NATIONAL RENEWABLE ENERGY LABORATORY

Innovation for Our Energy Future

Wind Technologies and Evolving Opportunities

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NREL is a national laboratory of the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy operated by the Alliance for Sustainable Energy, LLC

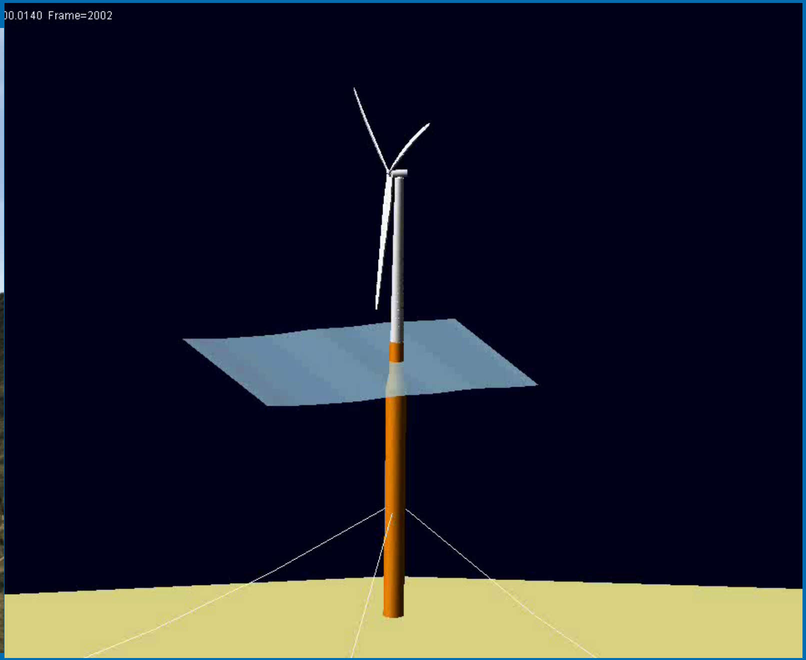
Opportunities for Wind Technology

- National Wind Technology Center – Research
  - Blades
  - Generators
  - Wind Resource
- Wind – Market Update
  - PTC
  - RPS
- Wind Technology Overview
  - Larger Rotors
  - Taller Towers
  - Improved Controls
- Wind Resource
  - Improved Assessment

National Wind Technology Center - Research

National Wind Technology Center Overview

- Turbine testing since 1977
- Leader in development of design and analysis codes
- Pioneers in component testing
- Unique test facilities
  - Blade Testing
  - Dynamometer
  - CART turbines
- Modern utility-scale turbines
- Approx. 150 staff on-site
- Budget approx. $35M
- Many CRADAs with industry
- Leadership roles for international standards



National Wind Technology Center Vision

The NWTC will be an <u>essential</u> partner for the technical development and large-scale deployment of wind power.

Goals:

- Improve windplant power production
- Reduce windplant capital cost
- Improve windplant reliability and lower O&M cost
- Eliminate barriers to large-scale deployment

LCOE

Blade Testing Facilities

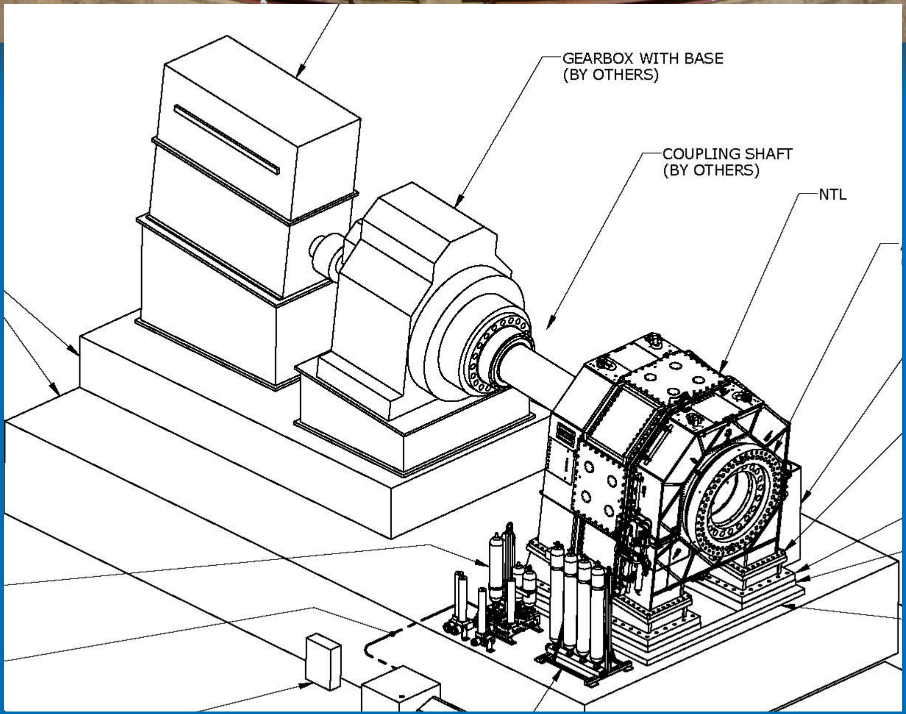
- NREL has developed and patented advanced blade testing
- NREL supports R&D blade testing for DOE and industry
- Supporting development of new blade test facilities worldwide

New Large Blade Test Facility:

- Boston, MA with Massachusetts Technology Collaborative
- Static and Fatigue tests of blades up to 90 m
- NREL staff to operate facility

Drivetrain Testing

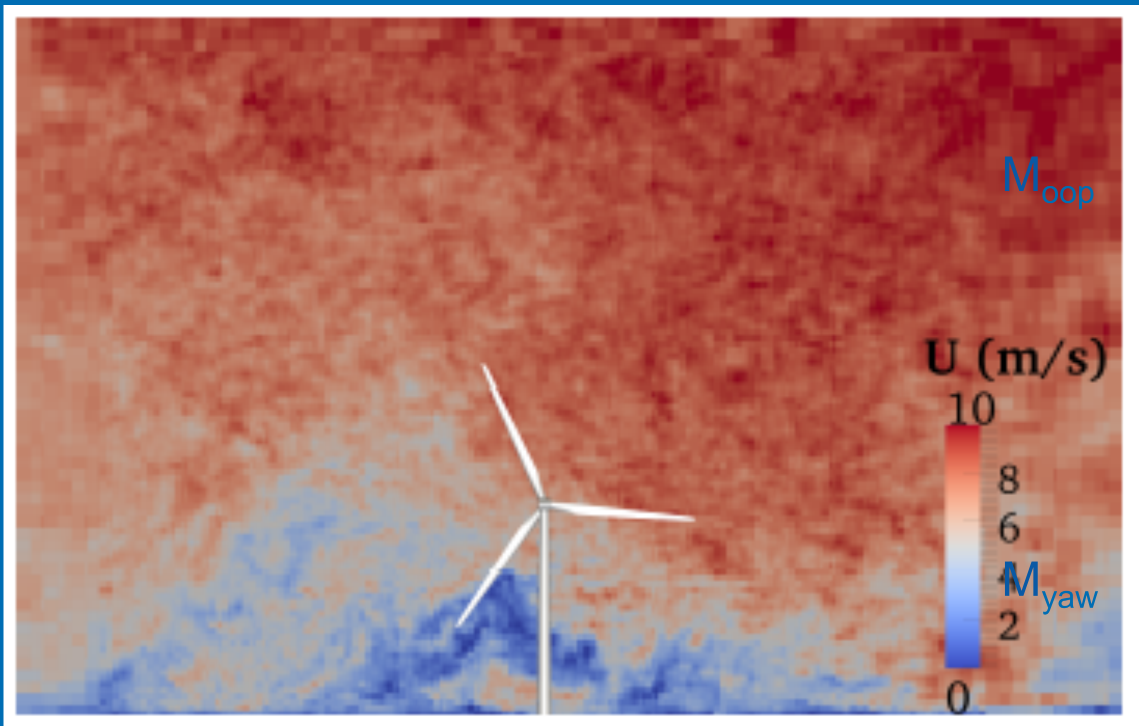
- 2.5 MW Dynamometer
  - Commissioned 1999
  - Steady use by industry
  - Used in R&D activities
  - Key facility for Gearbox Reliability Collaborative
  - Basic shaft load capability added in FY2010
- Dynamometer Upgrade
  - $10M Recovery Act funding
  - New 5 MW driveline
  - Robust shaft loading system
  - Commissioniedin 2013

