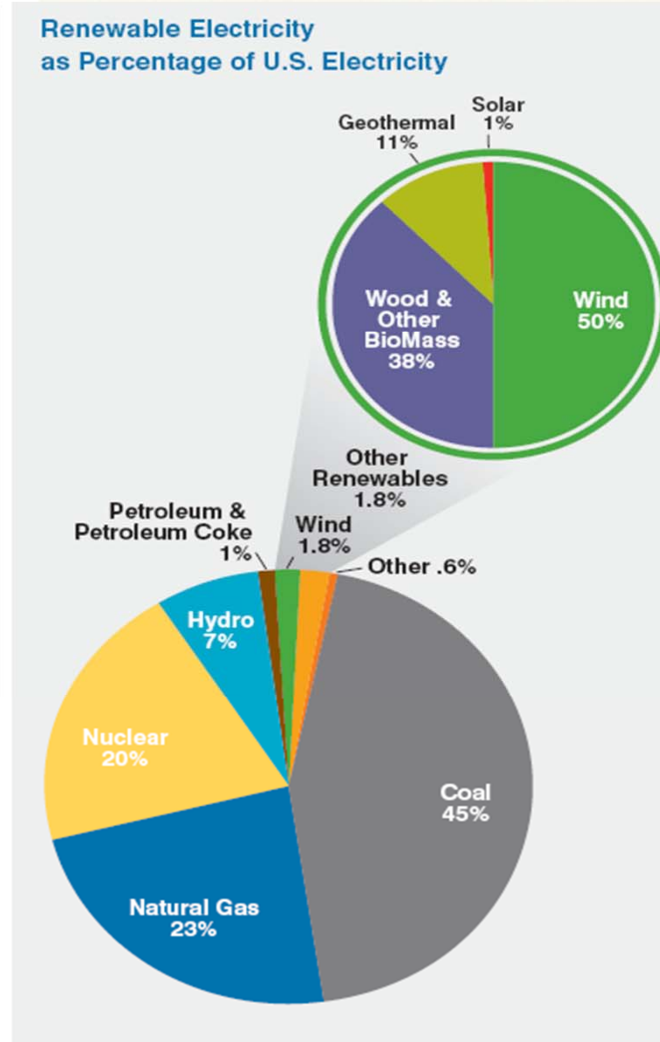
Installed Capacity in the United States





- All renewable energy sources provided 10.5% of the U.S. power mix in 2009;
- Wind generation is approaching the two percent mark of the U.S. power mix, reaching 1.8% of U.S. generation in 2009;
- Hydro generation is approximately 7%. DOE focus and investment in efficiency upgrades and water use optimization.

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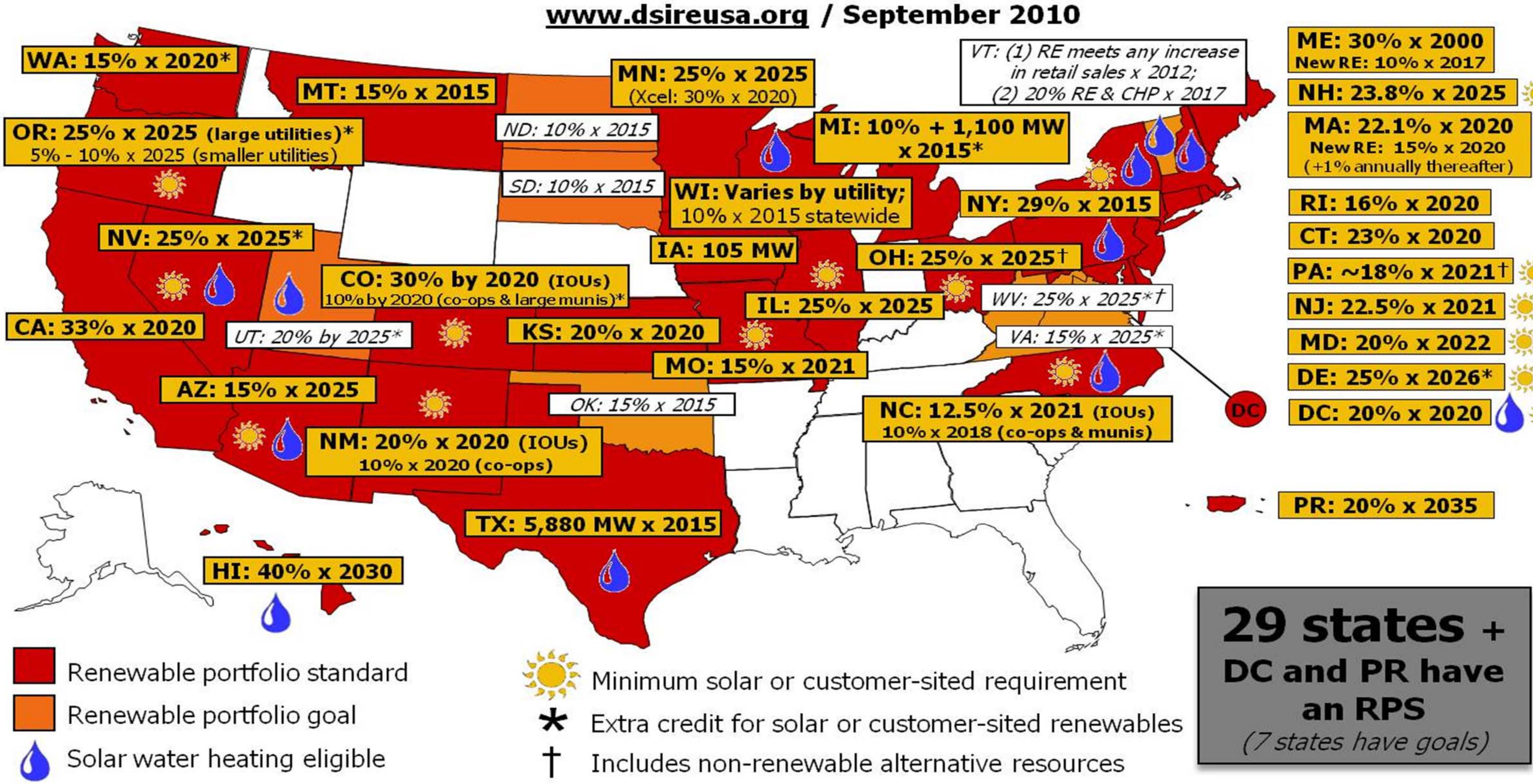
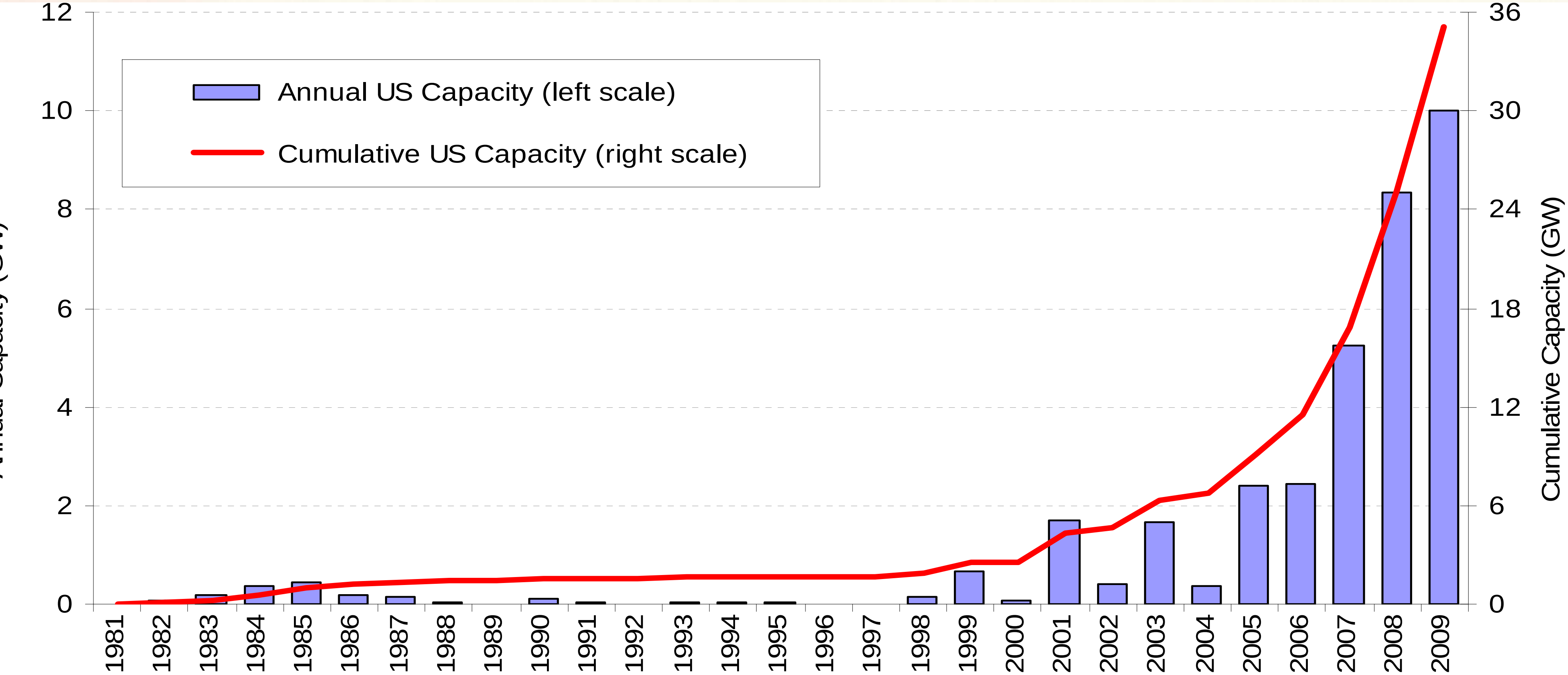
Renewable Portfolio Standards



Laboratories

U.S. Wind Power Capacity Up >40% in 2009



Record year for new U.S. wind power capacity:

- 10 GW of wind power added in 2009, bringing total to ~35 GW
- Nearly $21 billion in 2009 project investment

Source: DOE 2009 Wind Technologies Report

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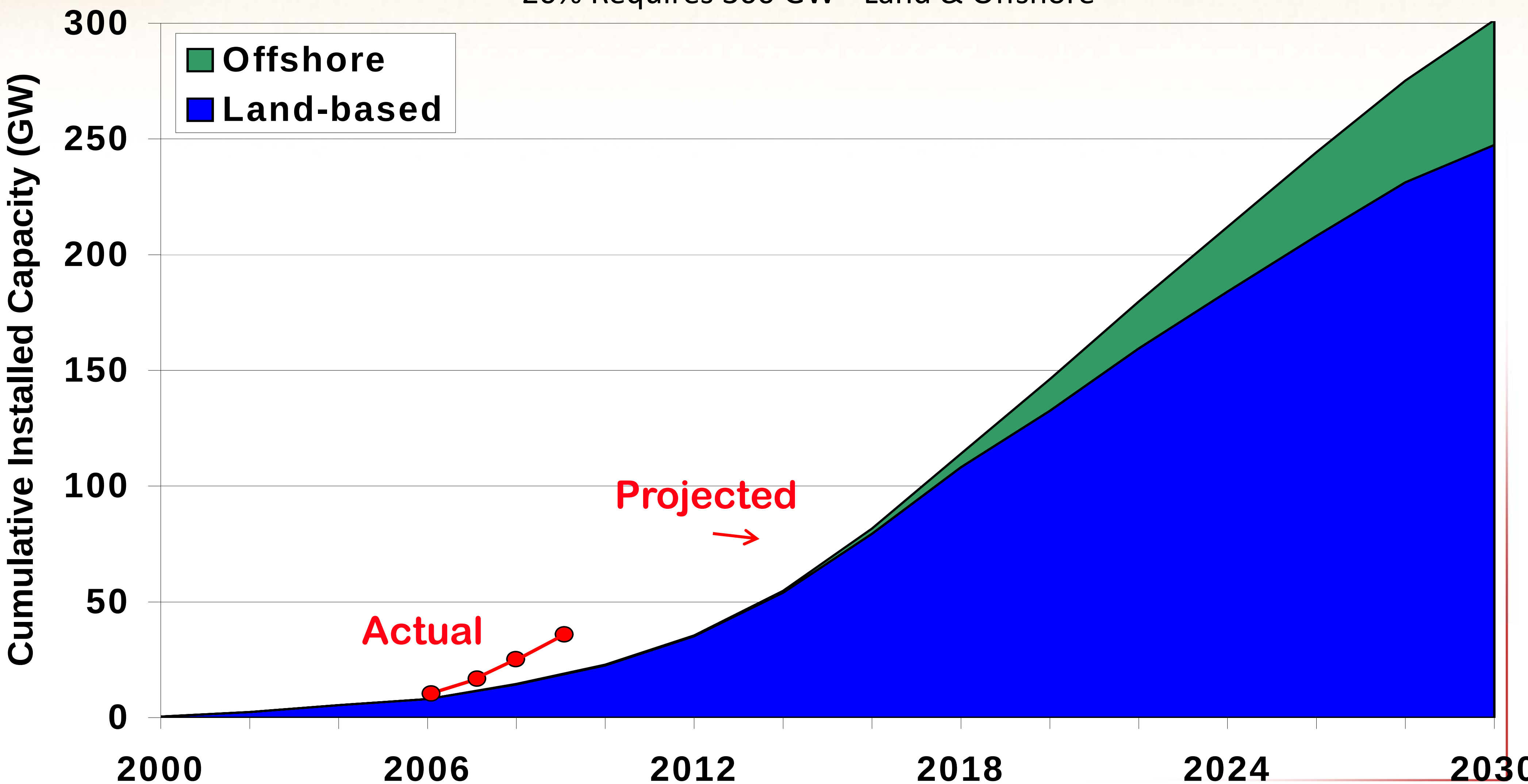
Projected Growth

