U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

2016 Wind Technologies Market Report: Summary

Ryan Wiser & Mark Bolinger

Lawrence Berkeley National Laboratory

August 2017

2016 Wind Technologies Market Report

Purpose, Scope, and Data:

- Publicly available annual report summarizing key trends in the U.S. wind power market, with a focus on 2016
- Scope primarily includes wind turbines over 100 kW in size
- Separate DOE-funded reports on distributed and offshore wind
- Data sources include EIA, FERC, SEC, AWEA, etc. *(see full report)*

Report Authors:

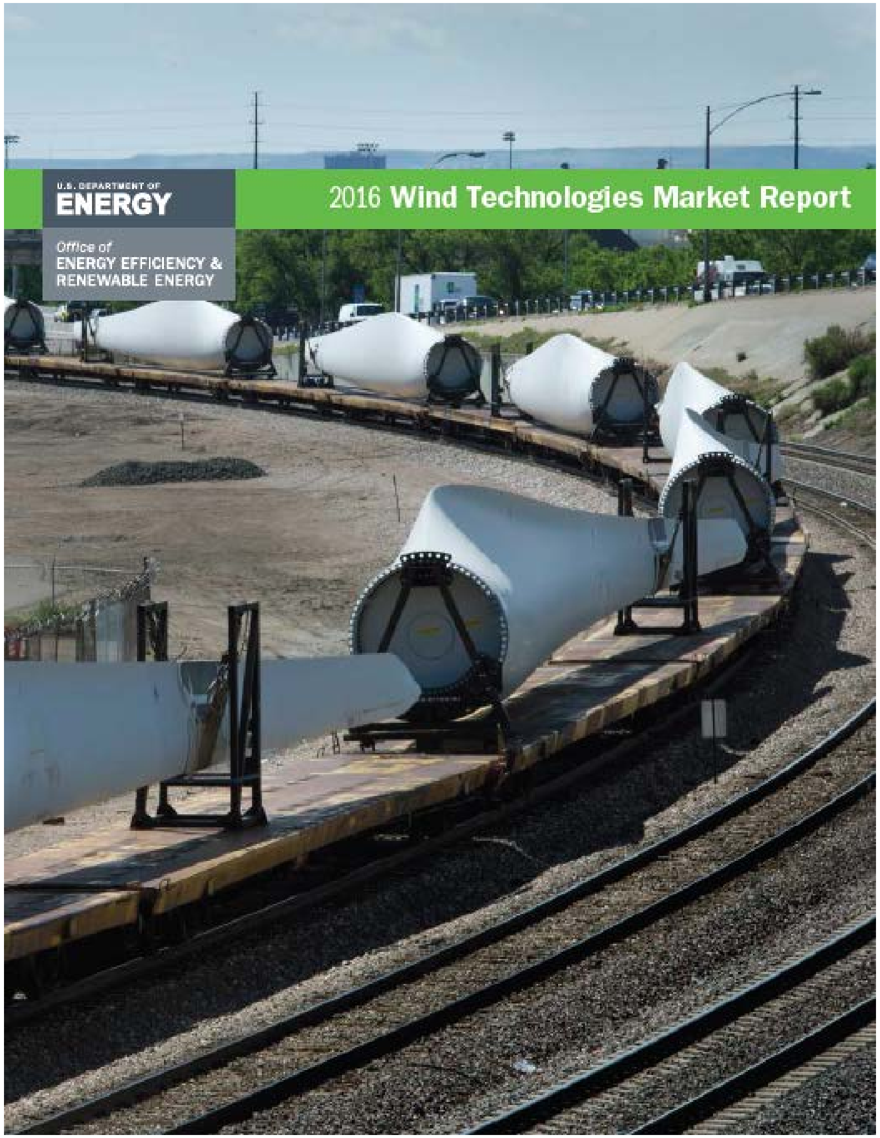
- Primary authors: Ryan Wiser and Mark Bolinger, Berkeley Lab
- Contributions from others at Berkeley Lab, Exeter Associates, NREL

Funded by: U.S. DOE Wind Energy Technologies Office

Available at: http://energy.gov/eere/wind

Report Contents

- Installation trends
- Industry trends
- Technology trends
- Performance trends
- Cost trends
- Wind power price trends
- Policy & market drivers
- Future outlook



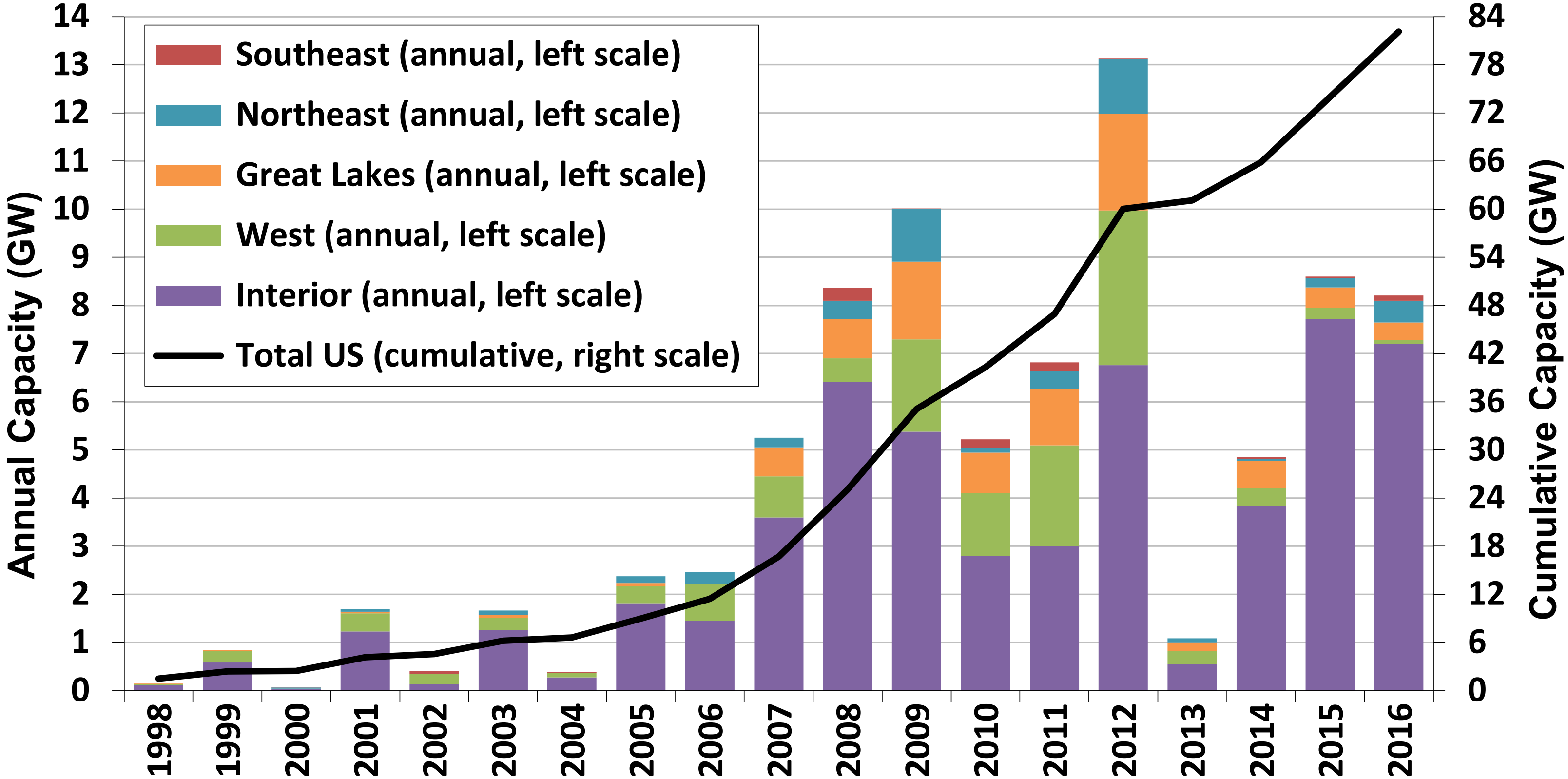
Key Findings

- Wind capacity additions continued at a rapid pace in 2016, w/ significant additional new builds anticipated over next four years in part due to PTC
- Wind has been a significant source of new electric generation capacity additions in the U.S. in recent years
- Supply chain continued to adjust to swings in domestic demand, but domestic content for nacelle assembly, towers, and blades is strong
- Turbine scaling is significantly boosting wind project performance, while the installed cost of wind projects has declined
- Wind power sales prices are at all-time lows, enabling economic competitiveness despite low natural gas prices
- Growth beyond current PTC cycle remains uncertain: could be blunted by declining federal tax support, expectations for low natural gas prices and solar costs, and modest electricity demand growth

