ENERGY

2014

Technical Training and Technology Showcase

Wind Technologies & Evolving Opportunities

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Opportunities for Wind Technology

- National Wind Technology Center – Research
  - Blades
  - Generators
  - Wind resource.
- Wind Market Update
  - Recession impacts
  - PTC
  - RPS.
- Wind Technology Overview
  - Larger rotors
  - Taller towers.
- Wind Resource
  - Improved wind maps & assessment.

Photo by Dennis Schroeder, *NREL 25861*

National Renewable Energy Laboratory
National Wind Technology Center
Research & Development

Photo by Dennis Schroeder, *NREL 25861*

National Renewable Energy Laboratory

Photo by Dennis Schroeder, *NREL 21794*

National Renewable Energy Laboratory Campus

Photo by Dennis Schroeder, *NREL 25861*

High-Performance Buildings at the National Renewable Energy Laboratory

National Wind Technology Center Overview

- Turbine testing since 1977
- Leader in 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.

Photo by Dennis Schroeder, *NREL 25904*

R&D goals:

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

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.

Photo by Rob Wallen, *NREL 17398*

- Dynamometer upgrade
  - $10M Recovery Act funding
  - New 5-MW driveline
  - Robust shaft-loading system
  - Commissioned in 2013.

Photo by Mark McDade, *NREL 24472*

Windplant Aerodynamics Research

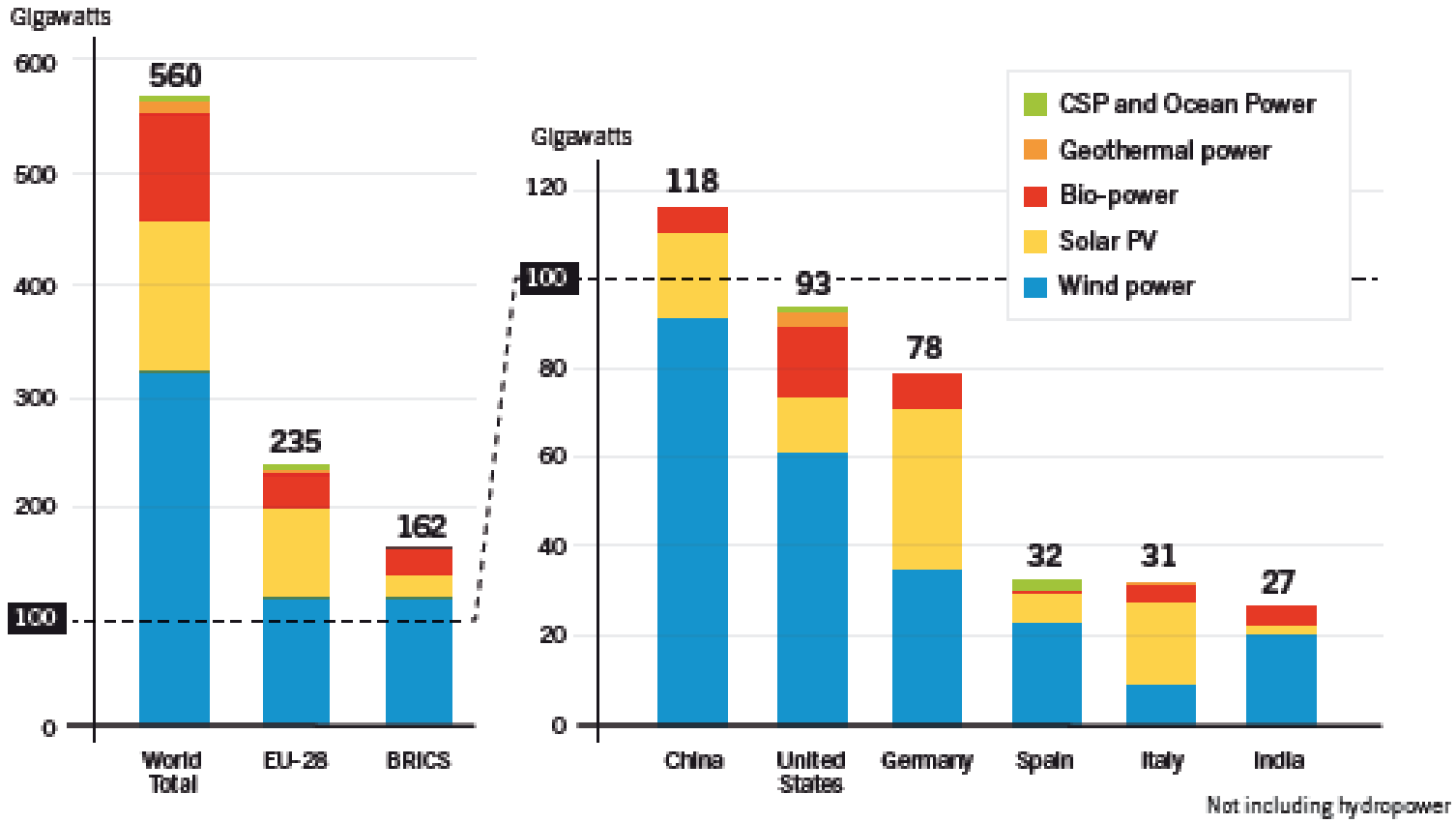
- Power performance and reliability influences are reduced in arrays.
- Understanding inflow / array interaction is key.
- Computational models, control paradigms, and hardware development will be required.
- A detailed understanding of the following is required:
  - Rotor wake interactions
  - PBL characteristics
  - Inflow / wind farm interaction
  - Complex terrain effects.

Wind Energy Market Trends

Photo by Dennis Schroeder, *NREL 25861*

Worldwide Renewable Energy Capacity Update

Figure 4. Renewable Power Capacities in World, EU-28, BRICS, and Top Six Countries, 2013



Source: See Endnote 49 for this section.

Source: RENS21. 2104. *Renewables 2014 Global Status Report*
http://www.ren21.net/Portals/0/documents/Resources/GSR/2014/GSR2014_full%20report_low%20res.pdf

Worldwide Wind Market Update

The U.S. Fell to 6th Place in Annual Wind Power Capacity Additions

Annual Capacity (2013, MW)		Cumulative Capacity (end of 2013, MW)	
China	16,088	China	91,460
Germany	3,237	**United States**	**61,110**
India	1,987	Germany	34,468
United Kingdom	1,833	Spain	22,637
Canada	1,599	India	20,589
United States	**1,087**	United Kingdom	10,946
Brazil	948	Italy	8,448
Poland	894	France	8,128
Sweden	724	Canada	7,813
Romania	695	Denmark	4,747
Rest of World	7,045	*Rest of World*	51,031
TOTAL	**36,137**	**TOTAL**	**321,377**

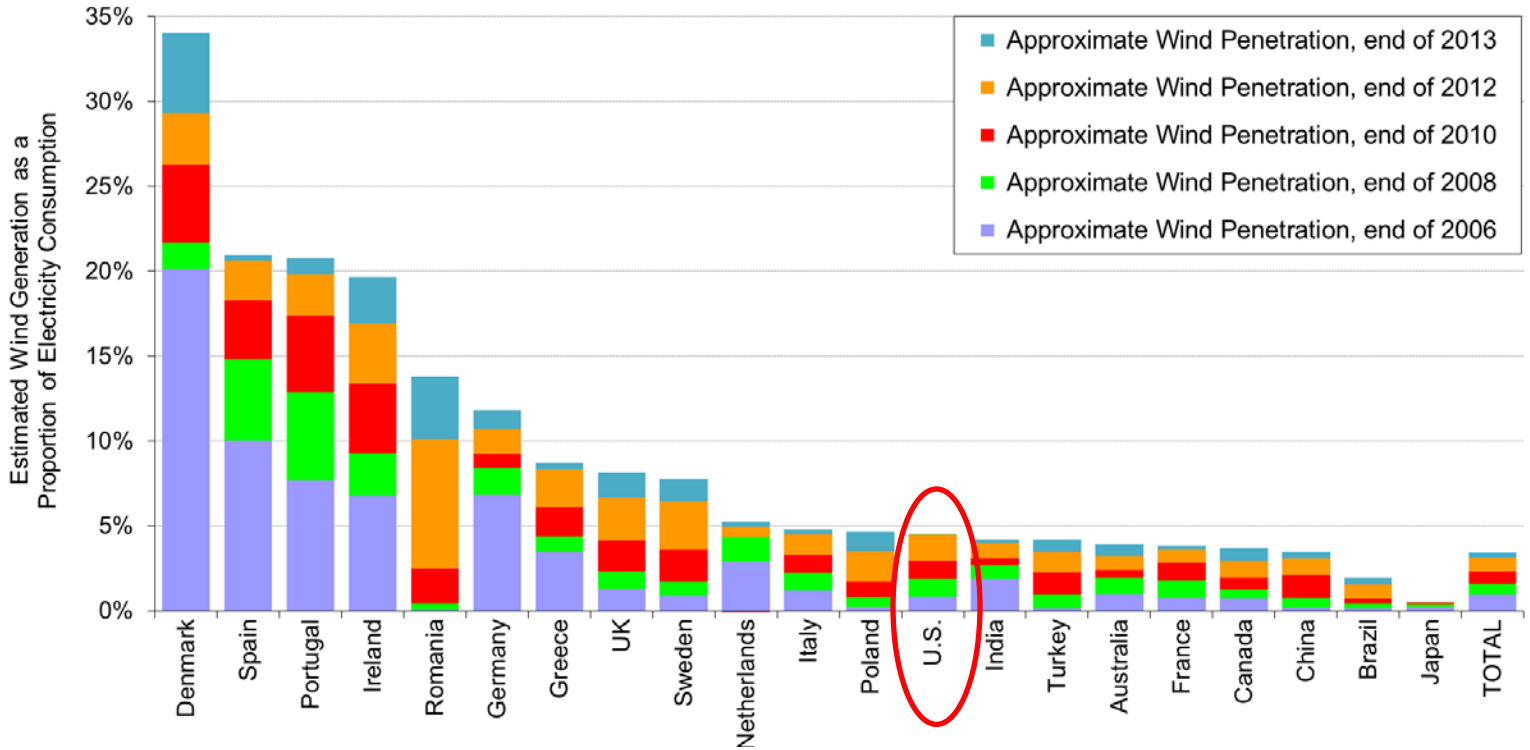
Source: Navigant; AWEA project database for U.S. capacity

- Led by decline in U.S. market, global additions 20% lower in 2013
- United States remains a distant second to China in cumulative capacity

Source: Wiser, R. A Preview of the 2013 Wind Technologies Market Report, WINDExchange Summit, Las Vegas, NV. May 8, 2014

Wind as a Percentage of Electricity Consumption

United States Lagging Other Countries in Wind as a Percentage of Electricity Consumption



Note: Figure only includes the countries with the most installed wind power capacity at the end of 2013

Source: Wiser, R. A Preview of the 2013 Wind Technologies Market Report, WINDExchange Summit, Las Vegas, NV. May 8, 2014

Wind Power Additions Hit a New Record in 2006
PTC-Driven Results

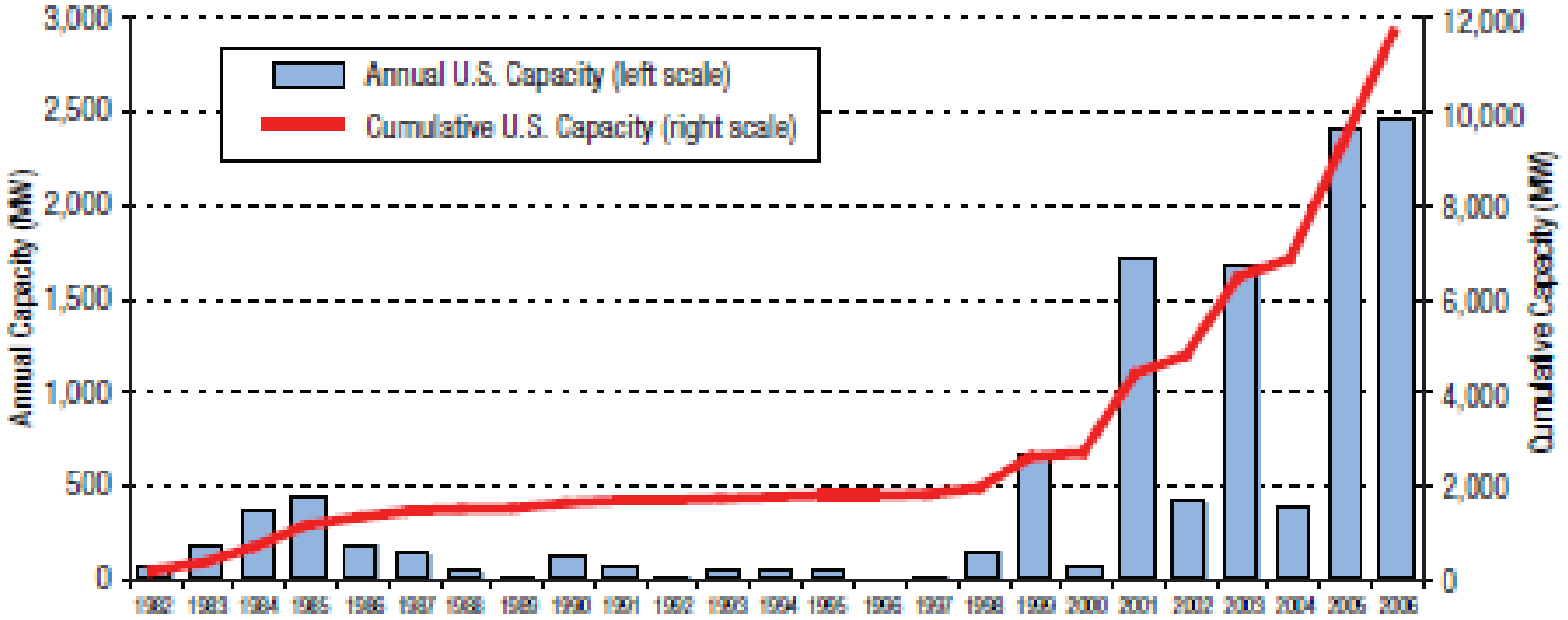
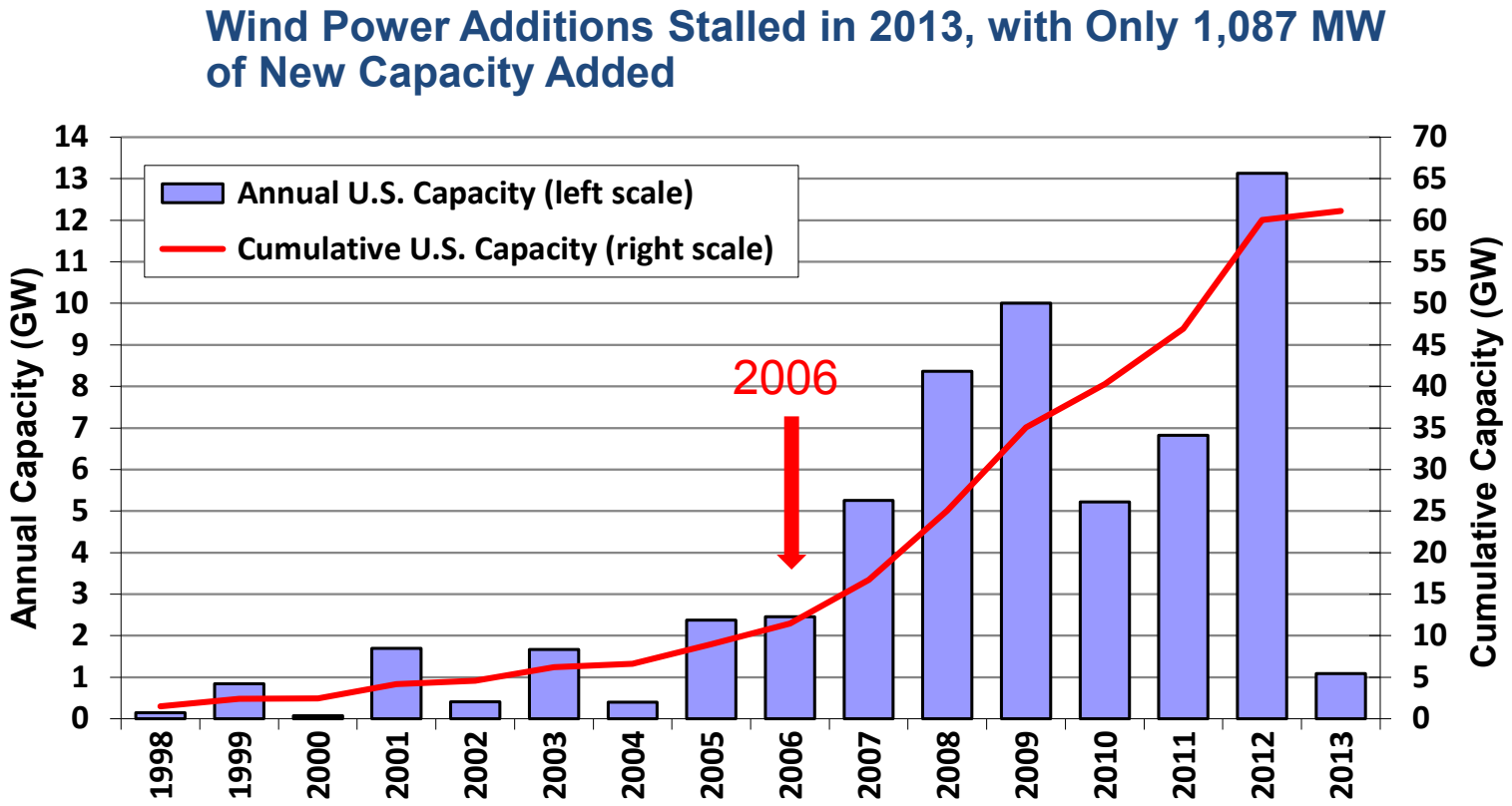