20% Requires 300 GW - Land & Offshore



Source: DOE 20% Wind Energy by 2020 Report

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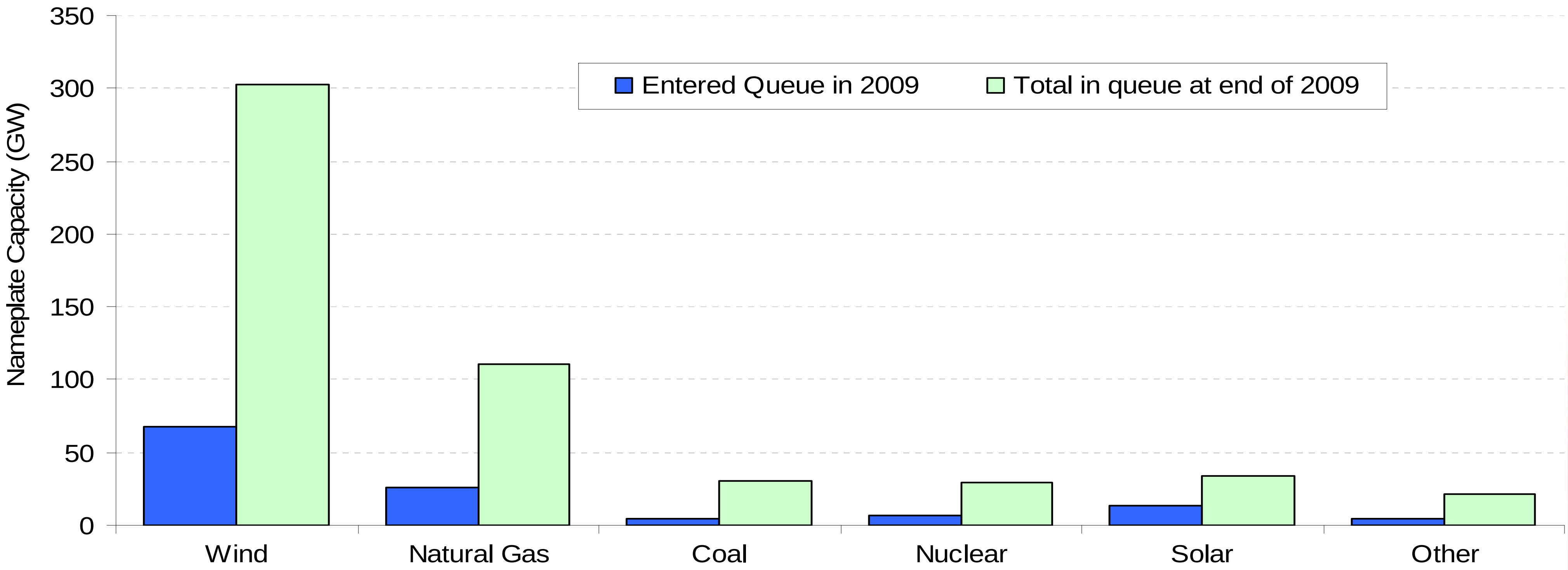
Wind Power Capacity In Queue

- **Roughly 300 GW in Transmission Interconnection Queues.**

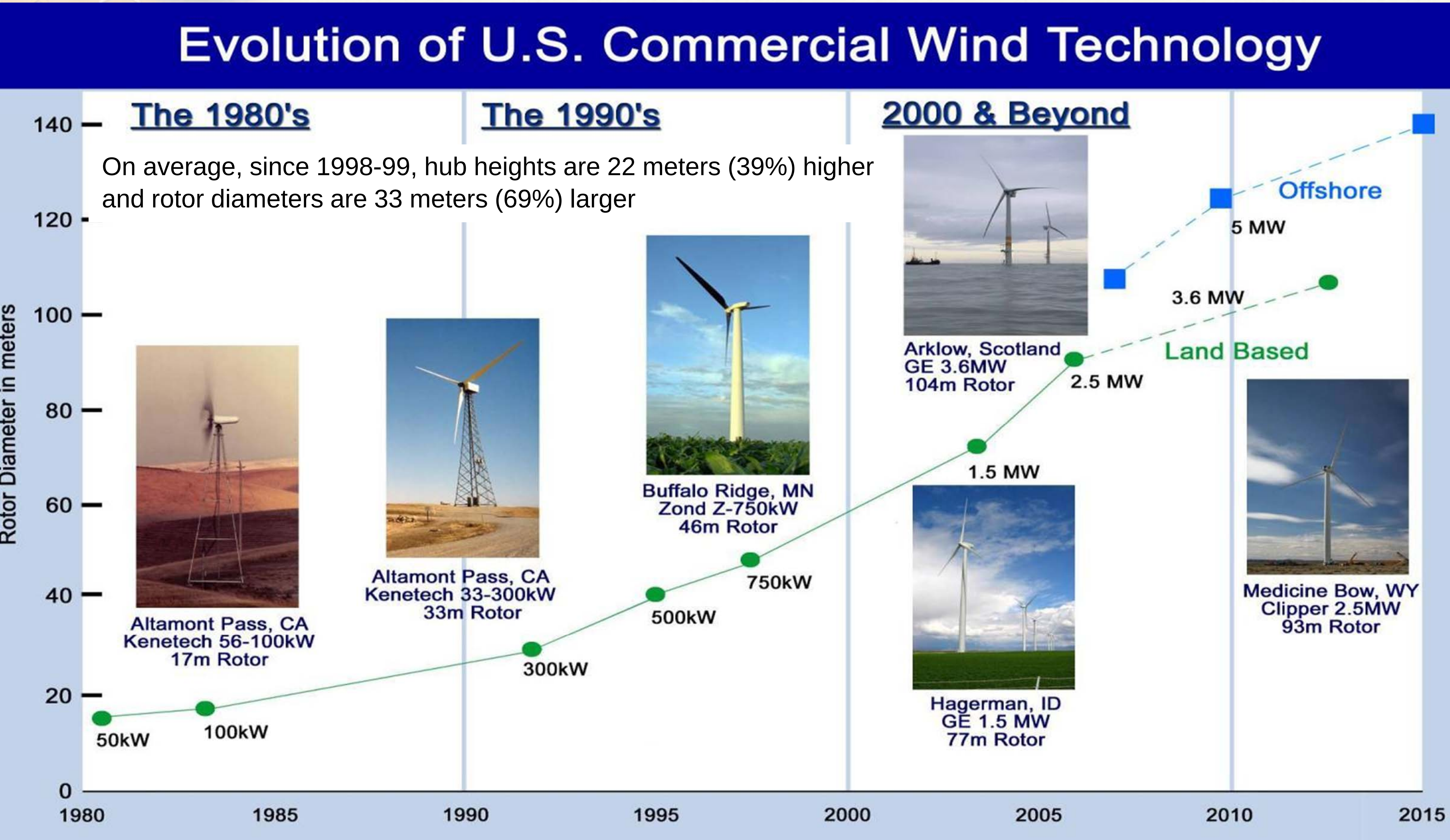


Not all of this capacity will be built….

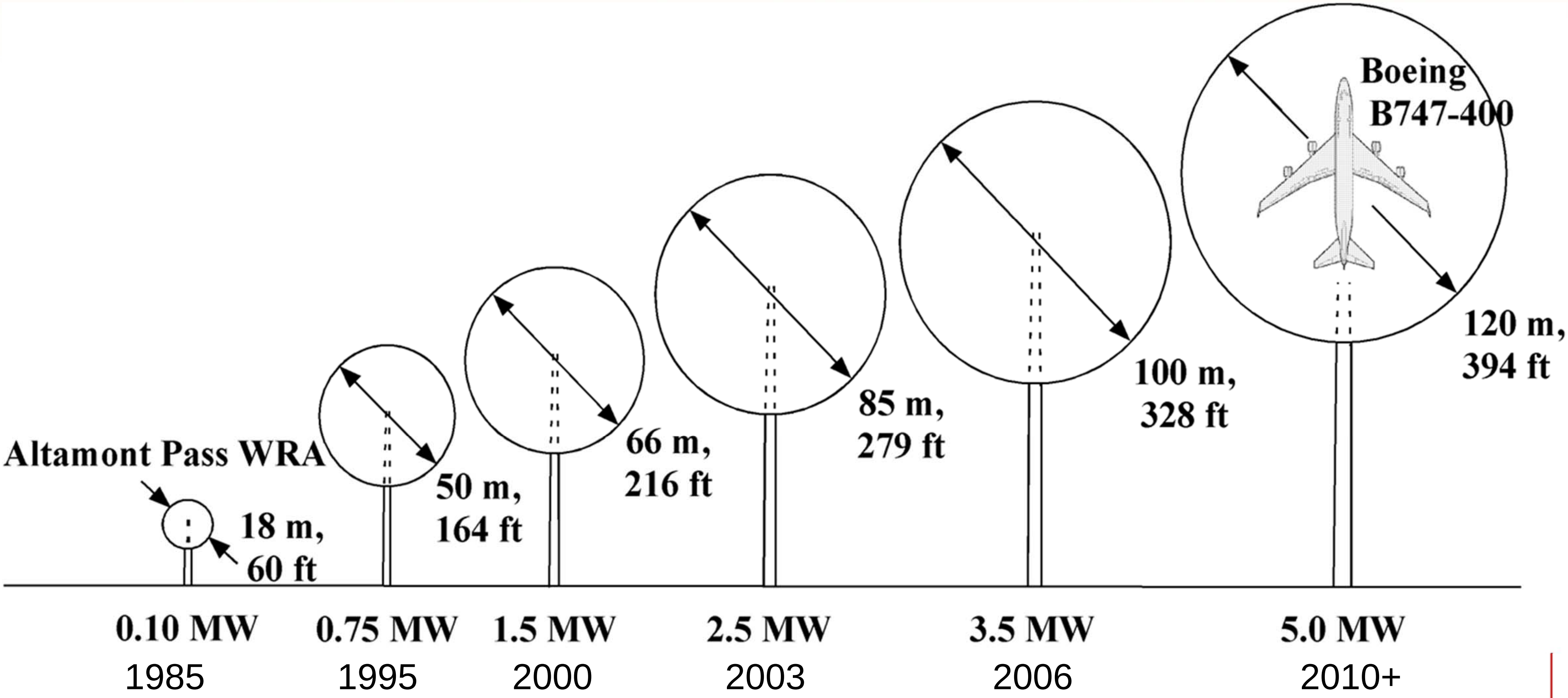
Source: DOE 2009 Wind Technologies Report

Average Hub Heights and Rotor Diameters Have Increased

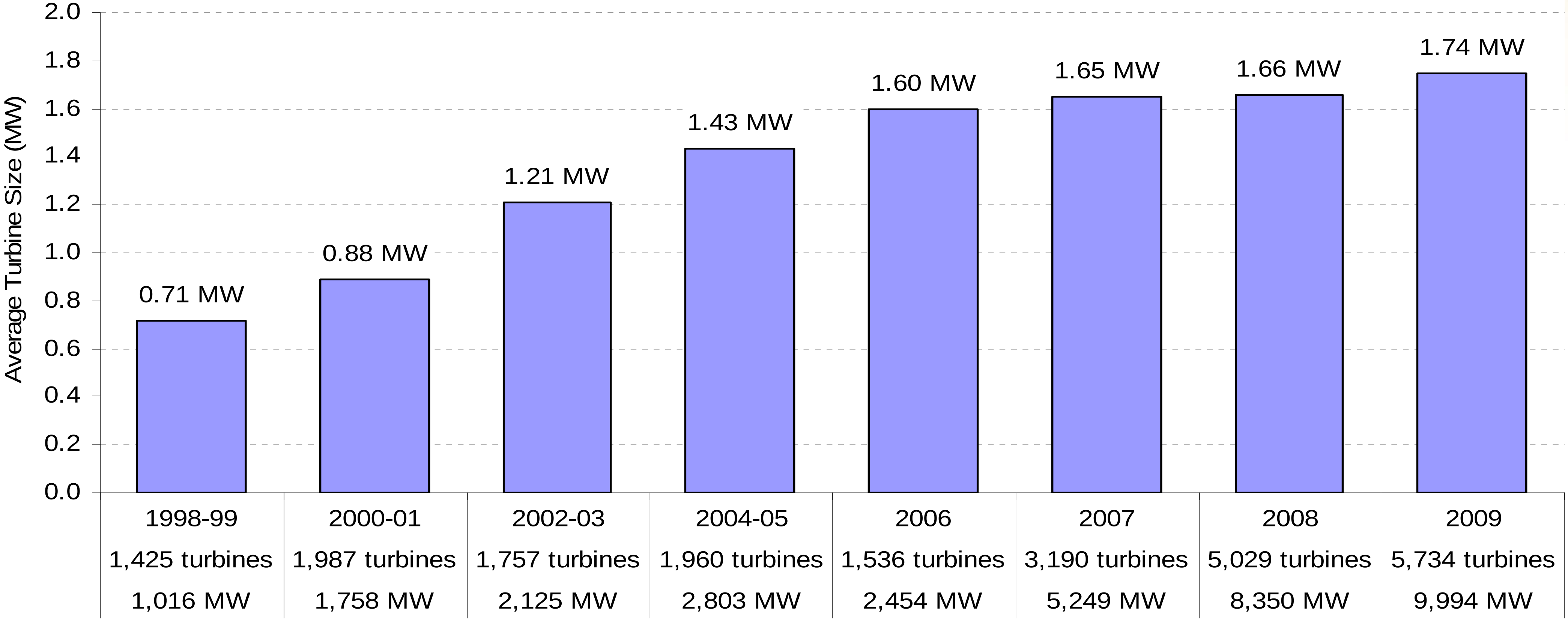
On average, since 1998-99, hub heights are 22 meters (39%) higher and rotor diameters are 33 meters (69%) larger



Turbines Getting Larger



Average Turbine Size Higher in 2009



25% of turbines installed in 2009 were larger than 2.0 MW, up from 19% in 2008, 16% in 2006 & 2007, and just 0.1% in 2004-05.

