Seminar on Renewable Generation and Grid 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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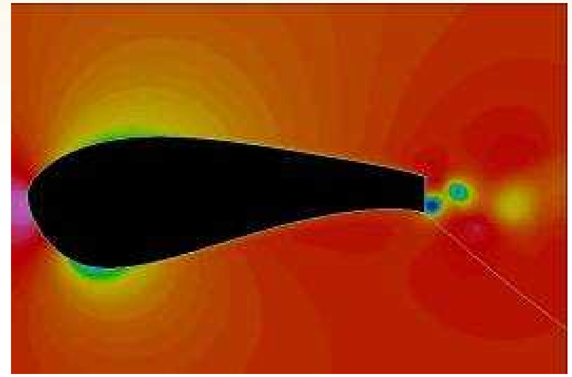
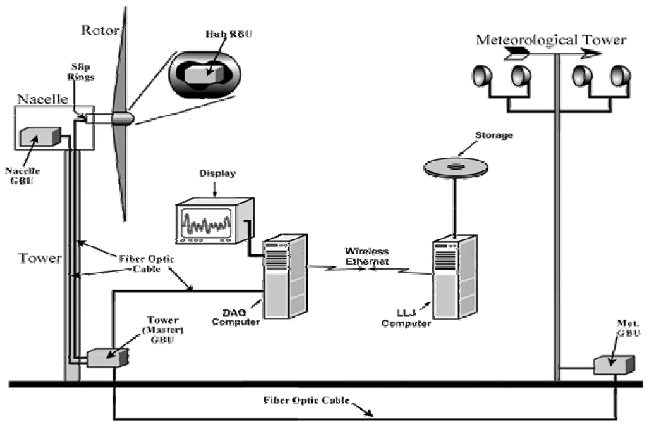
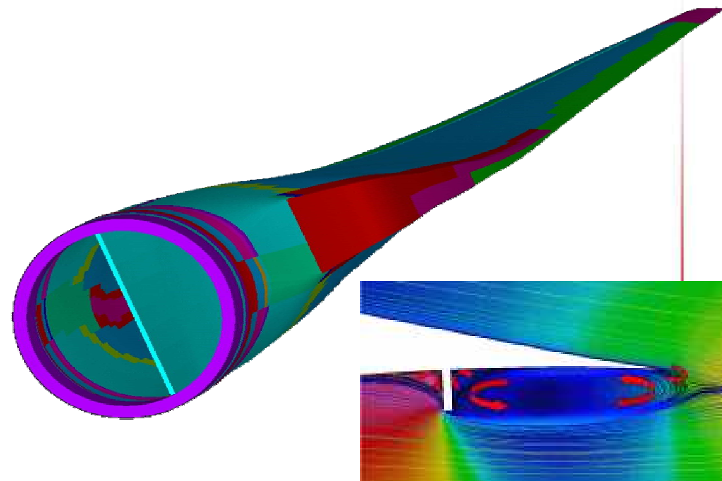
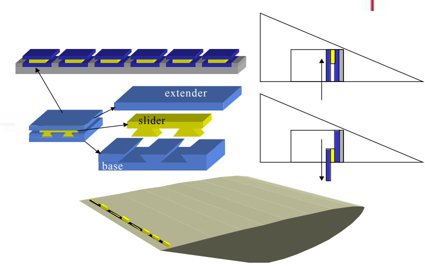
SNL's Wind Energy Program

- 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









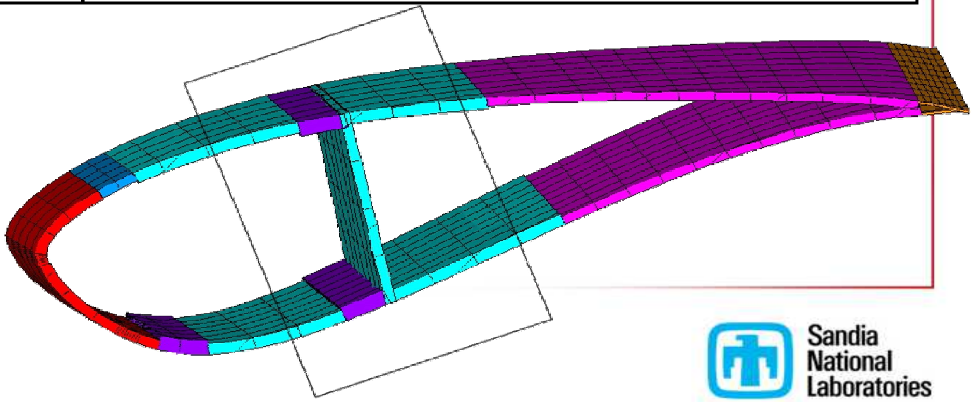
Department Background & Accomplishments

- **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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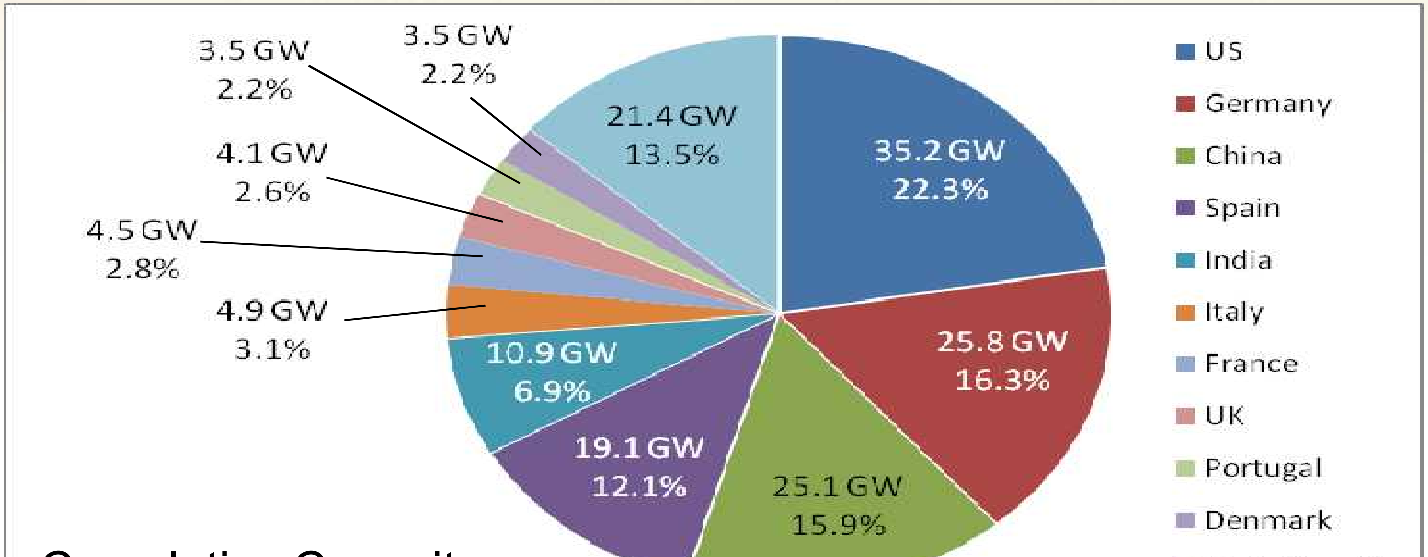
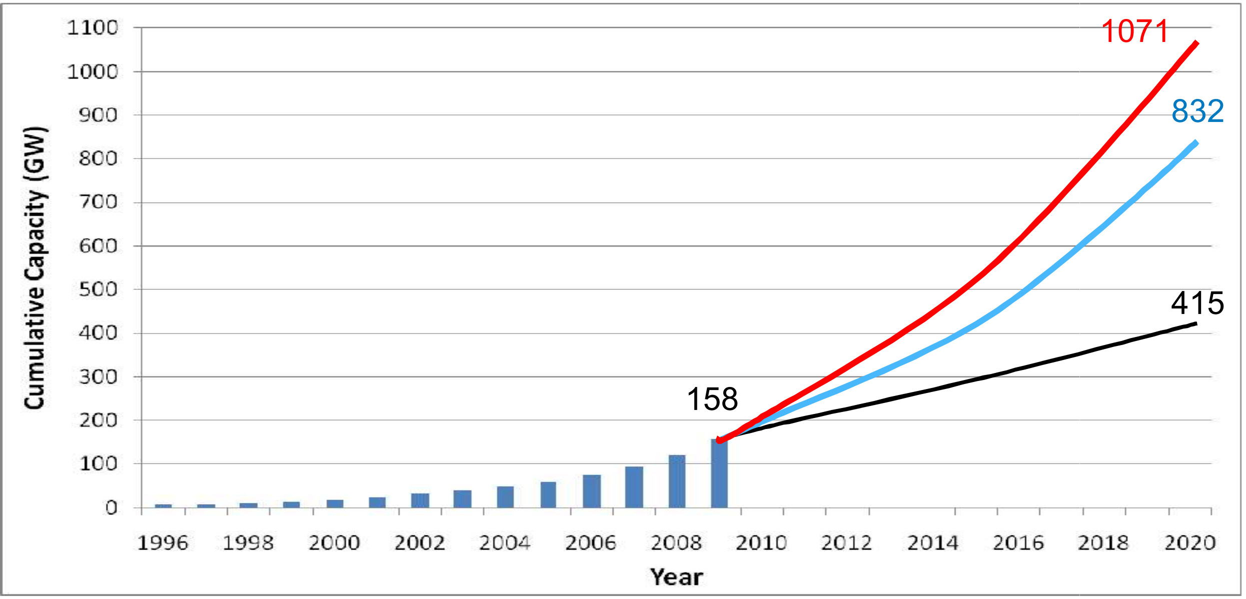
Global Installed Capacity