Figure 1. Annual and Cumulative Growth in U.S. Wind Power Capacity

- 13.1 GW of wind added in 2012, more than 90% higher than 2011
- $25 billion invested in wind power project additions
- Cumulative wind power capacity up by 28%, bringing total to 60 GW

Source: Annual Report on U.S. Wind Power Installation, Costs, and Performance Trends: 2006. (Wiser, R.; Bolinger, M. (2007). Annual Report on U.S. Wind Power Installation, Cost, and Performance Trends: 2006. 24 pp.; NREL Report No. TP-500-41435; DOE/GO-102007-2433

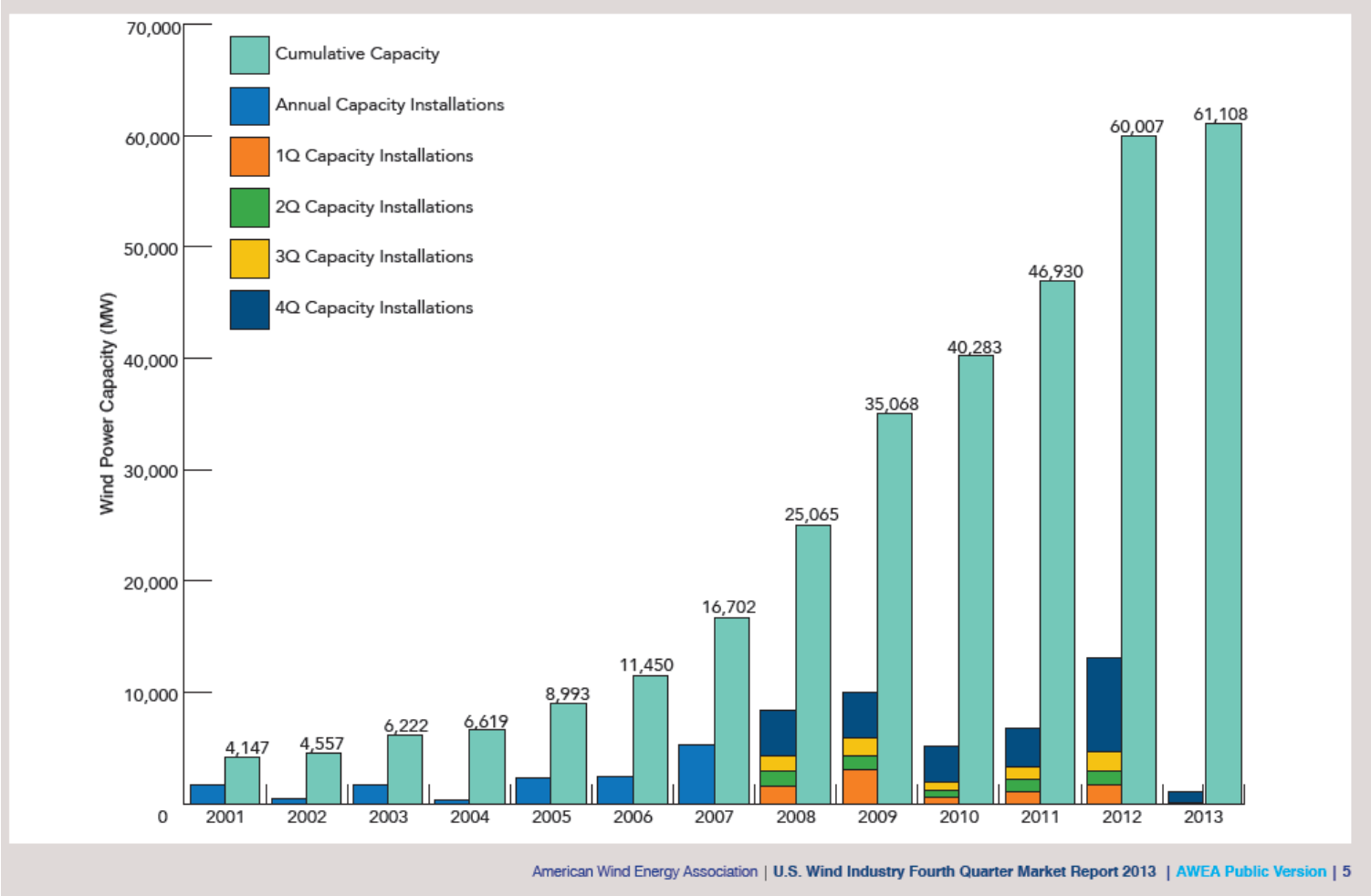
Wind Power Additions: New Record in 2012 Due to Expiring PTC-Driven Results; 2013 Slowdown



- Capacity additions in 2013 were just 8% of 2012 additions
- $1.8 billion invested in wind power project additions
- Cumulative wind capacity up by less than 2%, bringing total to 61 GW

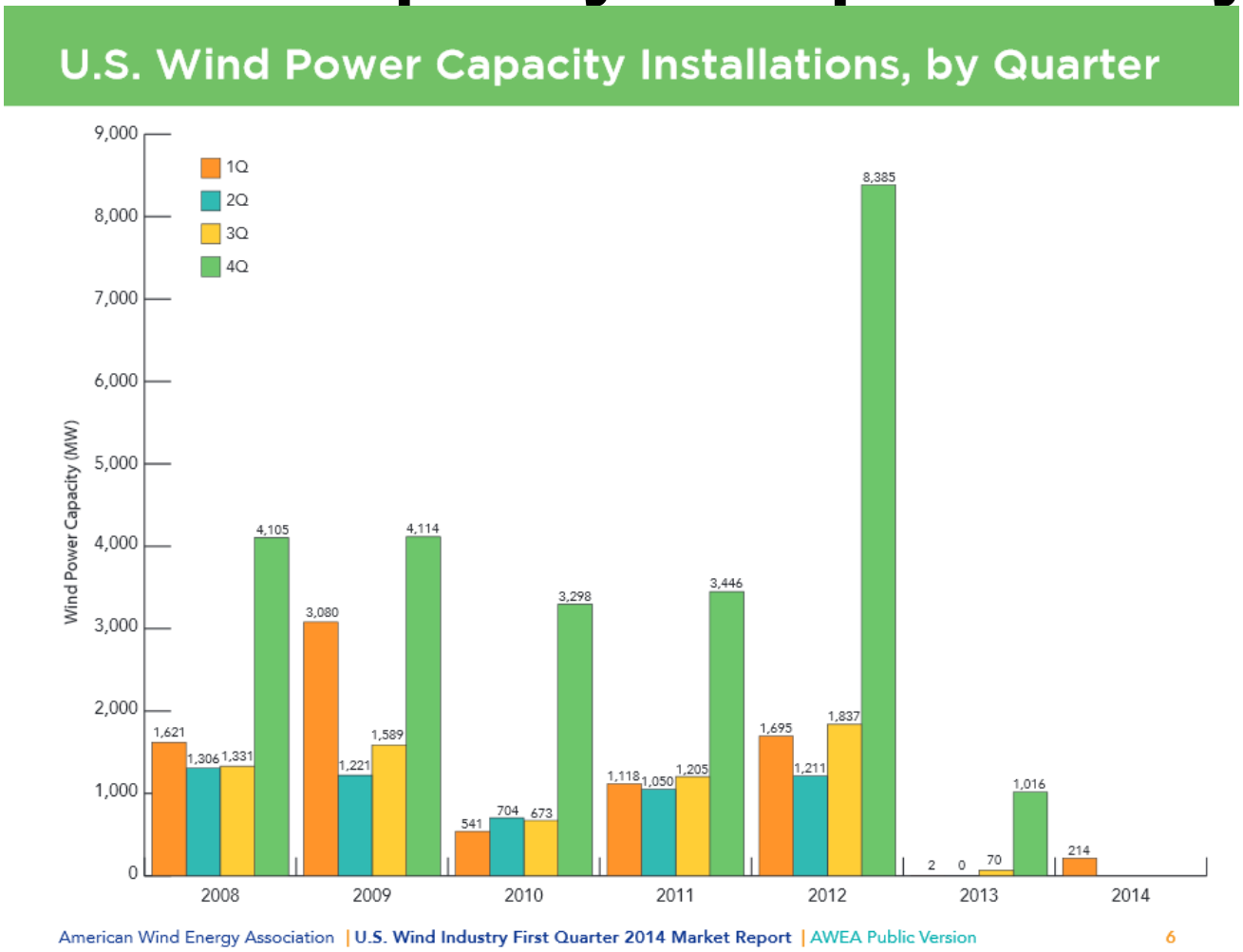
Source: Wiser, R. A Preview of the 2013 Wind Technologies Market Report, WINDExchange Summit, Las Vegas, NV. May 8, 2014

U.S. Wind Power Capacity Growth



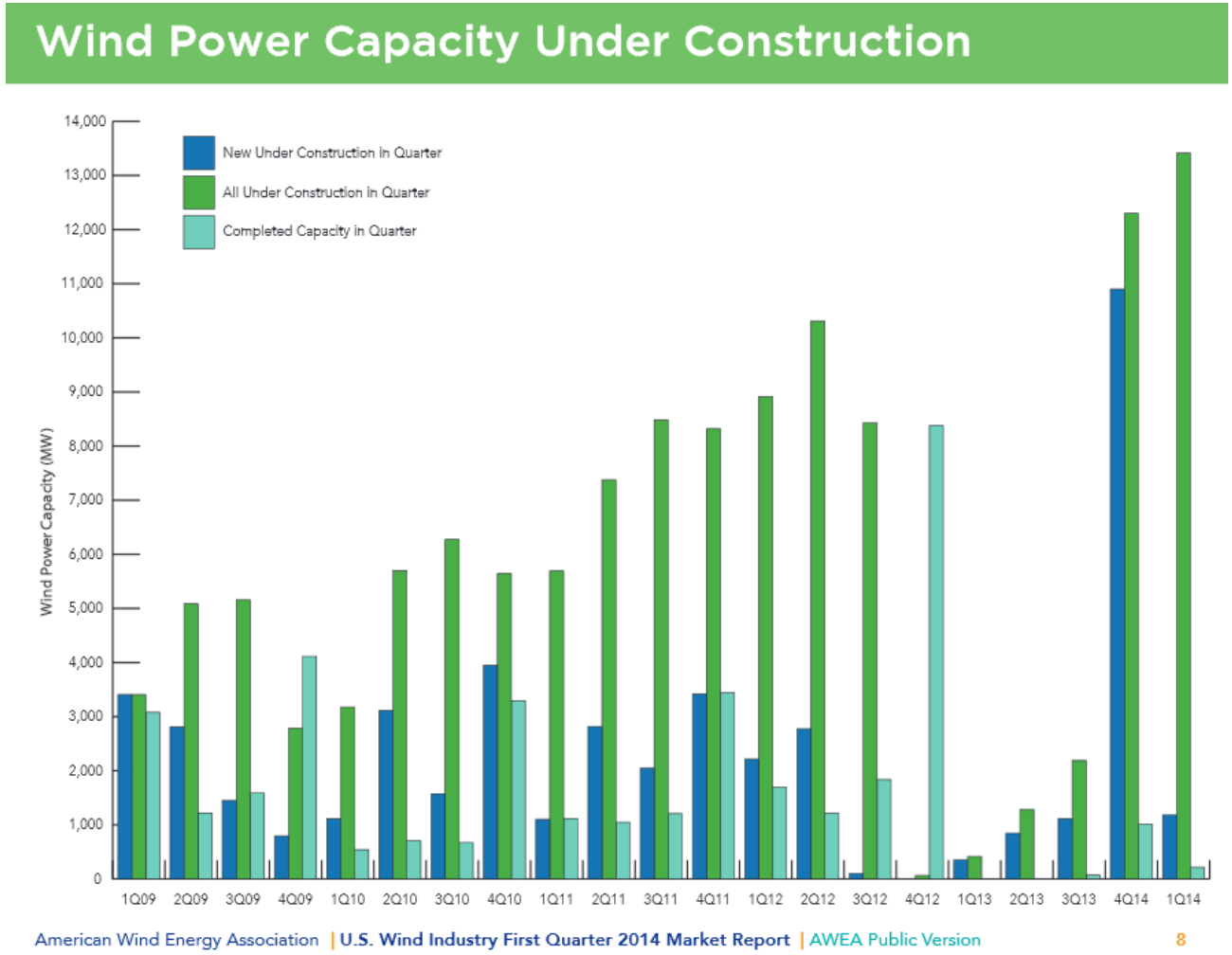
Source: http://awea.files.cms-plus.com/FileDownloads/pdfs/AWEA%204Q2013%20Wind%20Energy%20Industry%20Market%20Report_Public%20Version.pdf
AWEA U.S. Wind Industry - Fourth Quarter 2013 Market Report; January 30, 2014