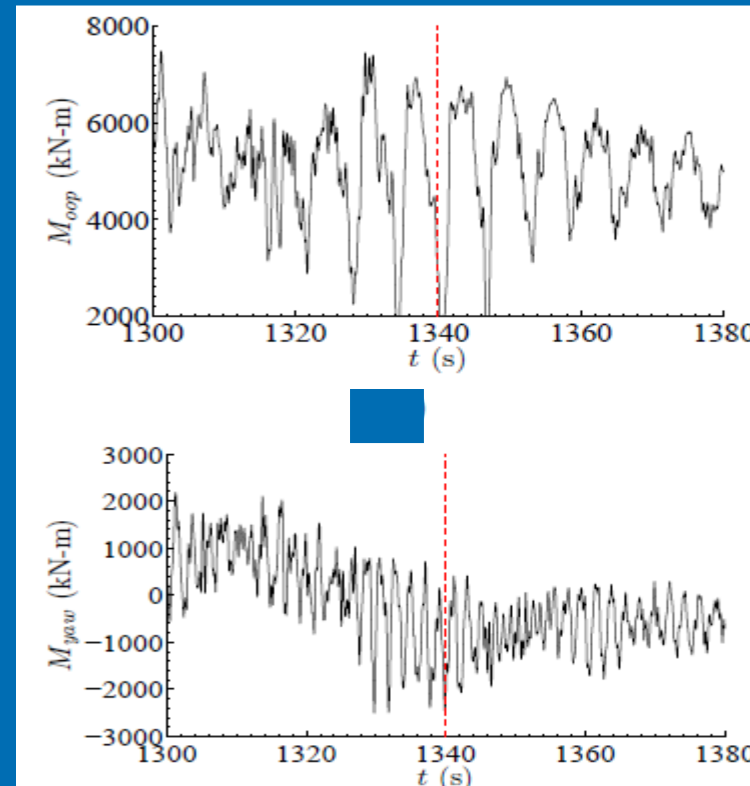


Windplant Aerodynamics Problem

- Power performance and reliability influenced reduced in arrays.
- Understanding inflow / array interaction is key.
- Computational models, control paradigms and hardware development will be required.
- Requires a detailed understanding of:
  - Rotor Wake Interactions
  - PBL Characteristics
  - Inflow / Wind farm Interaction
  - Complex Terrain Effects
- Major "Grand Challenge"

Physics-Based Array Aerostructural Dynamics





Interaction with low speed streak

Wind – Market Trends

Wind –Market Update - Worldwide

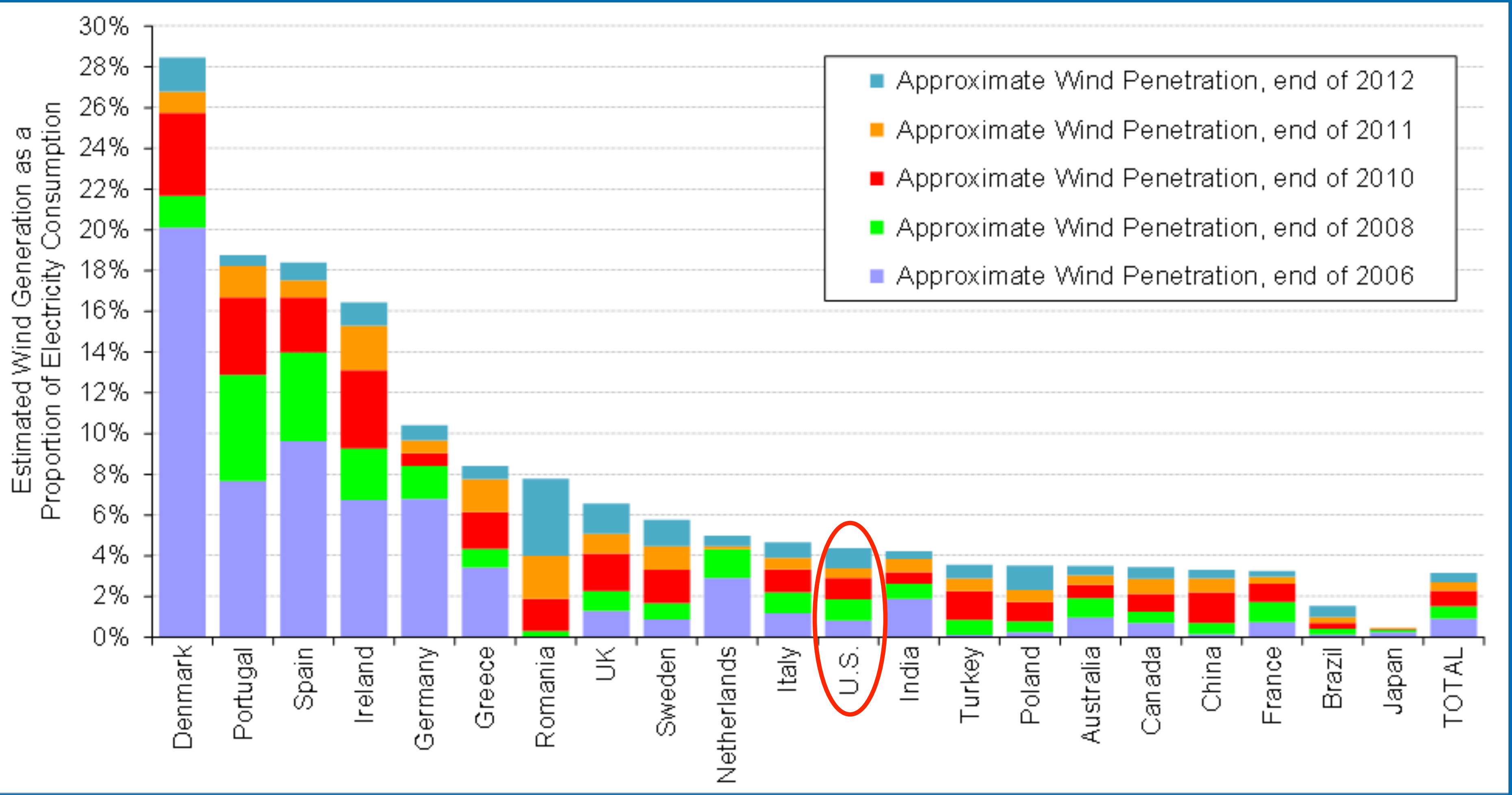
Table 1. International Rankings of Wind Power Capacity

Annual Capacity (2012, MW)		Cumulative Capacity (end of 2012, MW)	
United States	13,131	China	75,372
China	12,960	United States	60,005
Germany	2,415	Germany	31,467
India	2,336	Spain	22,462
United Kingdom	1,958	India	18,602
Italy	1,272	United Kingdom	9,113
Spain	1,112	Italy	7,998
Brazil	1,077	France	7,593
Canada	936	Canada	6,214
Romania	923	Portugal	4,363
Rest of World	6,838	*Rest of World*	42,368
TOTAL	**44,958**	**TOTAL**	**285,558**

Source: Navigant; AWEA project database for U.S. capacity

Source: http://www.windpoweringamerica.gov/pdfs/workshops/2013_summit/wiser.pdf
2012 Wind Technologies Market Report Summary, WPA All-States Summit, May 8, 2013

Wind As a Percentage of Electricity Consumption



Note: Figure only includes the countries with the most installed wind power capacity at the end of 2012

Source: http://www.windpoweringamerica.gov/pdfs/workshops/2013_summit/wiser.pdf
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Wind Power Additions Hit a New Record in 2006