Source: DOE 2009 Wind Technologies Report

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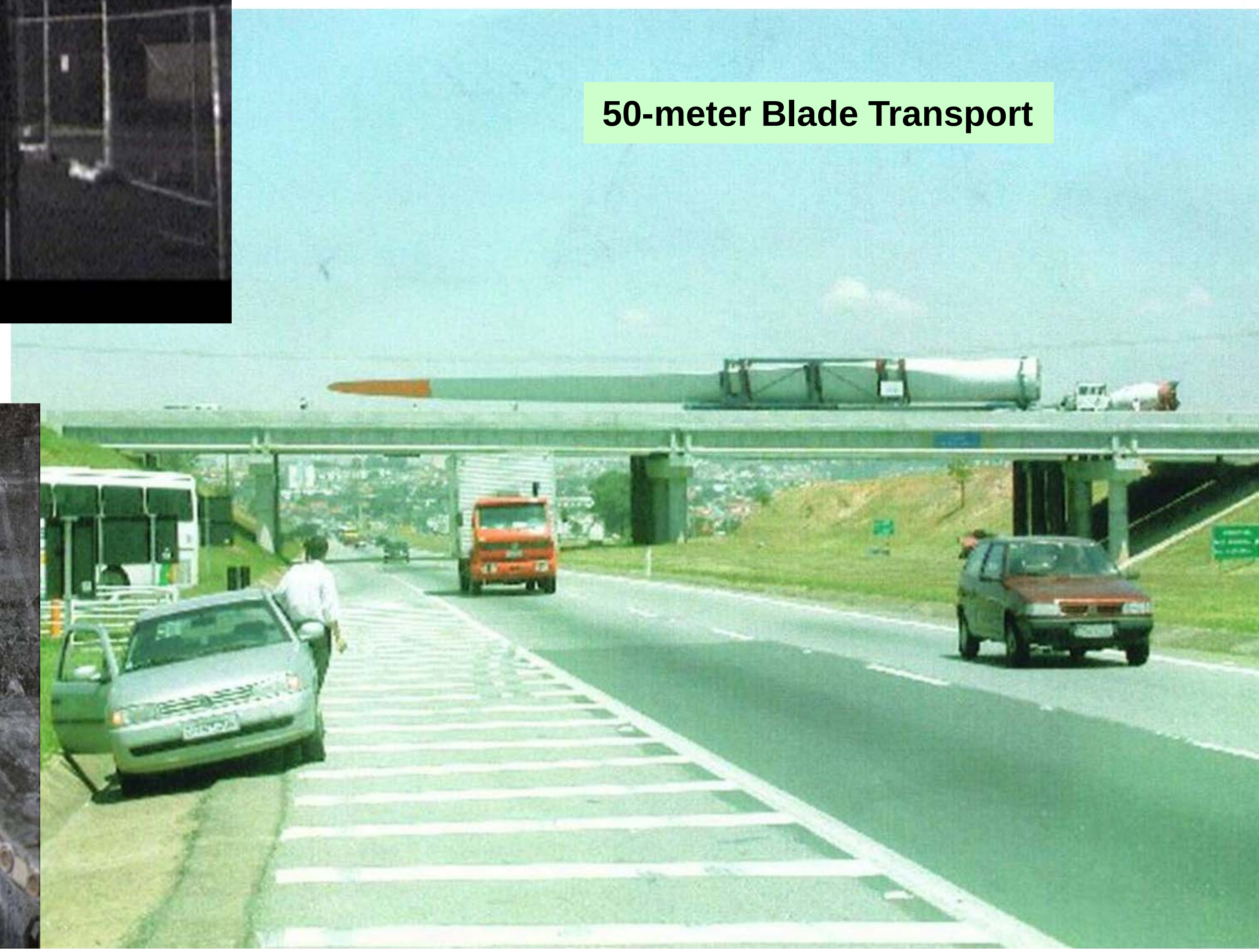
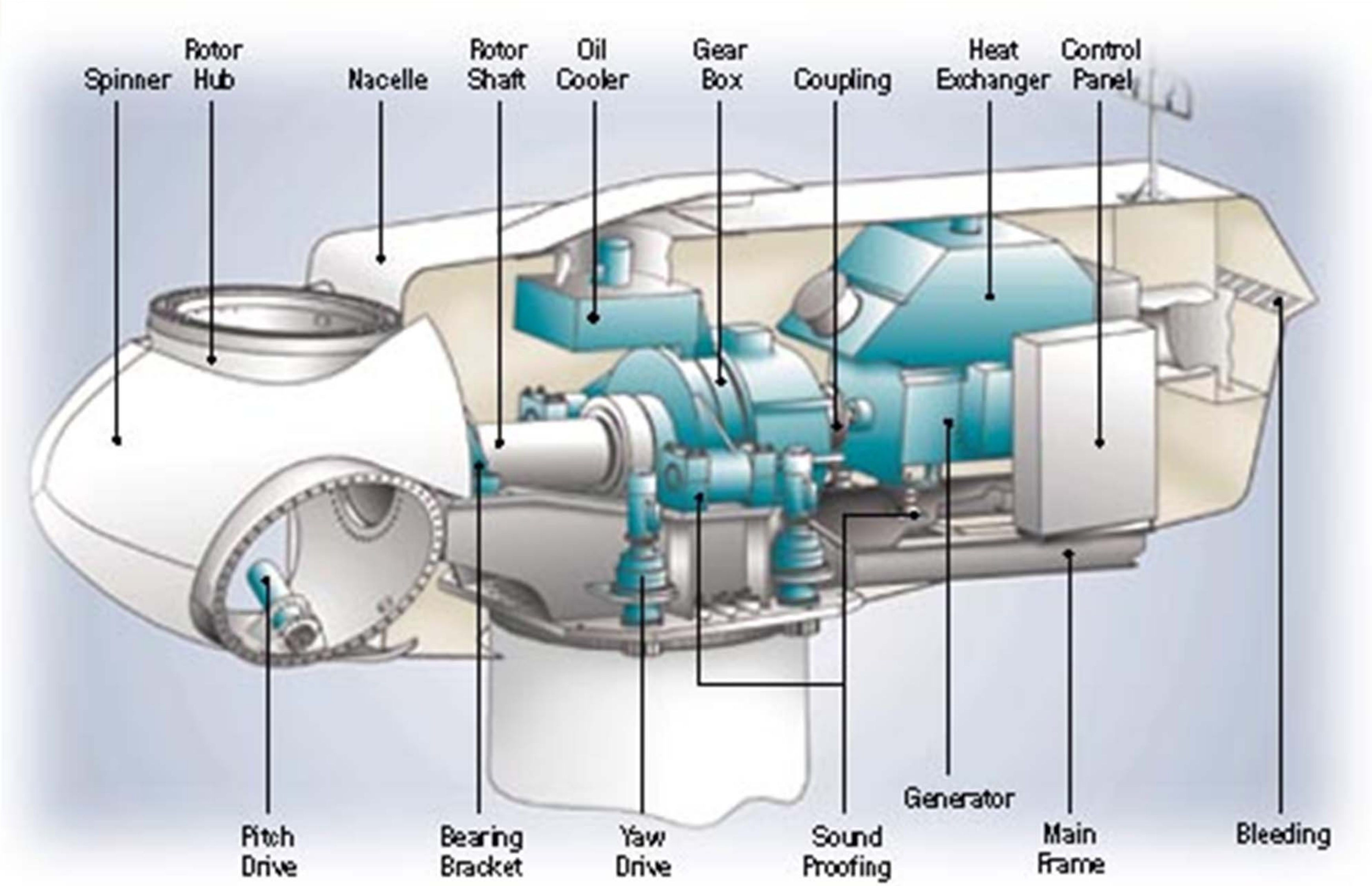
Logistics become difficult as size increases

45-meter Blade Fatigue Test at NREL/NWTC



Typical Modern Turbine



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Taxonomy of a Wind Plant

Over 8,000 individual components in a single wind turbine

Wind Turbine

Blade
- Aero-dynamic brake
- Internal structure - laminates
- Lightning protection
- Paint and coatings
- Skins – laminates
- T-bolt/root insert
- De-icing system

Rotor
- Nose cone
- Pitch system
- Hub
- Slip ring
- Root attachment

Drivetrain
- Low speed shaft
- High speed shaft
- Braking system

Gearbox
- Bearings
- Gears
- Lube system
- Housing
- Torque arm system

Generator
- Cooling system
- Stator
- Rotor
- Housing
- Commutator and brushes
- Bearings

Electrical
- Power converter
- PFC system
- Soft starter
- Wiring and connections
- Grounding system
- Main transformer
- Components

Nacelle
- Enclosure
- Meteorological equipment
- FAA lights
- Internal environment
- Crane

Yaw
- Cable twist/untwirst
- Brake
- Drives
- Bearings (slew ring)
- Gear
- Damper
- Hydraulics

Control system
- Sensors
- Communications
- SCADA interface
- Controller
- Cabinet
- UPS

Foundation & tower
- Foundation
- Tower structure
- Tower equipment

Balance of plant
- Substation
- Meteorological tower
- SCADA
- Converter
- Grid connection
- Collection and distribution
- Metering and relays

Maintenance
- Troubleshooting
- Fault Reset
- Scheduled Maintenance
- Miscellaneous

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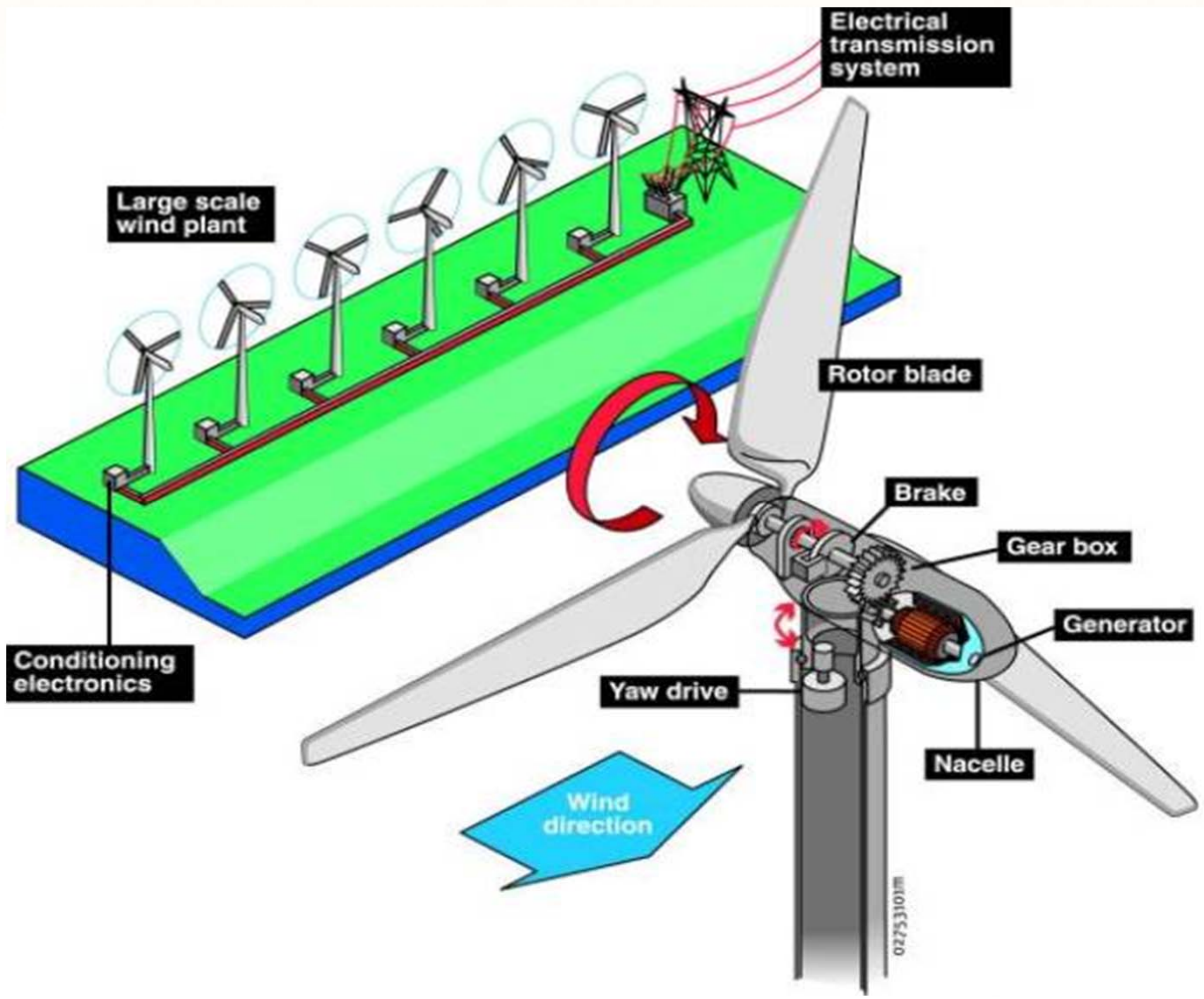
Typical Wind Farm Components