Wind Power Capacity Completions by Quarter



Source: http://awea.files.cms-plus.com/FileDownloads/pdfs/1Q2014%20AWEA%20Public%20Report.pdf
AWEA U.S. Wind Industry - First Quarter 2014 Market Report; April 29, 2014

Wind Power Capacity under Construction

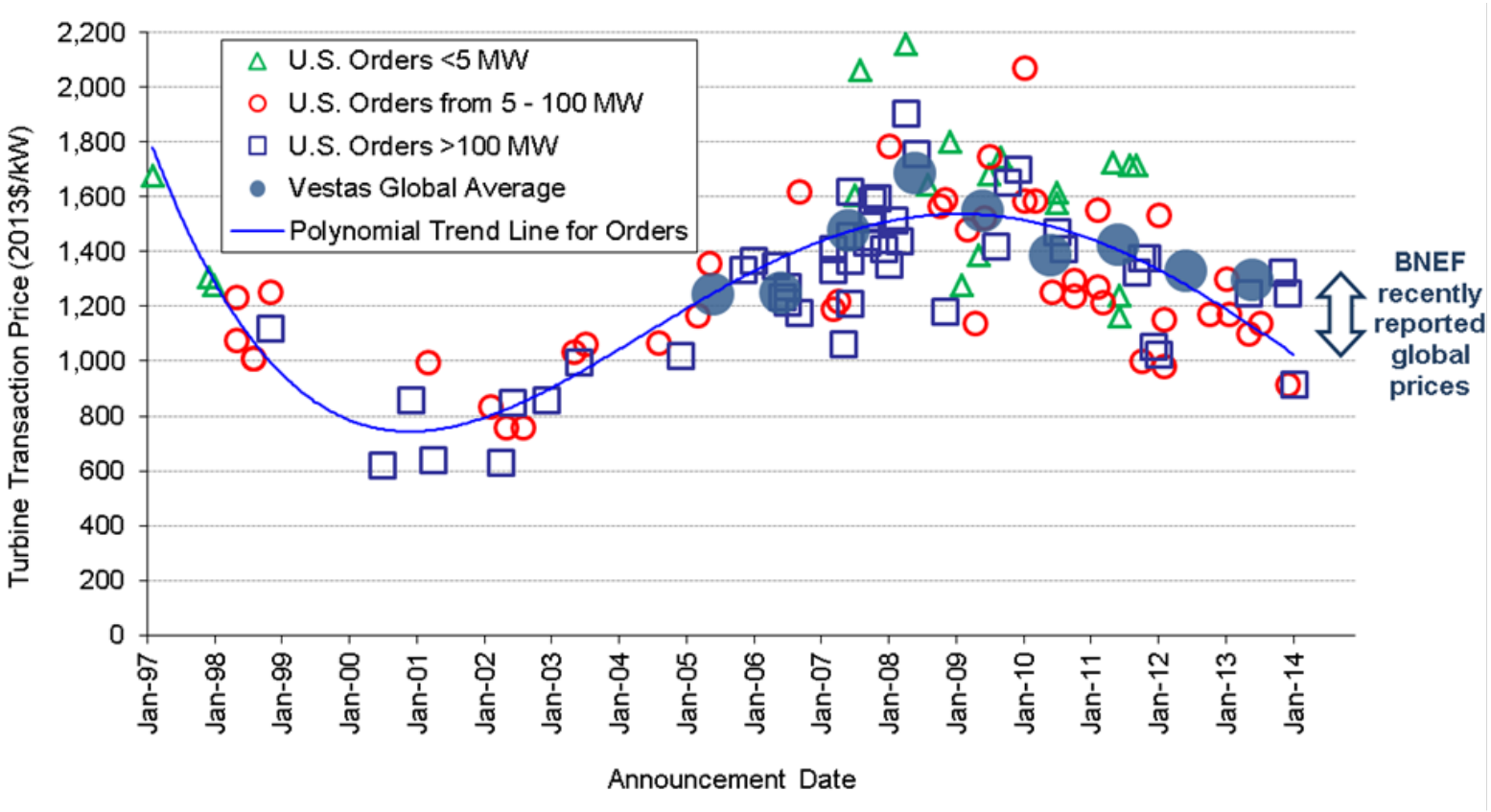


Source: http://awea.files.cms-plus.com/FileDownloads/pdfs/1Q2014%20AWEA%20Public%20Report.pdf
AWEA U.S. Wind Industry - First Quarter 2014 Market Report; April 29, 2014

Wind Energy Price & Cost Trends

Photo by Dennis Schroeder, *NREL 25861*

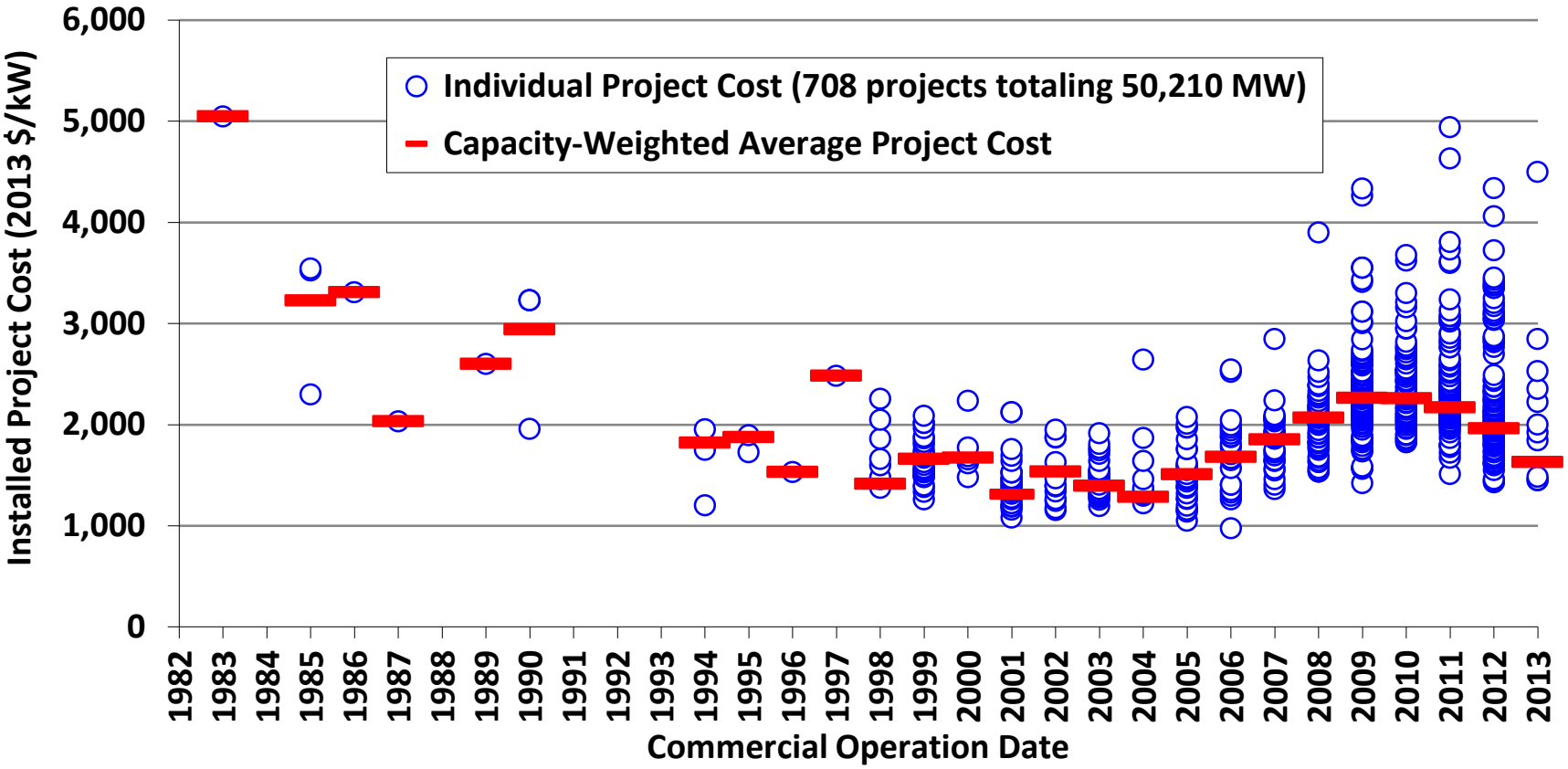
Wind Turbine Prices Remained Well Below the Levels Seen Several Years Ago



- Recent turbine orders in the range of $900-1,300/kW, with more-favorable terms for buyers and improved technology

Source: Wiser, R. A Preview of the 2013 Wind Technologies Market Report, WINDExchange Summit, Las Vegas, NV. May 8, 2014

Lower Turbine Pricing Reflected in Reported Total Project Costs

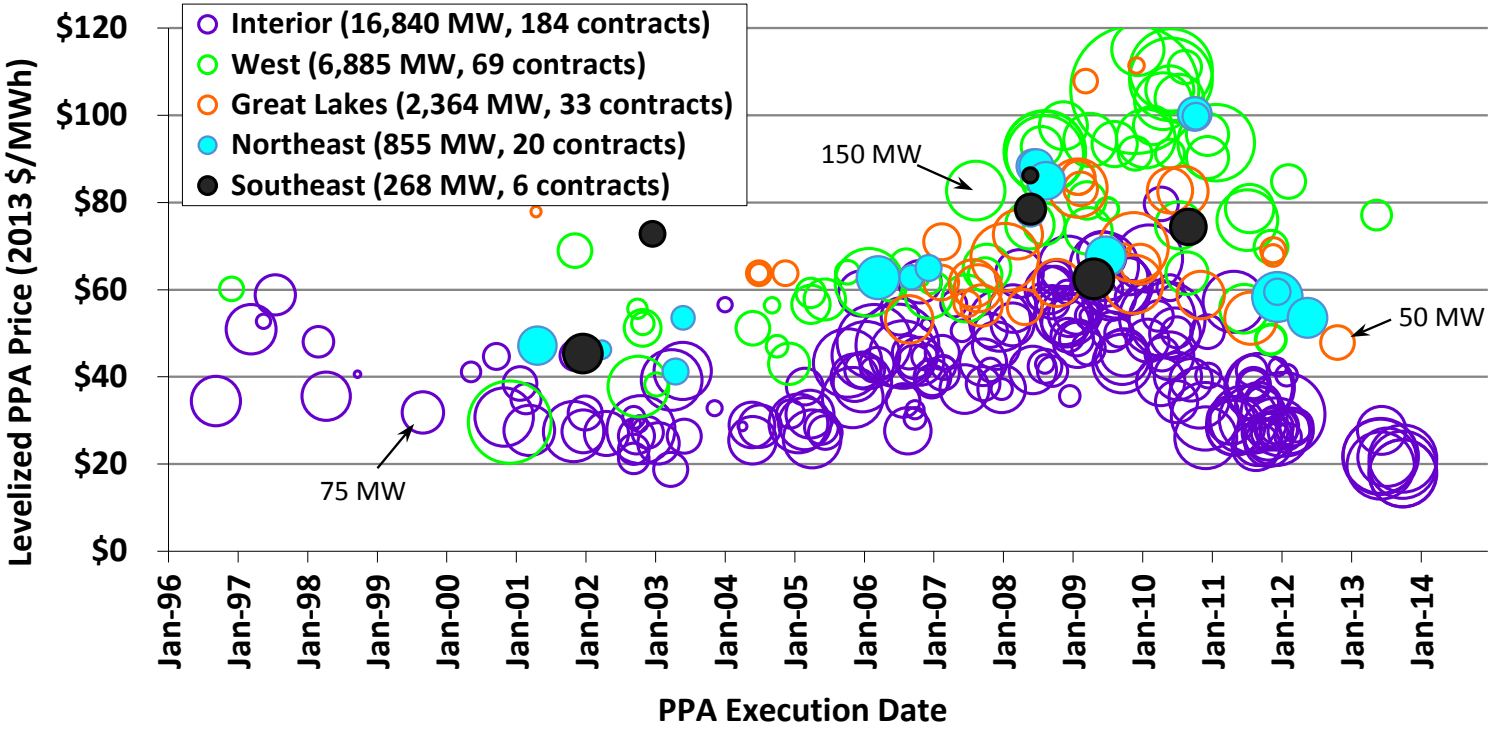


- Limited sample for 2013 had average cost of $1,630/kW

Source: Wiser, R. A Preview of the 2013 Wind Technologies Market Report, WINDExchange Summit, Las Vegas, NV. May 8, 2014

Wind Turbine Cost Trends

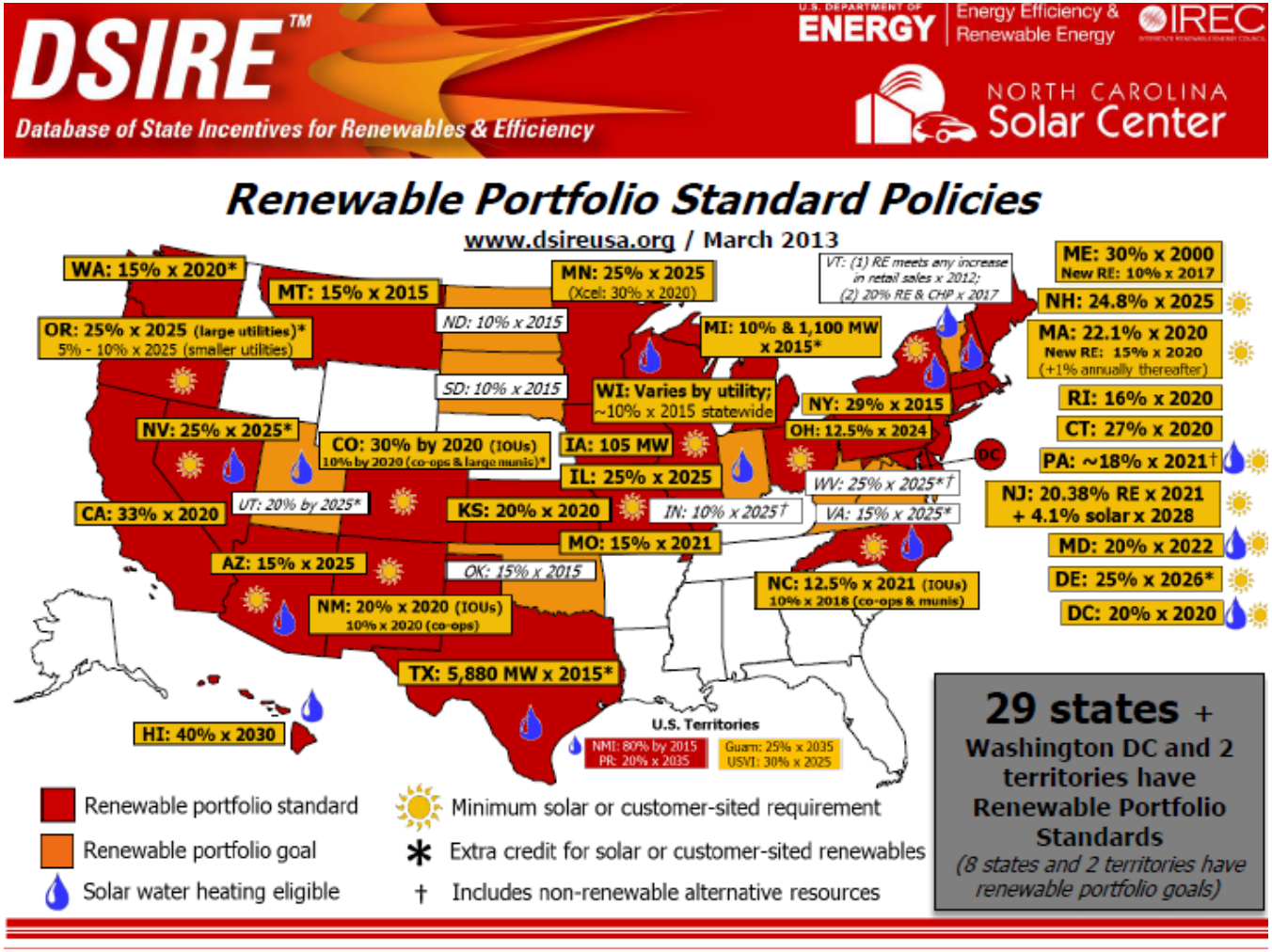
Lower Costs and Better Capacity Factors Enable Aggressive Recent PPA Pricing