PTC- Driven Results

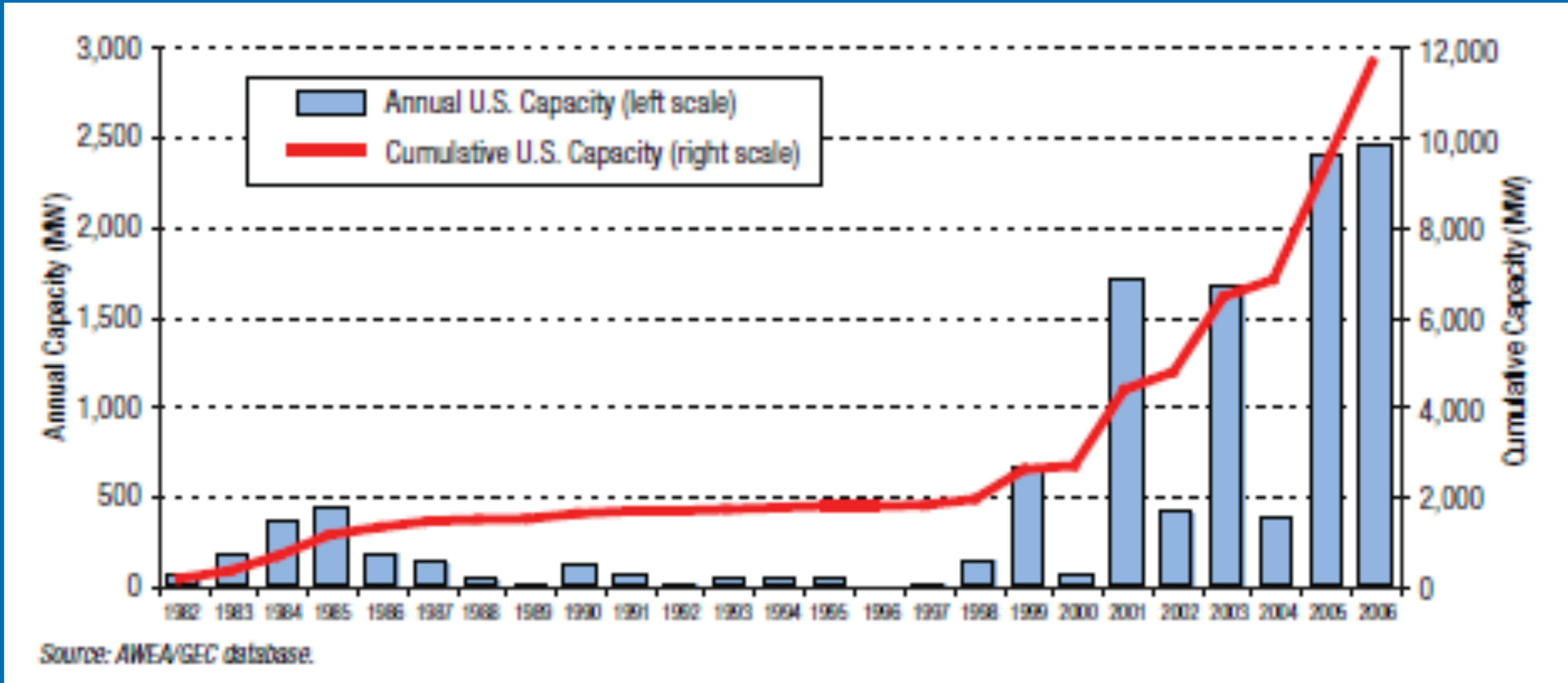
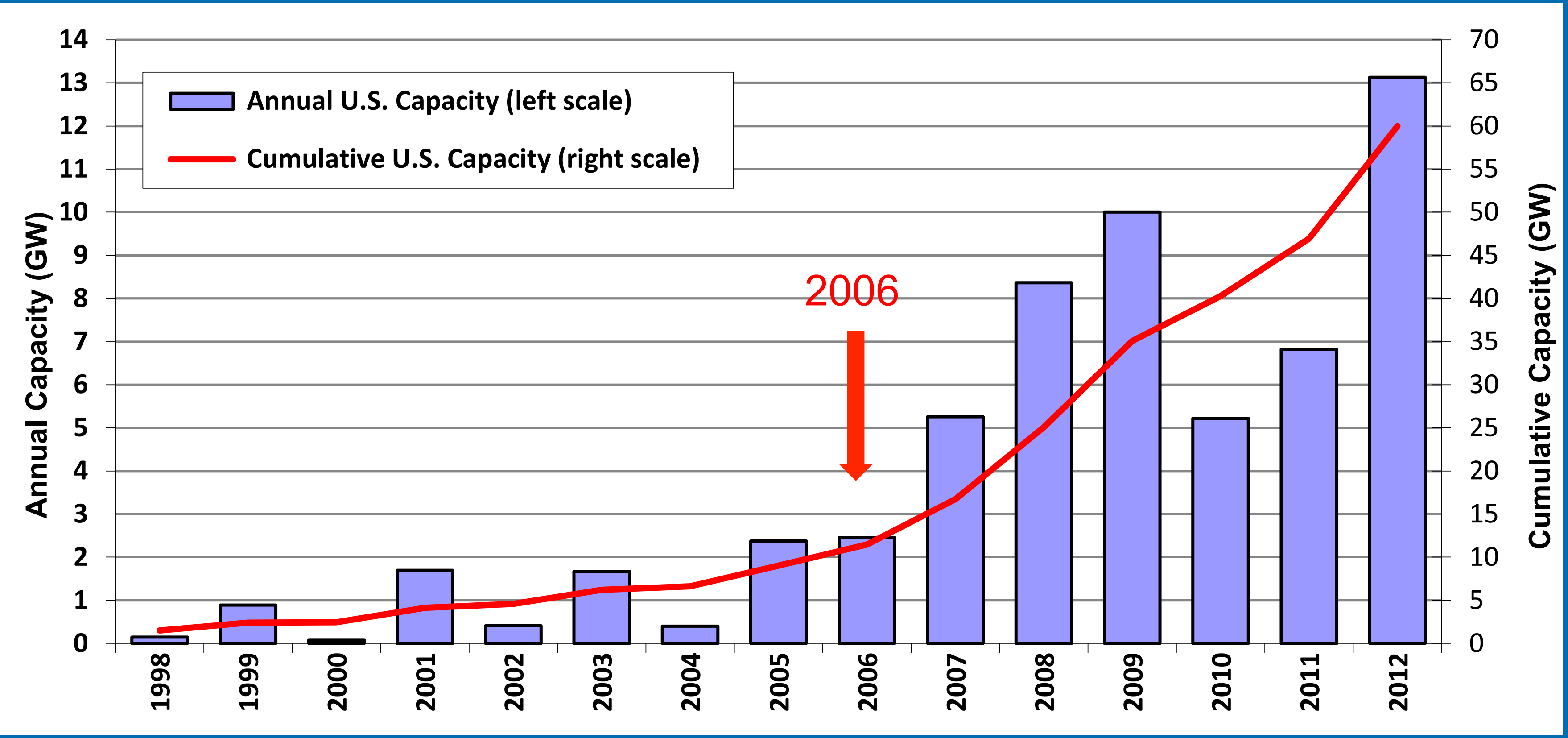


Figure 1. Annual and Cumulative Growth in U.S. Wind Power Capacity

Source: http://www.windpoweringamerica.gov/pdfs/workshops/2006_summit/wiser.pdf
2006 Wind Technologies Market Report Summary,