- Turbine
- Foundations
- Electrical Collection System
- Power quality conditioning
- Substation
- SCADA
- Roads
- Maintenance facilities



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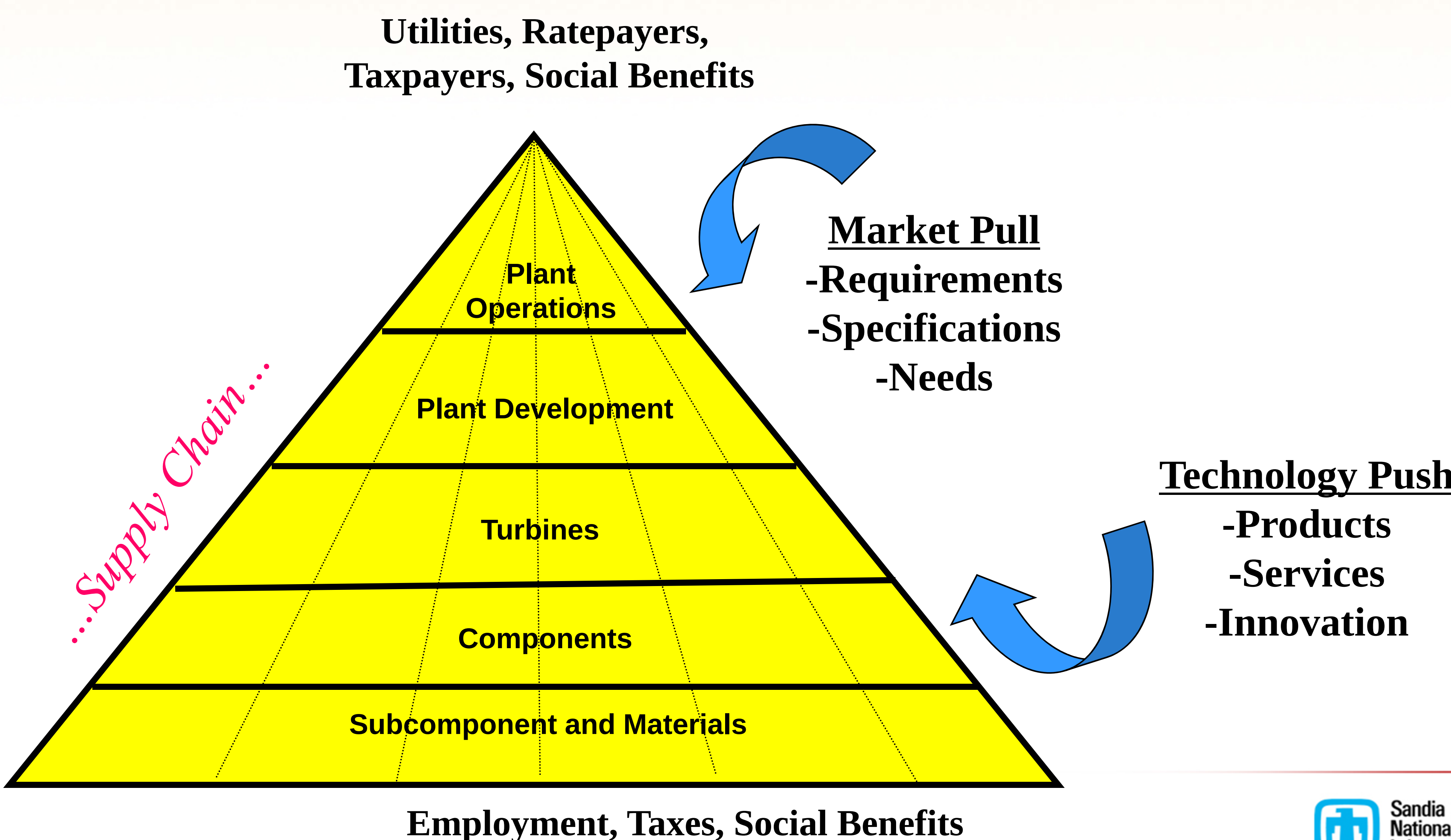
Wind Turbine Supply Chain Model



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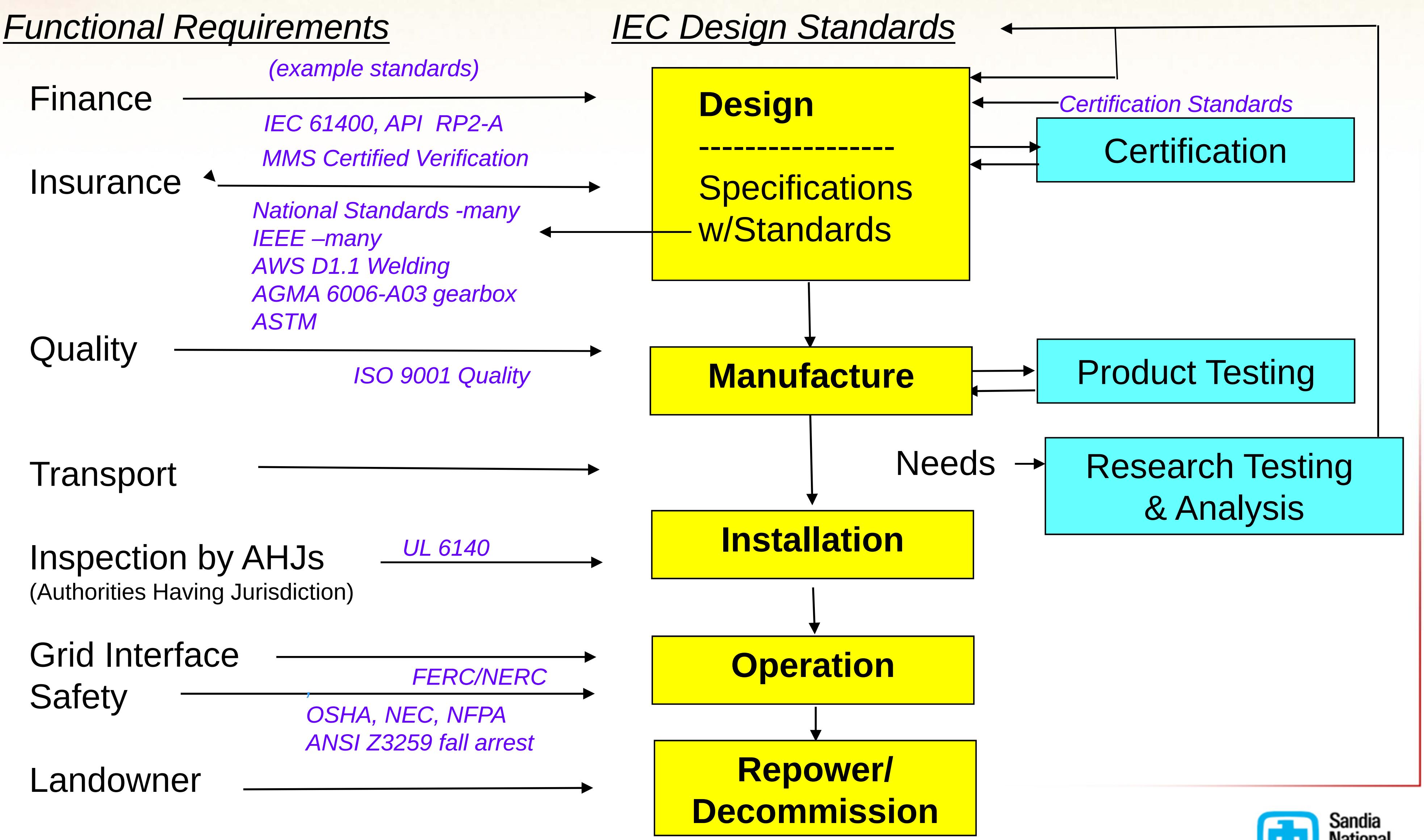
Another Perspective with Adjacent R&D Space



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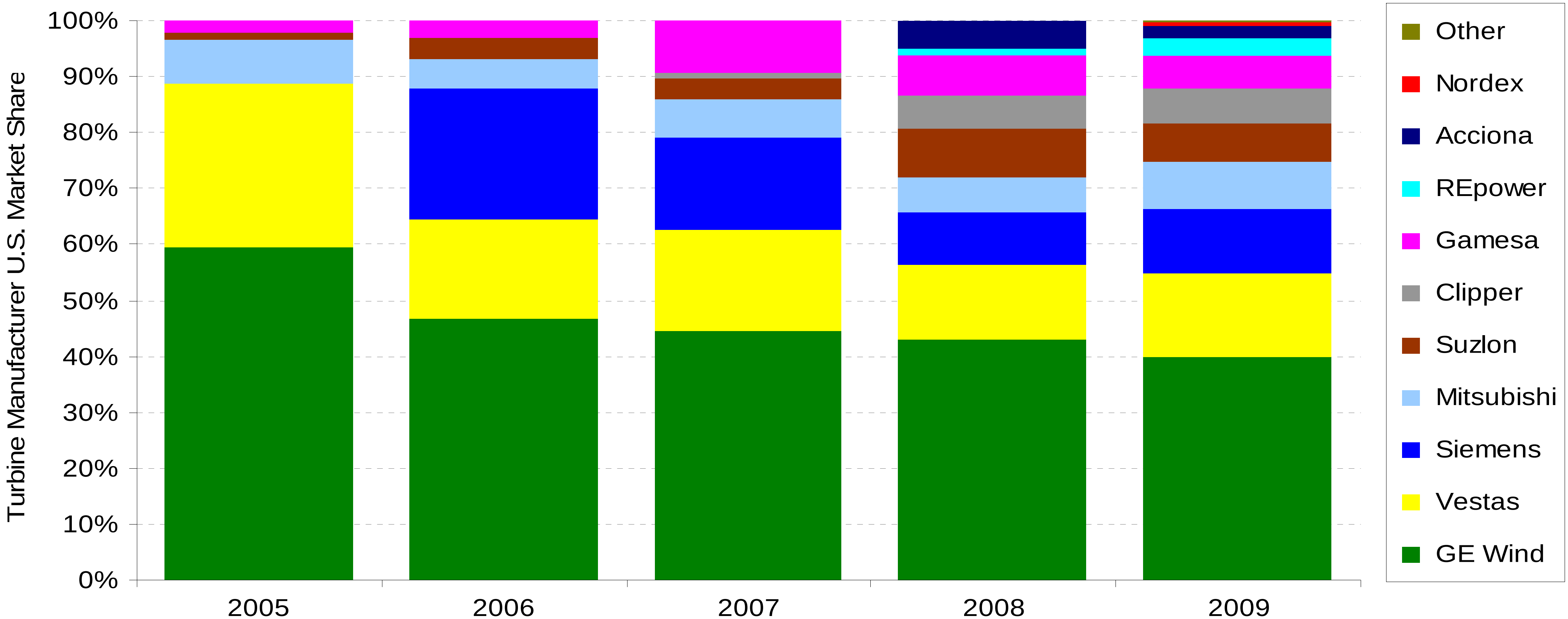
US Turbine Vendors

- **GE Remained the Top Turbine Vendor in the U.S. Market, But a Growing Number of Other Manufacturers Are Capturing Market Share.**



- Chinese and South Korean manufacturers seeking entry into U.S. market;
- For first time in 2009, a turbine vendor from China (Goldwind) saw sales in the U.S.

Source: DOE 2009 Wind Technologies Report

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Wind Power Basics

Air Density **Rotor Area** **Wind Speed**

$$WindPower = \frac{1}{2}\rho A C_P V_\infty^3$$

Wind Power output is proportional to wind speed cubed.