Cumulative 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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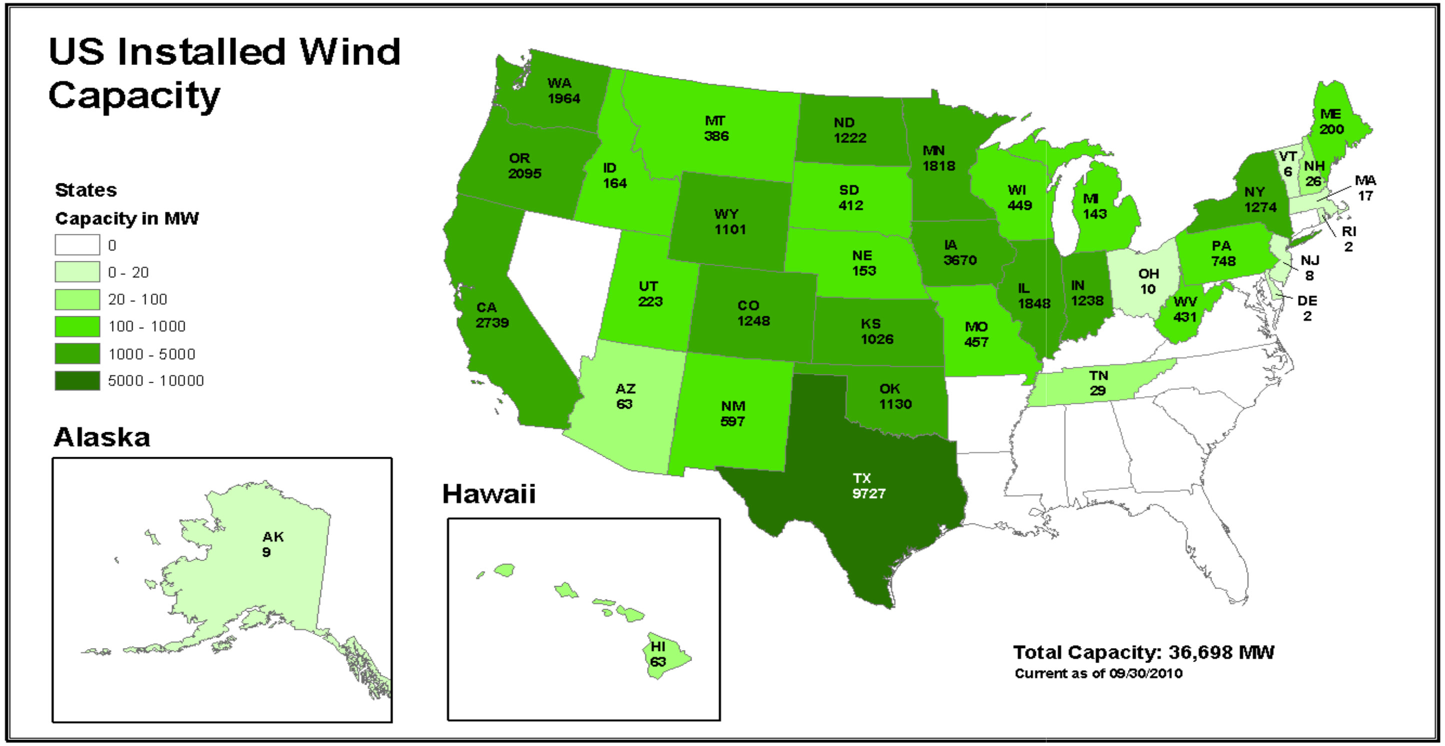
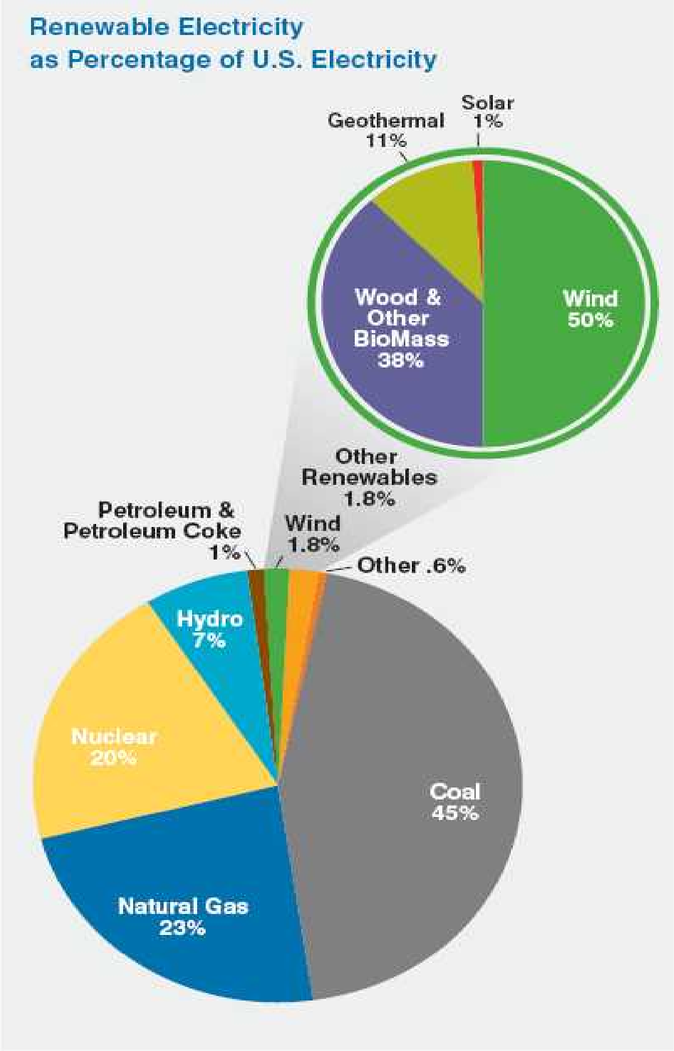
Installed Capacity in the United States





- 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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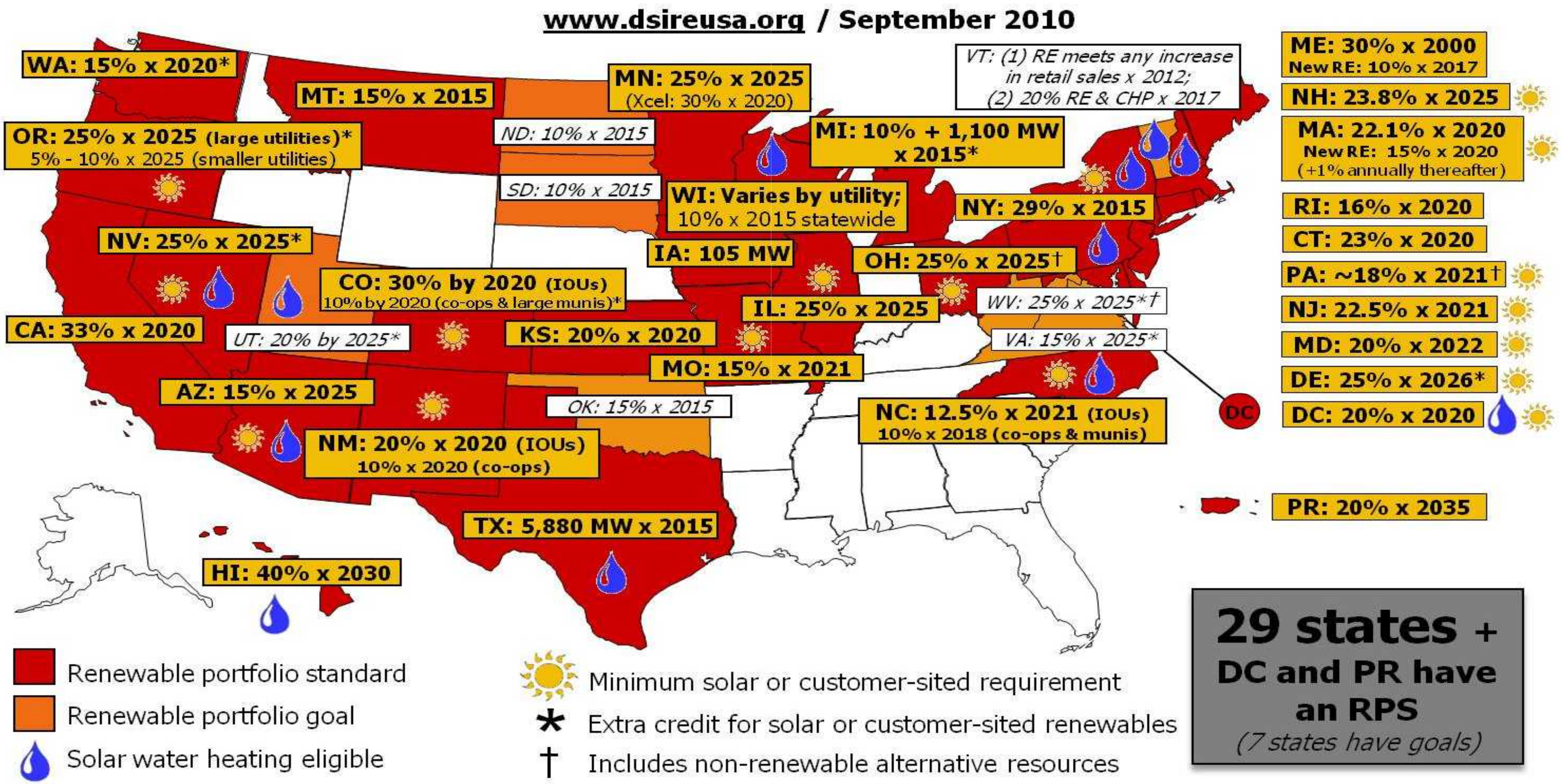
Renewable Portfolio Standards



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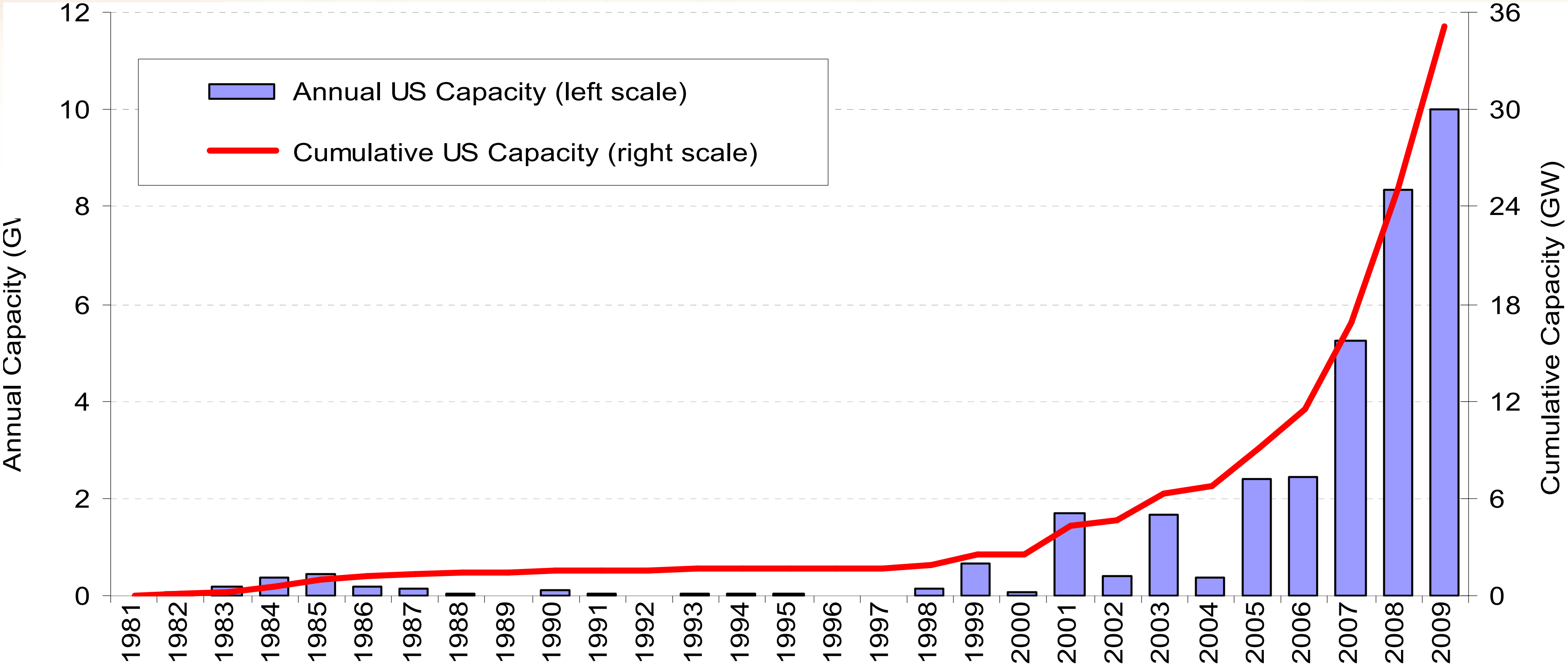
U.S. Wind Power Capacity Up >40% in 2009