Wind Power Additions Hit a New Record in 2012

Expiring PTC- Driven Results



Source: http://www.windpoweringamerica.gov/pdfs/workshops/2013_summit/wiser.pdf
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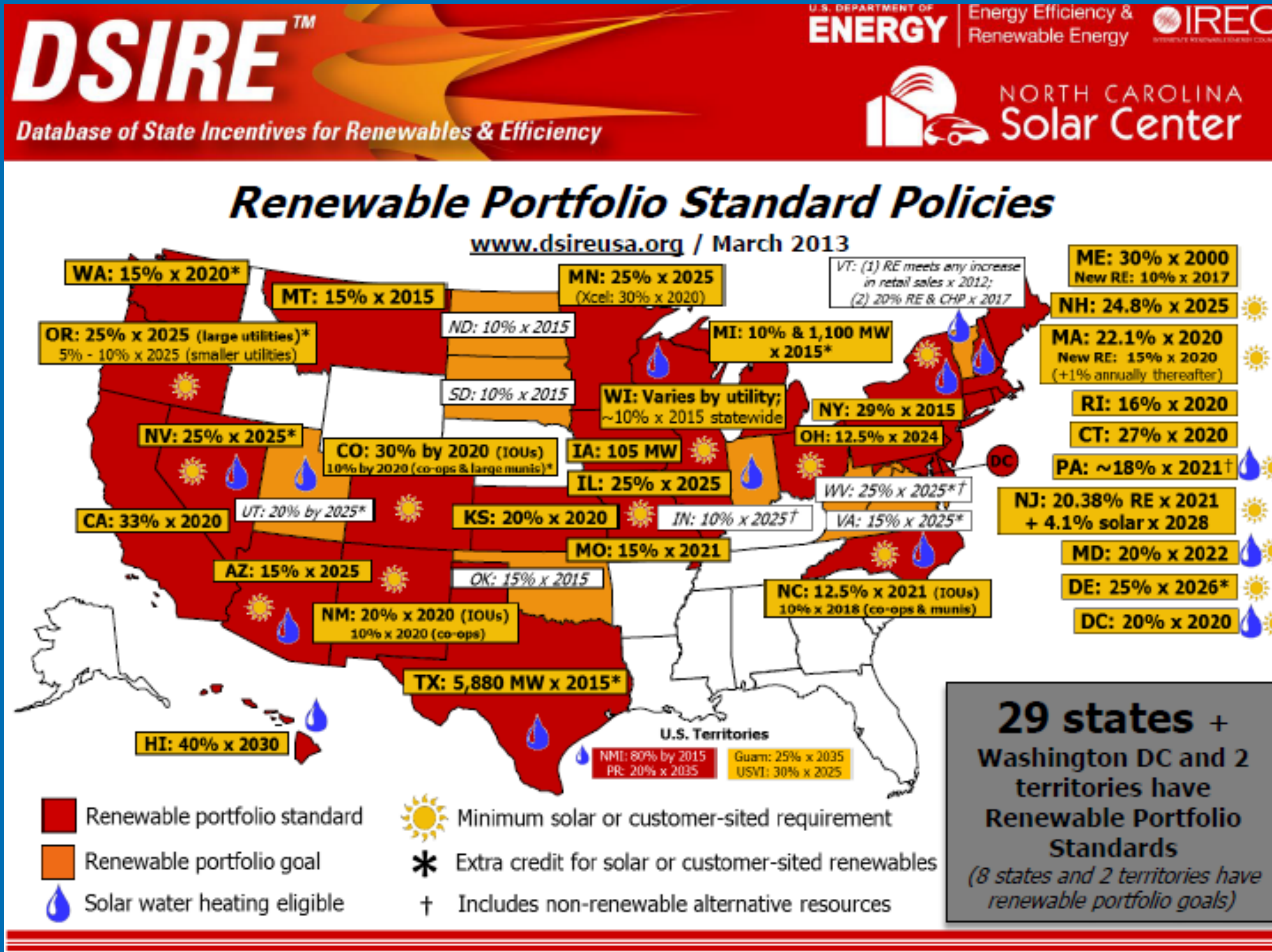
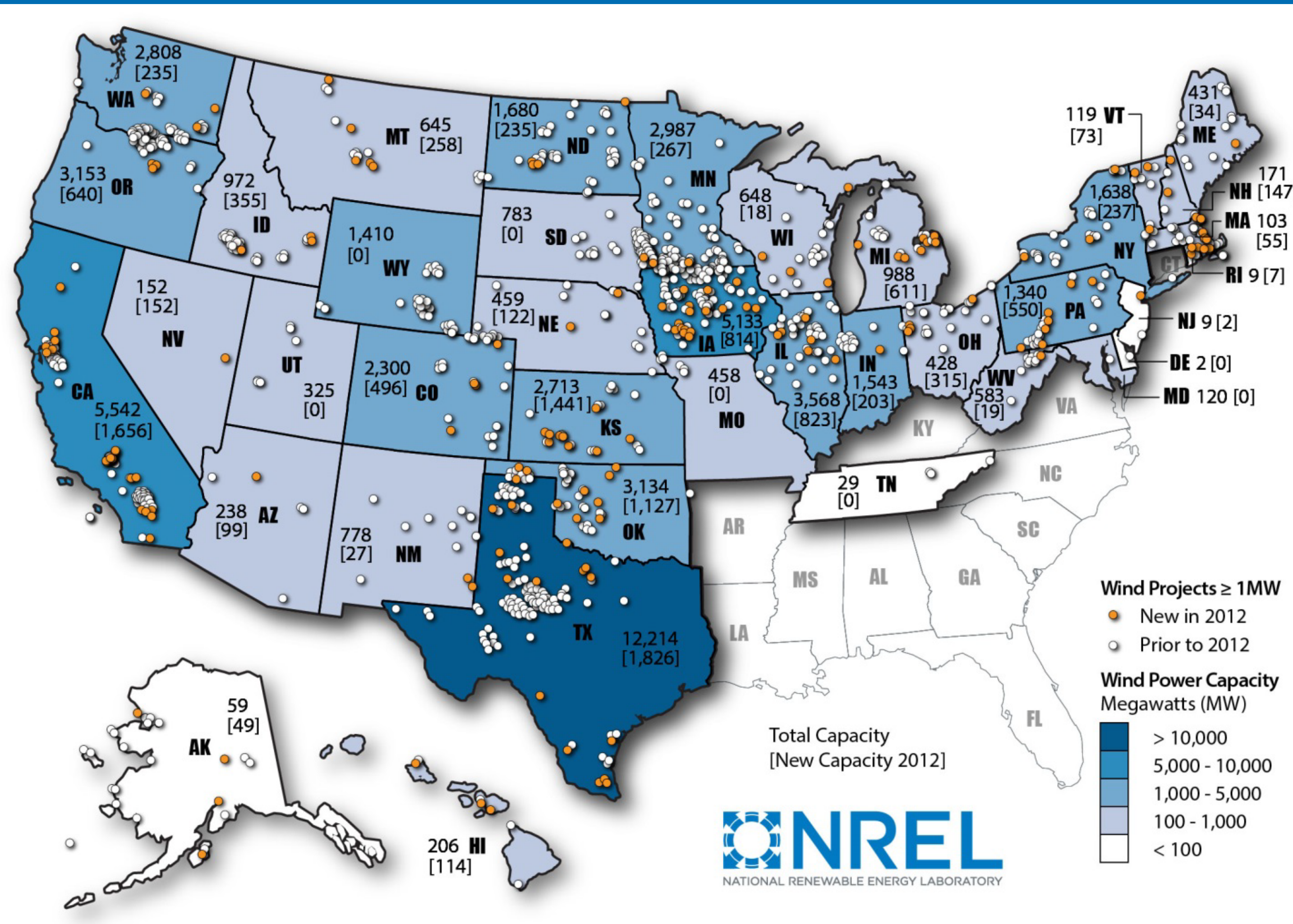
Incentives – Renewable Portfolio Standards (RPS)



Wind Capacity – State by State



At end of 2012:

- Texas > 2 X wind capacity as any other state
- 22 states had >500 MW of capacity (15 > 1 GW, 10 > 2 GW)
- 2 states >20% of total in-state generation from wind (9 > 10%, 17 > 5%)

Source: http://www.windpoweringamerica.gov/pdfs/workshops/2013_summit/wiser.pdf
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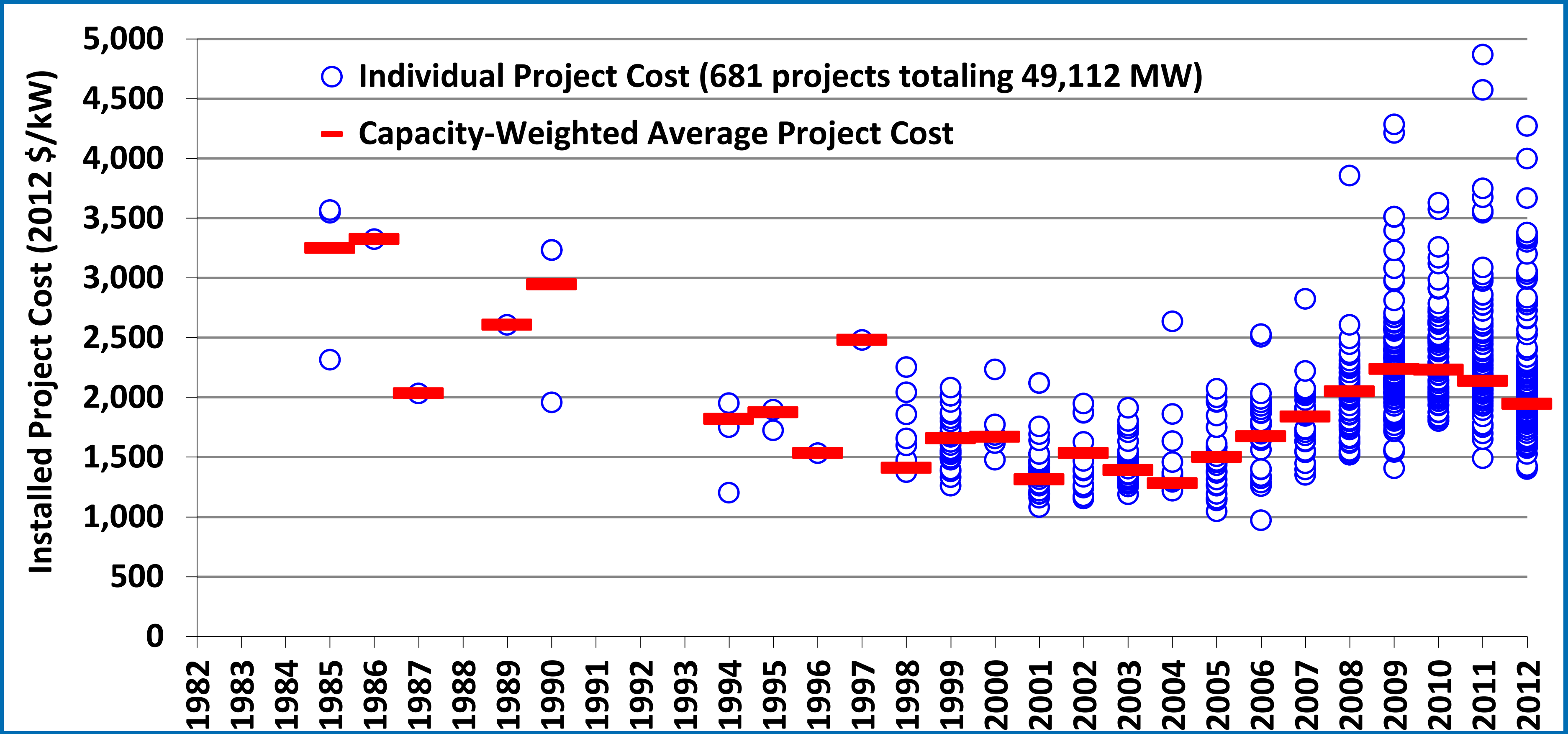
Lower Turbine Pricing Starting To Show Up In Reported Total Project Costs