Installation Trends

Installation Trends

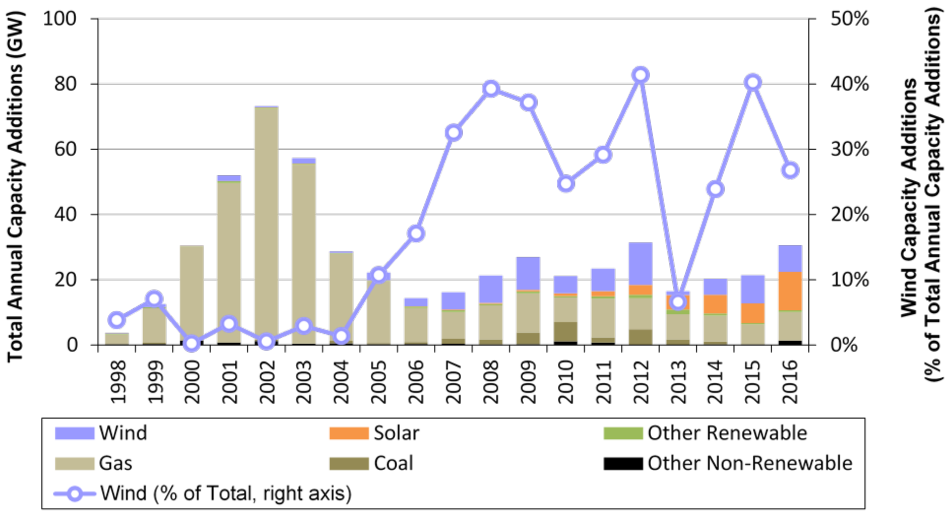
Wind Additions Continued at a Rapid Pace in 2016, with 8,203 MW of New Capacity, Bringing Total to 82 GW

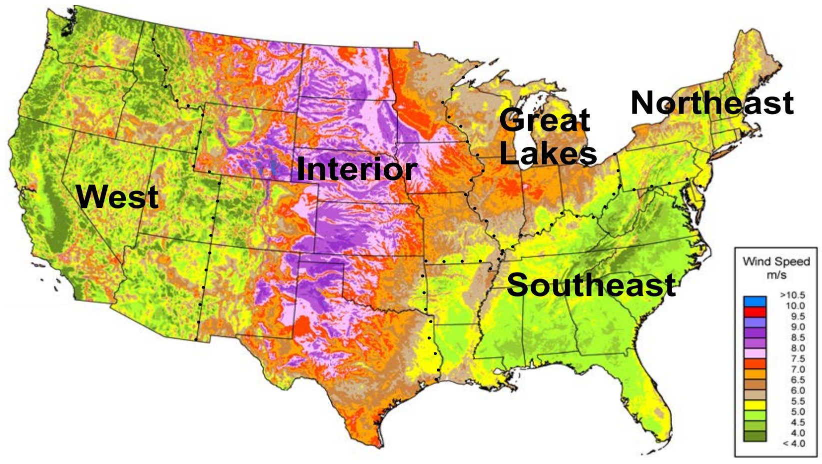


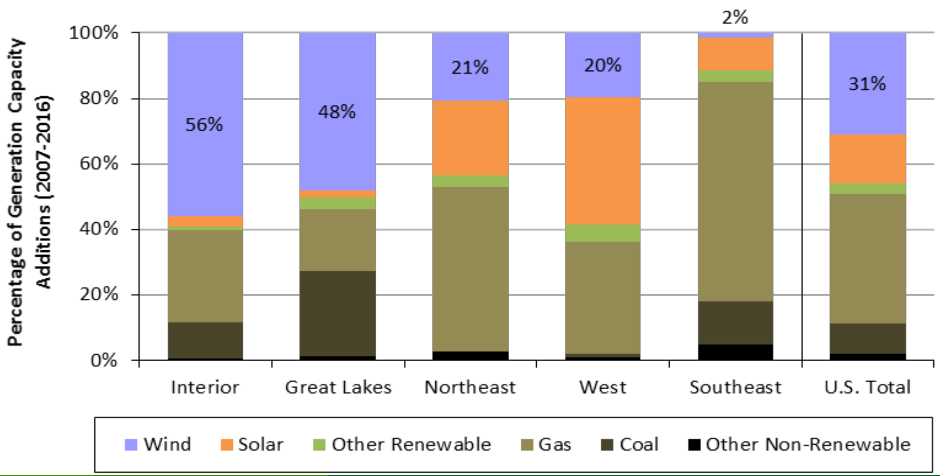
- $13 billion invested in wind power project additions in 2016
- Nearly 90% of new 2016 capacity located in the Interior region
- First offshore project—30 MW in Rhode Island—commissioned

Installation Trends

Wind Power Represented 27% of Electric-Generating Capacity Additions in 2016







- Over last decade, wind has comprised 31% of capacity additions nation-wide, and a much higher proportion in some regions

Installation Trends

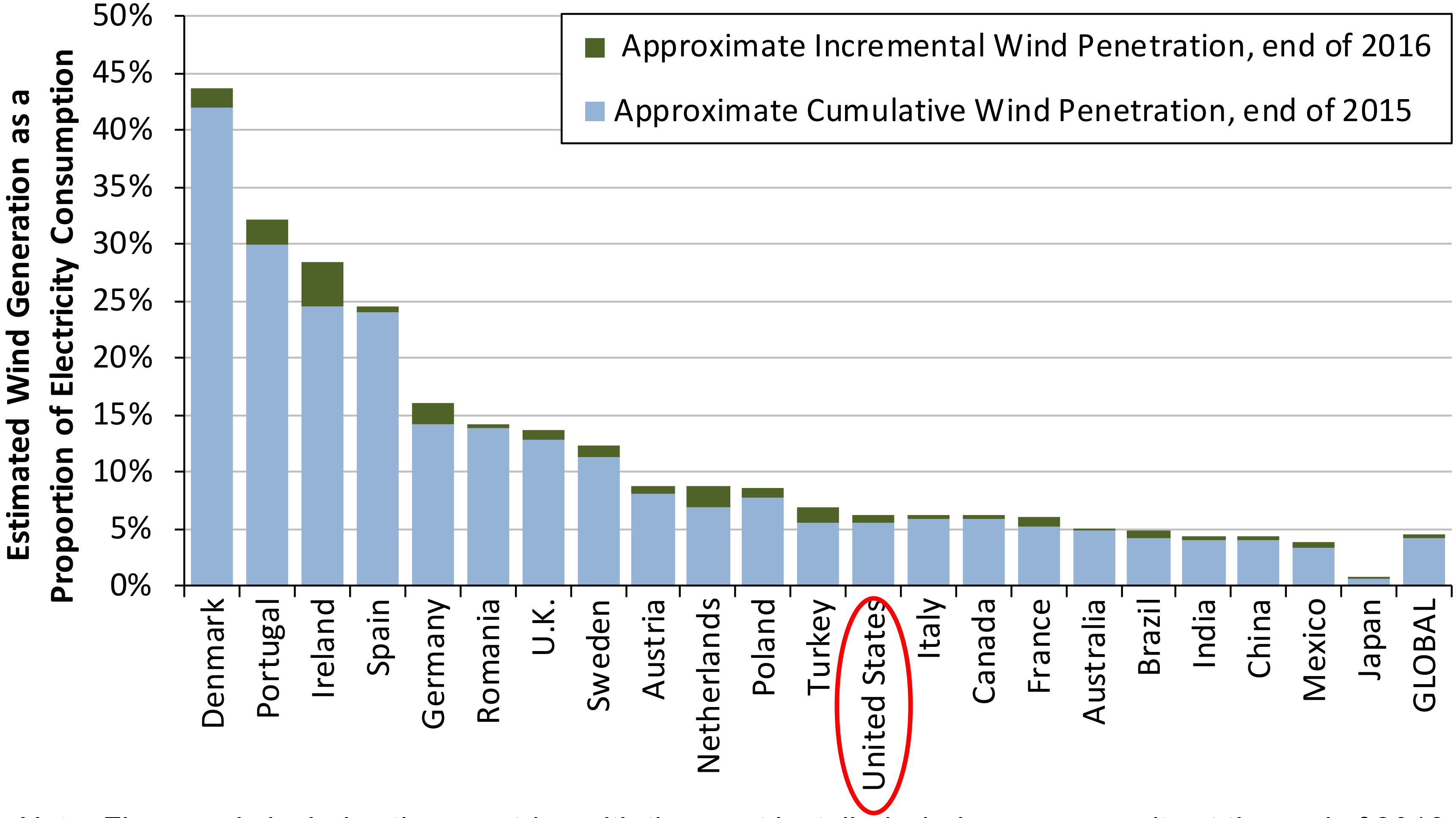
The U.S. Placed 2rd in Annual Wind Power Capacity Additions in 2016