- Lowest prices we have ever seen in the U.S. market, despite the trend toward lower-quality wind resource sites in general

Source: Wiser, R. A Preview of the 2013 Wind Technologies Market Report, WINDExchange Summit, Las Vegas, NV. May 8, 2014

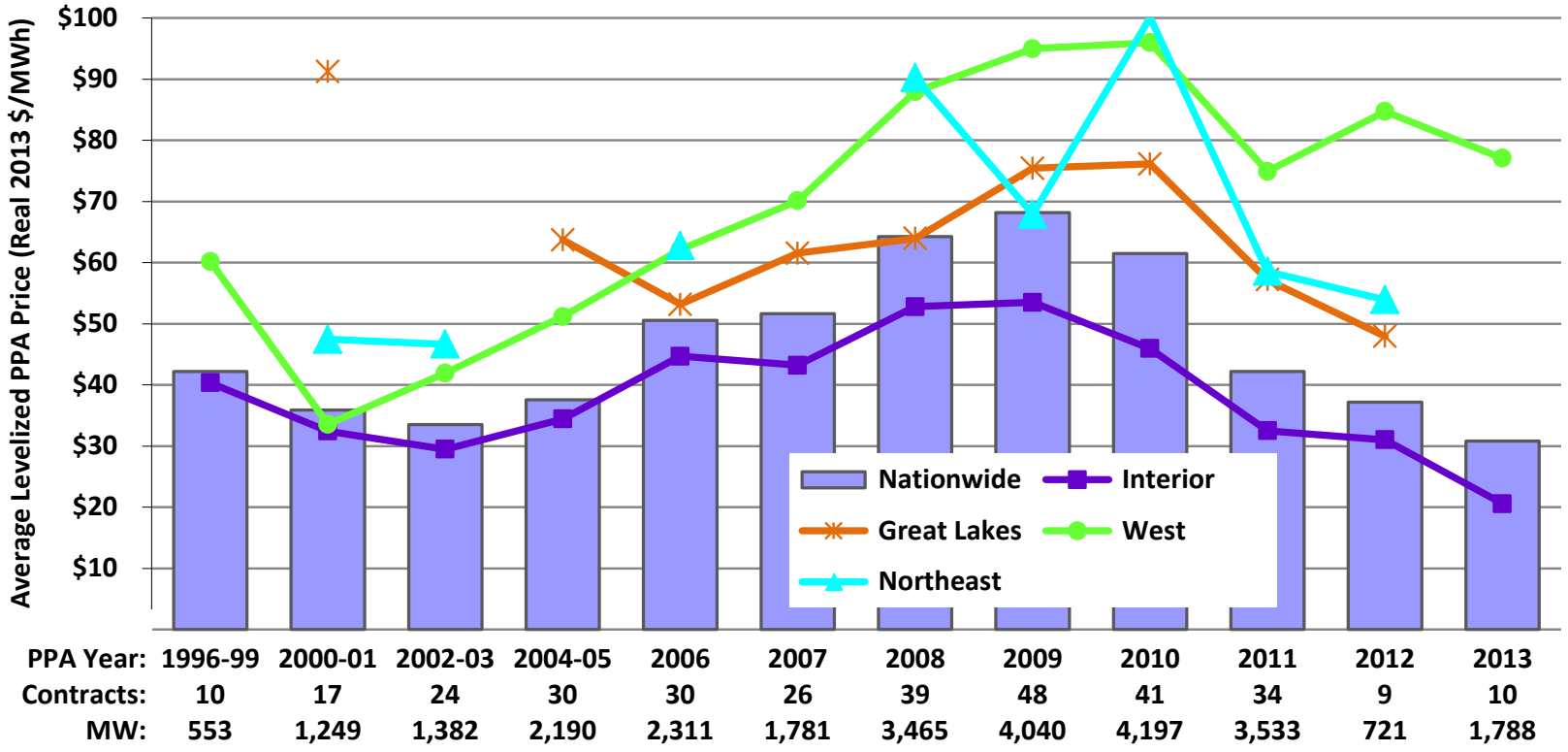
Incentives – Renewable Portfolio Standards (RPS)



Source: Database of State Incentives for Renewables & Efficiency (funded by the U.S. Department of Energy) . Accessed 7/10/2014

"The Database of State Incentives for Renewables & Efficiency (DSIRE) is a comprehensive source of information on state, local, utility, and federal incentives and policies that promote renewable energy and energy efficiency. Established in 1995 and funded by the U.S. Department of Energy, DSIRE is an ongoing project of the N.C. Solar Center and the Interstate Renewable Energy Council."

A Smoother Look at the Time Trend Shows Steep Recent Pricing Decline; Especially Low Pricing in Interior Region



PPA Year:	1996-99	2000-01	2002-03	2004-05	2006	2007	2008	2009	2010	2011	2012	2013
Contracts:	10	17	24	30	30	26	39	48	41	34	9	10
MW:	553	1,249	1,382	2,190	2,311	1,781	3,465	4,040	4,197	3,533	721	1,788

- Lowest prices we have ever seen in the U.S. market, despite the trend toward lower-quality wind resource sites in general

Source: Wiser, R. A Preview of the 2013 Wind Technologies Market Report, WINDExchange Summit, Las Vegas, NV. May 8, 2014

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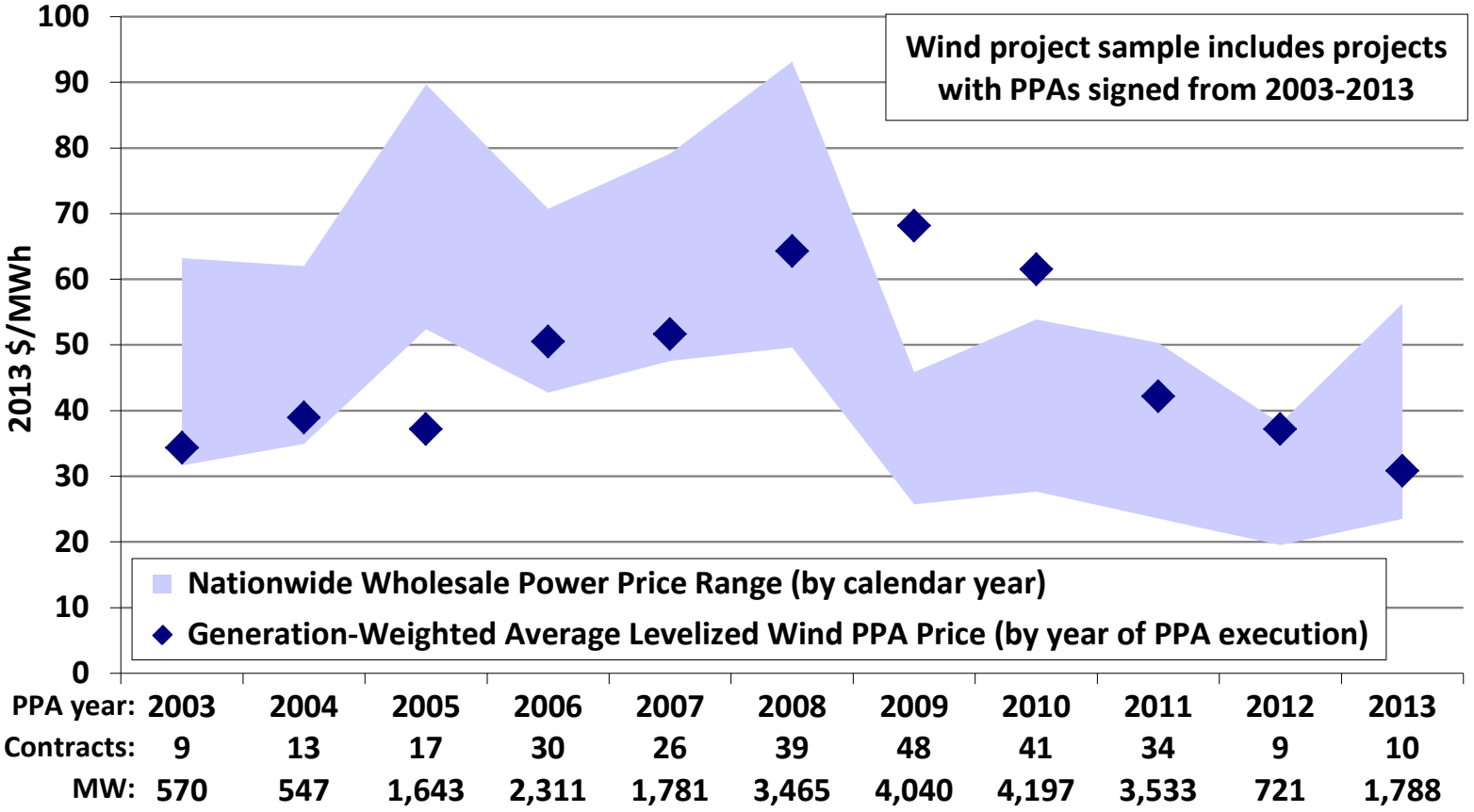
Wind Prices (Especially in Interior, w/ PTC) Are Hard to Beat: Toward the Lower End of Average Wholesale Electric Prices in 2013



Source: Wiser, R. A Preview of the 2013 Wind Technologies Market Report, WINDExchange Summit, Las Vegas, NV. May 8, 2014

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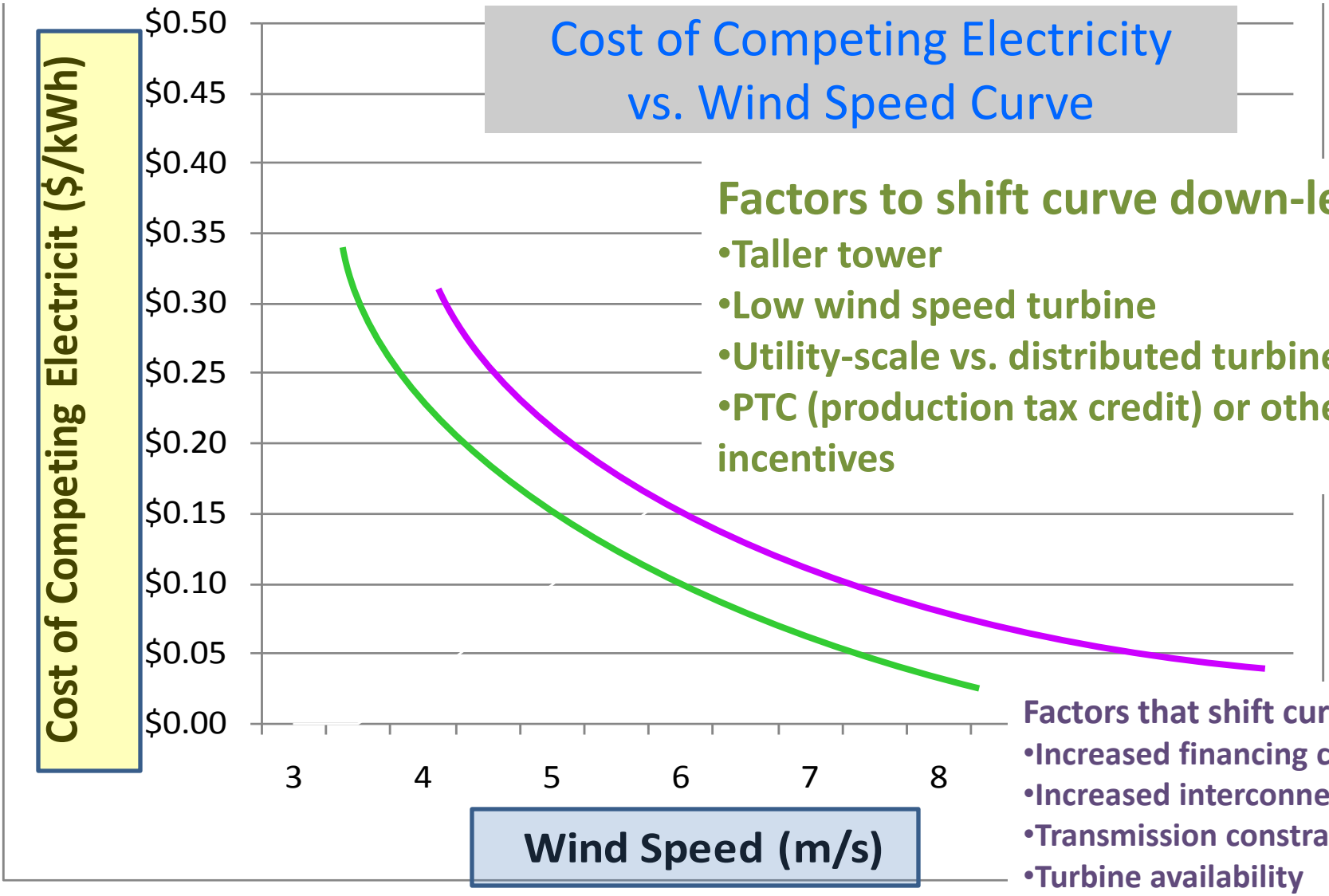
Is Wind Economic? It Depends