Source: http://www.windpoweringamerica.gov/pdfs/workshops/2013_summit/wiser.pdf
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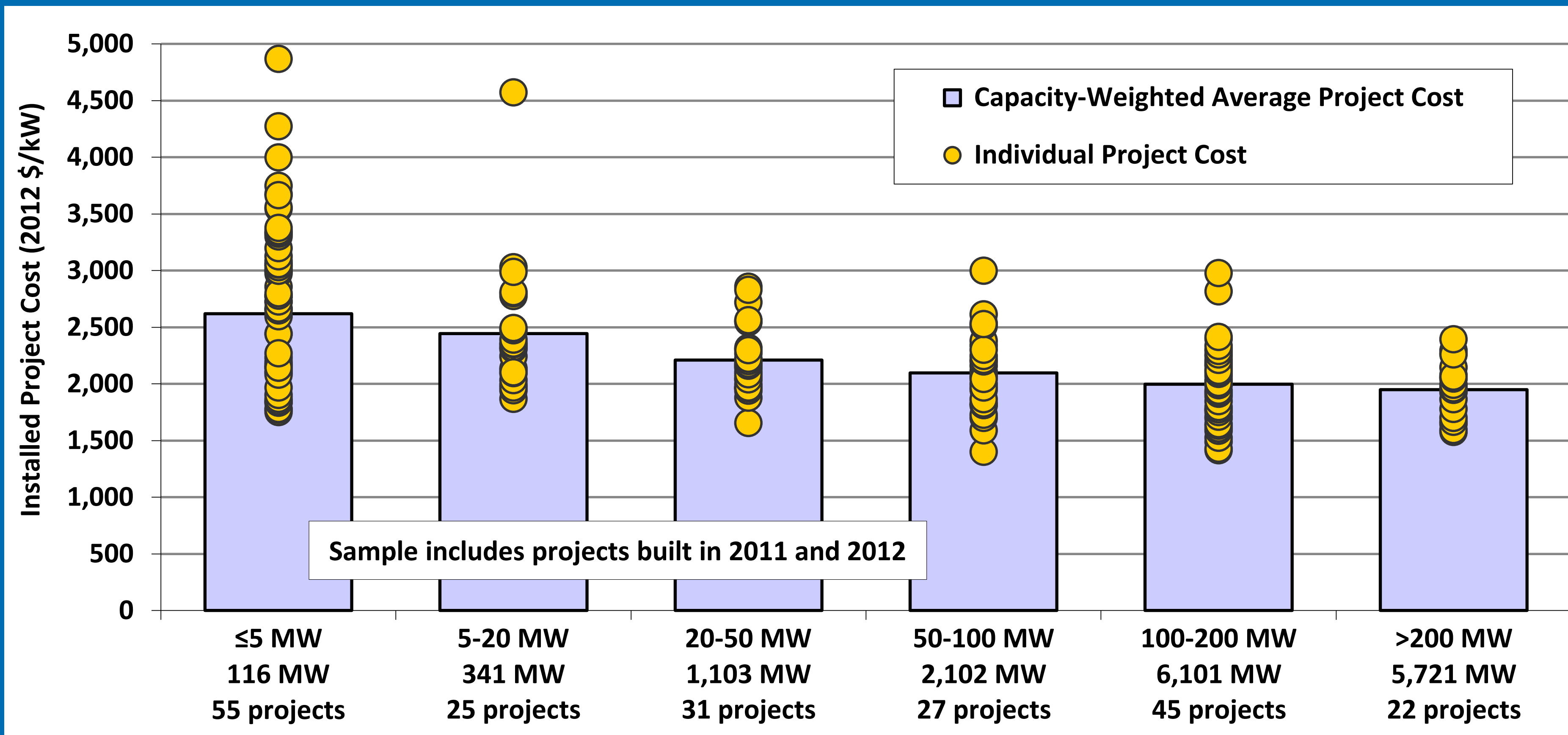
Economies of Scale – Project Size Matters



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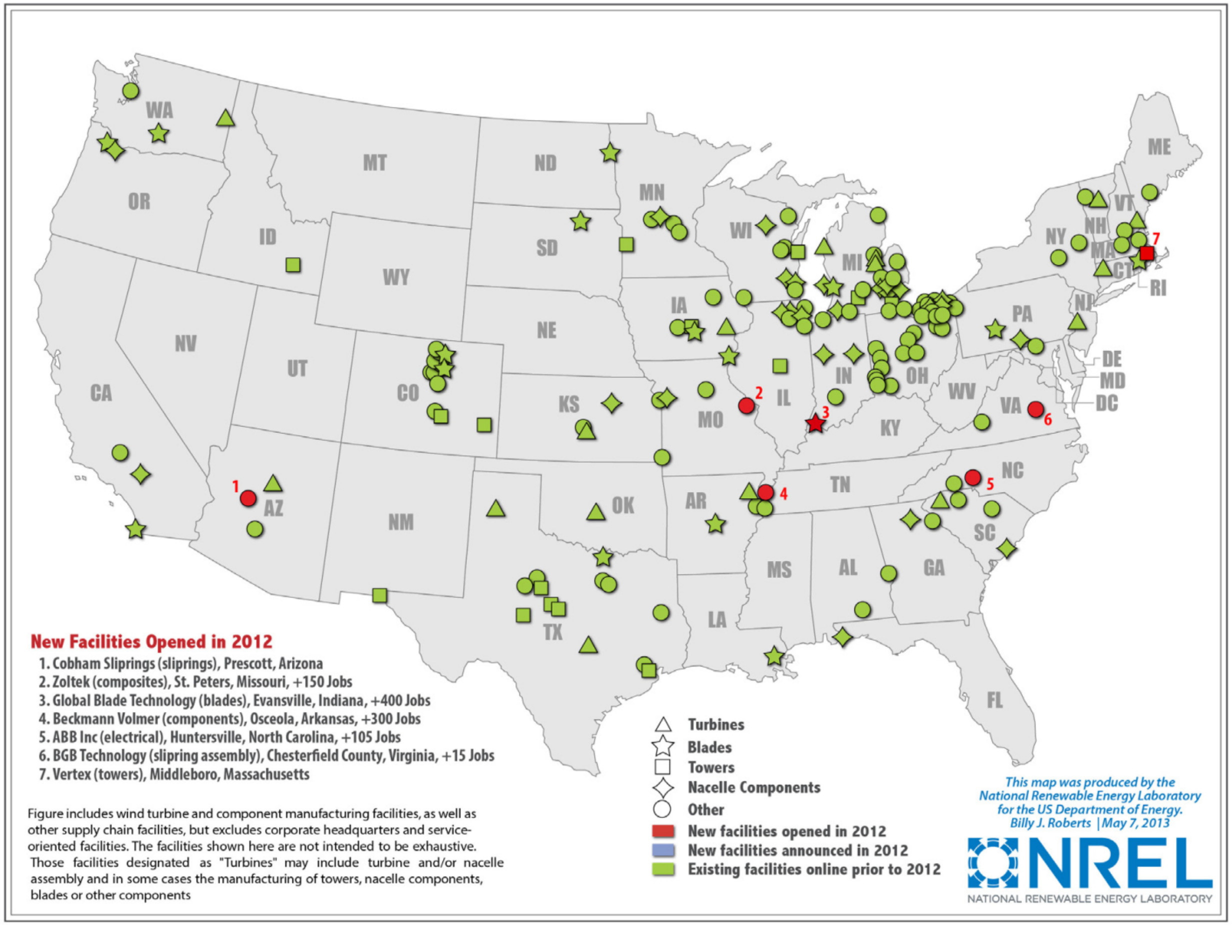
Domestic Manufacturing of Wind



Over 160 manufacturing plants capable of producing 12 GW/yr

Source: http://www.windpoweringamerica.gov/pdfs/workshops/2013_summit/wiser.pdf
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1,000 MW of New Wind Power in Colorado

JEDI Model Version W1.09.03e

Wind energy's economic "ripple effect"

Project Development & Onsite Labor Impacts

Landowner Revenue:
- $3 million/year

Local Property Taxes:
- $5.7 million/year

Construction Phase:
- 502 new jobs
- $39 million to local economies

Operational Phase:
- 51 new jobs
- $3.4 M/year to local economies

Turbine & Supply Chain Impacts

Construction Phase:
- 3,059 new jobs
- $414.8 million to local economies

Operational Phase:
- 73 new jobs
- $16.3 million/year to local economies

Induced Impacts

Construction Phase:
- 1,197 new jobs
- $143.1 million to local economies

Operational Phase:
- 63 new jobs
- $7.6 million/year to local economies

Totals (construction + 20 years)

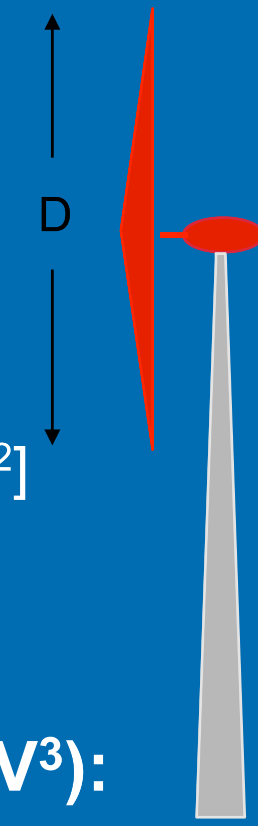
Total economic benefit:	$1.32 billion
New local jobs during construction:	4,758
New local long-term jobs:	187

Construction Phase = 1-2 years
Operational Phase = 20+ years

Wind – Technology Trends

Power in Wind Equation

Wind energy is kinetic energy -- mass and momentum



Derived from K.E. = $\frac{1}{2} mv^2$

$P = A * \rho * V^3/2$

- P = Power of the wind [Watts]
- A = Windswept area of rotor (blades) = $\pi D/4 = \pi r^2$ [m^2]
- ρ = Density of the air [kg/m^3] (at sea level at 15°C)
- V = Velocity of the wind [m/s]