Annual Capacity (2016, MW)		Cumulative Capacity (end of 2016, MW)	
China	23,370	China	168,732
United States	**8,203**	**United States**	**82,143**
Germany	5,443	Germany	50,018
India	3,612	India	28,700
Brazil	2,014	Spain	23,074
France	1,561	United Kingdom	14,543
Turkey	1,387	France	12,066
Netherlands	887	Canada	11,900
United Kingdom	736	Brazil	10,740
Canada	702	Italy	9,257
Rest of World	6,727	*Rest of World*	75,576
TOTAL	**54,642**	**TOTAL**	**486,749**

- U.S. also remains a distant second to China in cumulative capacity
- Global wind additions in 2016 were 14% below their record high in 2015

Installation Trends

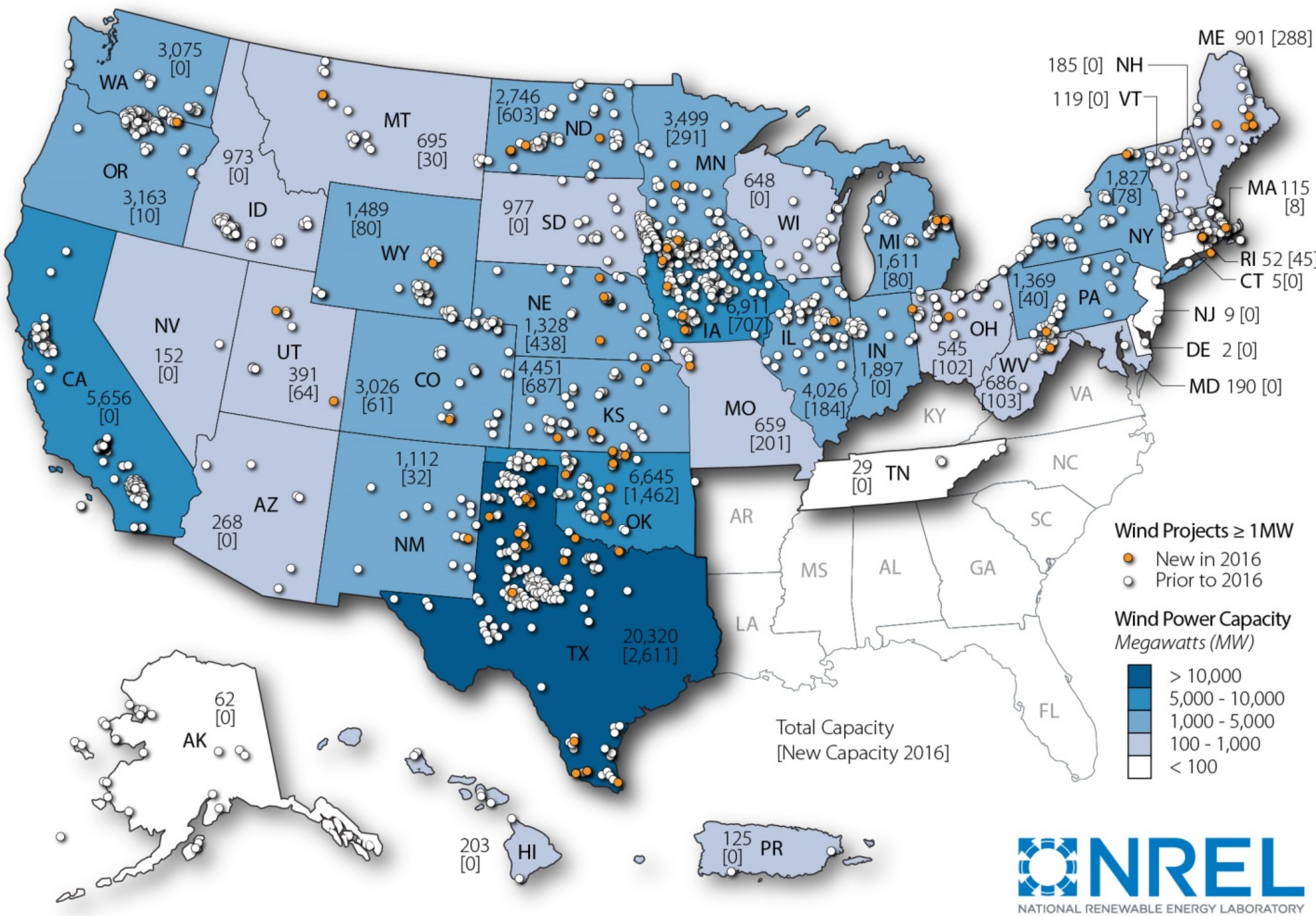
U.S. Lagging Other Countries in Wind As a Percentage of Electricity Consumption



Note: Figure only includes the countries with the most installed wind power capacity at the end of 2016

Installation Trends

Geographic Spread of Wind Projects in the United States Is Reasonably Broad



Note: Numbers within states represent cumulative installed wind capacity and, in brackets, annual additions in 2016

Installation Trends

Texas Installed the Most Wind Capacity in 2016; 14 States >10% Wind Energy

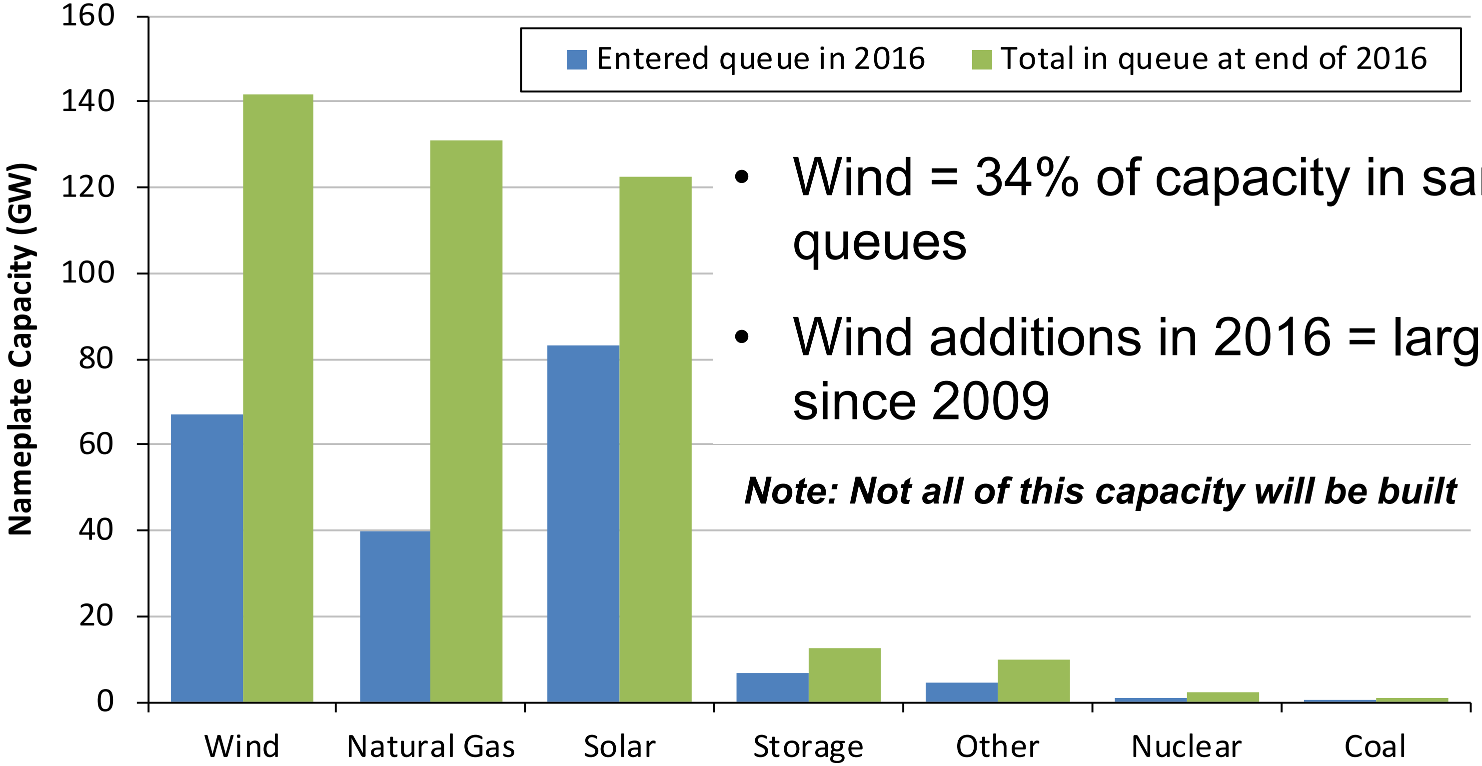
Installed Capacity (MW)				Percentage of In-State Generation	
Annual (2016)		Cumulative (end of 2016)		Actual (2016)*	
Texas	2,611	Texas	20,320	Iowa	36.6%
Oklahoma	1,462	Iowa	6,911	South Dakota	30.3%
Iowa	707	Oklahoma	6,645	Kansas	29.6%
Kansas	687	California	5,656	Oklahoma	25.1%
North Dakota	603	Kansas	4,451	North Dakota	21.5%
Nebraska	438	Illinois	4,026	Minnesota	17.7%
Minnesota	291	Minnesota	3,499	Colorado	17.3%
Maine	288	Oregon	3,163	Vermont	15.4%
Missouri	201	Washington	3,075	Idaho	15.2%
Illinois	184	Colorado	3,026	Maine	13.9%
West Virginia	103	North Dakota	2,746	Texas	12.6%
Ohio	102	Indiana	1,897	Oregon	12.1%
Michigan	80	New York	1,827	New Mexico	10.9%
Wyoming	80	Michigan	1,611	Nebraska	10.1%
New York	78	Wyoming	1,489	Wyoming	9.4%
Utah	64	Pennsylvania	1,369	Montana	7.6%
Colorado	61	Nebraska	1,328	Washington	7.1%
Rhode Island	45	New Mexico	1,112	California	6.9%
Pennsylvania	40	South Dakota	977	Hawaii	6.7%
New Mexico	32	Idaho	973	Illinois	5.7%
Rest of U.S.	48	*Rest of U.S.*	6,041	*Rest of U.S.*	1.0%
TOTAL	**8,203**	**TOTAL**	**82,143**	**TOTAL**	**5.6%**