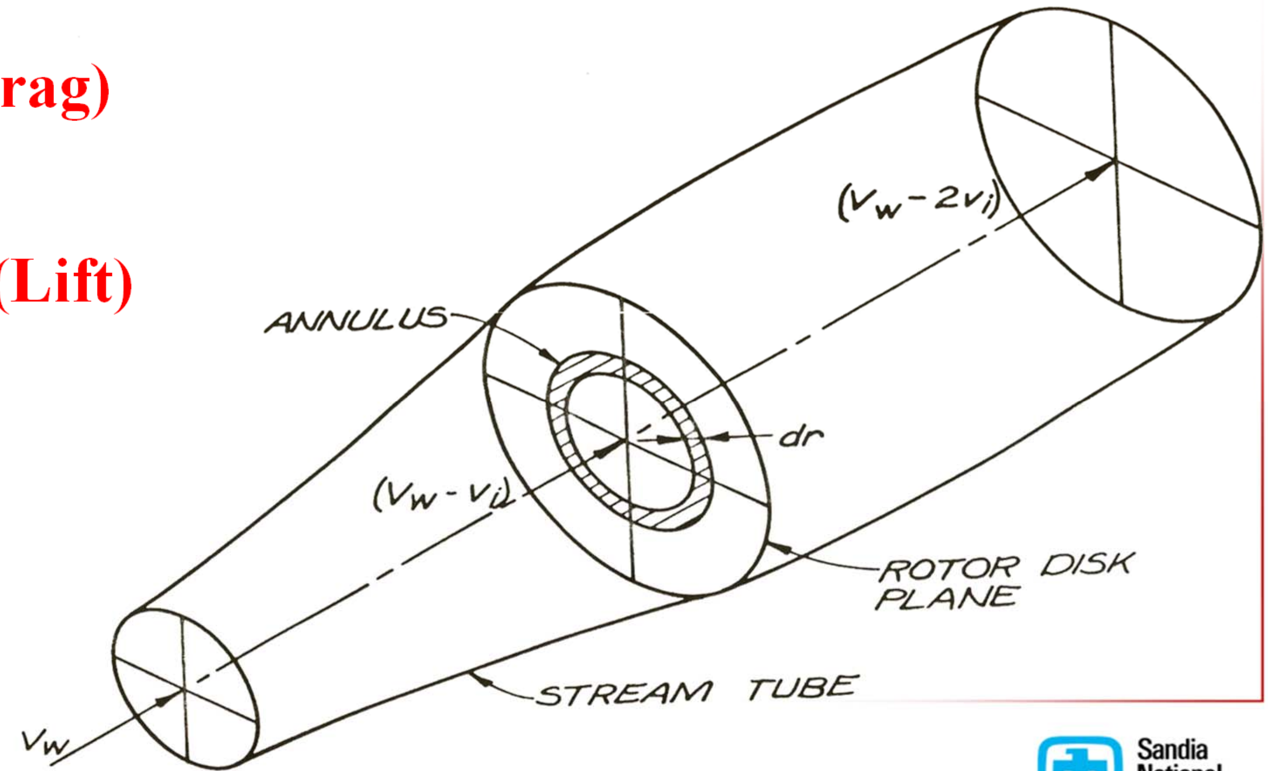
$$C_{P\max} \cong 0.3$$ **(Drag)**

$$C_{P\max} \cong 0.59$$ **(Lift)**

The Betz Limit

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

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



Generation Potential

Depends on:

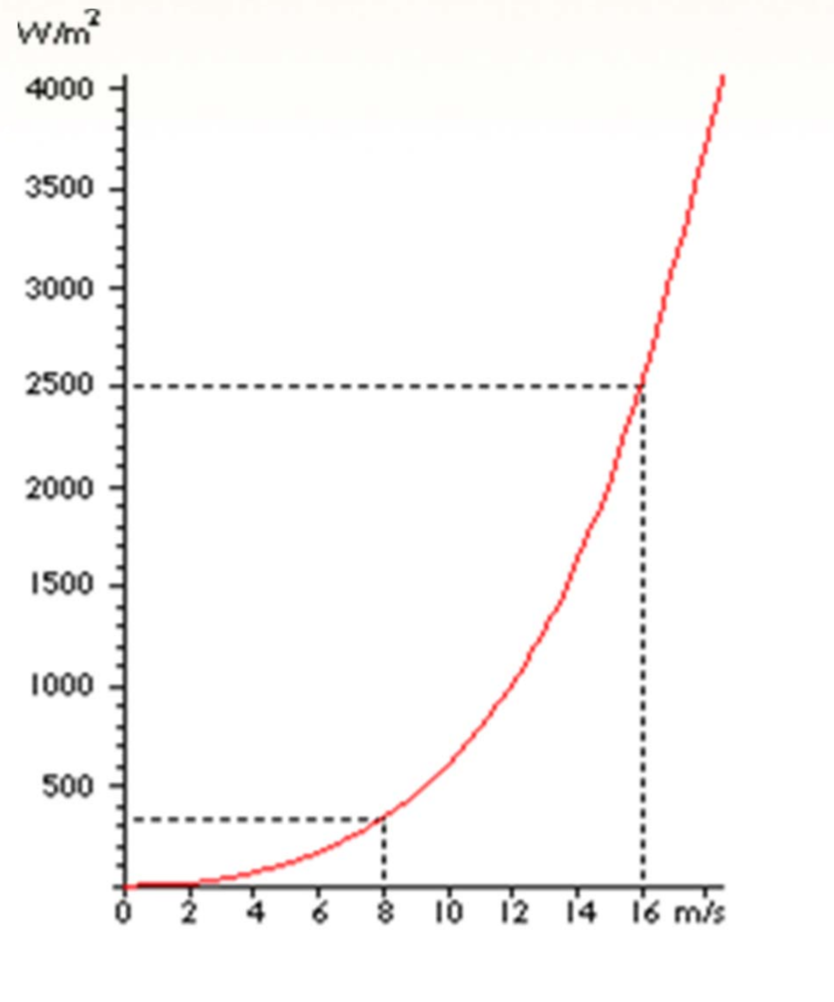
- Available resource;
- Turbulence characteristics;
- Terrain and roughness influences;
- Turbine characteristics.

Remember…

Power in the wind = $K \, {}^{1}/_{2} \, \rho \, A \, V^3$

- wind speed, V
- swept area, A
- air density, ρ
- conversion efficiency constant, K
- 45% efficiency for modern machines

→ Power ~ (wind speed)^3



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Turbine Power Basics

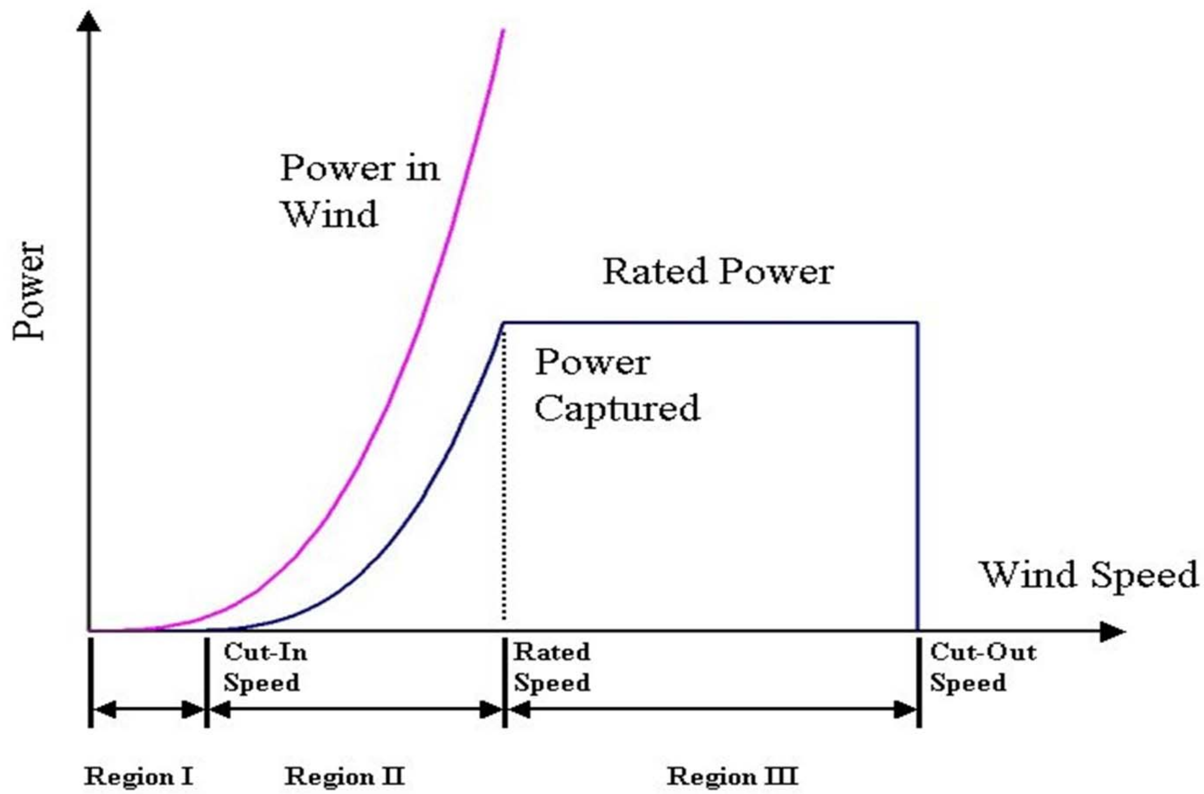
Regions of the Power Curve

Region I – not enough power to overcome friction

Region II – Operate at maximum efficiency at all times

Region III – Fixed power operation

Wind Turbine Power Curve



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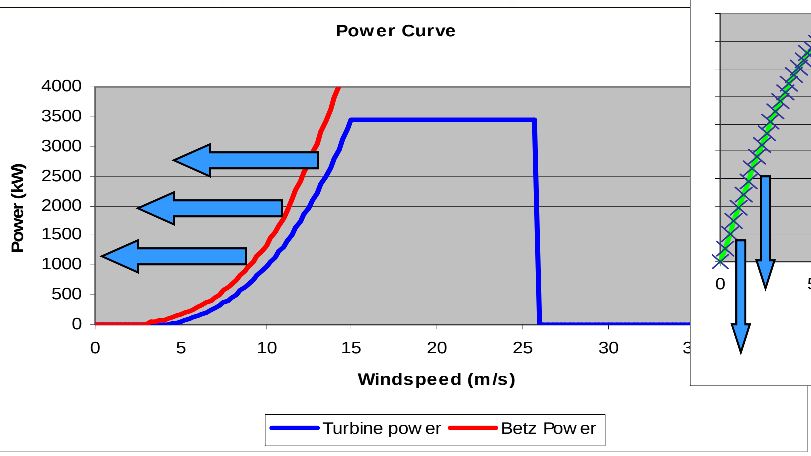
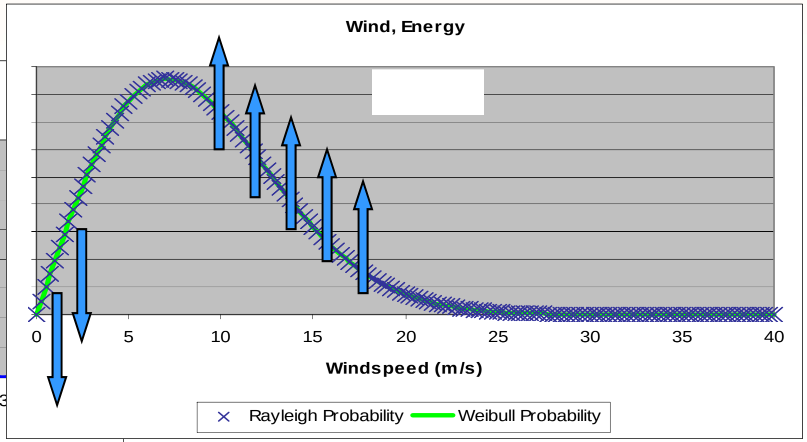
Performance Enhancement Options

Resource

Power





The cost benefits are constrained by the *squared-cubed* law

Larger Rotor

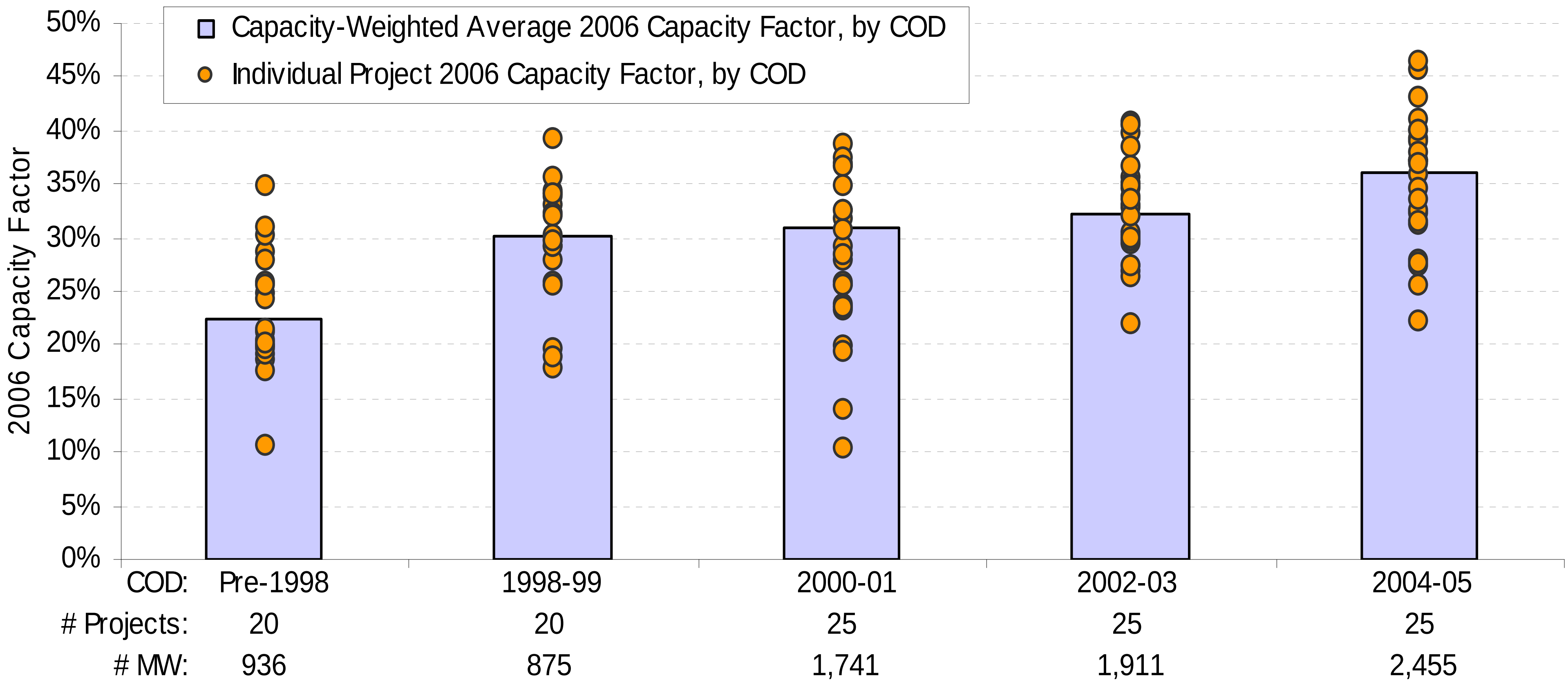
Taller Tower

Rotor *costs* increase with diameter *cubed,* Rotor *power* grows with the diameter *squared*

Tower costs increase with height to the *fourth* power

We can only win this battle if we build rotors that are smarter and components that are lighter to beat the squared-cubed law.