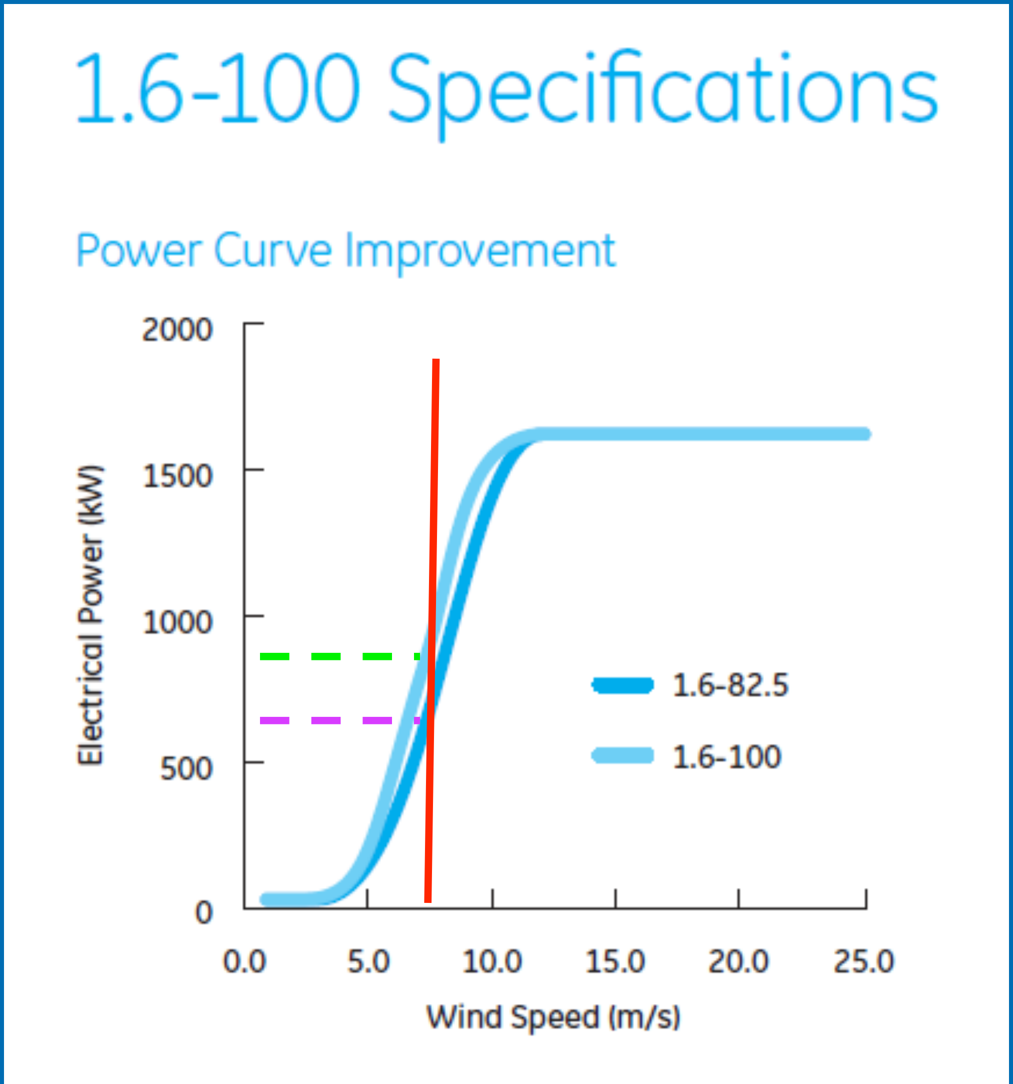
Wind energy is proportional to velocity cubed (V^3):

– 25% higher wind speed ≈ 2x's the power available

–If wind speed is doubled, power increases by a factor of eight ($2^3 = 8$)!

Small differences in average speed cause
big differences in energy production!

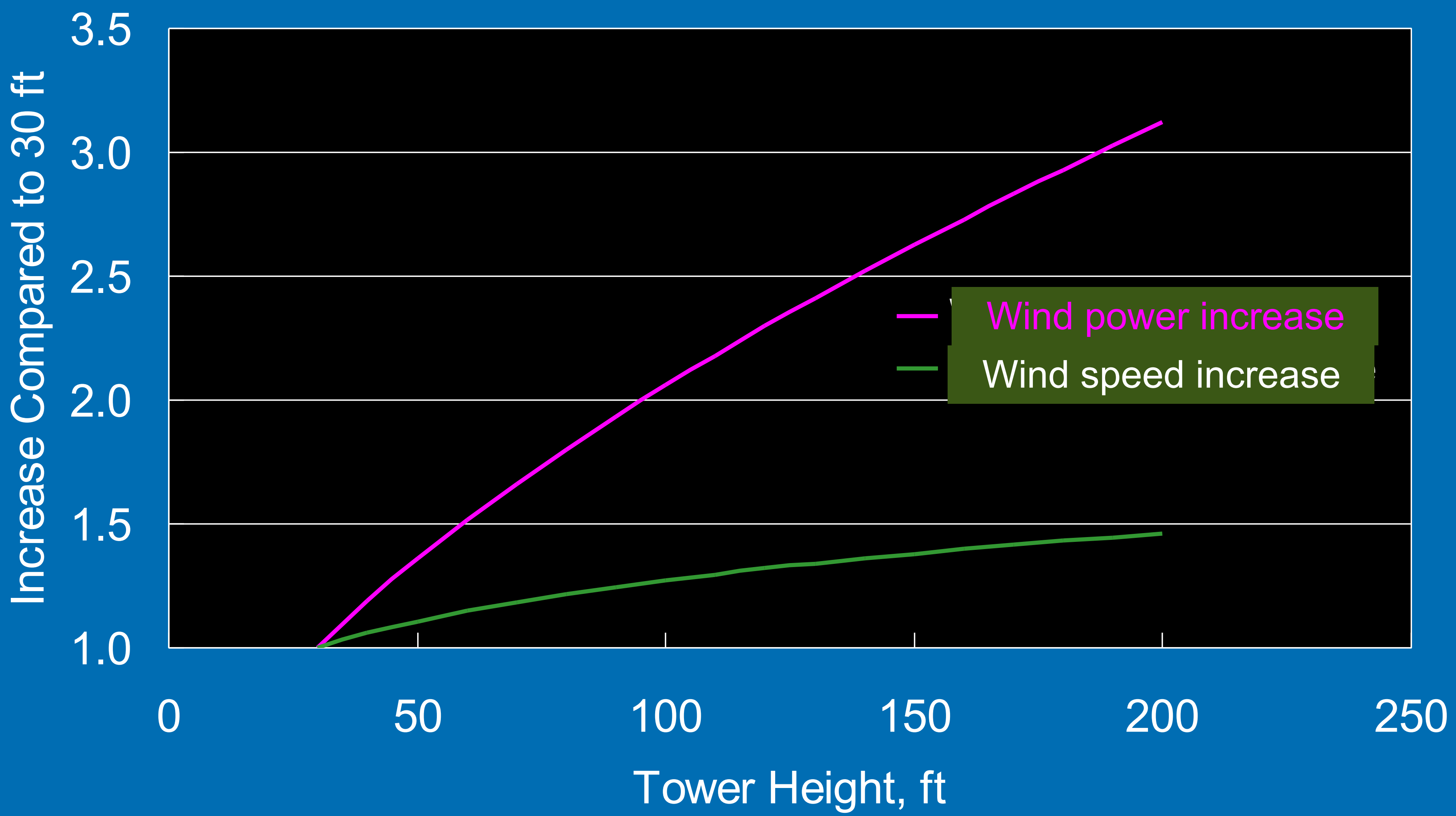
GE 1.6 MW wind turbine



This graph is of the GE 1.6-100 1.6 MW with 100m rotor (low wind speed turbine – suitable for Kaneohe) and 82.5m rotor (suitable for sites without extreme wind or turbulence). The enlarged rotor moves the power curve to the left so the turbine produces more power (and energy) at lower wind speeds.

At 7 m/s, it might have produced ~500kW with 82.5m rotor, but with 100m rotor it will produce ~700kW – that is a 40% increase !! Over the course of a year, it really makes a difference.