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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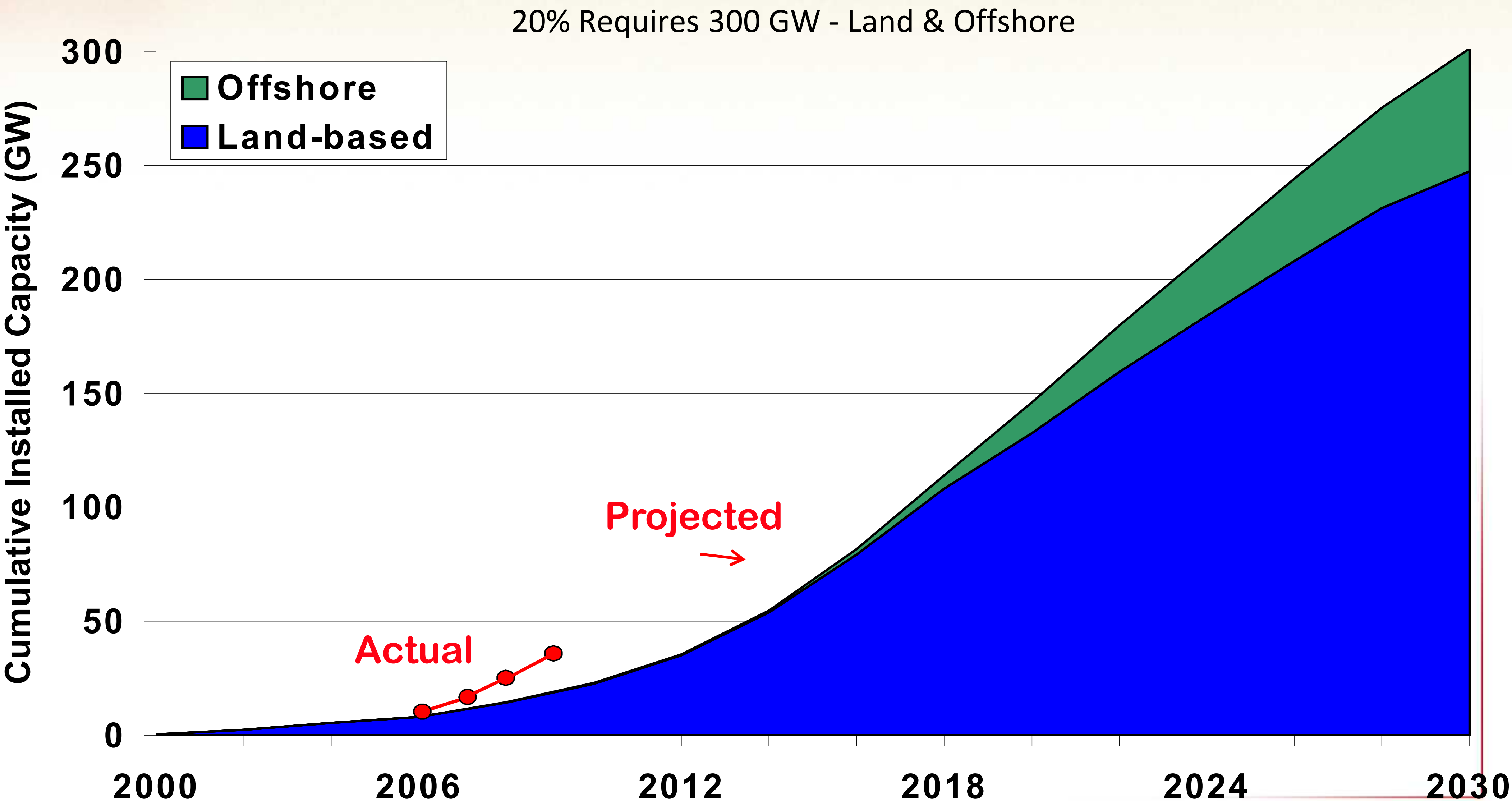
Projected Growth



Source: DOE 20% Wind Energy by 2020 Report

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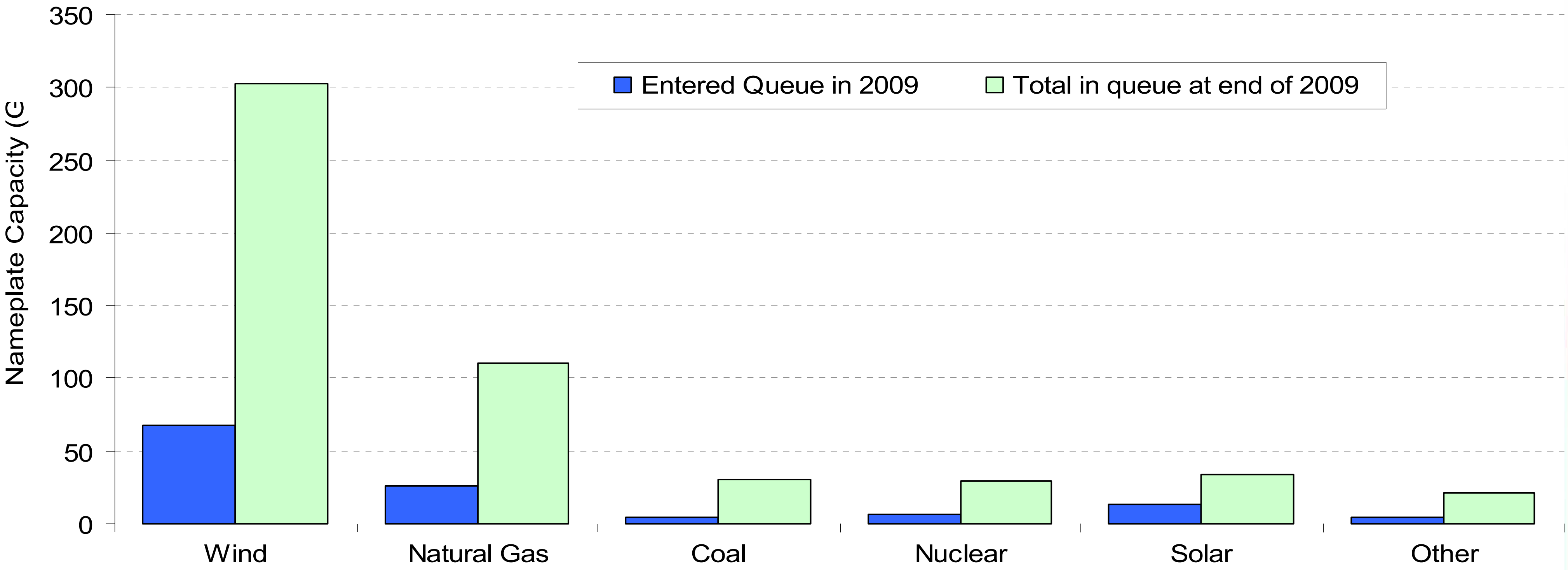
Wind Power Capacity In Queue

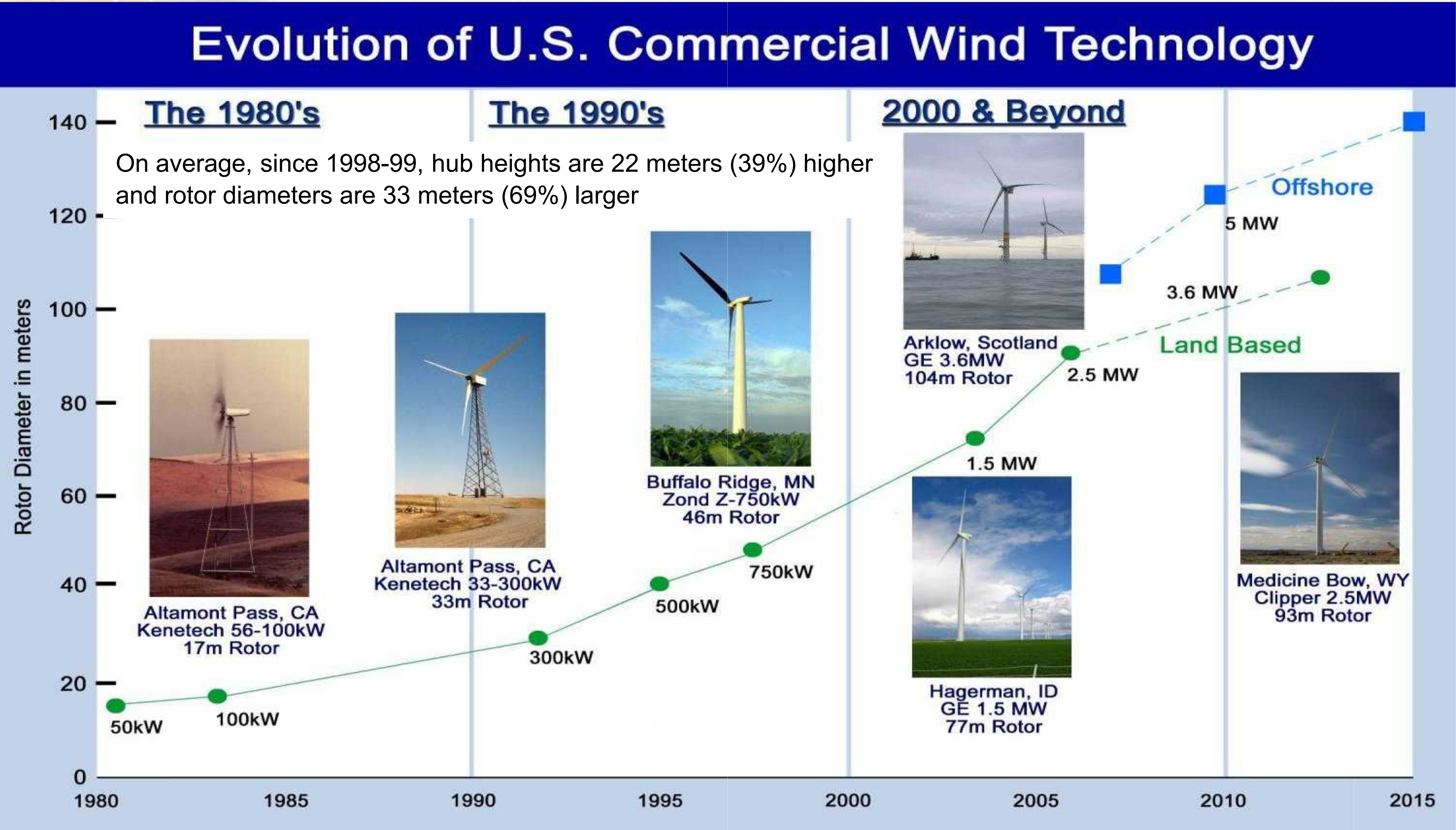
- Roughly 300 GW in Transmission Interconnection Queues.



Not all of this capacity will be built….

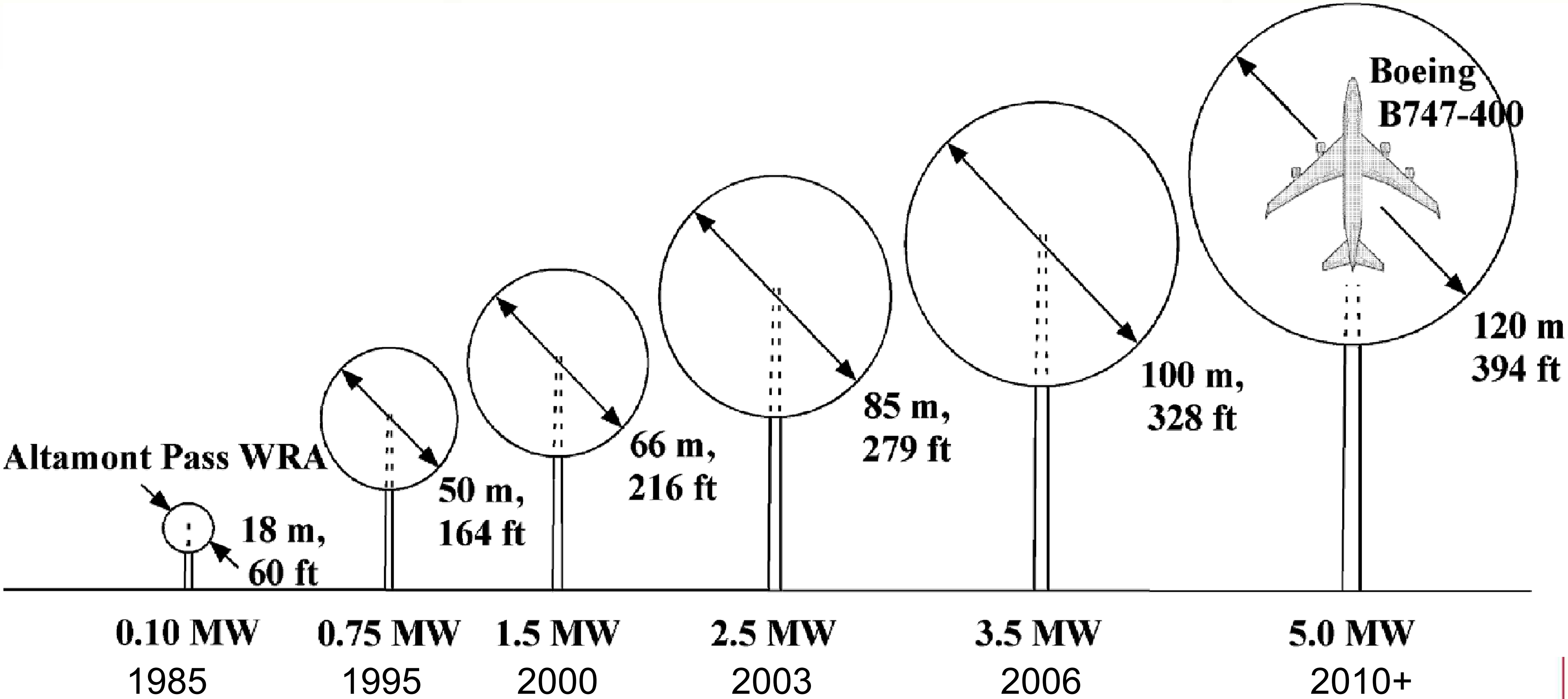
Source: DOE 2009 Wind Technologies Report