Reported Capacity Factors



CF = Generated Energy in a period of time / (Rated Power x Time period)

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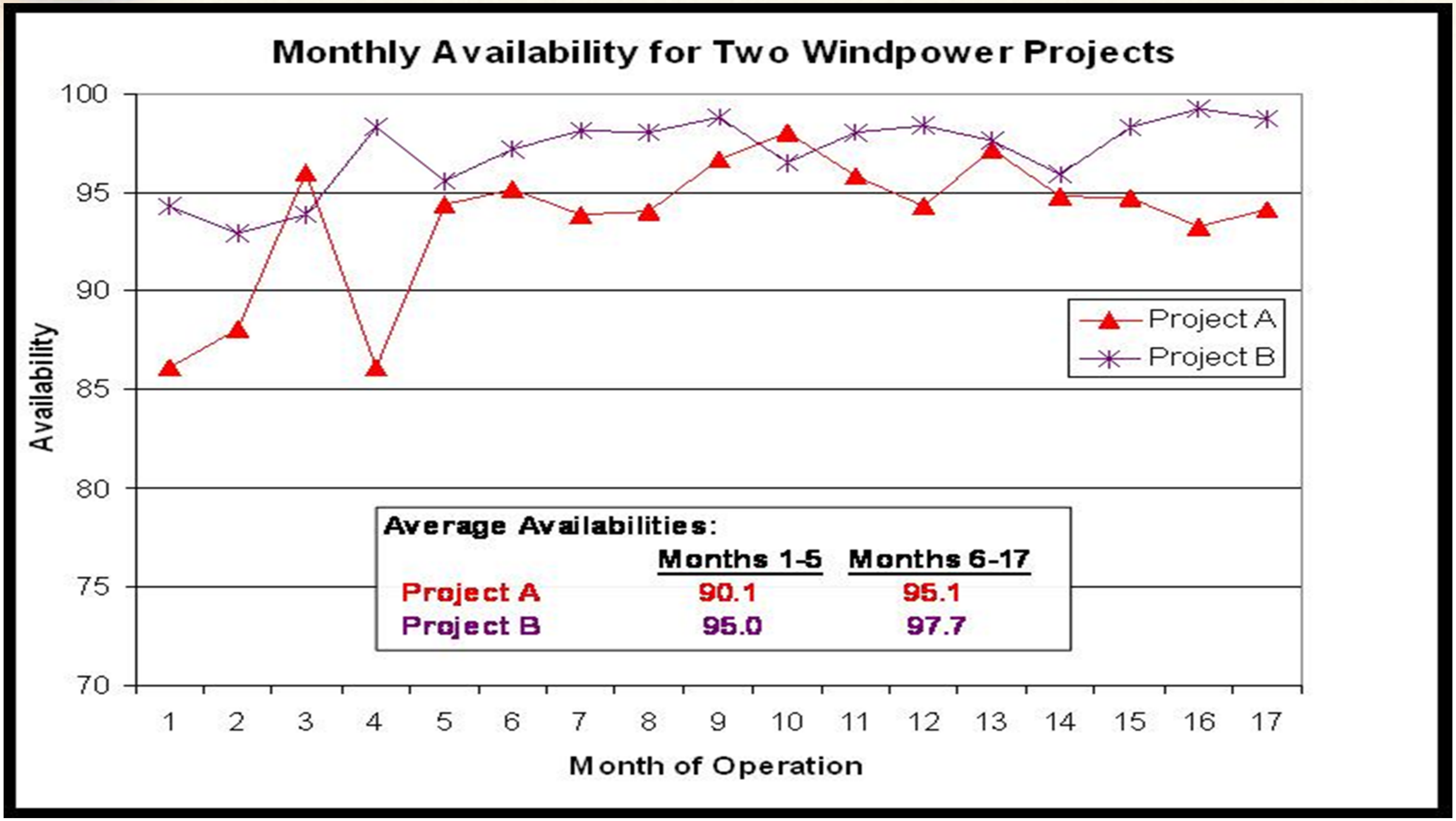
Availability



Simple Definition:

- **Availability = turbine available time/total time**

More detailed definitions are commonly used in contracts

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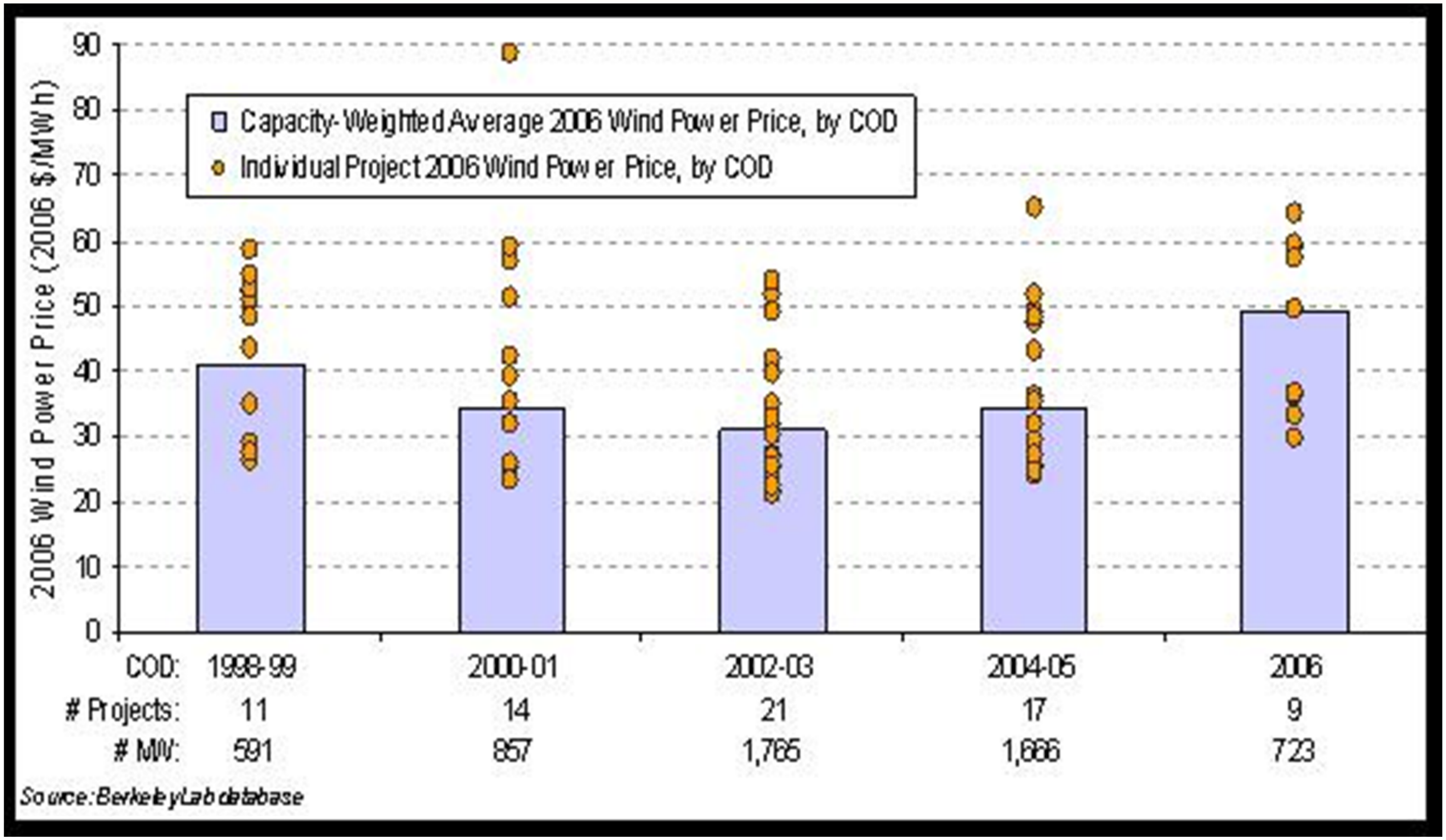
Cost of Energy: Sales Prices



Rising prices were caused by:

- Weak Dollar
- Growing commodity prices
    - steel
    - copper
    - concrete
- Limited availability of machines

Reliability Program Goals and Objectives

Working through industry partnerships to:

- **Develop National reliability baseline statistics for the US wind energy industry**
  - **Turbine component failure rates are higher than expected by some**
  - **This is the first long-term, data based, national effort to quantify and track these failures**
- **Guide efforts to address important component reliability problems**
- **Provide feedback for improving design and manufacturing practices**
- **Help wind plants:**
  - **Optimize O&M practices**
    - Preventive maintenance
    - Parts inventory optimization
    - Condition-Based Maintenance (CBM)
    - Prognostic & Health Management (PHM)

Technology Improvement Summary 20% by 2030 Report

Subsystem	Description	Increased Energy	Capital Cost
Towers	Taller with new materials/self erecting	+11/+11/+11	+8/+12/+20
Rotors	Lighter & larger with smart structures	+35/+25/+10	-6/-3/+3
Site Energy	Improved reliability – less losses	+7/+5/0	0/0/0
Drive Train	Innovative designs – high reliability	+8/+4/0	-11/-6/+1
Manufacturing	Process evolution and automation	0/0/0	-27/-13/-3
Totals		+61/+45/+21	-36/-10/+21

20% Report, Table 2-1, page 41 (working from 2002 baseline)

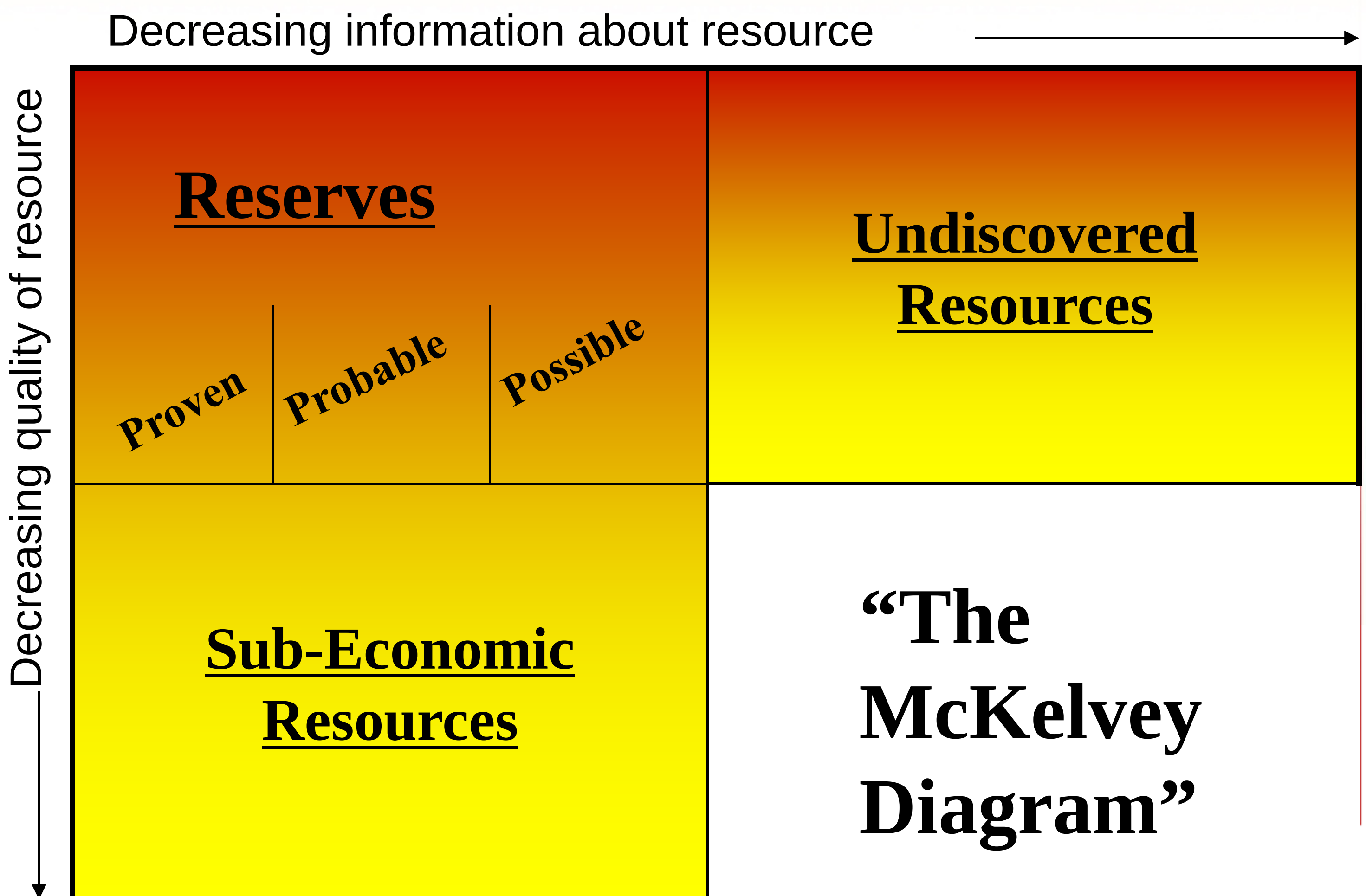
Wind Development Overview

WHTP Mission: Focus the passion, ingenuity, and diversity of the Nation, to enable rapid expansion of wind and water power production of clean, affordable, reliable, domestic energy for national security, economic stimulation, and global sustainable health.