Wind Speed and Power Increase with Height Above the Ground

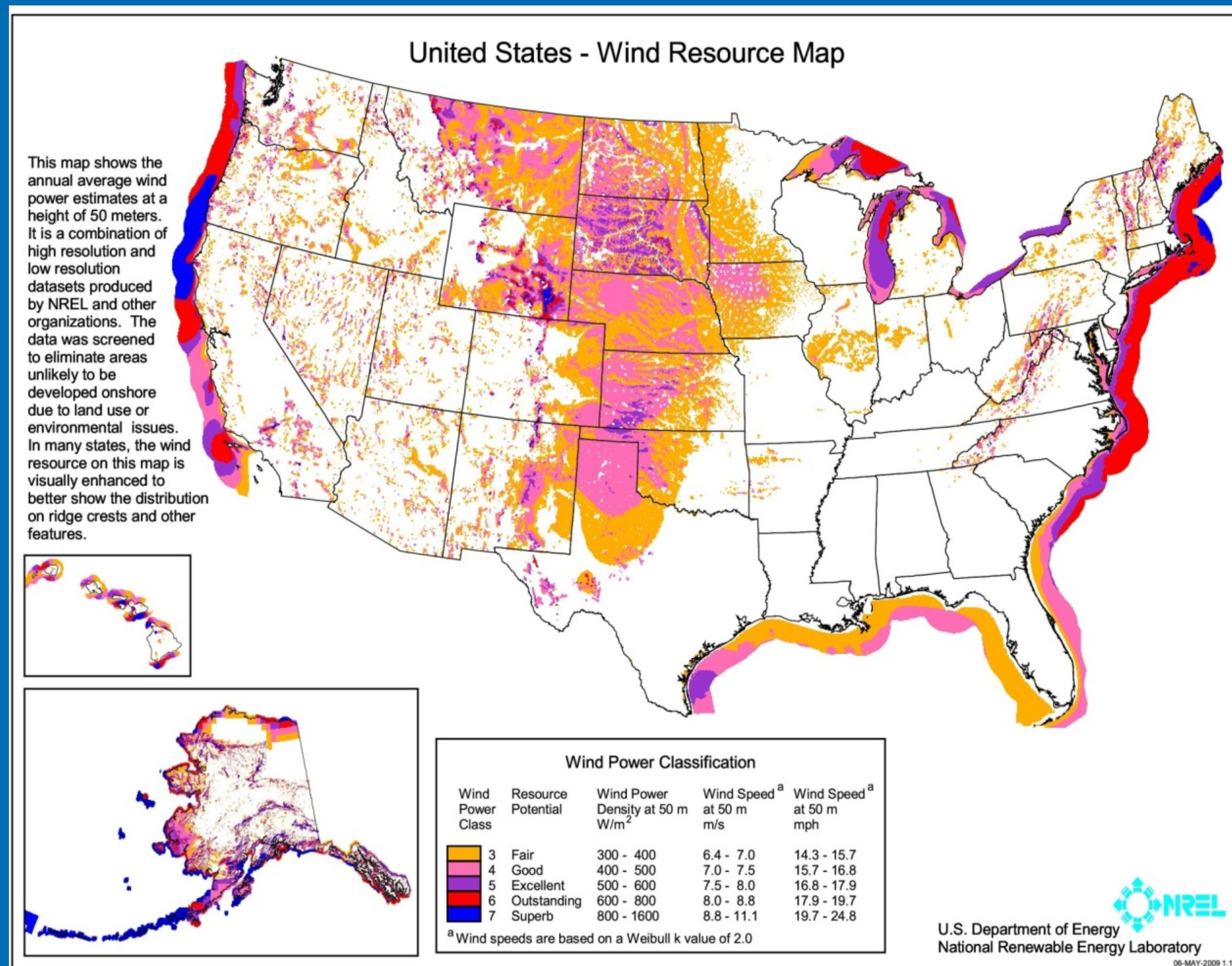


Wind – Wind Resource

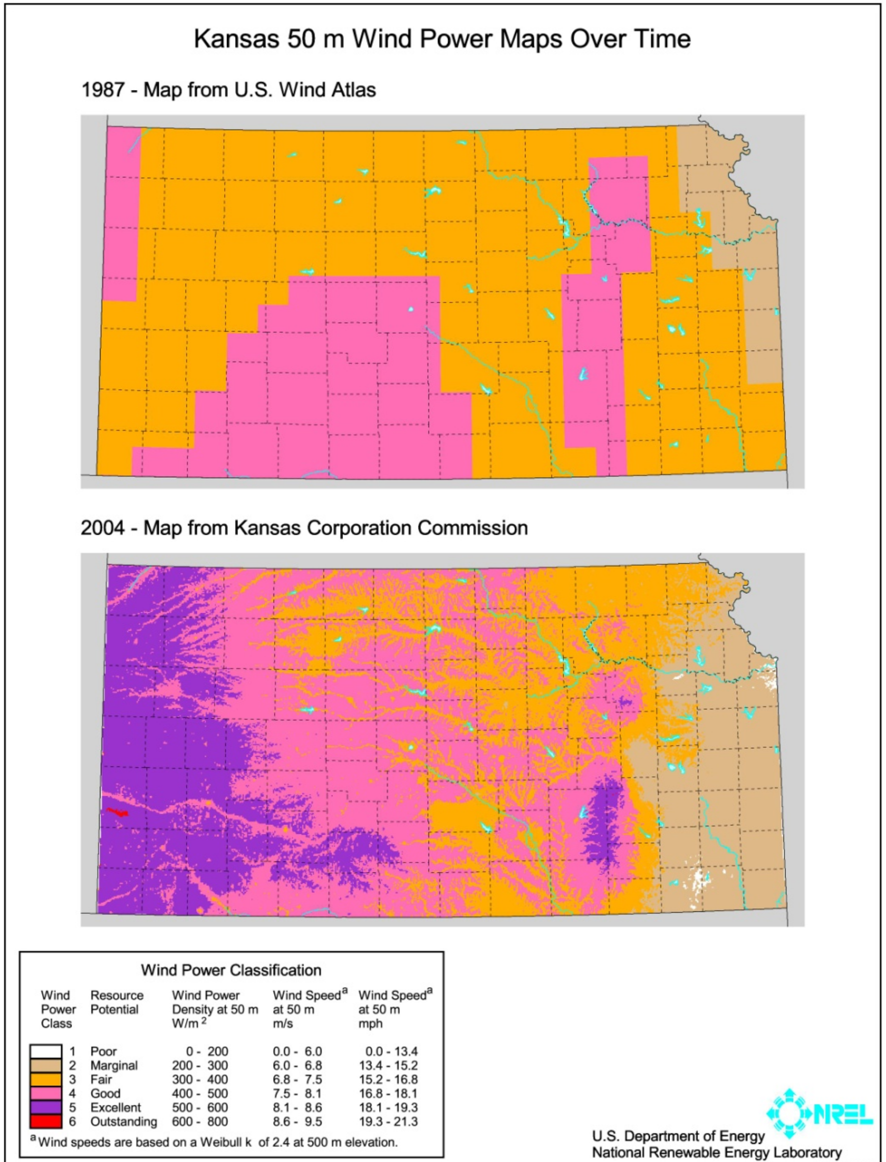
Wind Resource Mapping: Wind Class at 50-m Height

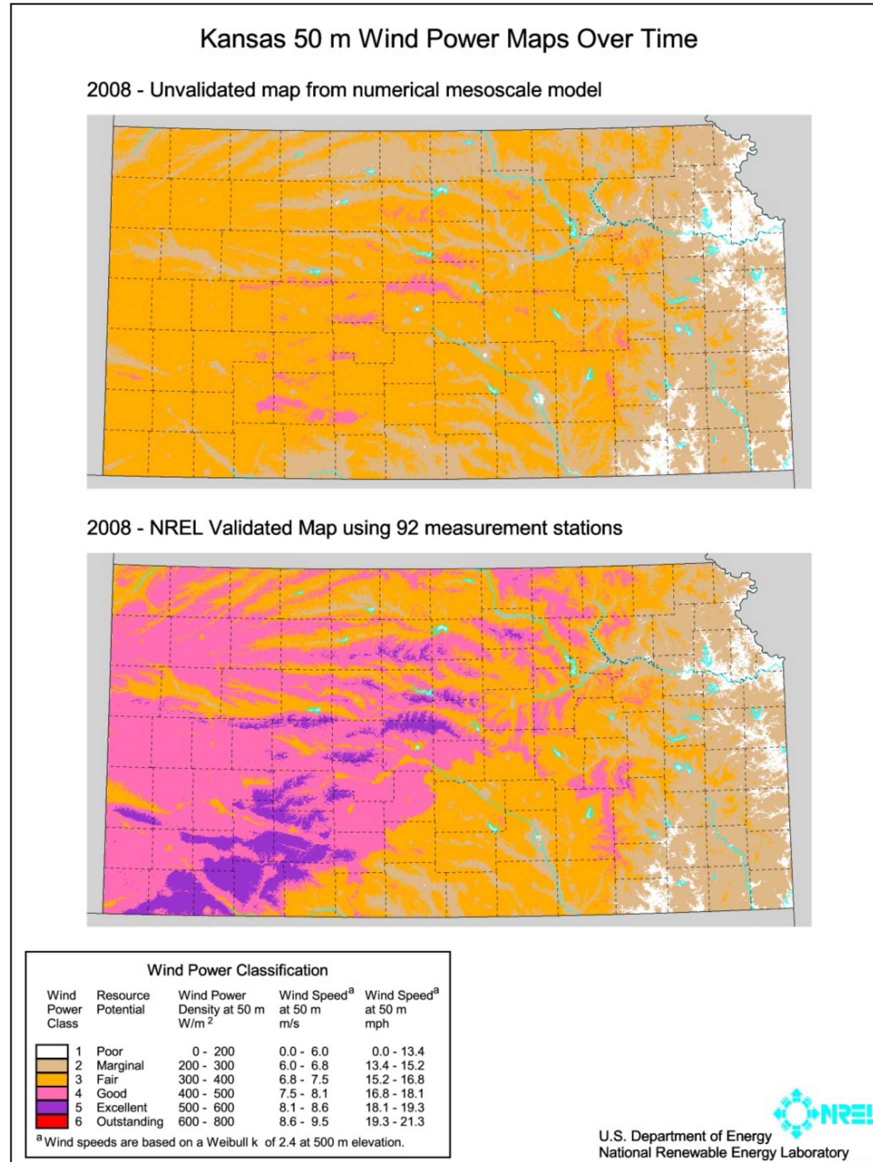
50-m wind mapping (2001-2009)