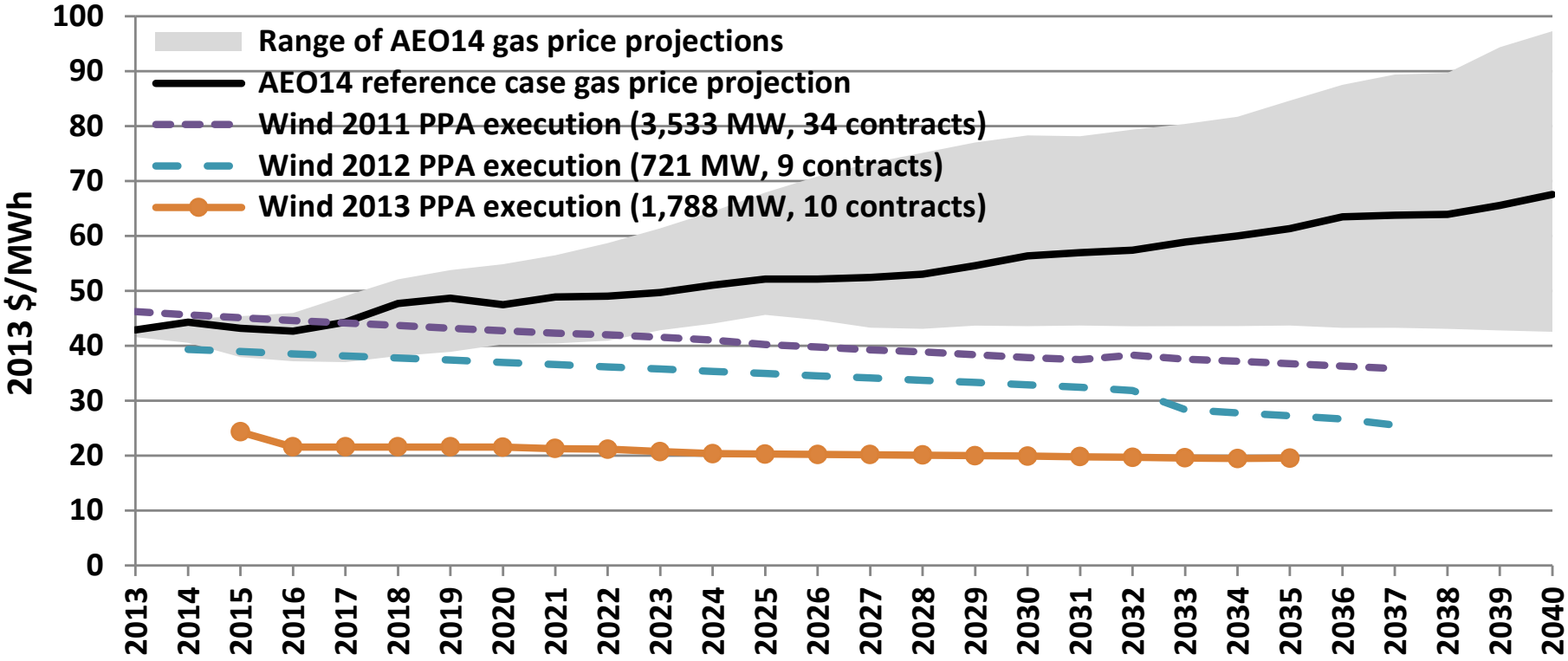
Factors to shift curve down-left:

- Taller tower
- Low wind speed turbine
- Utility-scale vs. distributed turbine
- PTC (production tax credit) or other incentives

Factors that shift curve up-right:

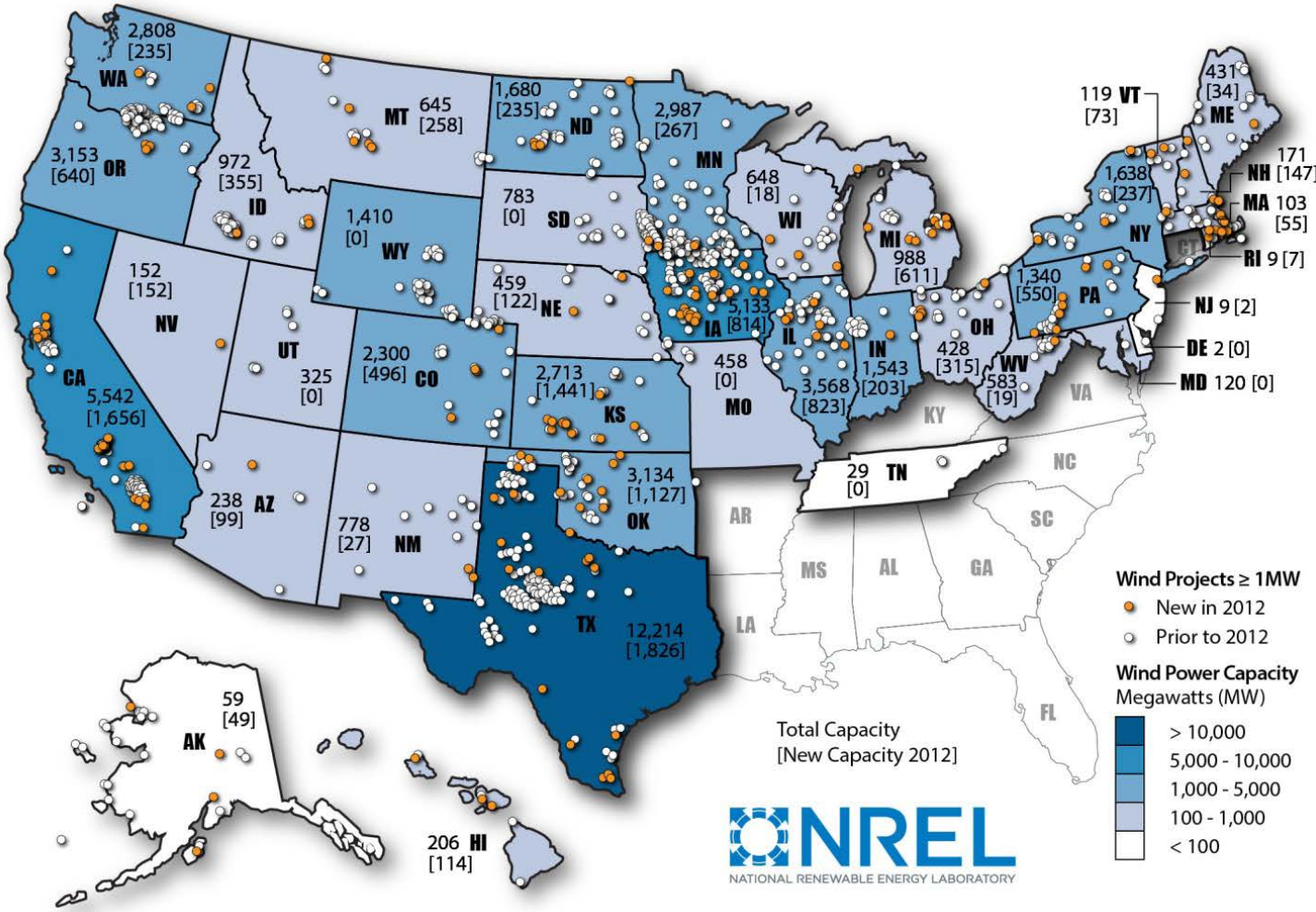
- Increased financing costs
- Increased interconnection costs
- Transmission constraints
- Turbine availability

Wind Prices (w/ PTC) Are Hard to Beat: Below the Current & Expected Future Cost of Burning Fuel in Natural Gas Plants



Source: Wiser, R. A Preview of the 2013 Wind Technologies Market Report, WINDExchange Summit, Las Vegas, NV. May 8, 2014

Wind Capacity by State

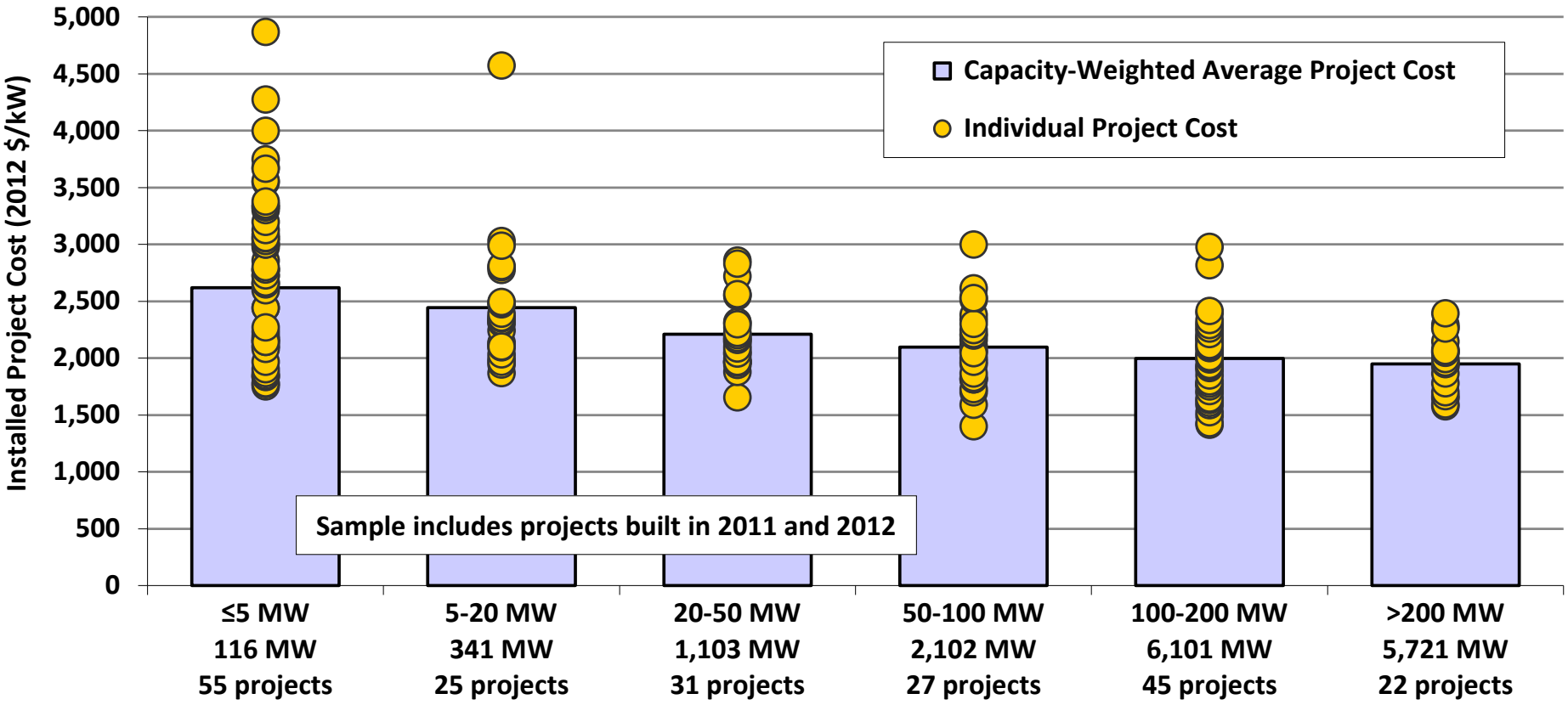


At end of 2012:

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

Source: http://apps2.eere.energy.gov/wind/windexchange/pdfs/workshops/2013_summit/wiser.pdf
2012 Wind Technologies Market Report Summary; WPA All-States Summit; May 8, 2014

Economies of Scale – Project Size Matters



Source: http://apps2.eere.energy.gov/wind/windexchange/pdfs/workshops/2013_summit/wiser.pdf
2012 Wind Technologies Market Report Summary; WPA All-States Summit; May 8, 2014

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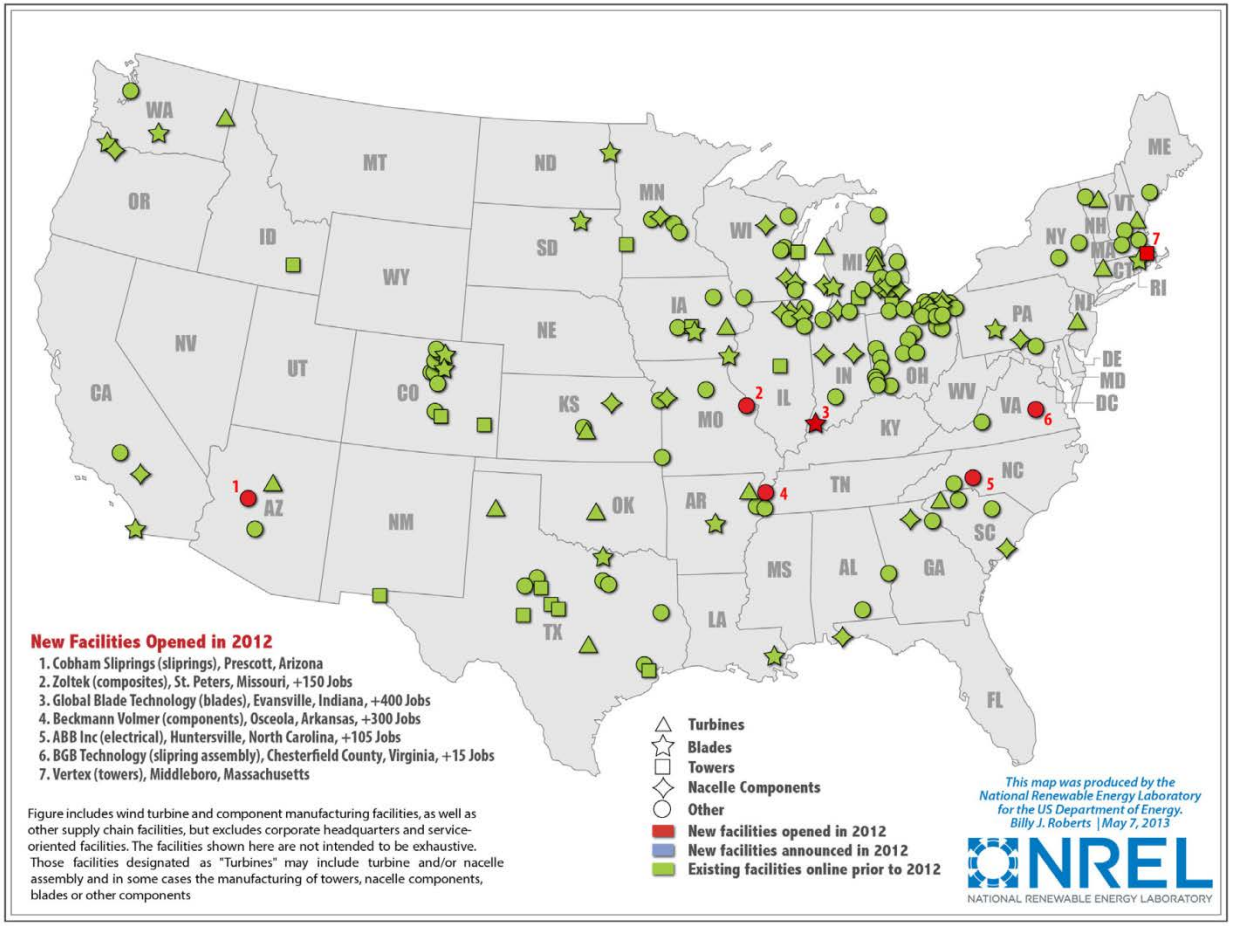
Domestic Wind-Related Manufacturing