* Based on 2016 wind and total generation by state from EIA's *Electric Power Monthly*.

- Texas had almost 3 times as much wind capacity as the next-highest state
- 26 states had > 500 MW of capacity at end of 2016 (18 > 1 GW, 10 > 3 GW)
- IA = 37% of total in-state generation from wind; SD = 30%, KS = 30%; 14 states > 10%)

Installation Trends

Interconnection Queues Demonstrate that a Substantial Amount of Wind Is Under Consideration



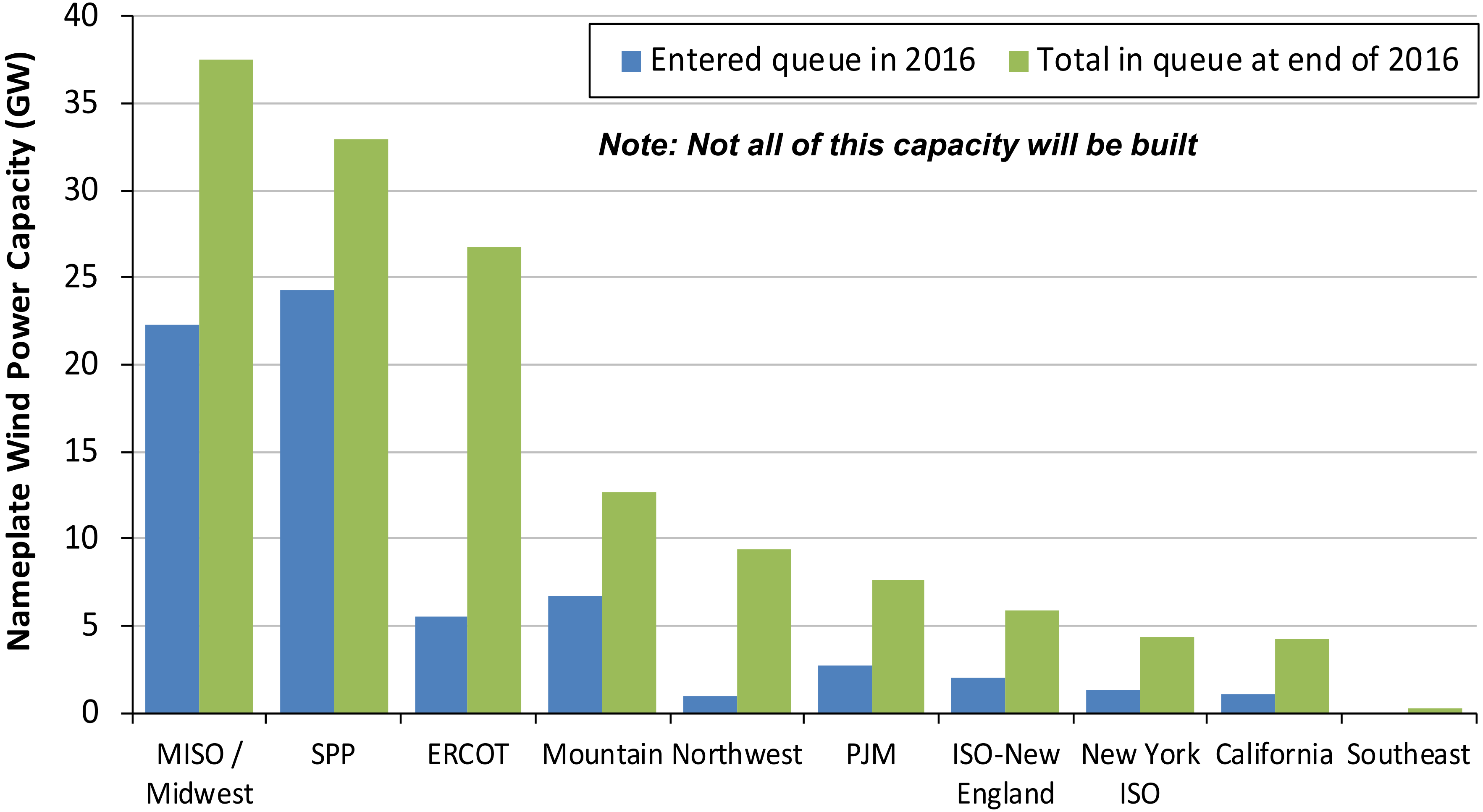
- Wind = 34% of capacity in sampled 35 queues
- Wind additions in 2016 = largest amount since 2009

Note: Not all of this capacity will be built

- AWEA reports 21 GW of capacity under construction or in advanced development at end of 1Q2017