- Culmination of long-term project that began in 2001; jointly funded by states and DOE/WPA
- Comprehensive validation of WPA maps using available measurement data
- Incorporated state maps by others to produce a national wind map ("patchwork quilt" evident in some regions)
- 50-m wind potential estimates to support U.S. 20% wind scenario study

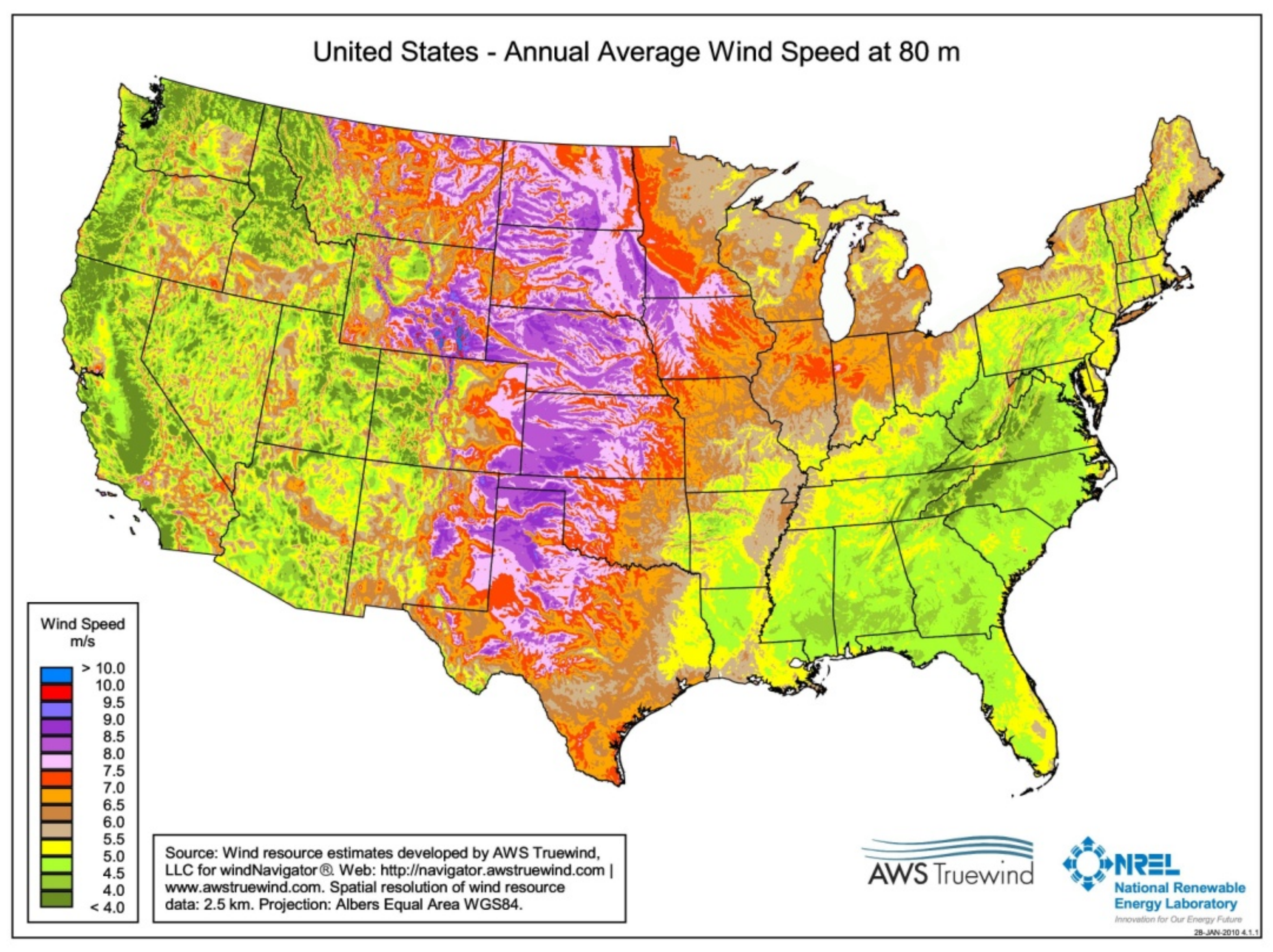


Changes in Wind Maps Over Time – Kansas Example

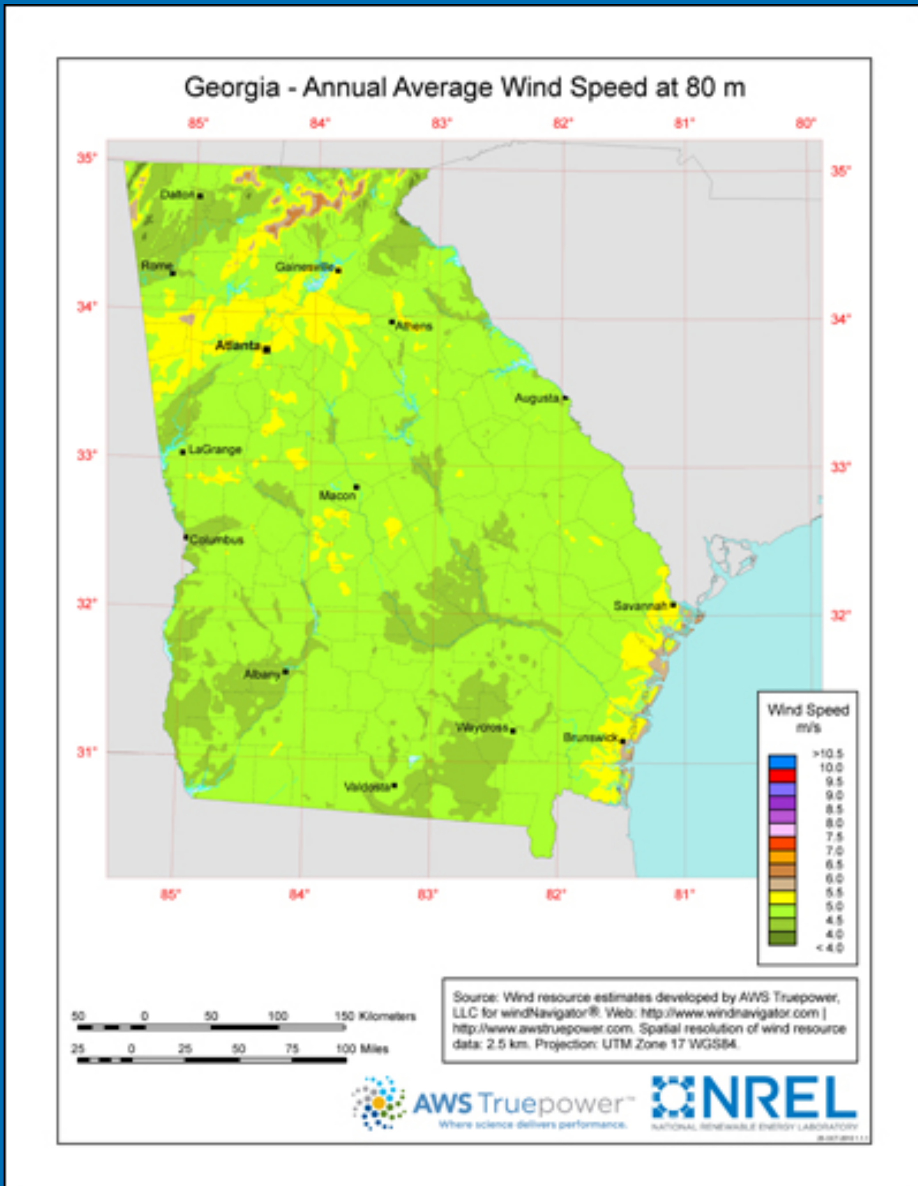




New US Wind Resource Map – Wind Speed at 80-m



Georgia – New Turbines Provide Greater Wind Potential



Increasing hub height from 80 to 100m:

- Doubles the potential wind capacity in Georgia at sites with a 30% capacity factor from 200 to 400MW

- Quadruples potential wind capacity at 25% capacity factor sites from 500 to 2000 MW

Opportunities for Wind Technology

- National Wind Technology Center – Research
- Wind – Incentives & Markets
- Wind Technology Improvements
- Wind Resource Assessment Improvements