More than 160 manufacturing plants capable of producing 12 GW/yr

Source: http://apps2.eere.energy.gov/wind/windexchange/pdfs/workshops/2013_summit/wiser.pdf
2012 Wind Technologies Market Report Summary; WPA All-States Summit; May 8, 2014

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

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

Totals (construction + 20 years)

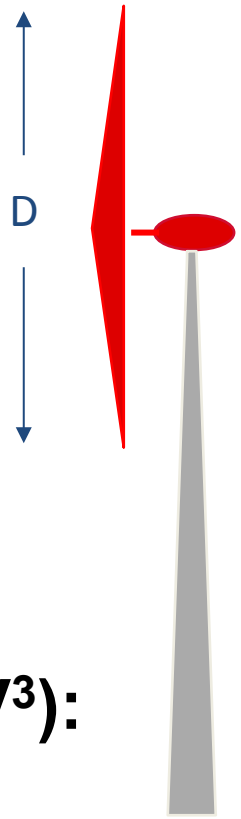
Total economic benefit: $1.32 billion
New local jobs during construction: 4,758
New local long-term jobs: 187

Wind Turbine Technology Improvements

Photo by Dennis Schroeder, *NREL 25861*

Power in Wind Equation

Wind energy is kinetic energy – mass and momentum



Derived from K.E. = ½ 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]

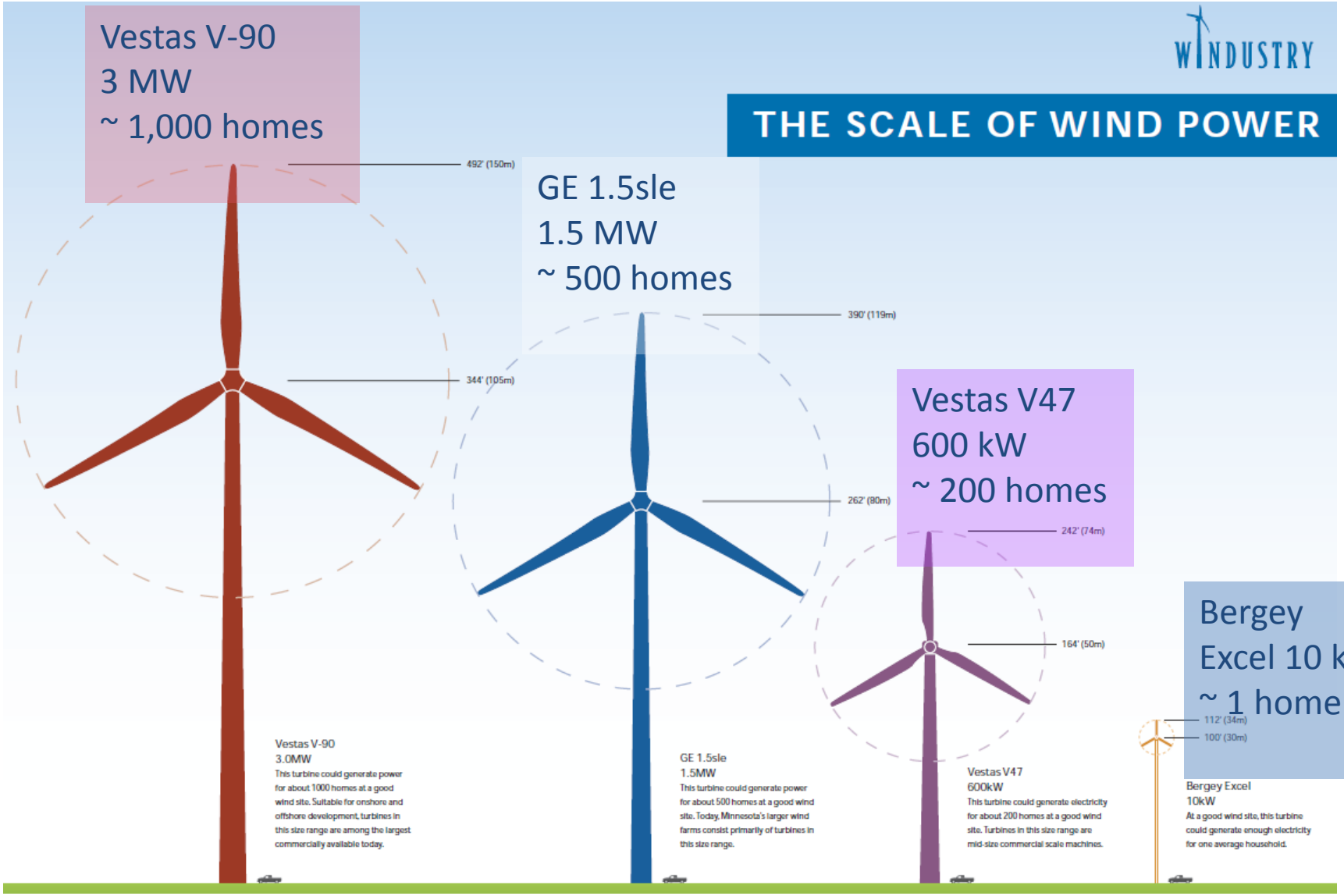
Wind energy is proportional to velocity cubed (V^3):

– 25% higher wind speed ≈ 2 times the power available

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

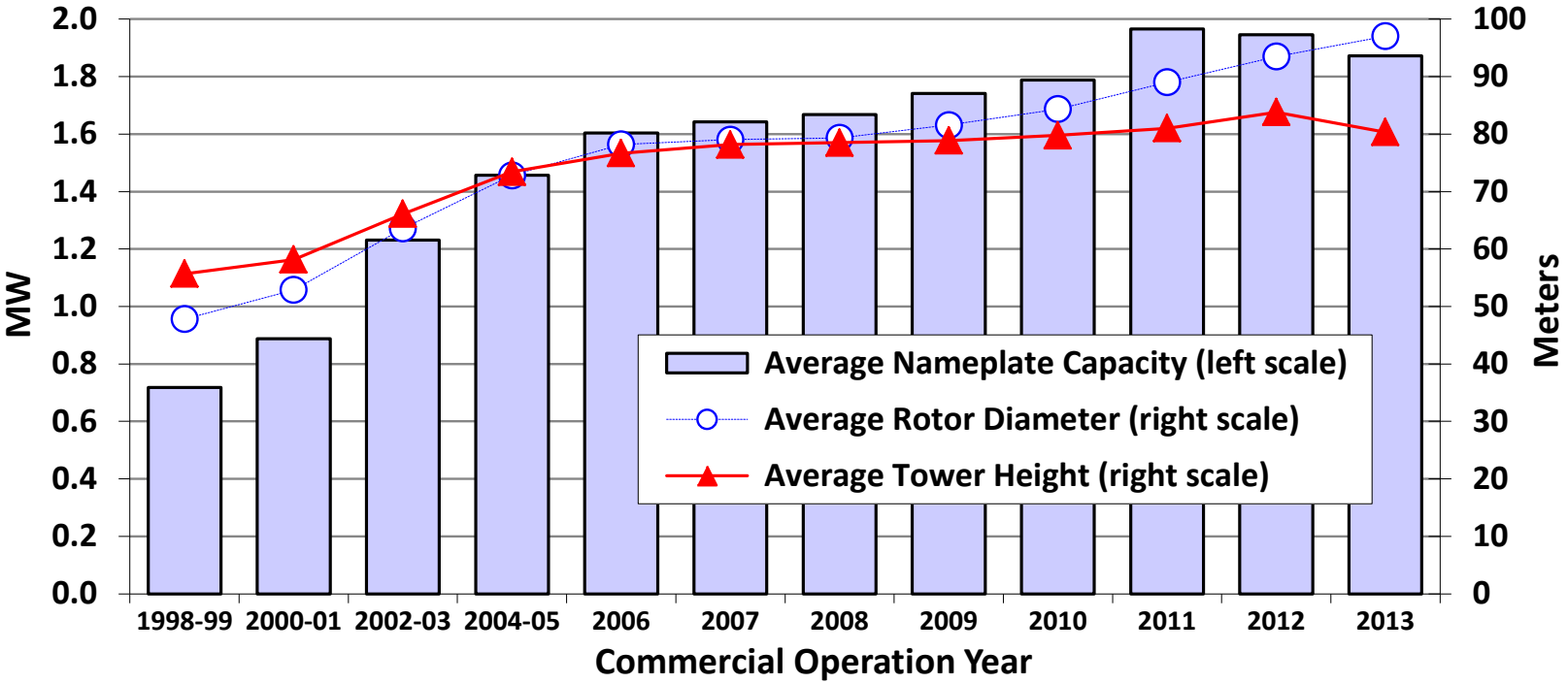
Small differences in average speed cause big differences in energy production!

Turbine – Sized to Economic Project Goals



Wind Turbine Performance Trends

Performance Is Impacted by the Physical Characteristics of the Turbine Fleet, Including Larger-Rotor Machines

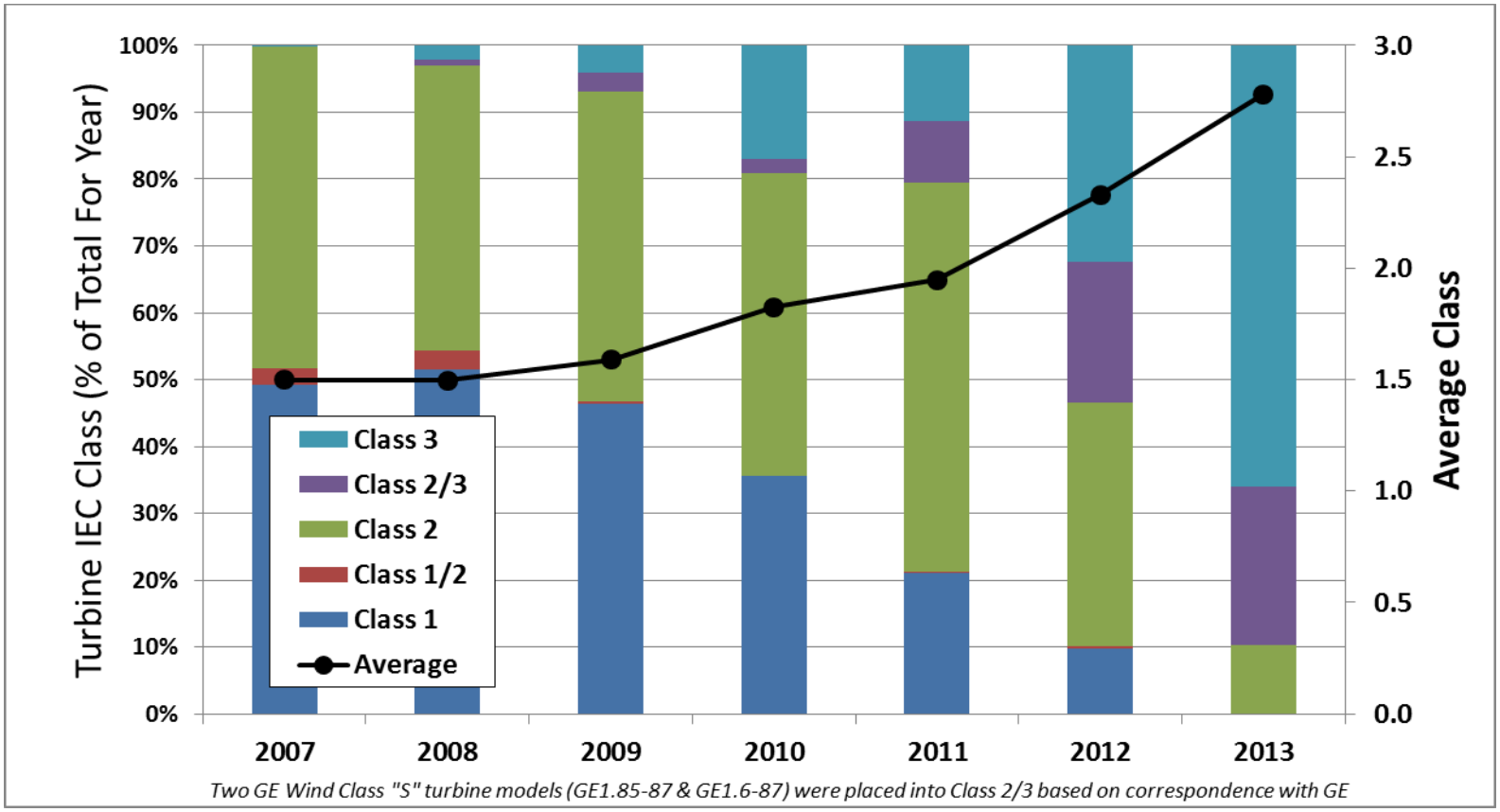


- Two periods of rapid scaling: 1998-2006 and 2009-present
- 2006-2008 mostly stagnant as OEMs focused on meeting demand

Source: Wiser, R. A Preview of the 2013 Wind Technologies Market Report, WINDExchange Summit, Las Vegas, NV. May 8, 2014

Wind Turbine Performance Trends

And the Increased Use of Lower Wind Speed Turbines, Now Also Often Used in Higher Wind Speed Sites (IEC Class)

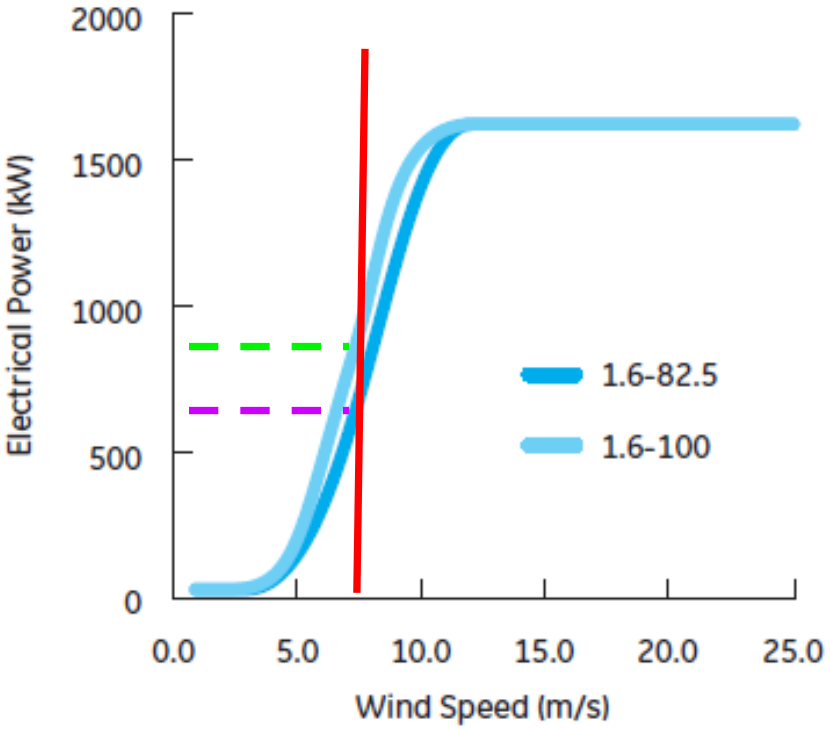


Source: Wiser, R. A Preview of the 2013 Wind Technologies Market Report, WINDExchange Summit, Las Vegas, NV. May 8, 2014