Installation Trends

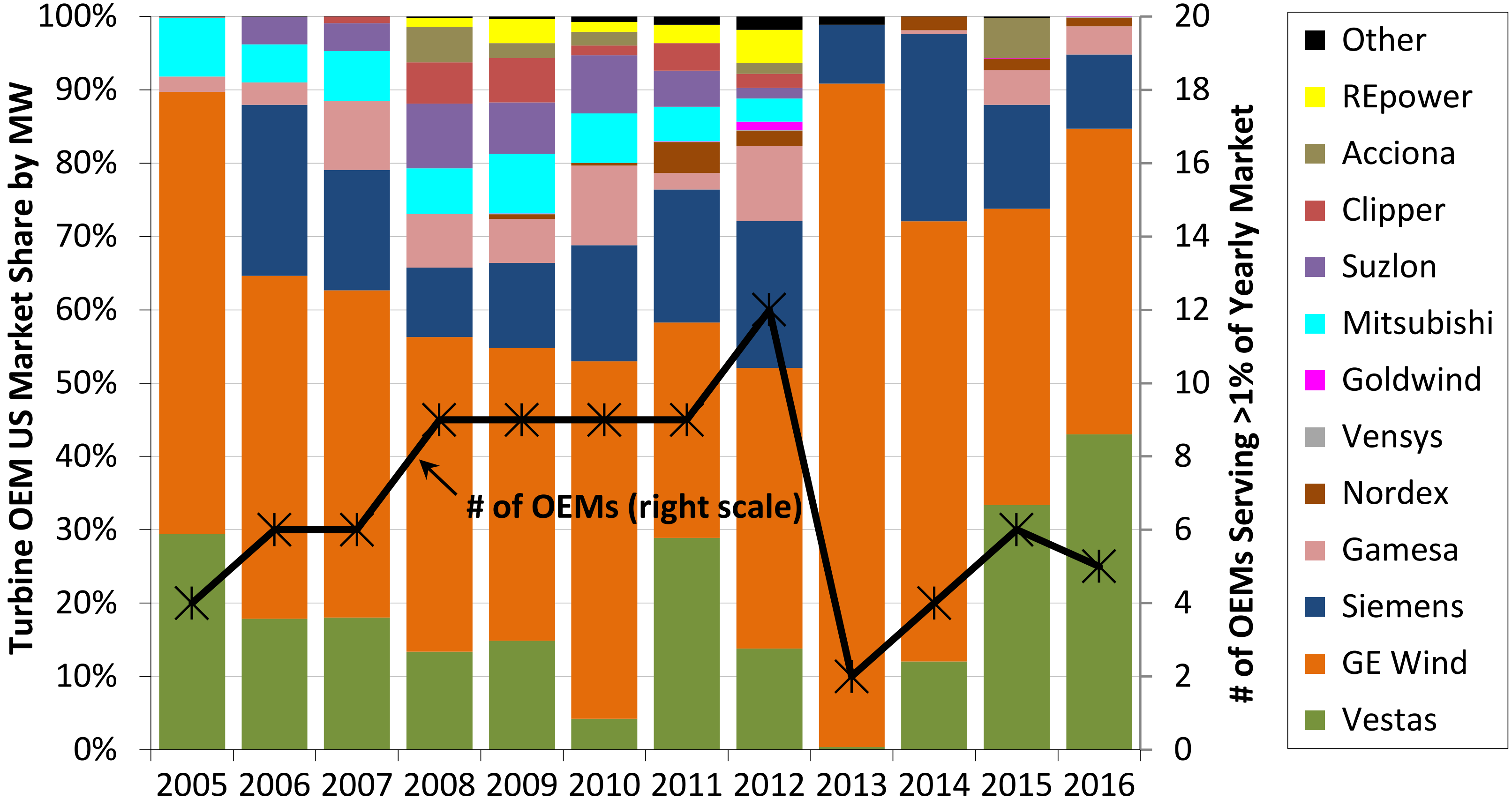
Larger Amounts of Wind Planned for Midwest, Southwest Power Pool, Texas



Industry Trends

Industry Trends

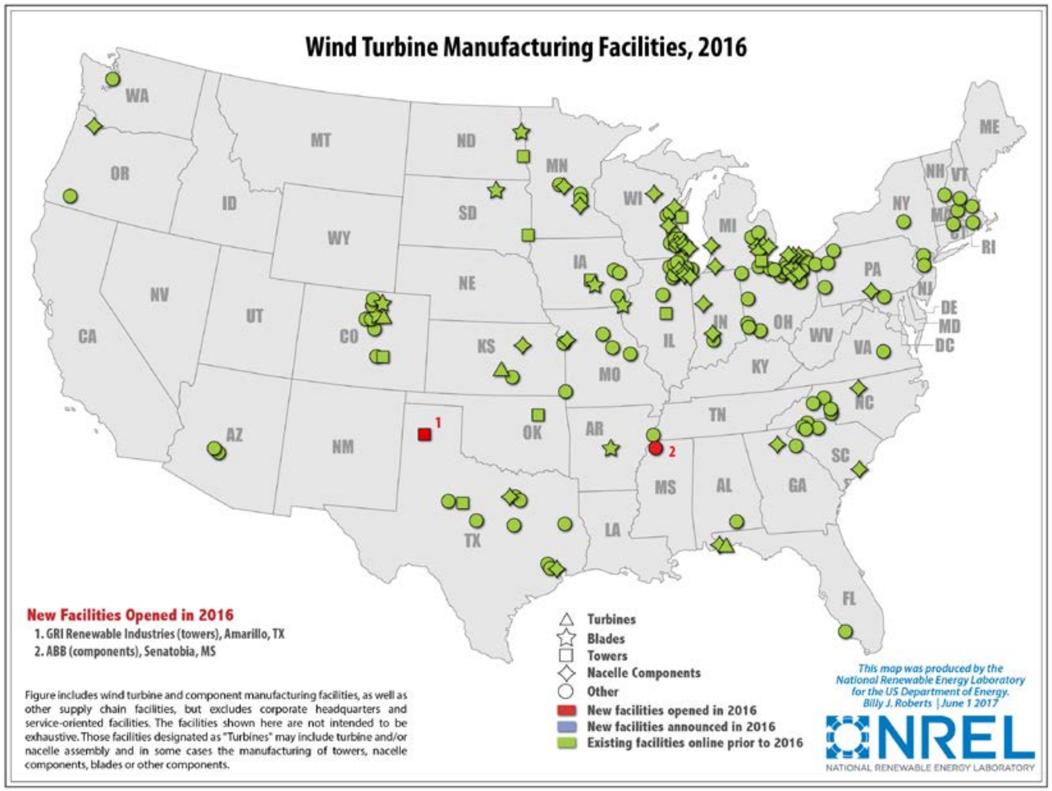
Vestas and GE Captured 85% of the U.S. Market in 2016



- Globally, Vestas, GE, and Goldwind were the top suppliers
- Chinese suppliers occupied 4 of the top 10 spots in the global ranking, based almost entirely on sales within their domestic market