- Wind Resource
- Infrastructure Requirements
- Land issues, permitting, environmental
- Value and financing

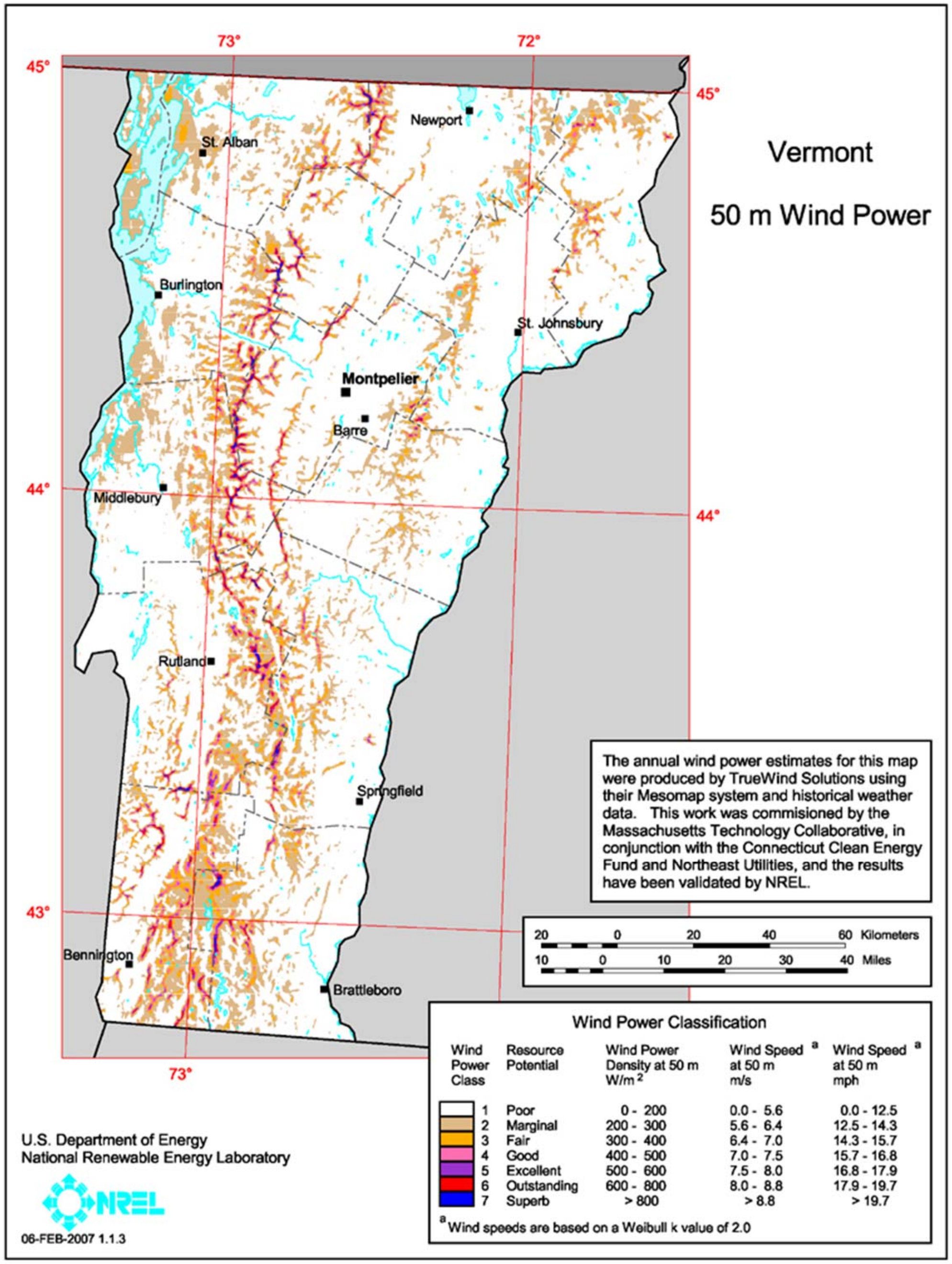
Wind Resource

What is known about the wind resource in a prospective location?
What is needed to be known?



Wind Resource

Wind Powering American Maps



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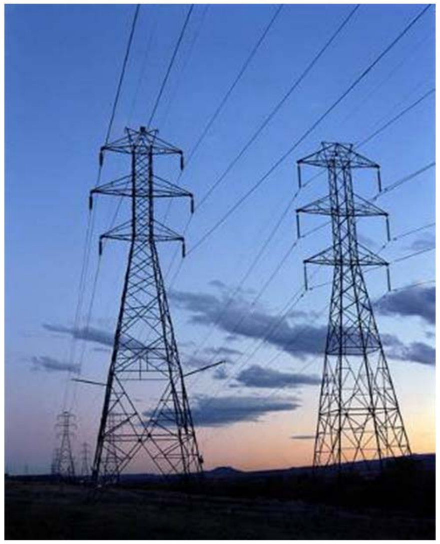
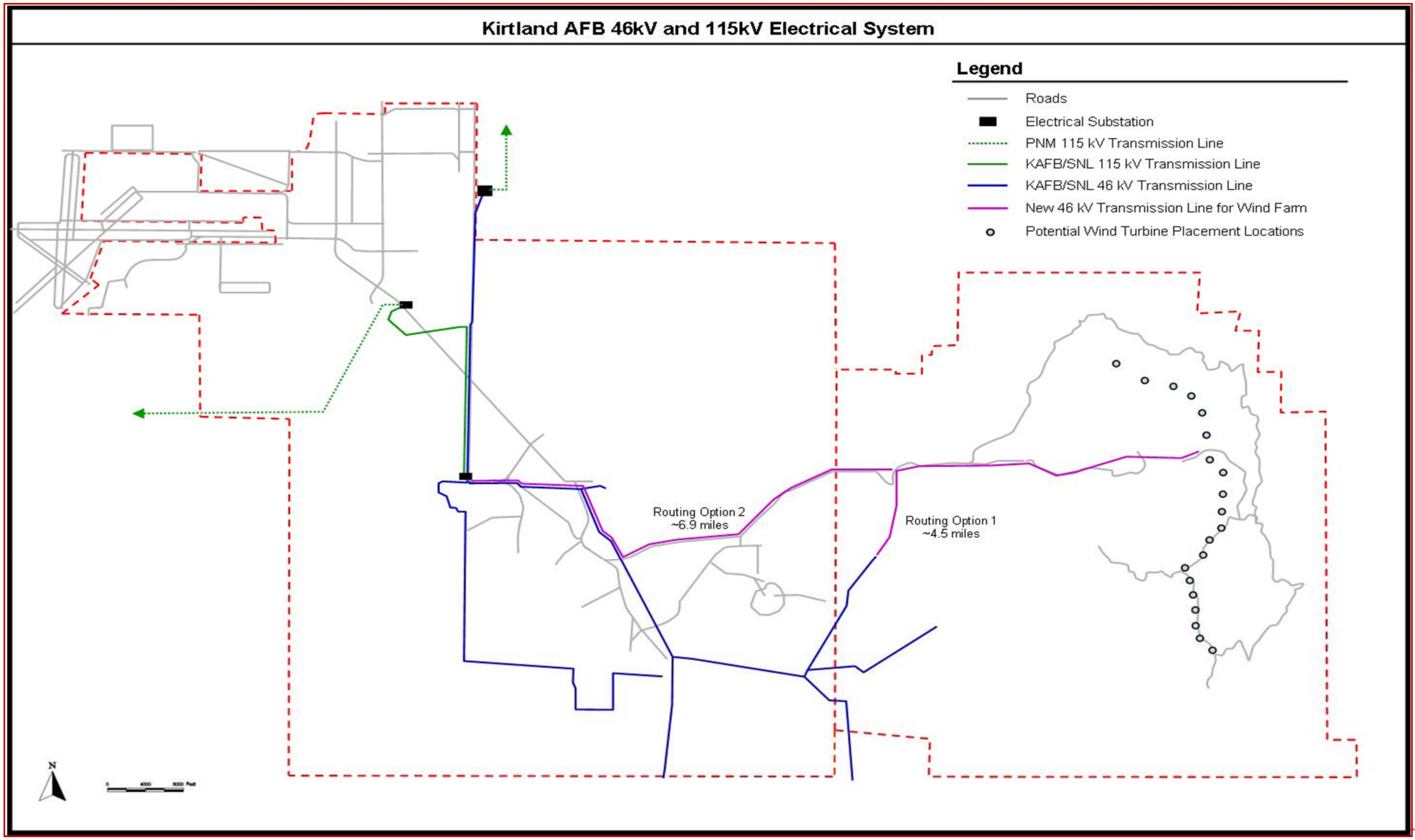
Infrastructure

- Need depends on size of plant
  - **Physical Size**
  - **Electrical Size**
- Roads/access
- Transmission interconnection/grid capacity
- Regulatory issues



Renewable System Interconnection role of WHTP!

Interconnection Study



Land, Siting, Permitting, Environmental

- Who owns the land?
- Where is it?
- How is the constructability?
- Preliminary site screening for avian, bat, wetlands, or other issues
- County ordinances
- Taxes
- Traffic, security, safety
- County ordinances
- Permits
- Environment assessments, EIS, NEPA

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Value = Benefits-Costs

What makes a market?
- Power purchase agreements
- Renewable portfolio standards
- Production tax Credits

Energy needs, demand growth
Present value analysis
Economies of scale, cost engineering
Rural electrification
Pro forma
- -energy losses, waking, performance curves

How financed?
Don’t forget operations and maintenance

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The Development Business

The development process needs clear definition of requirements teamwork, communication, clear-headed approaches creative solutions, dealing with external decision-makers, empowerment, ownership responsibility and continuous improvement.

Reality:
- Competition
- Cherry picking
- Reliability
- $$$

Phases of a project:
- Wild enthusiasm
- Disillusionment
- Panic
- Search for the guilty
- Punishment of the innocent
- Praise & honor for those not involved

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Wind Turbine Capabilities

Induction Generators:

- Absorbed VARS – no voltage support or control;
- Tripped due to voltage or frequency excursion;
- Provided no voltage control or droop control.

New Machines:

- Dynamic reactive power;
- Low (or zero) voltage ride-through;
- Dynamic real power control – droop control, ramp mitigation.

Source: Brendan Kirby, NREL Consultant

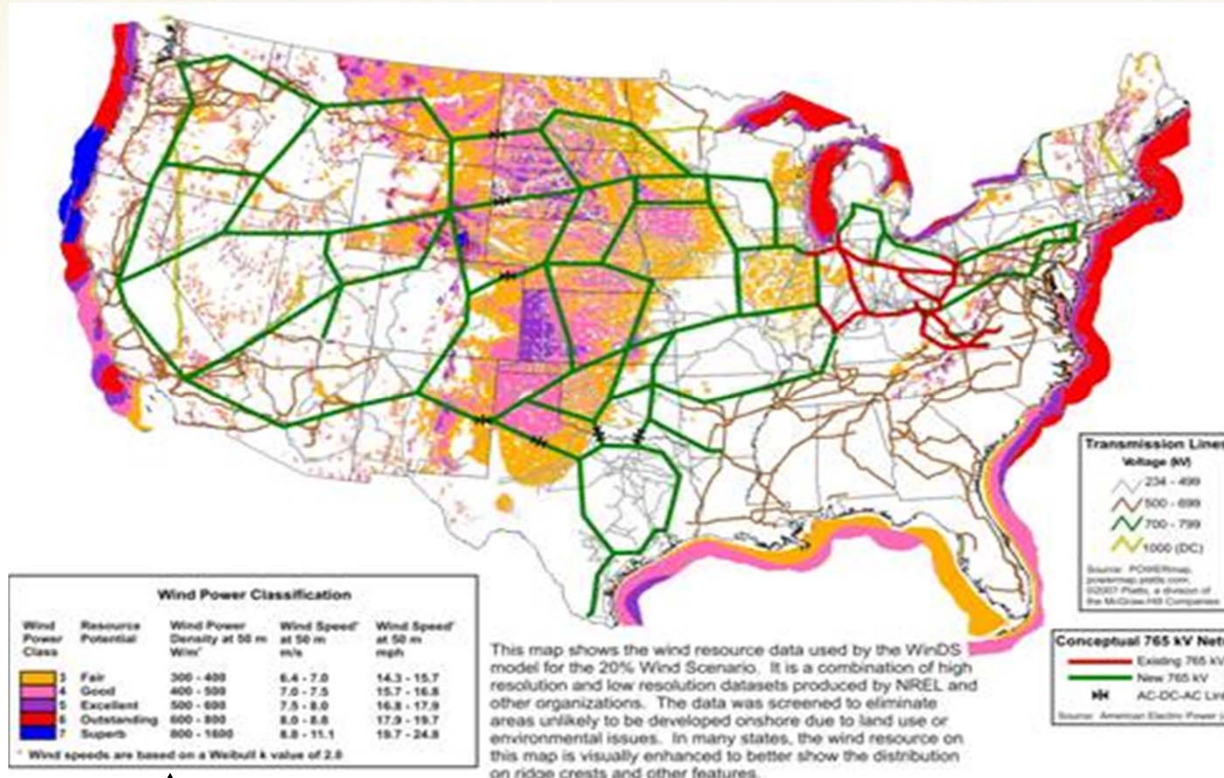
Wind Integration Challenges

Inability to Dispatch
- Weather determines output

Variability
- Increases difficulty to balance load

Uncertainty
- Can be forecasted to a large extent

Different Electrical Characteristics
- Lower inertia, voltage tolerance, reactive controls
- Still compatible with the grid