GE 1.6-MW Wind Turbine Example

1.6-100 Specifications

Power Curve Improvement



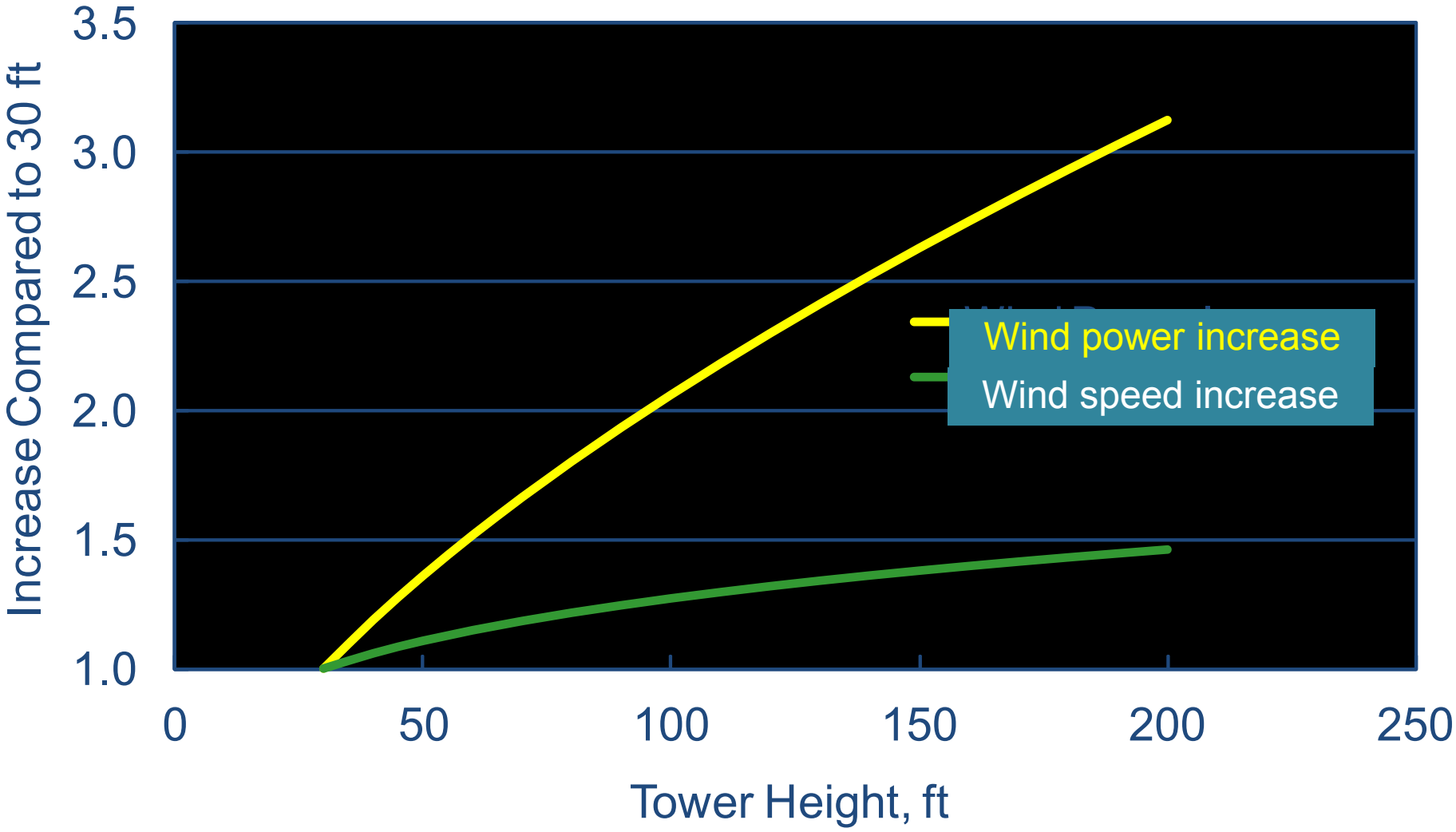
Courtesy of GE Power & Water

This power curve graph illustrates the GE 1.6-MW with 82.5-m rotor (suitable for very windy sites with some extreme wind or turbulence) and 100-m rotor (low wind speed turbine – suitable for sites with low wind speeds).

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 ~551 kW with an 82.5-m rotor, but with a 100-m rotor it will produce ~745 kW –**a 35% increase!!** Over the course of a year, it really makes a difference.

Wind Speed and Power Increase with Height above the Ground

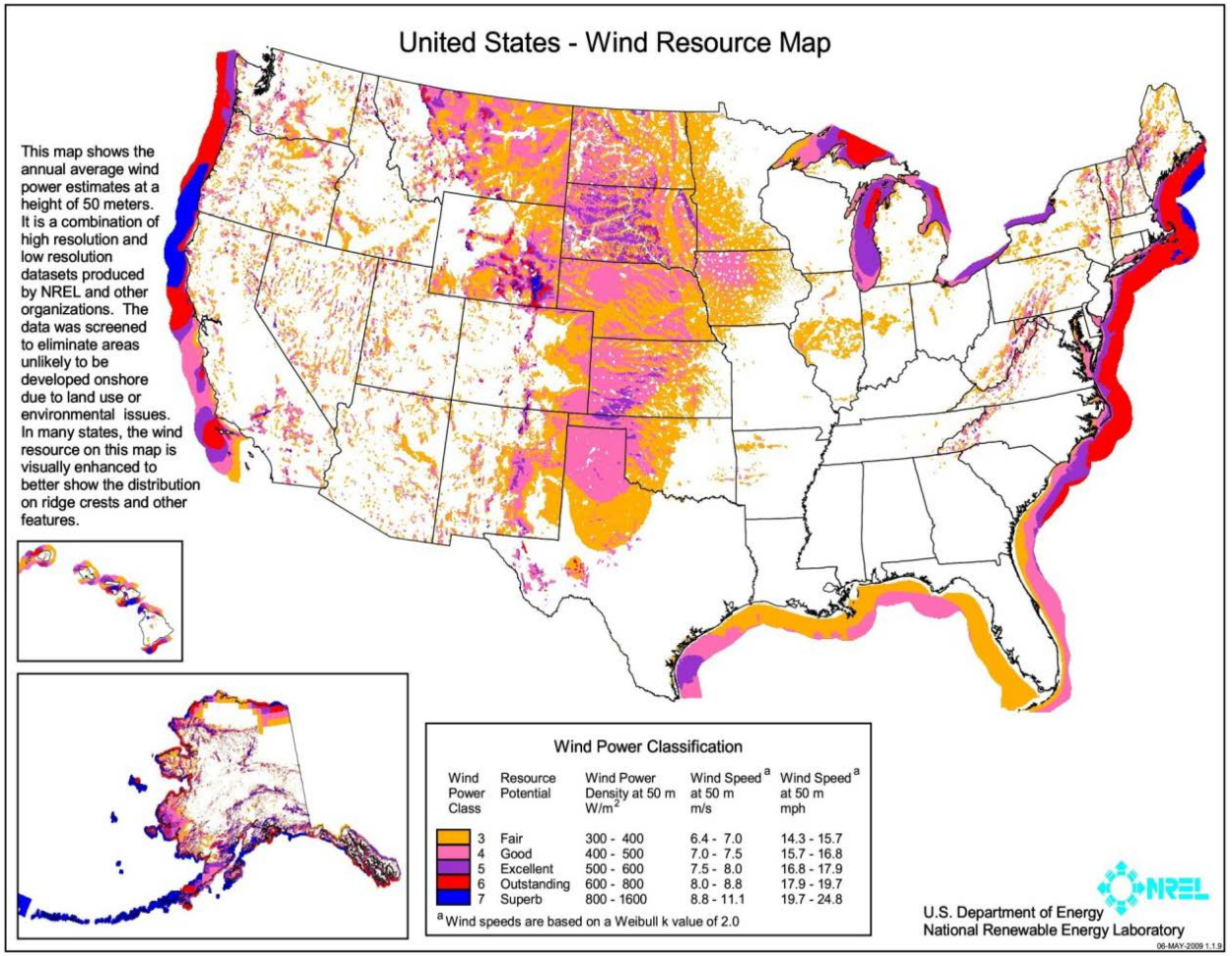


Wind Resource Characterization Improvements

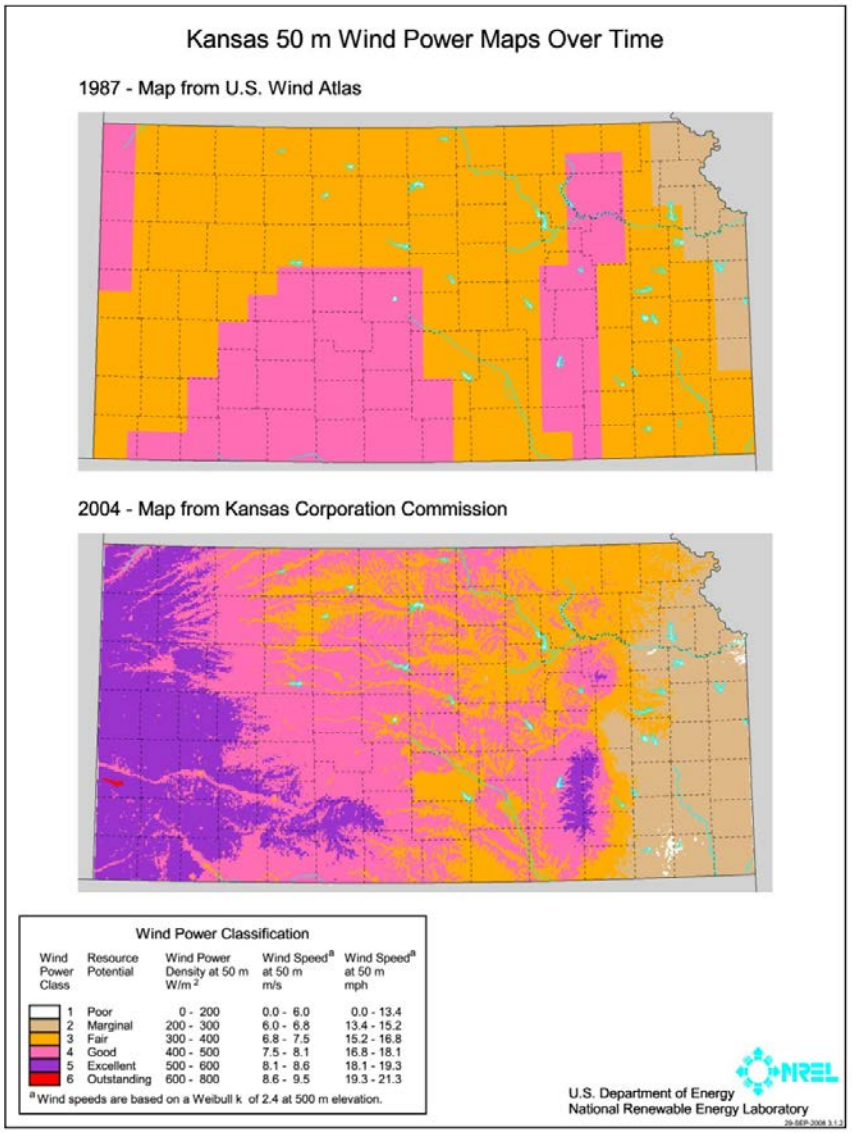
Photo by Dennis Schroeder, *NREL 25861*

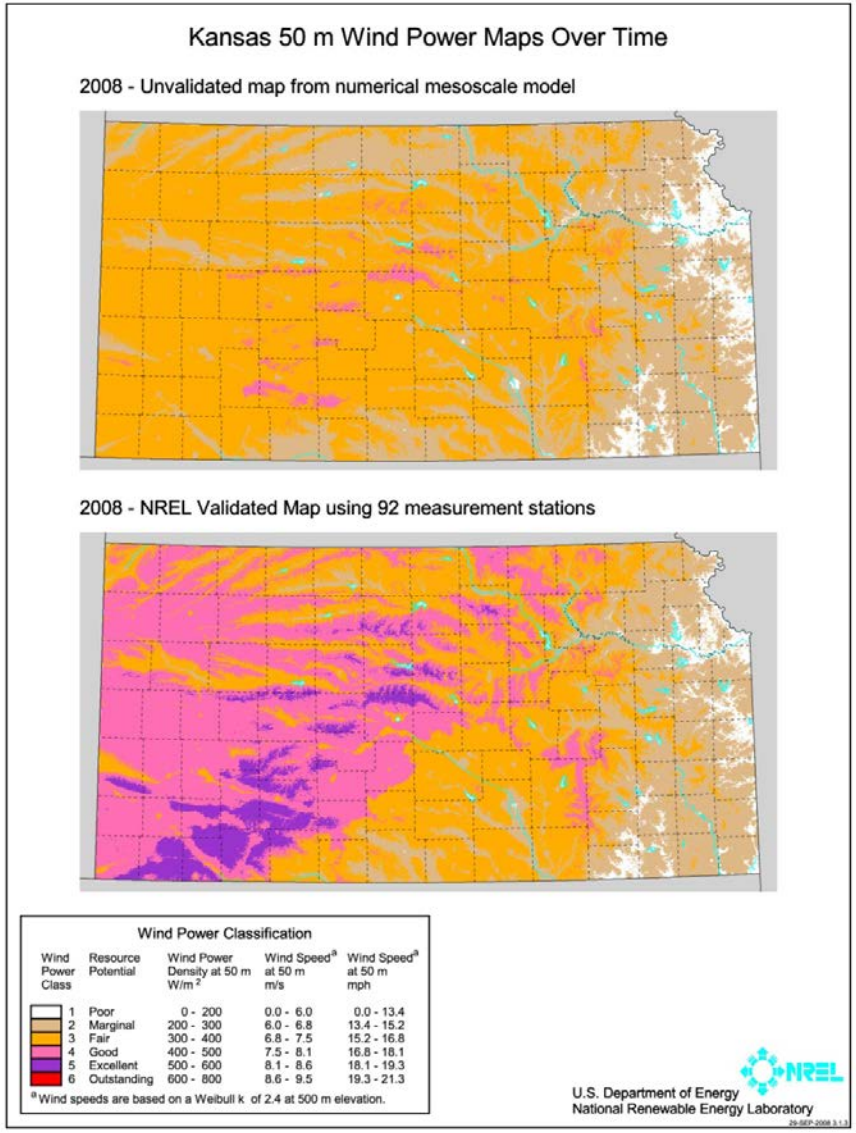
Wind Resource Mapping: Wind Class at 50-m Height

- **50-m wind mapping (2001-2009)**
  - Culmination of long-term project that began in 2001; jointly funded by states and DOE
  - Comprehensive validation of 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