Industry Trends

Manufacturing Supply Chain Continued to Adjust to Swings in Domestic Demand

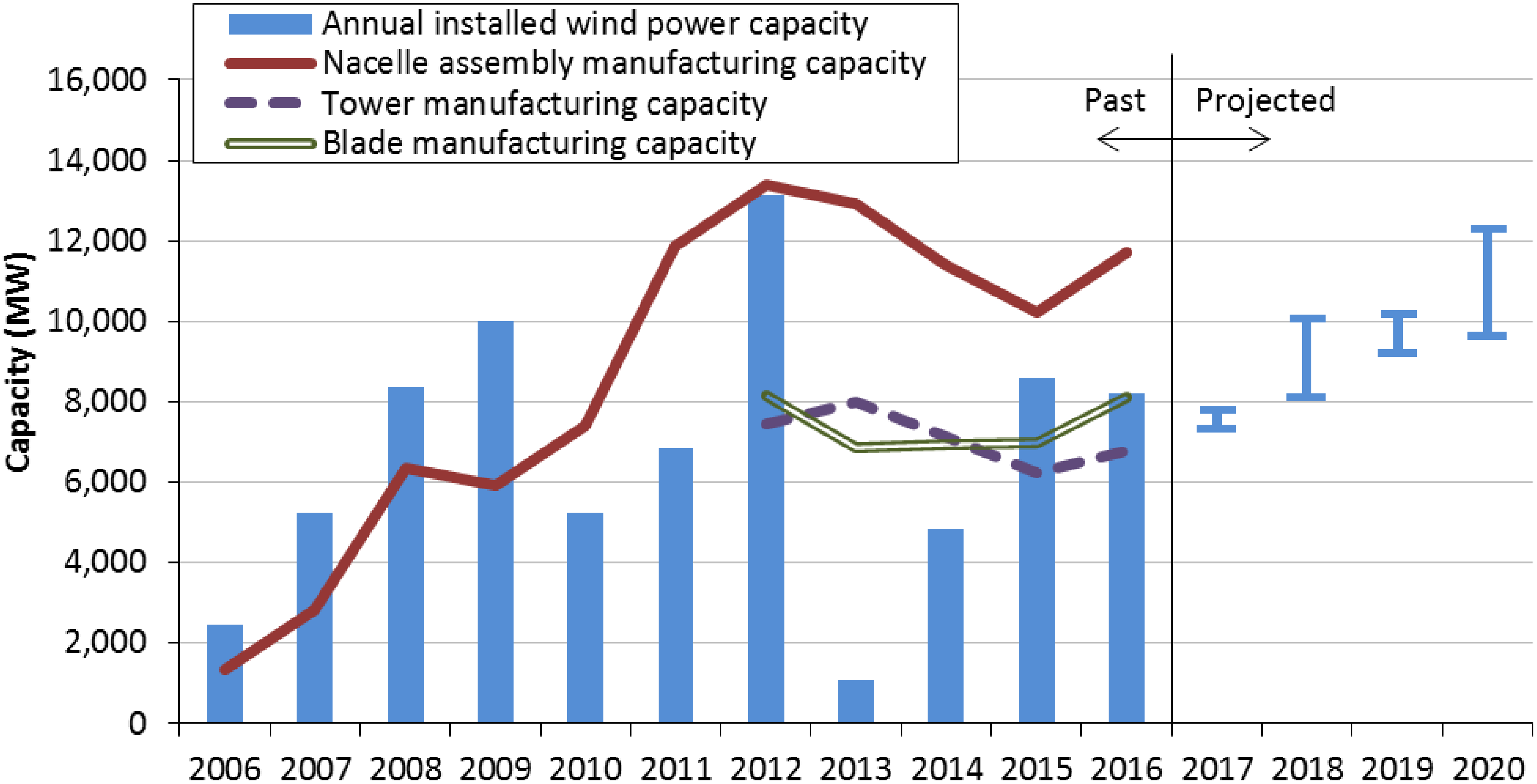


Note: map not intended to be exhaustive

- Continued near-term expected growth, but strong competitive pressures and possible reduced demand as PTC is phased down
- 3 domestic manufacturing facility closures in 2016; 2 new openings
- Many manufacturers remain, and “Big 3” OEMs all have at least one facility
- Wind related jobs increased 32% from 2015, to 102,000

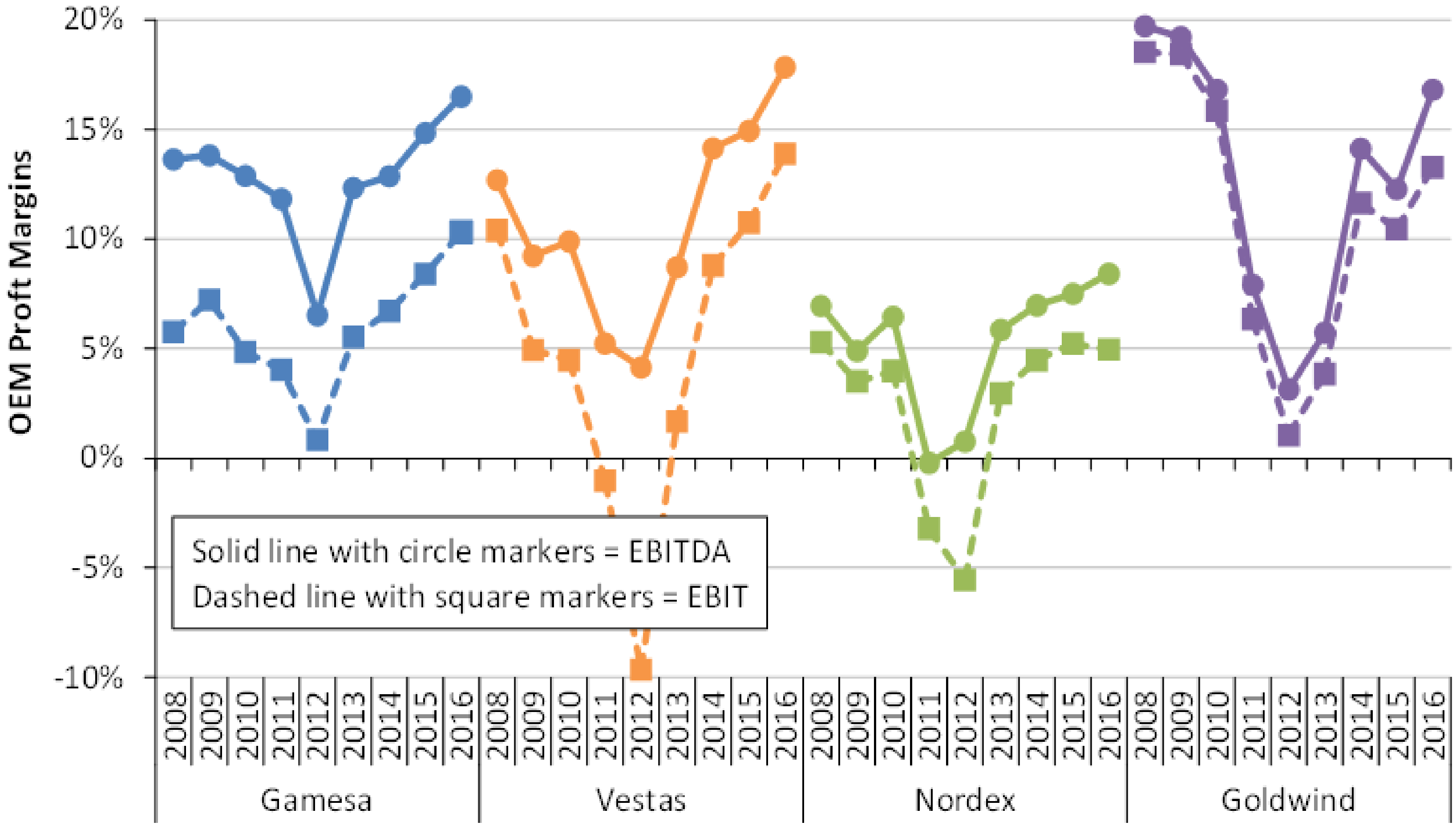
Industry Trends

Domestic Manufacturing Capability for Nacelle Assembly, Towers, and Blades Is Reasonably Well Balanced Against Near-Term Demand Forecasts