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



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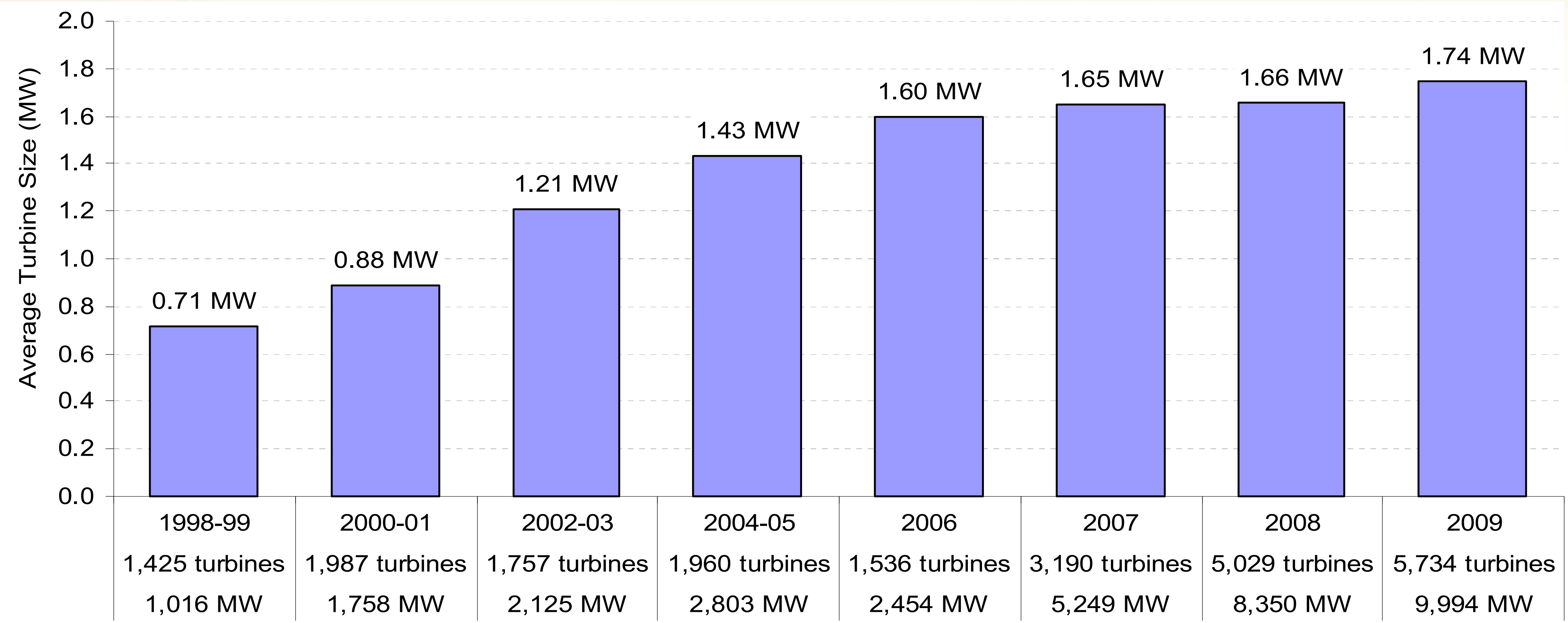
Average Turbine Size Higher in 2009



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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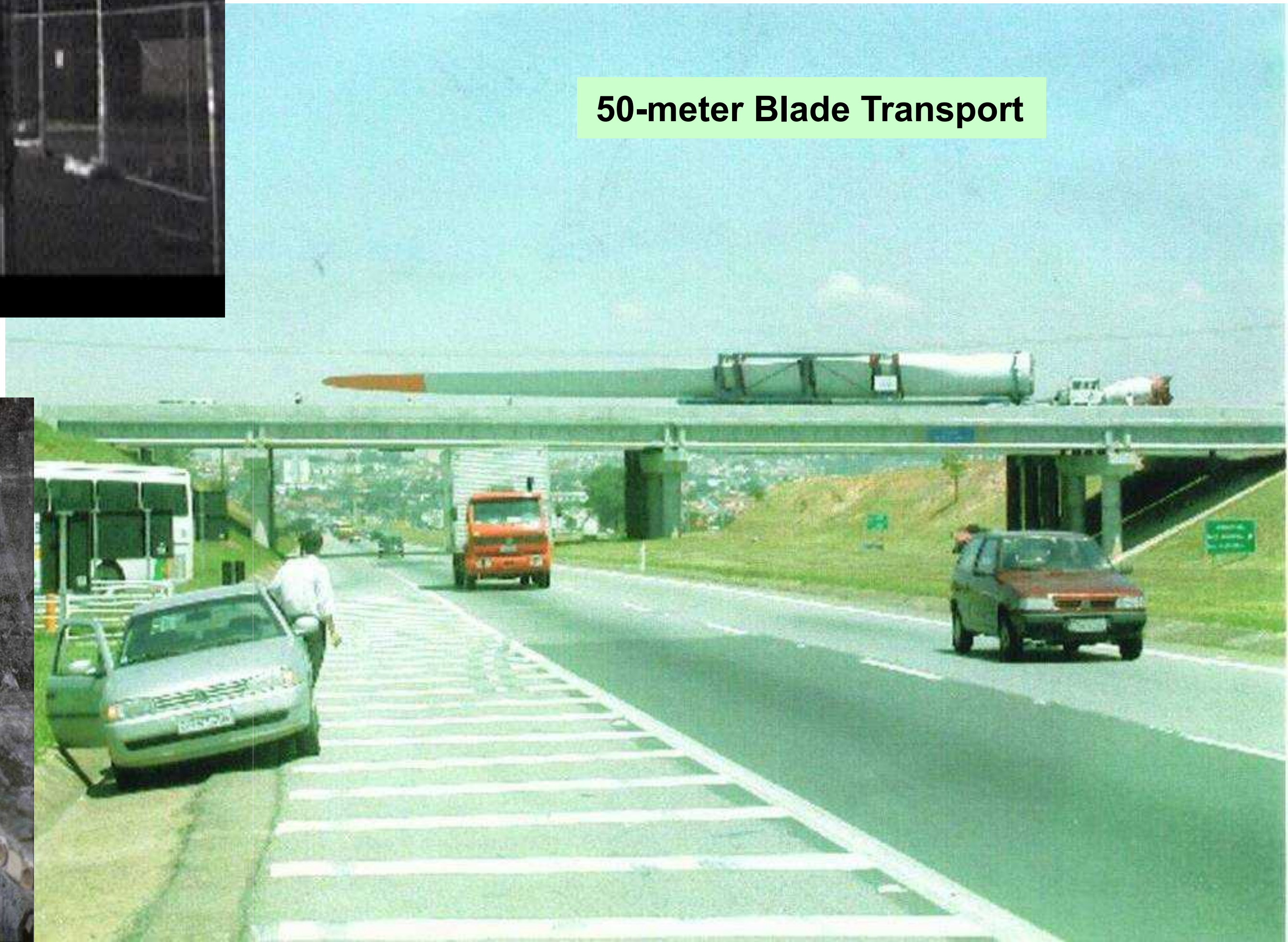
Logistics become difficult as size increases

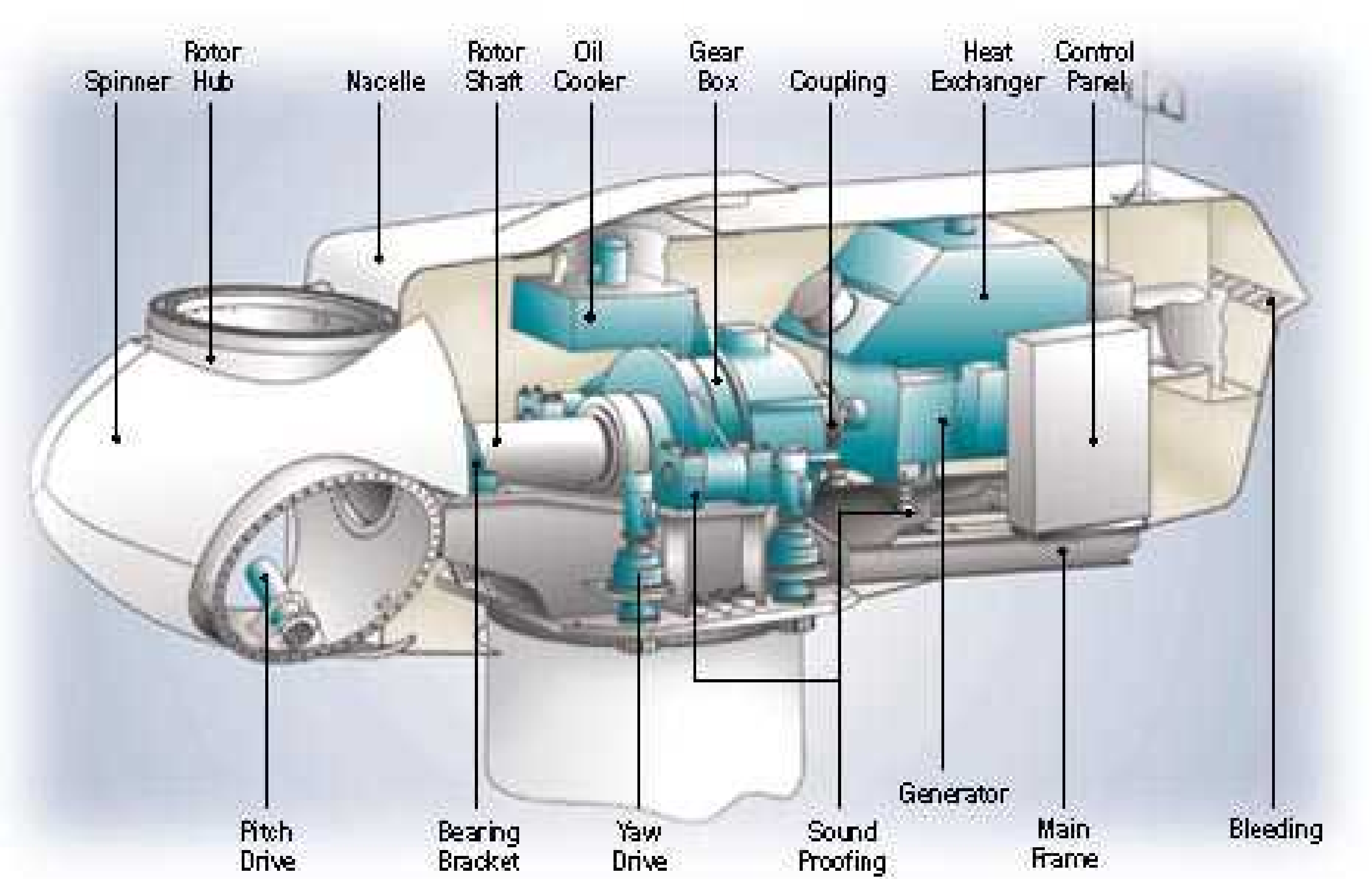
45-meter Blade Fatigue Test at NREL/NWTC