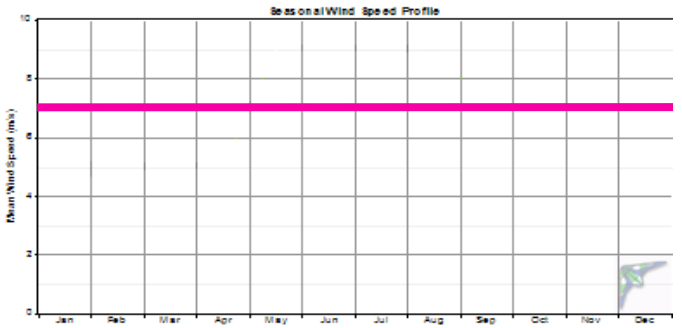




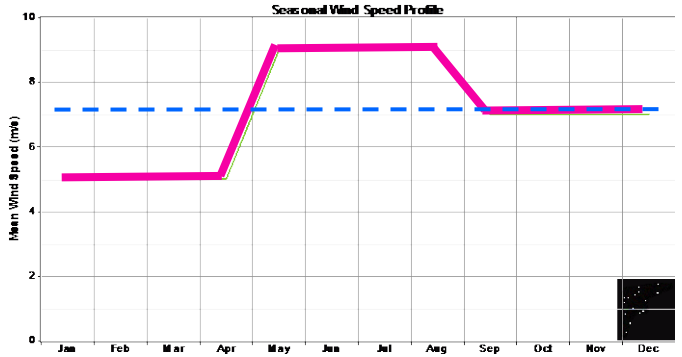
Importance of Wind Resource Assessment

Mean Annual Wind Speed = 7 m/s

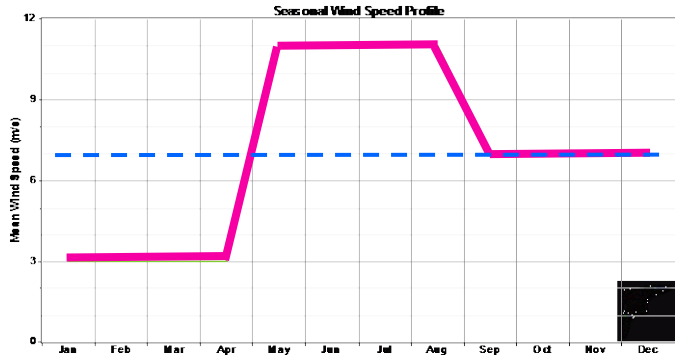
Steady 7 m/s



1/3 of year at 5 m/s
1/3 of year at 7 m/s
1/3 of year at 9 m/s

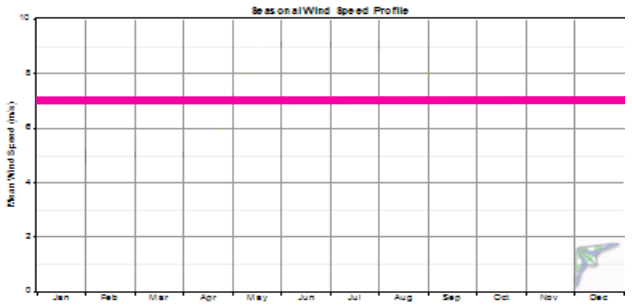


1/3 of year at 3 m/s
1/3 of year at 7 m/s
1/3 of year at 11 m/s

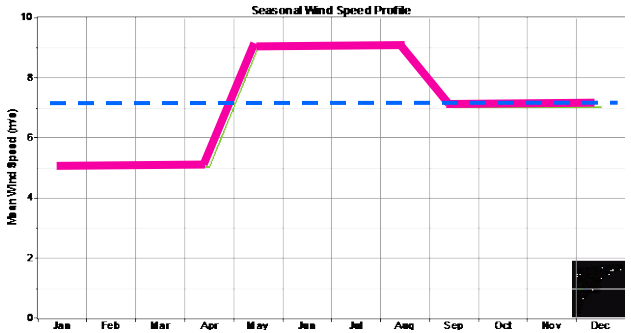


Not All 7 m/s Sites Are Equal!

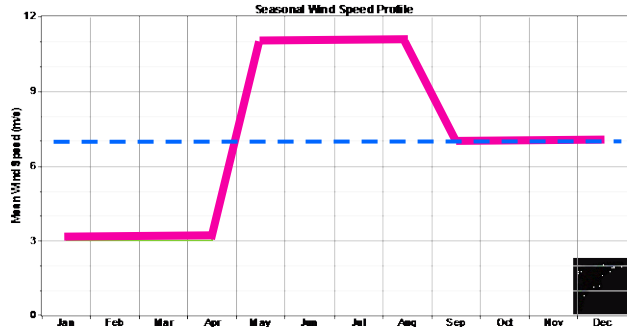
BASE CASE - STEADY WIND AT 7 M/S		
Annual Energy	1,878,107	kWh/yr
Annual Revenue/turbine	$112,686	$/yr/turb
Wind Farm Size	300	MW
Annual Revenue/Farm	$22,537,284	$/yr/turb



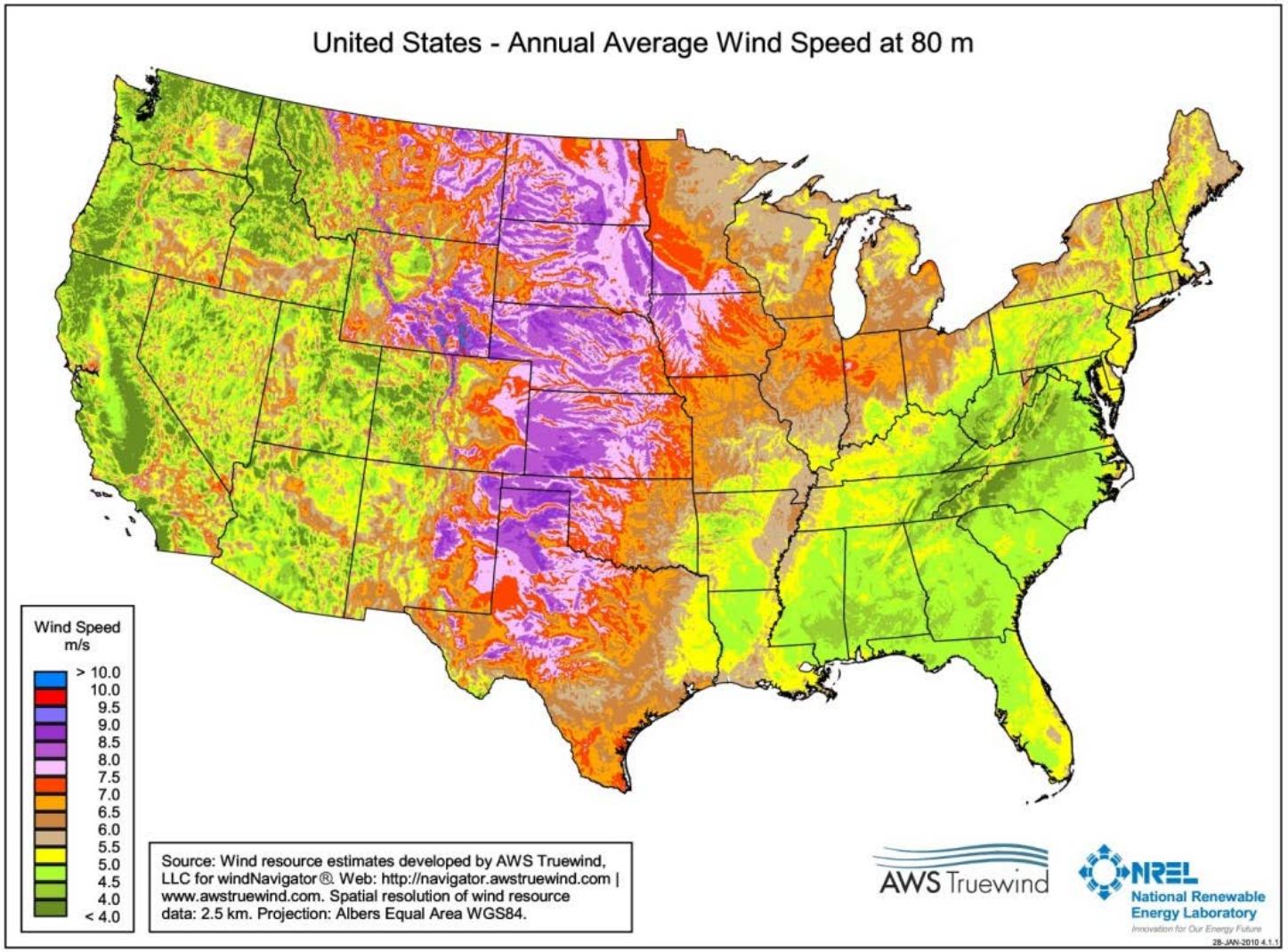
WIND SPEED AT 5 - 7 - 9 M/S		
Annual Energy	2,466,956	kWh/yr
Annual Revenue/turbine	$148,017	$/yr/turb
Wind Farm Size	300	MW
Annual Revenue/Farm	$29,603,471	$/yr/turb
Increase in Rev/Yr	$7,066,187	$/yr/farm
Energy & Rev Increase	31.4%	



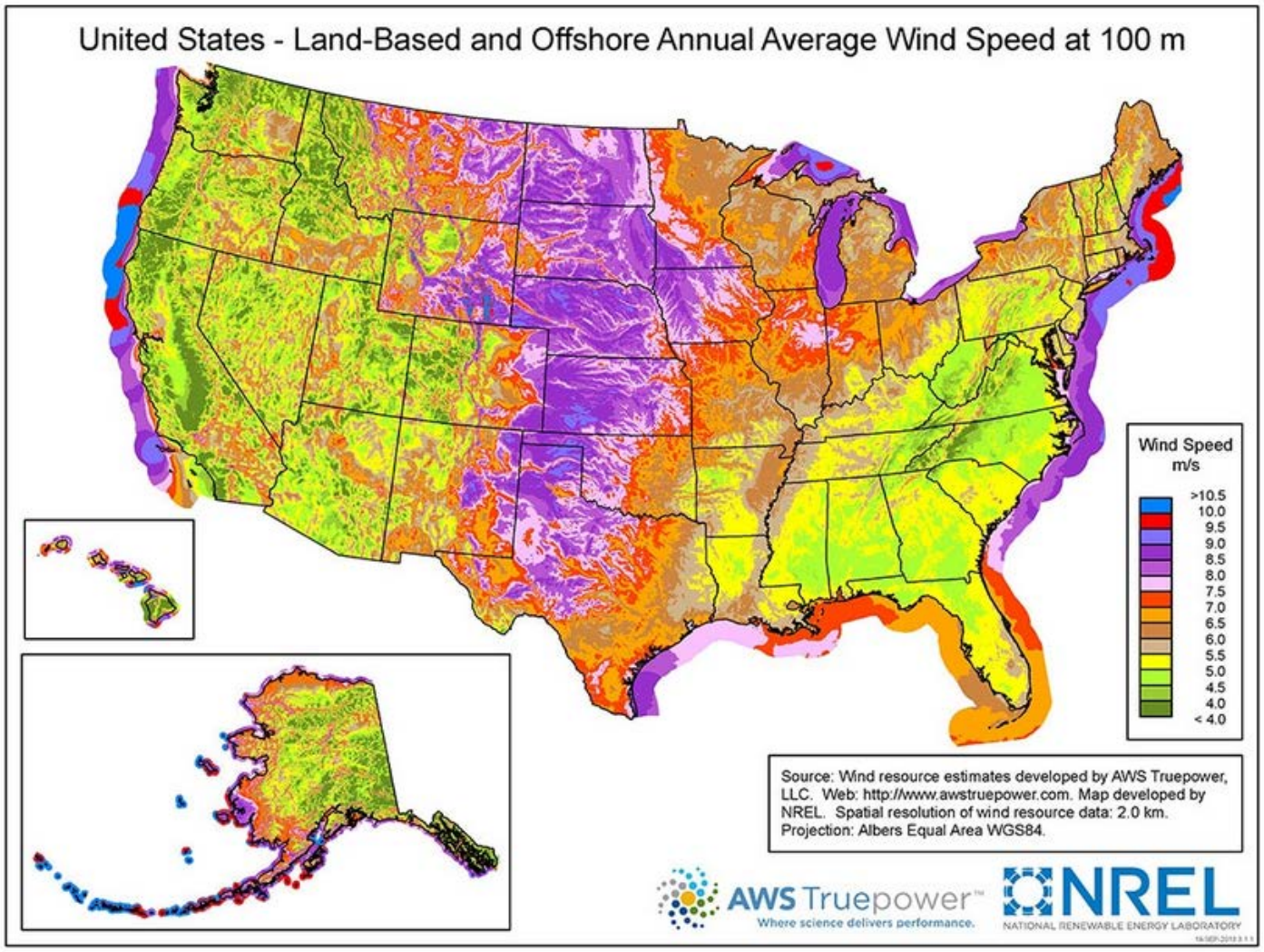
WIND SPEED AT 3 - 7 - 11 M/S		
Annual Energy	3,912,763	kWh/yr
Annual Revenue/turbine	$234,766	$/yr/turb
Wind Farm Size	300	MW
Annual Revenue/Farm	$46,953,158	$/yr/turb
Increase in Rev/Yr	$24,415,874	$/yr/farm
Energy & Rev Increase	108.3%	



Recent U.S. Wind Resource Map: Wind Speed at 80 m



New U.S. Wind Resource Map: Wind Speed at 100 m



Source: http://energy.gov/eere/wind/wind-resource-assessment-and-characterization

Rebound in Wind Installations in 2014 and 2015; Uncertainty Returns in 2016

2014-15 expected to be strong as developers commission projects that began construction in 2013 to receive PTC

- AWEA: 12 GW of wind under construction
- BNEF expects 15 GW in 2014-2015
- EIA expects 16.7 GW in 2014-2015
- Navigant expects 12.3 GW in 2014-2015.

2016 and beyond are uncertain: aggressive wind pricing may support higher growth but multiple headwinds

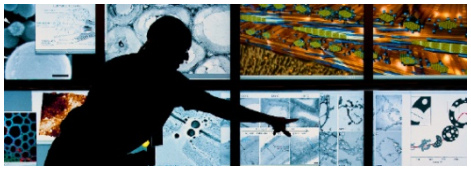
- Lack of clarity about federal tax incentives
- Low natural gas & wholesale electric prices
- Modest electricity demand growth
- Limited near-term demand from RPS policies.

Source: Wiser, R. A Preview of the 2013 Wind Technologies Market Report, WINDExchange Summit, Las Vegas NV. May 8, 2014

Opportunities for Wind Technology

- National Wind Technology Center – research
- Wind – incentives & markets
- Wind technology improvements
- Wind resource assessment improvements.

Questions?

For more info:

www.nrel.gov/wind/

www.nrel.gov/tech_deployment/wind.html

http://energy.gov/eere/wind/wind-program

www.awea.org/

www.nrel.gov/wind/resource_assessment.html

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