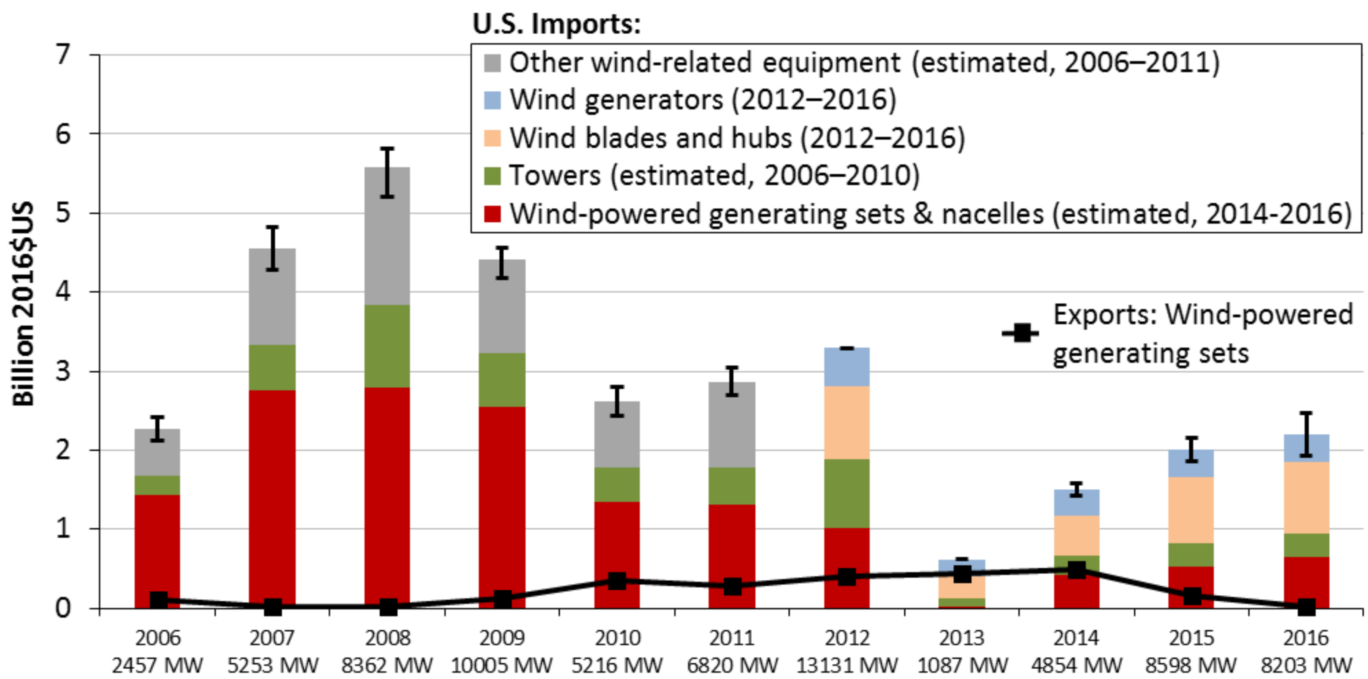
Industry Trends

Turbine OEM Profitability Has Generally Rebounded Over the Last Four Years



Industry Trends

Imports of Wind Equipment Are Sizable; Exports Continued to Decline in 2016

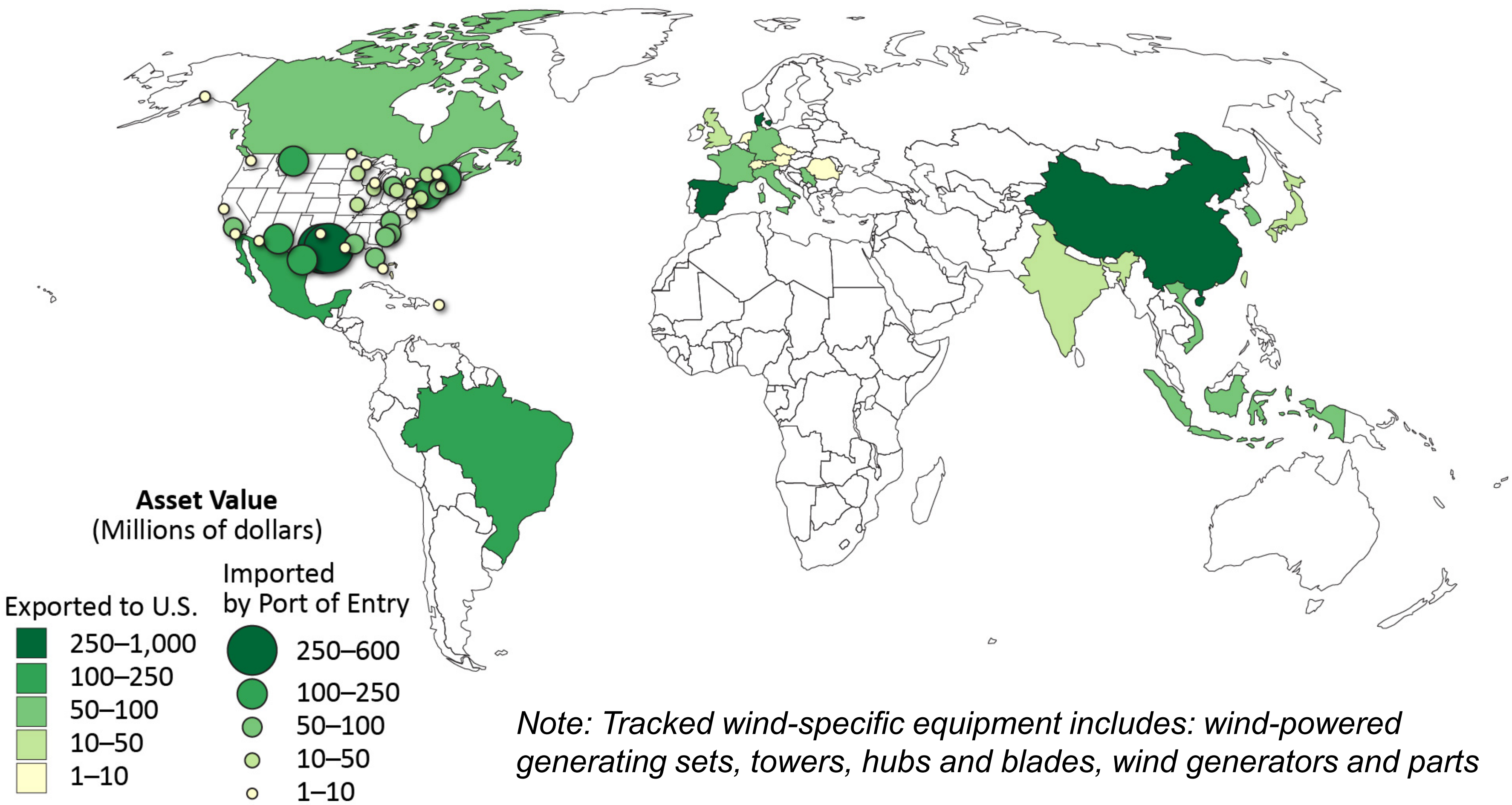


Notes: Figure only includes tracked trade categories; misses other wind-related imports; see full report for the assumptions used to generate this figure

- U.S. is a net importer of wind equipment
- Exports of wind-powered generating sets decreased to just $17 million in 2016; no ability to track other wind-specific exports, but total 'tower and lattice mast' exports equalled $46 million

Industry Trends

Tracked Wind Equipment Imports in 2016: 46% Asia, 40% Europe, 14% Americas

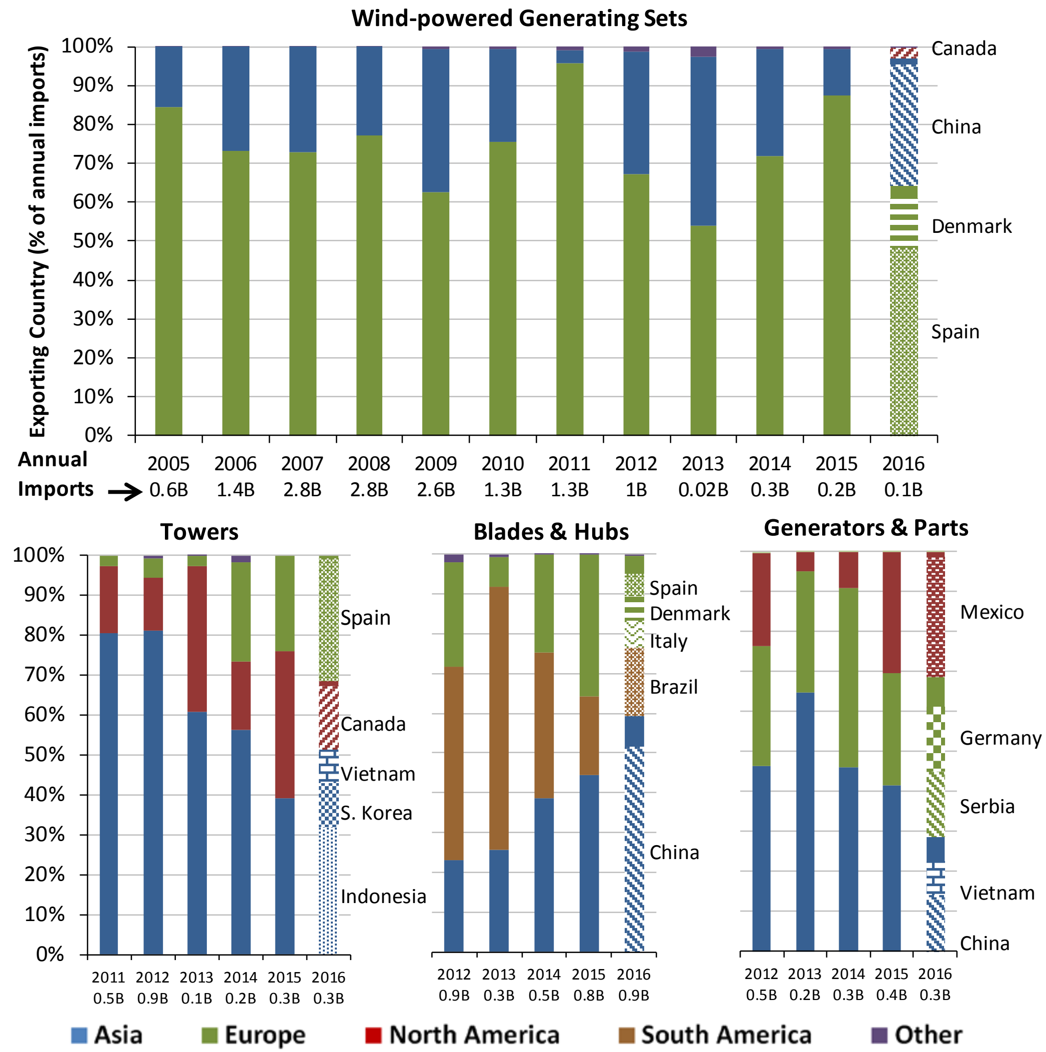


Note: Tracked wind-specific equipment includes: wind-powered generating sets, towers, hubs and blades, wind generators and parts

Industry Trends

Source Markets for Imports Vary Over Time, and By Type of Wind Equipment

- Majority of imports of wind-powered generating sets from home countries of OEMs, dominated by Europe
- Significant imports of towers from Asia, but some decline over time as tariff measures affected imports from China and Vietnam
- Majority of imports of blades & hubs from China, Brazil, Europe
- Globally diverse sourcing strategy for generators & parts