Courtesy of LM Glassfiber



50-meter Blade Transport

Typical Modern Turbine



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Taxonomy of a Wind Plant

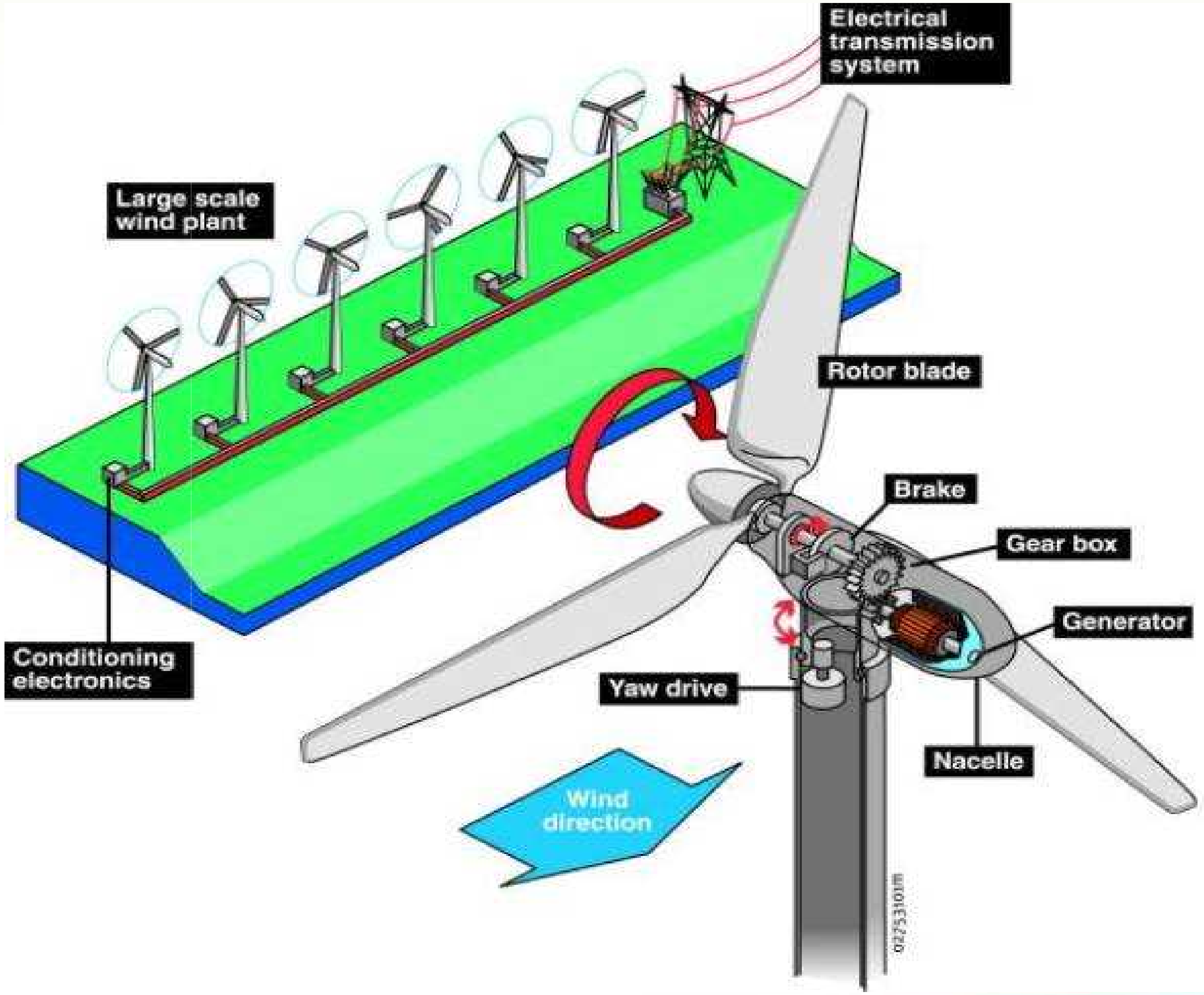
Over 8,000 individual components in a single wind turbine

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

Typical Wind Farm Components

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



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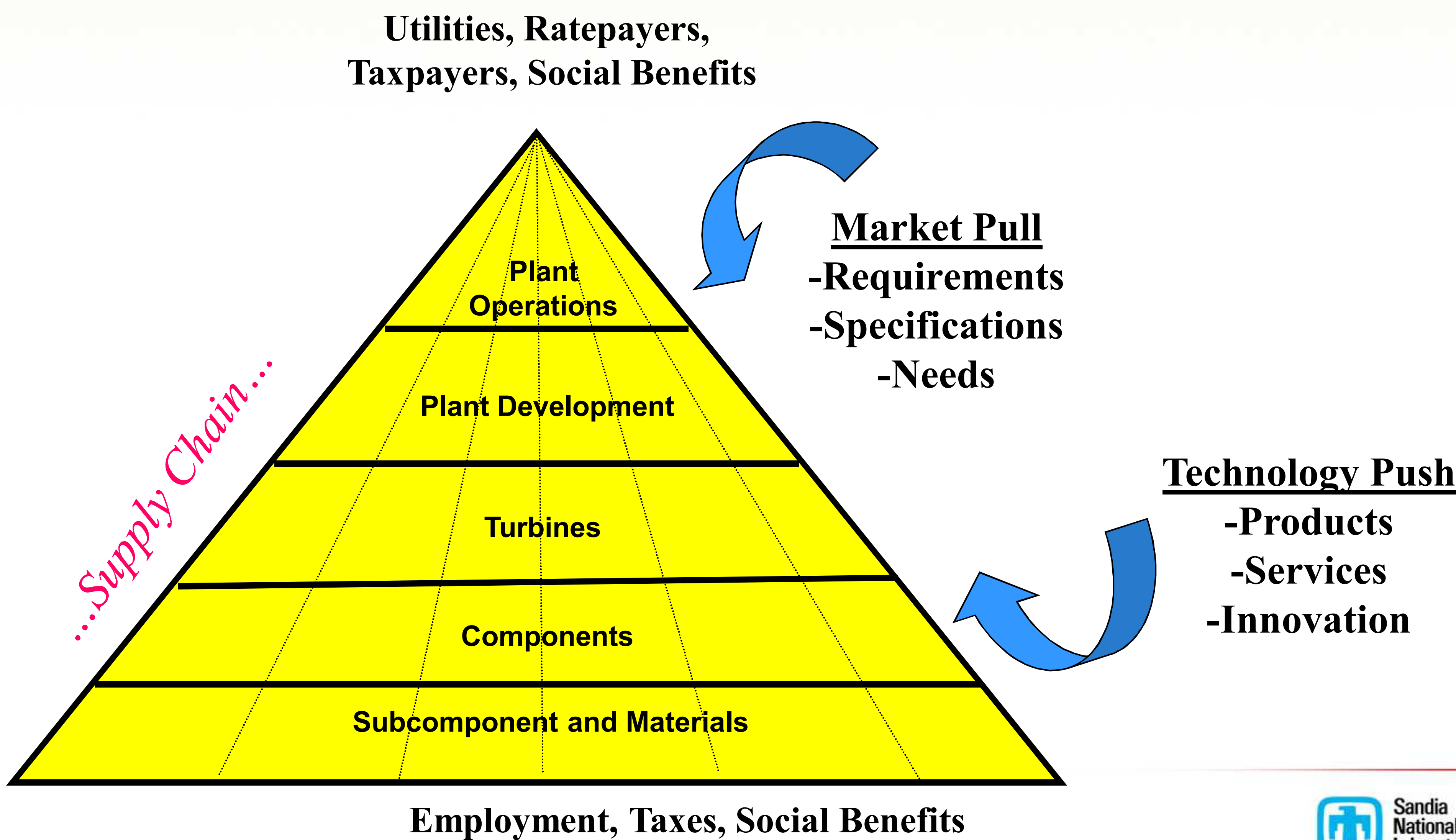
Wind Turbine Supply Chain Model



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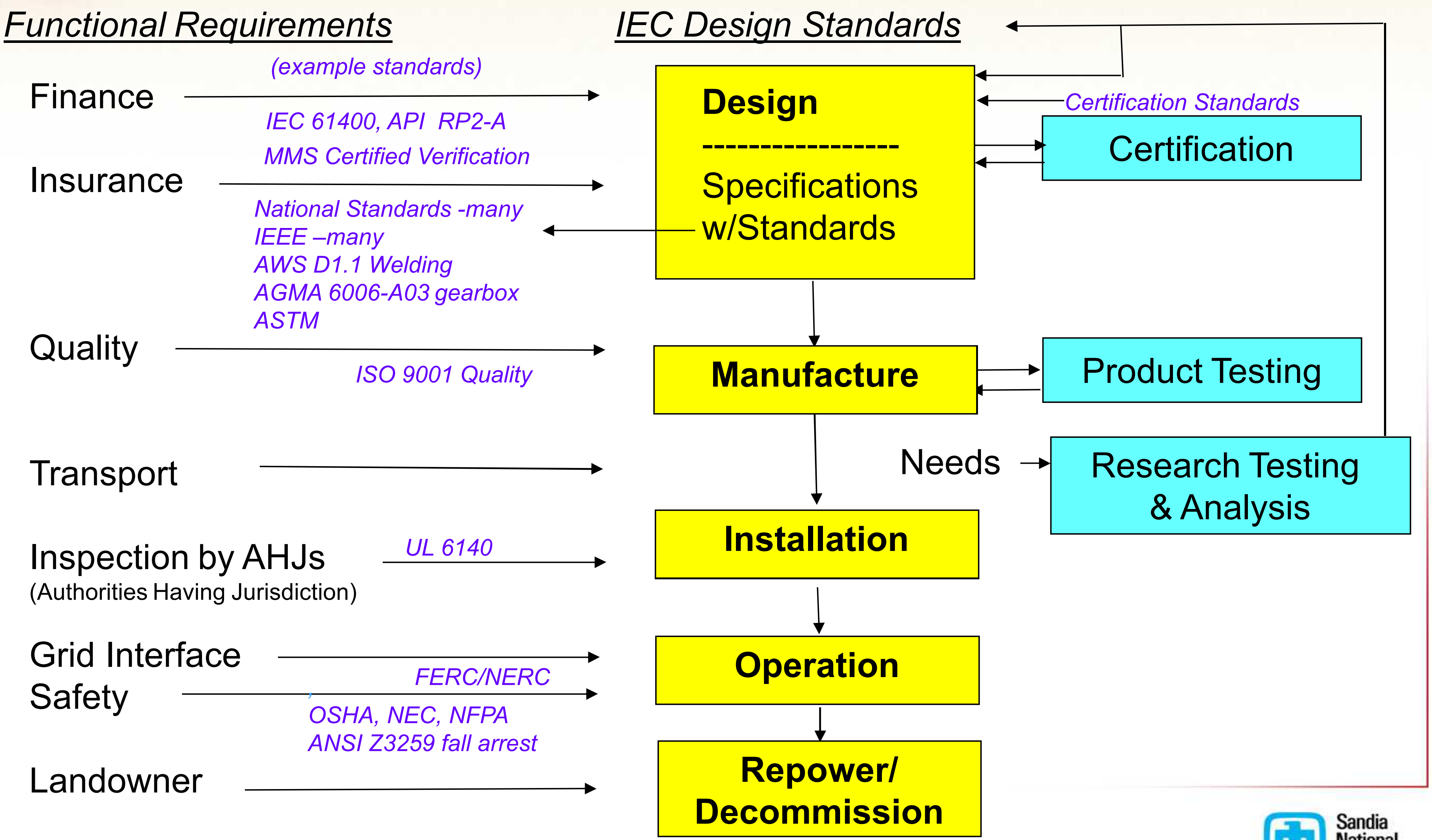
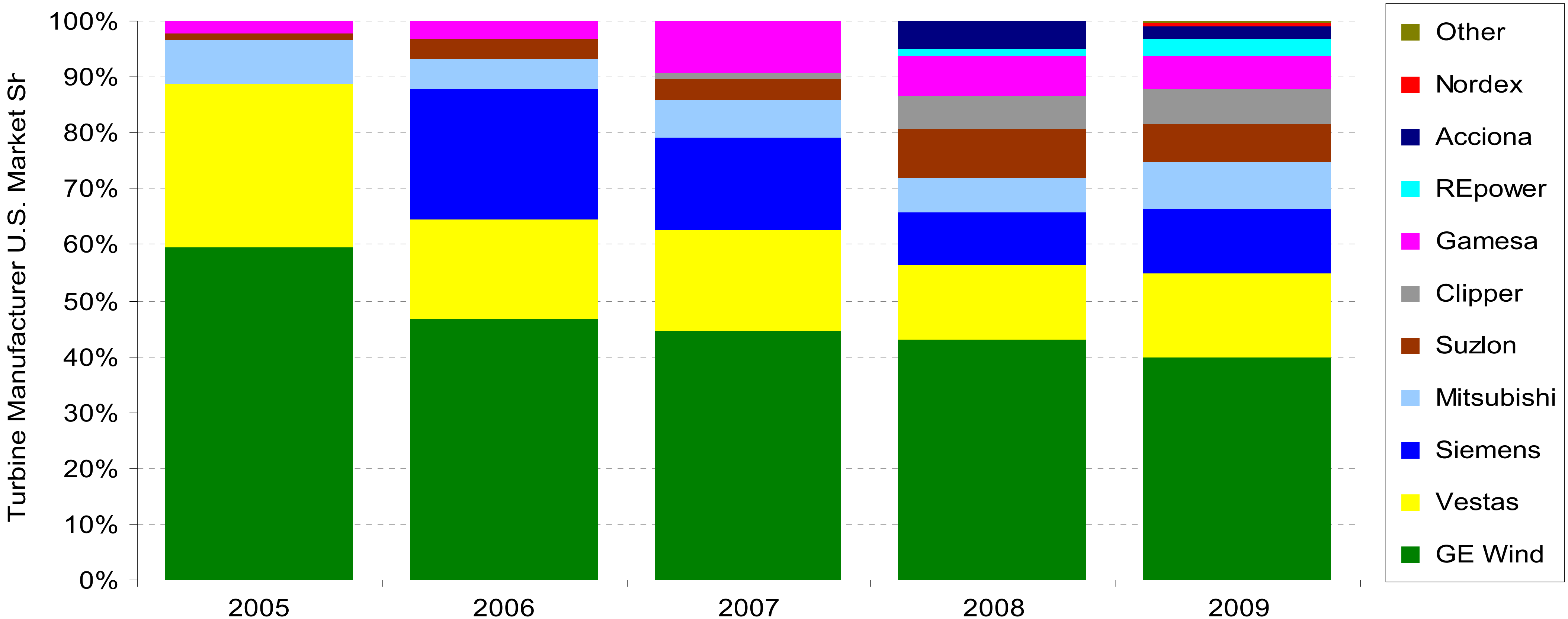
Another Perspective with Adjacent R&D Space