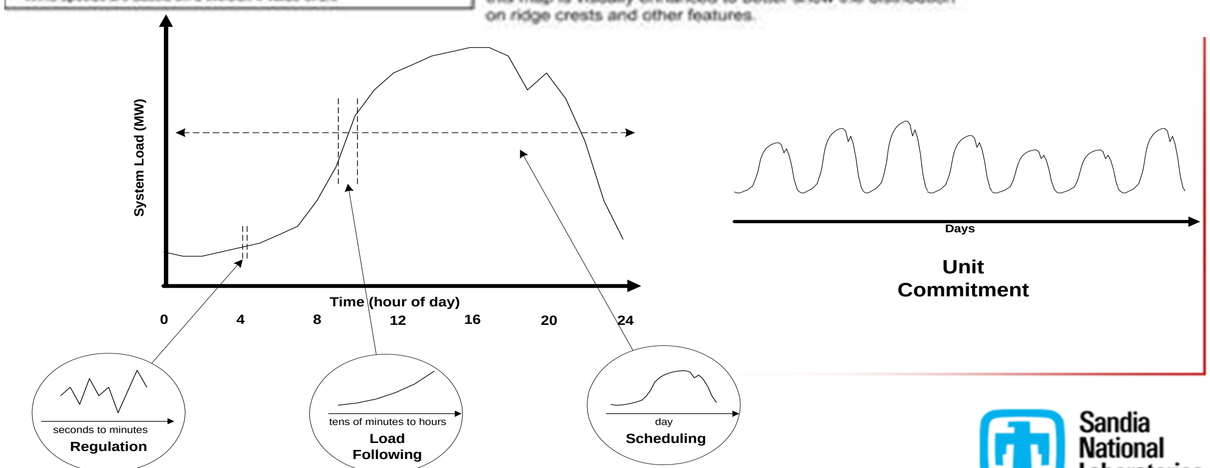


<u>Areas of Consideration:</u>

System Planning and Operation

Transmission Planning

Market Operation & Transmission Policy



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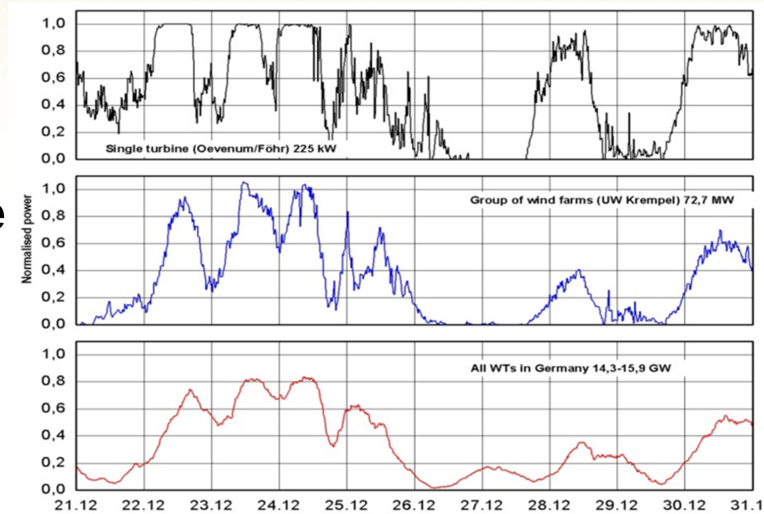
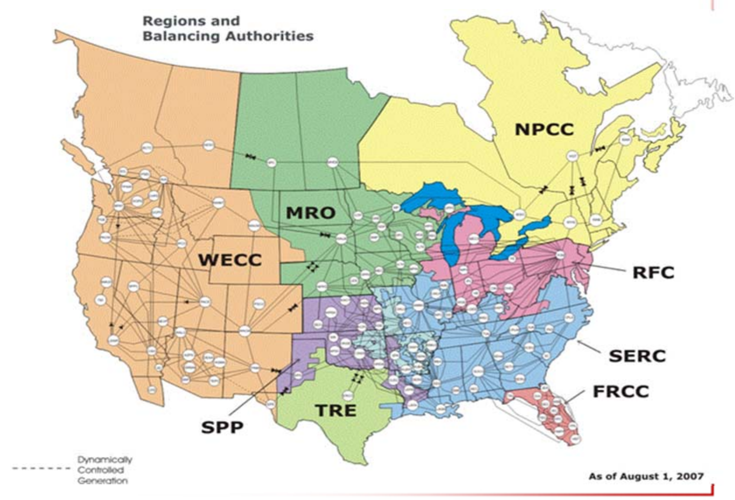
Questions of Interest for Integration Studies

- How do local wind resources compare with higher capacity factor wind that requires more transmission?
- How does geographic diversity of wind power reduce wind integration costs?
- How does offshore wind compare with onshore wind?
- How does balancing area cooperation affect wind power integration costs?
- How much transmission is needed to facilitate higher penetrations of wind power?
- What is the role of wind forecasting?
- How are wind integration costs spread over large market footprints and regions?
- What additional operating reserves are needed?





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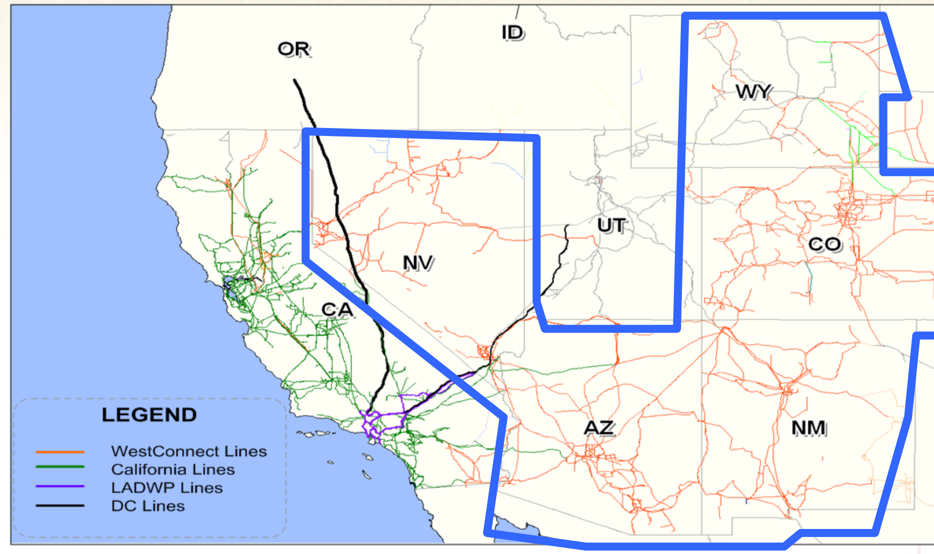
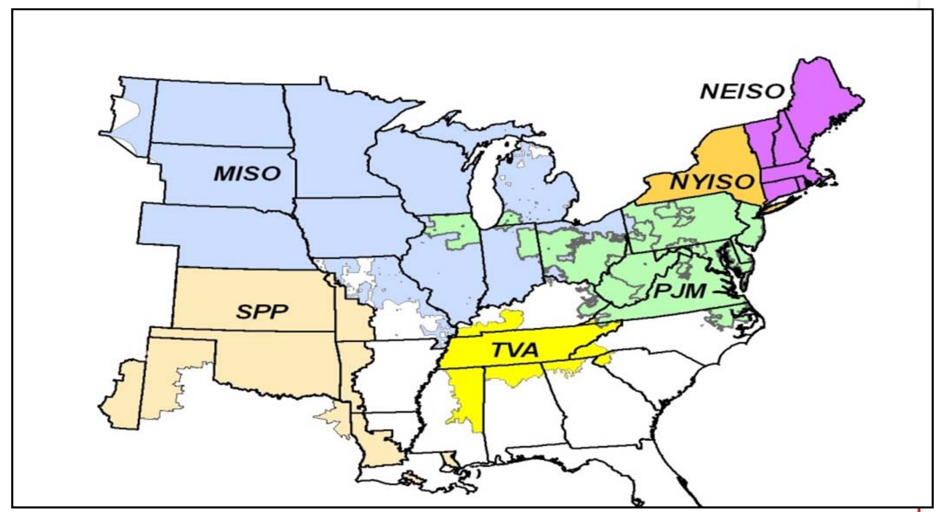
Broad Regional Studies

- Goal is to understand the costs and operating impacts due to the variability and uncertainty of 20-30% wind energy on the grid

- Heavily stakeholder driven scenario development and technical review

- Participation in other studies: Nebraska Power Authority, Portland General Electric, New England ISO, Southwest Power Pool, Hawaii, Arizona Power Authority





DOE work provides objective technical information on grid options

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Organizational and Study Web Links

Utility Wind Integration Group (UWIG) (www.uwig.org) and Wind Integration Library
http://www.uwig.org/opimpactsdocs.html

NREL Renewable System Integration publication web site
http://nreldev.nrel.gov/wind/systemsintegration/publications.html

Sandia National Labs Wind & Water Power Technology web site
http://windpower.sandia.gov

Eastern Wind Integration and Transmission Study (EWITS) http://wind.nrel.gov/public/EWITS/

Western Wind and Solar Integration Study (WWSIS) http://westconnect.com/planning_nrel.php

International Energy Agency, Task 25. Hannele Holttinen, et.al. ***Design and operation of power systems with large amounts of wind power State of the art report***.
http://www.vtt.fi/inf/pdf/workingpapers/2007/W82.pdf

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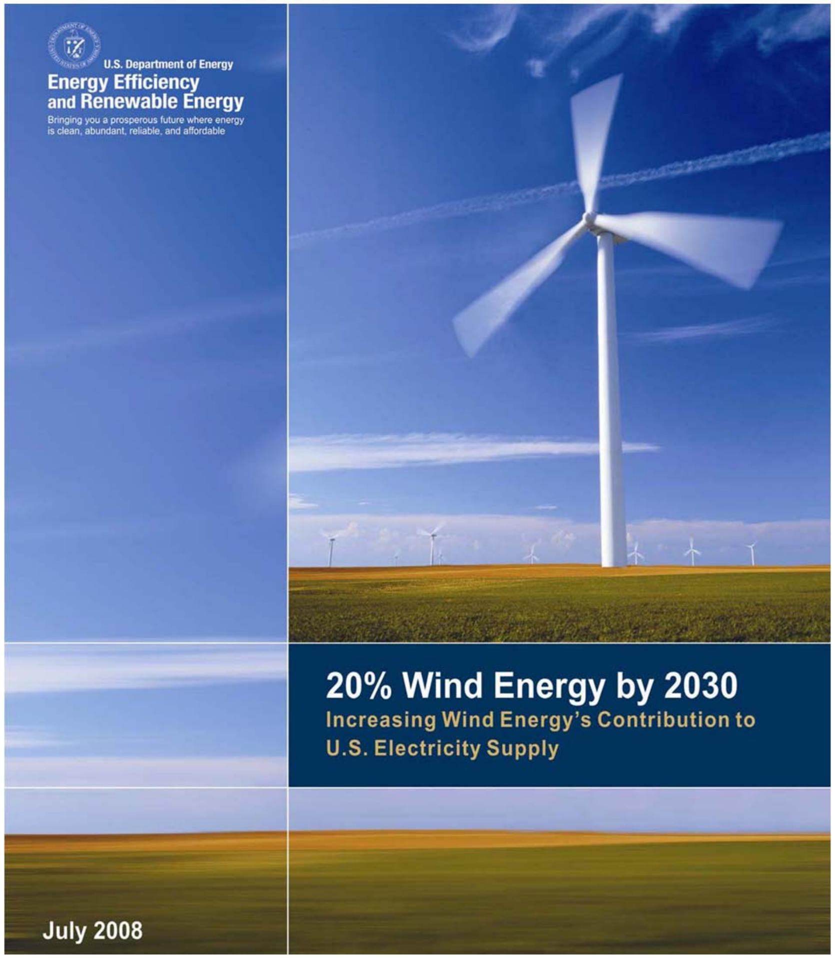
Sandia Publications are at sandia.gov/wind

- Active Aero Control Design
- Blades:
  - Adaptive
  - Aeroacoustics
  - Blade System Design Study
  - Carbon Hybrid
  - Flutter
  - General
  - Testing
- Computational Fluid Dynamics
- Control System Design:
  - Nonlinear Control Theory
  - Wind Turbine Blade Controls
- Data Acquisition and Field Measurements
- Fatigue and Reliability:
  - General
  - LIFE2
  - Loads
- Probability of Failure
- Health Monitoring
- Manufacturing
- Materials:
  - Aluminum
  - Bonded Joints
  - Composites
  - Material Testing and Fatigue
  - Property Determination
- Modal Testing and Analysis
- Non-destructive Testing
- NuMAD
- Partnerships:
  - Low Wind Speed Technology:
    - Knight & Carver
    - WindPACT
- Supervisory Control And Data Acquisition
- Structural Dynamics
- Turbine Systems
- Turbulence Simulation
- VAWT Archive
- Wind Plant Reliability
- Wind Powering America

And the Conclusion is….

There are **no fundamental technical barriers** to the integration of 20% wind energy into the nation's electrical system, but …. there needs to be a **continuing evolution of transmission planning and system operation policy and market development** for this to be most **economically achieved.**



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