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 → ρ; Rotor Area → A; Wind Speed → V_∞

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

Wind Power output is proportional to wind speed cubed.

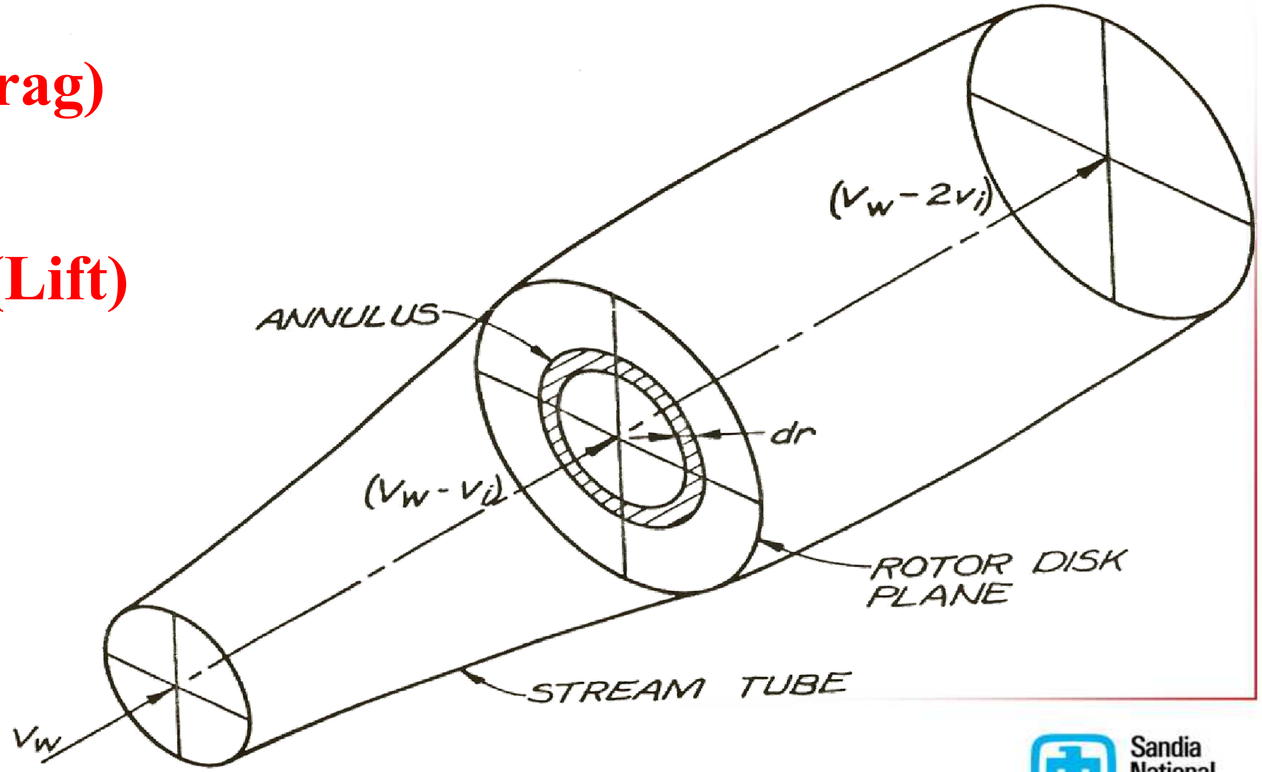
$$C_{P\max} \cong 0.3 \text{ (Drag)}$$

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

The Betz Limit

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

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



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Generation Potential

Depends on:

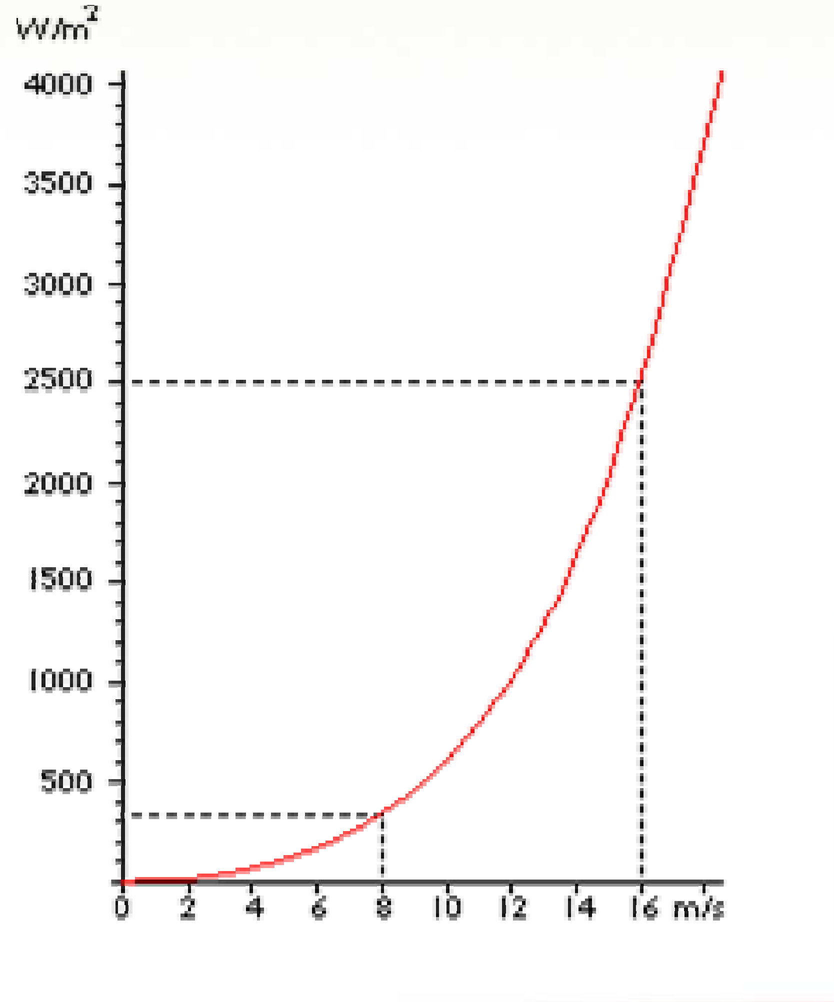
- Available resource;
- Turbulence characteristics;
- Terrain and roughness influences;
- Turbine characteristics.

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



Turbine Power Basics

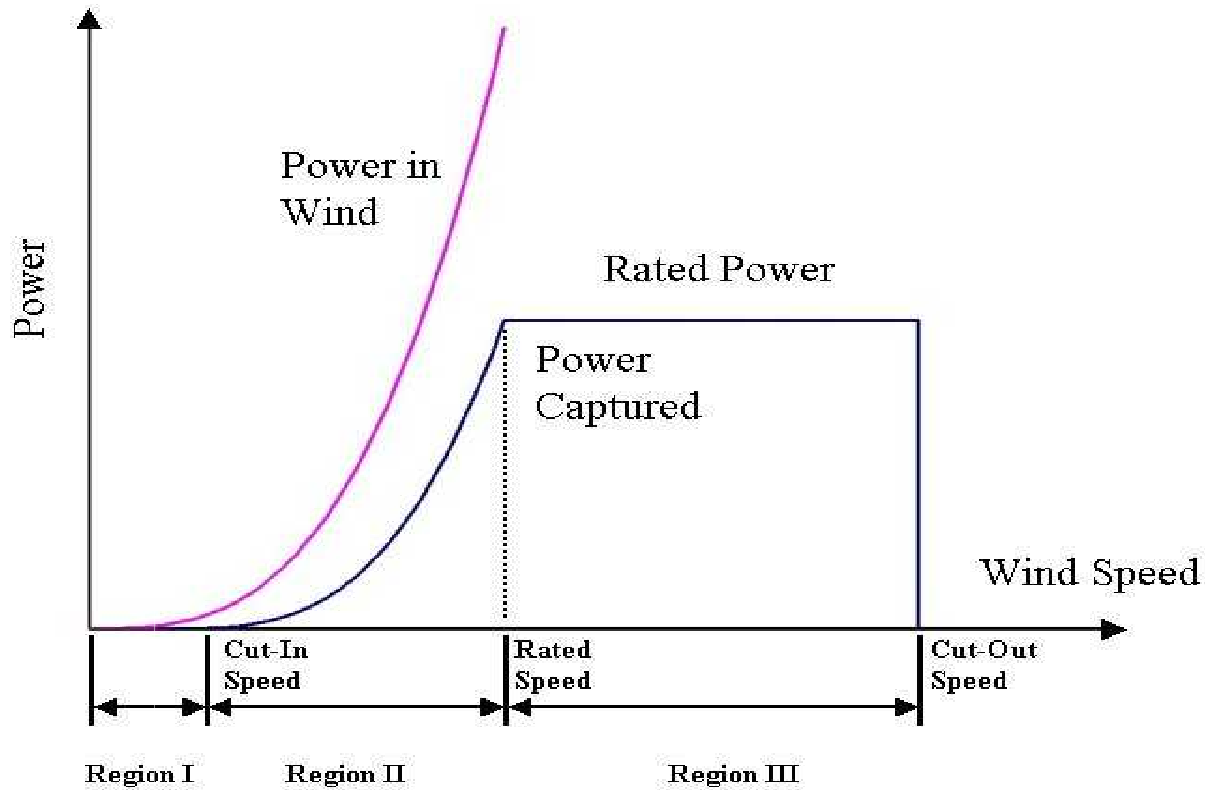
Regions of the Power Curve

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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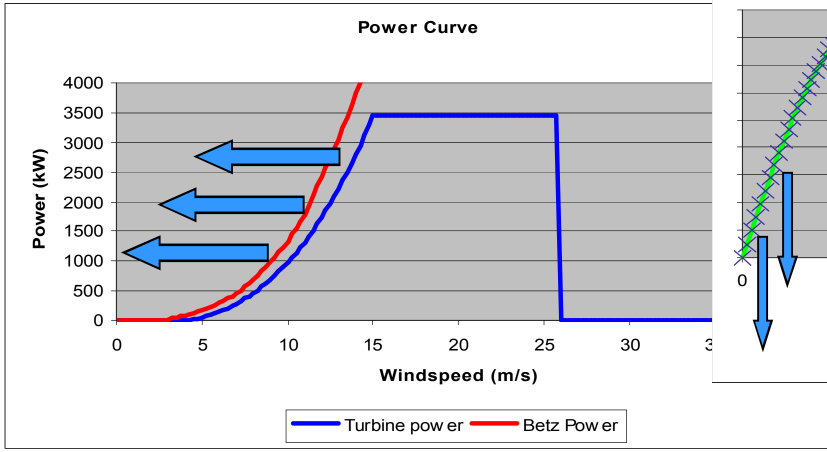
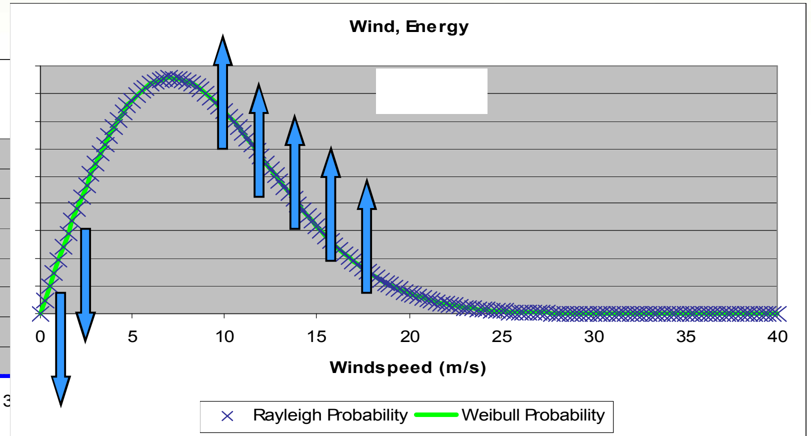
Performance Enhancement Options

Resource

Power





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

Larger Rotor

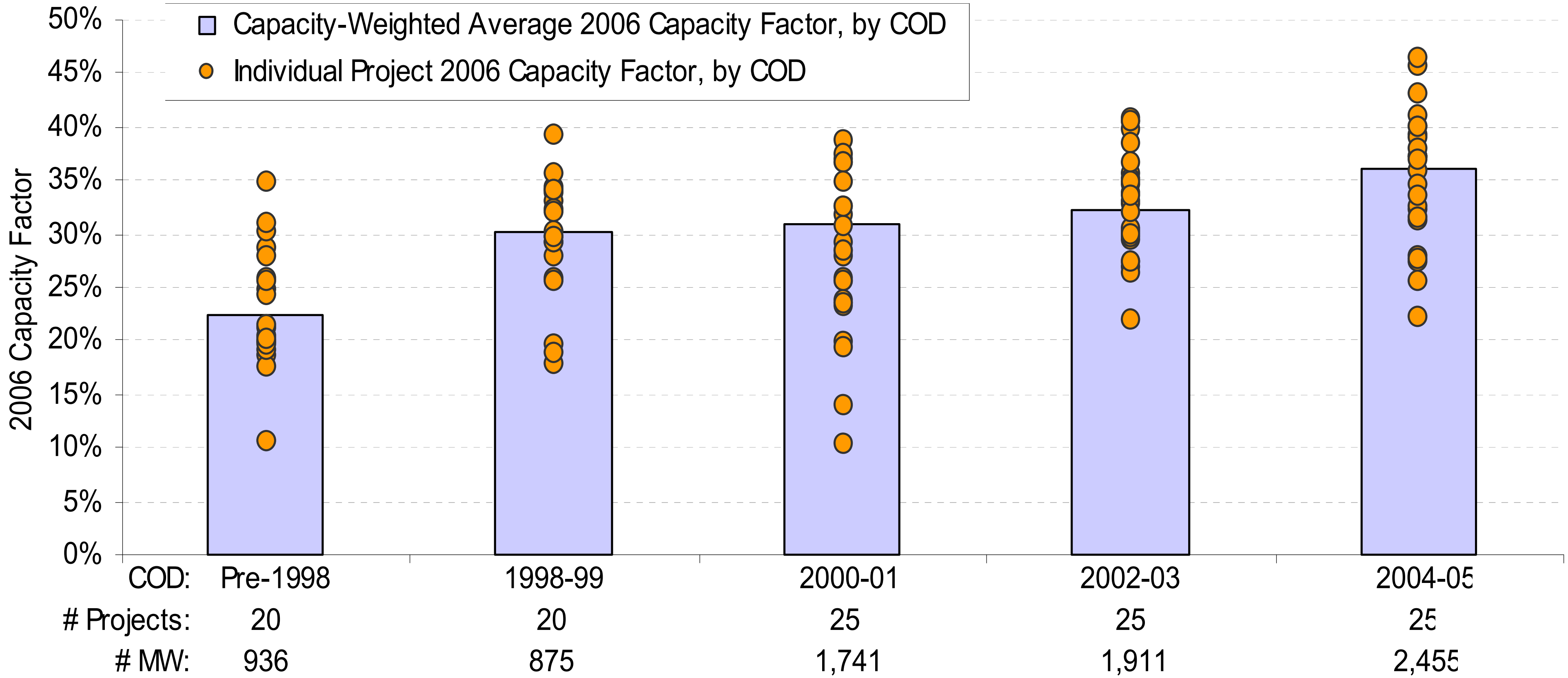
Rotor *costs* increase with diameter *cubed,* Rotor *power* grows with the diameter *squared*

Taller Tower

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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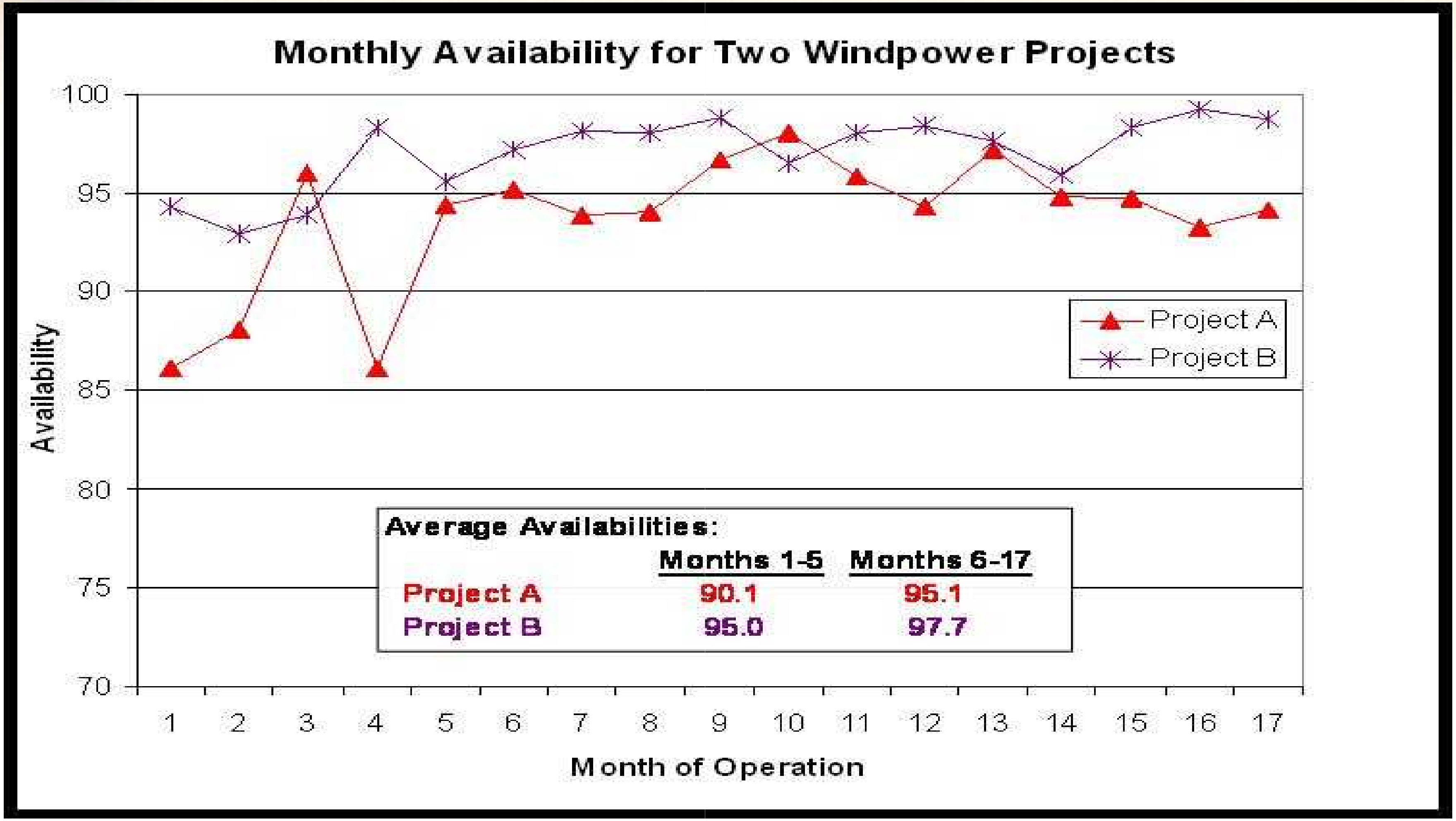
Availability



Simple Definition:

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

More detailed definitions are commonly used in contracts

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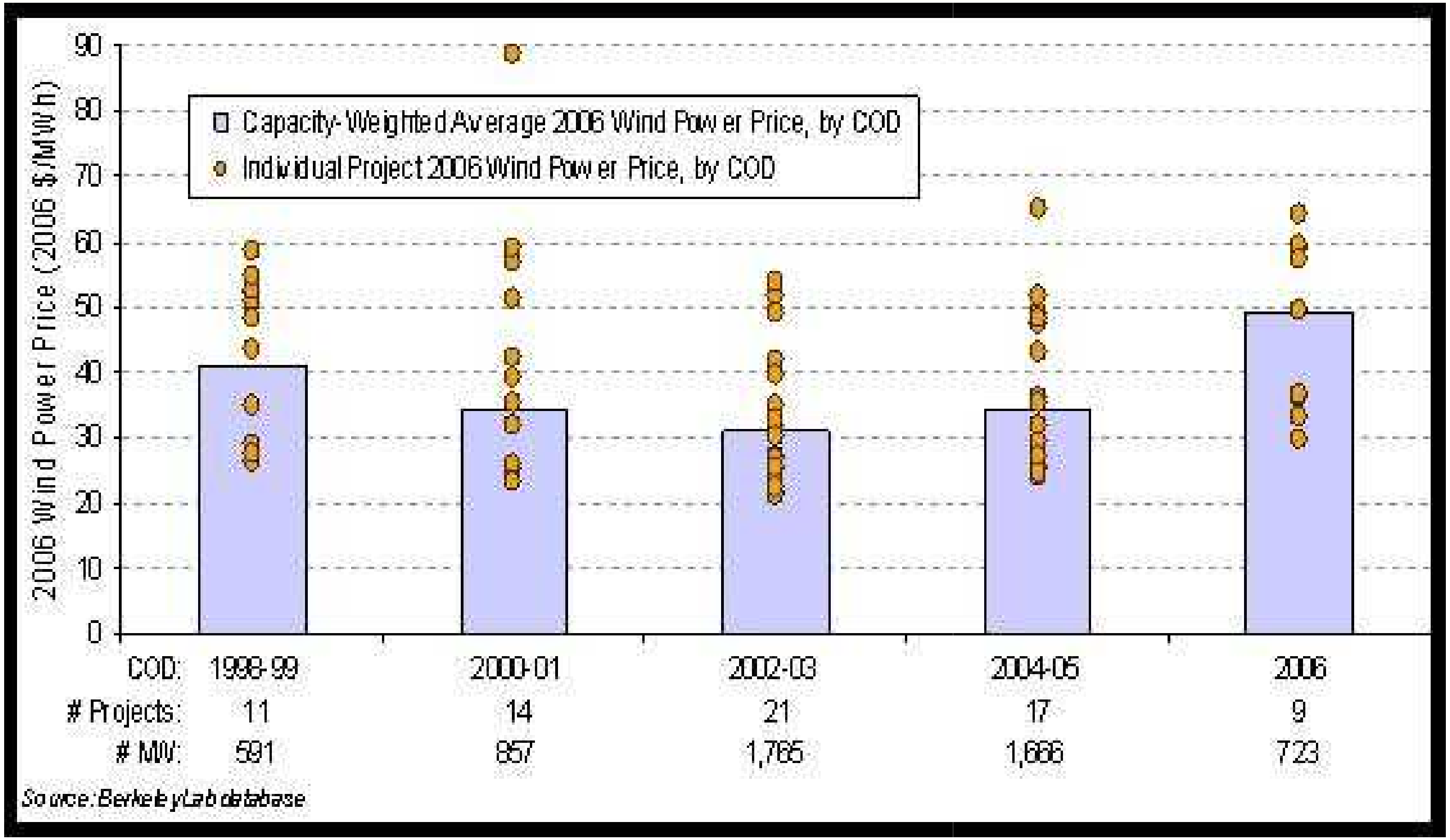
Cost of Energy: Sales Prices



Rising prices were caused by:

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

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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)

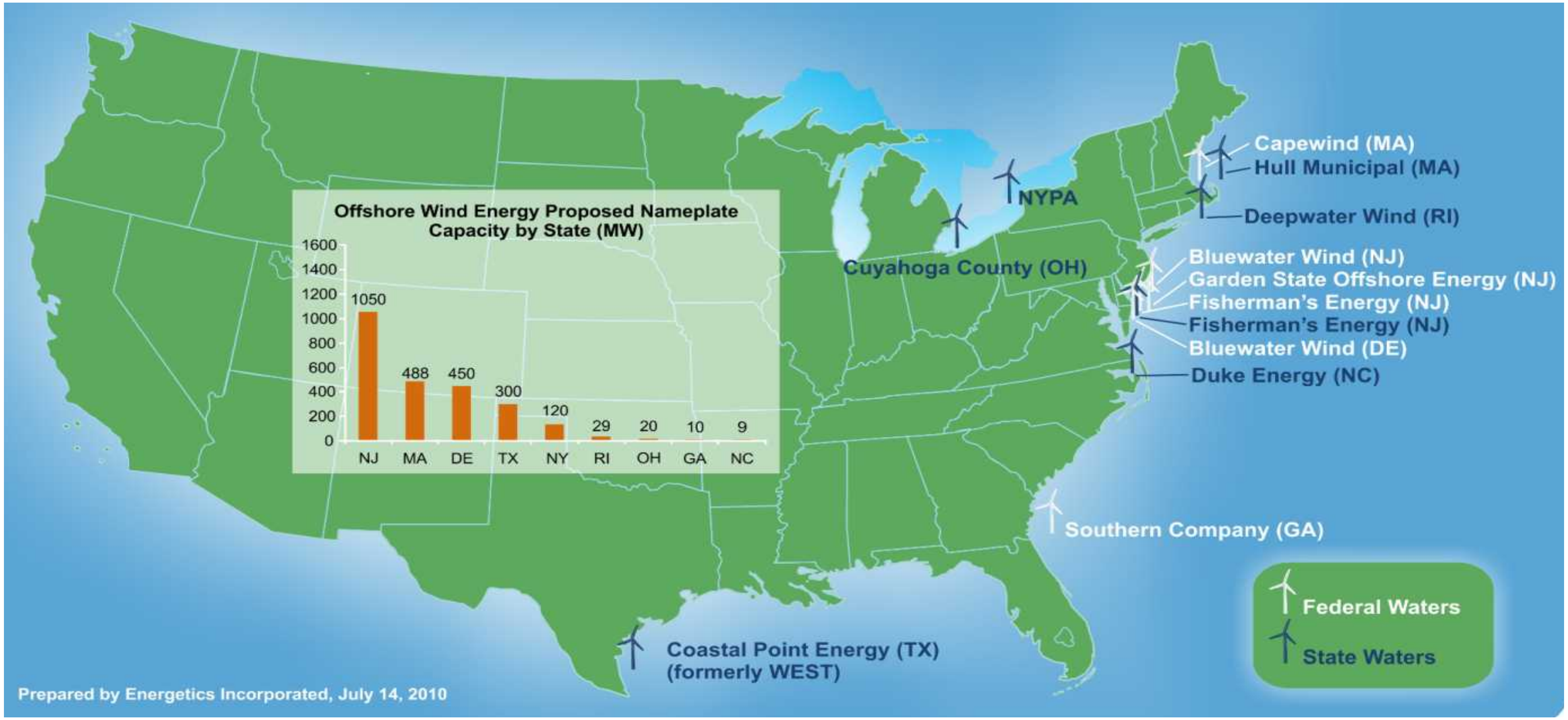
Offshore Wind

®Middelgruden.dk

Horn's Reef,
Denmark

Offshore in the United States?

- **No Offshore Projects Have Been Built in the U.S., But 13 Projects Are At a More-Advanced Permitting/Development Stage**



Cape Wind granted approval by Department of Interior in April 2010.

Source: DOE 2009 Wind Technologies Report

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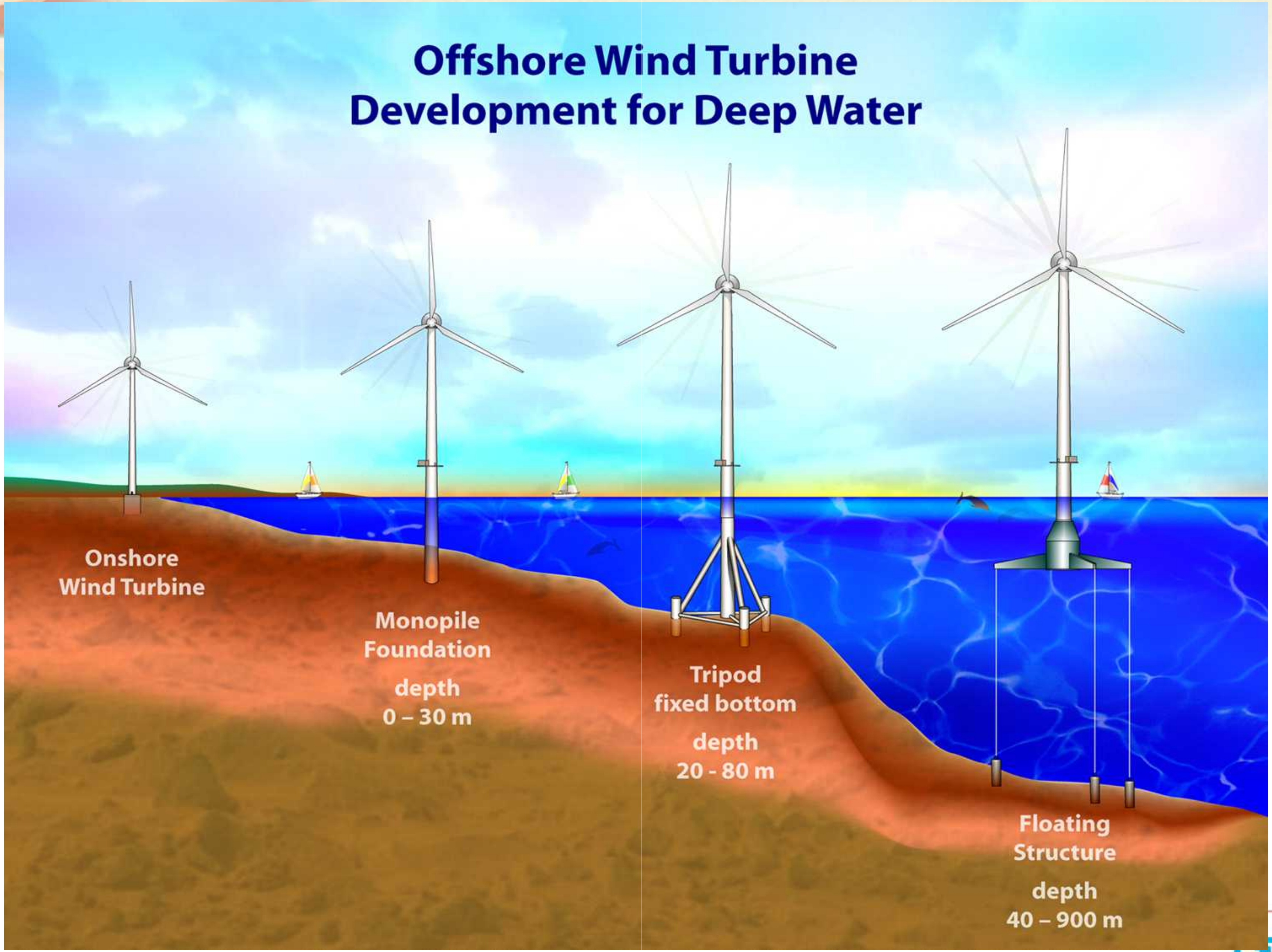

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Technology Improvement Summary
20% by 2030 Report

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)

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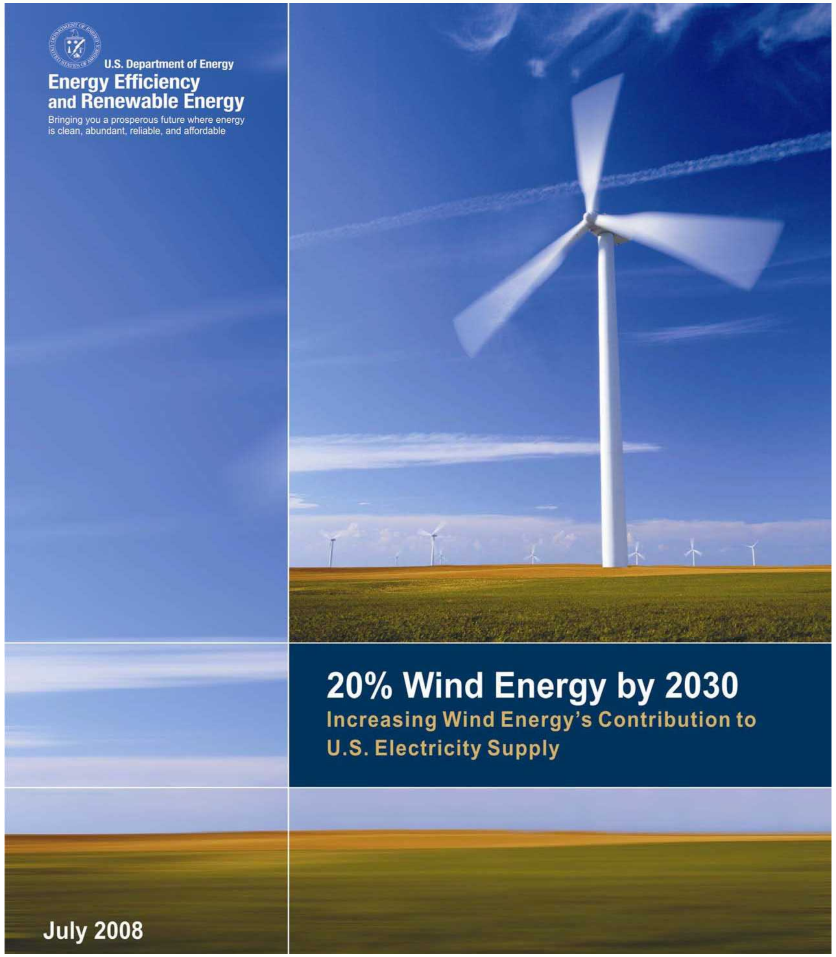
And the Conclusion is….

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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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

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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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