Industry Trends

Domestic Manufacturing Content Is Strong for Nacelle Assembly, Towers, and Blades, but U.S. Is Highly Reliant on Imports for Equipment Internal to the Nacelle

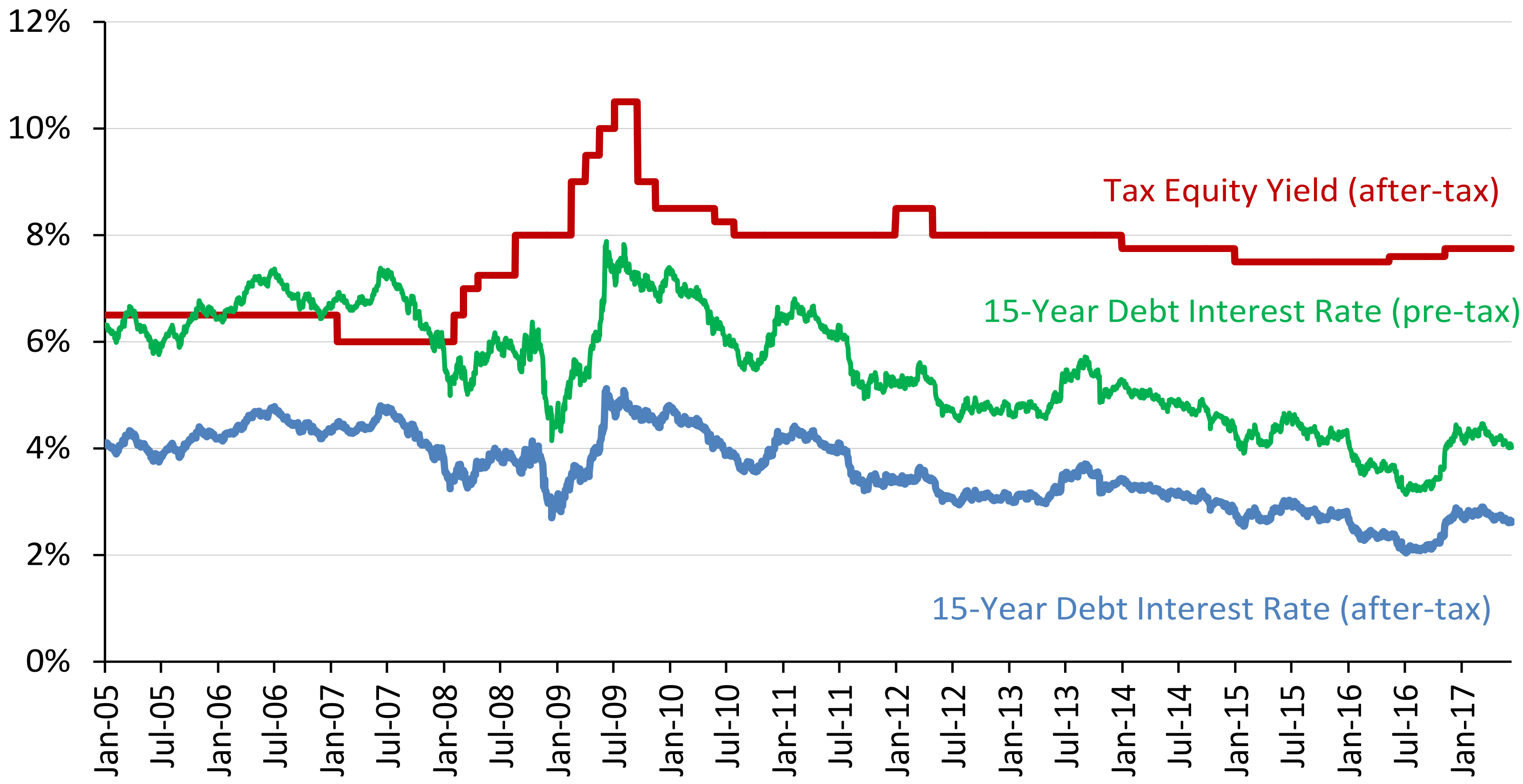
Domestic Content for 2016 Turbine Installations in the U.S.

Towers	Blades & Hubs	Nacelle Assembly
65-80%	50-70%	> 90% of nacelle assembly

- Imports occur in untracked trade categories, including many nacelle internals; nacelle internals generally have domestic content of < 20%

Industry Trends

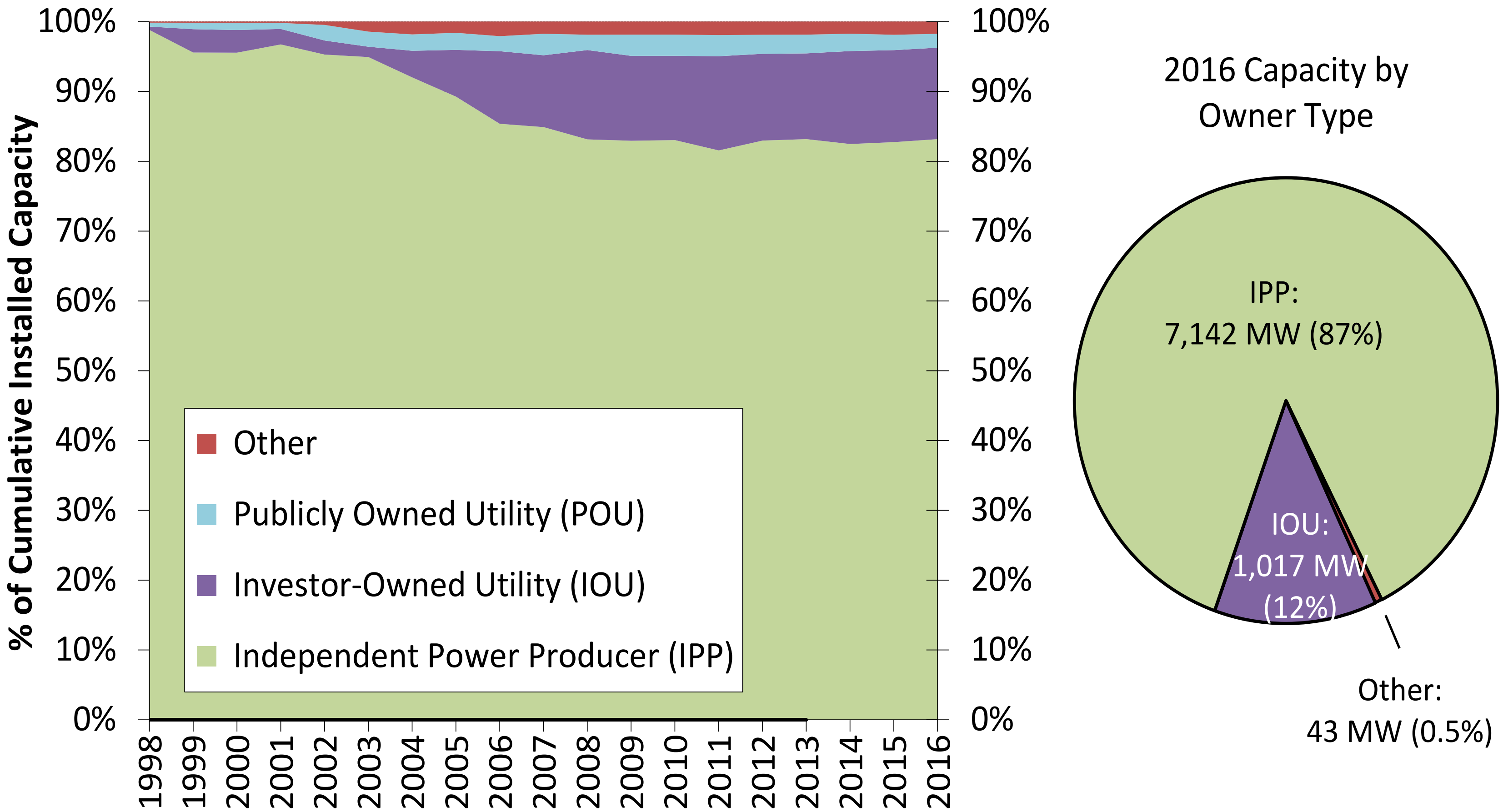
The Project Finance Environment Remained Strong in 2016



- Sponsors raised $6.4 billion of tax equity and $3.4 billion of debt in 2016
- Tax equity yields drifted slightly higher, as did debt interest rates late in the year—albeit from a particularly low starting point early in 2016

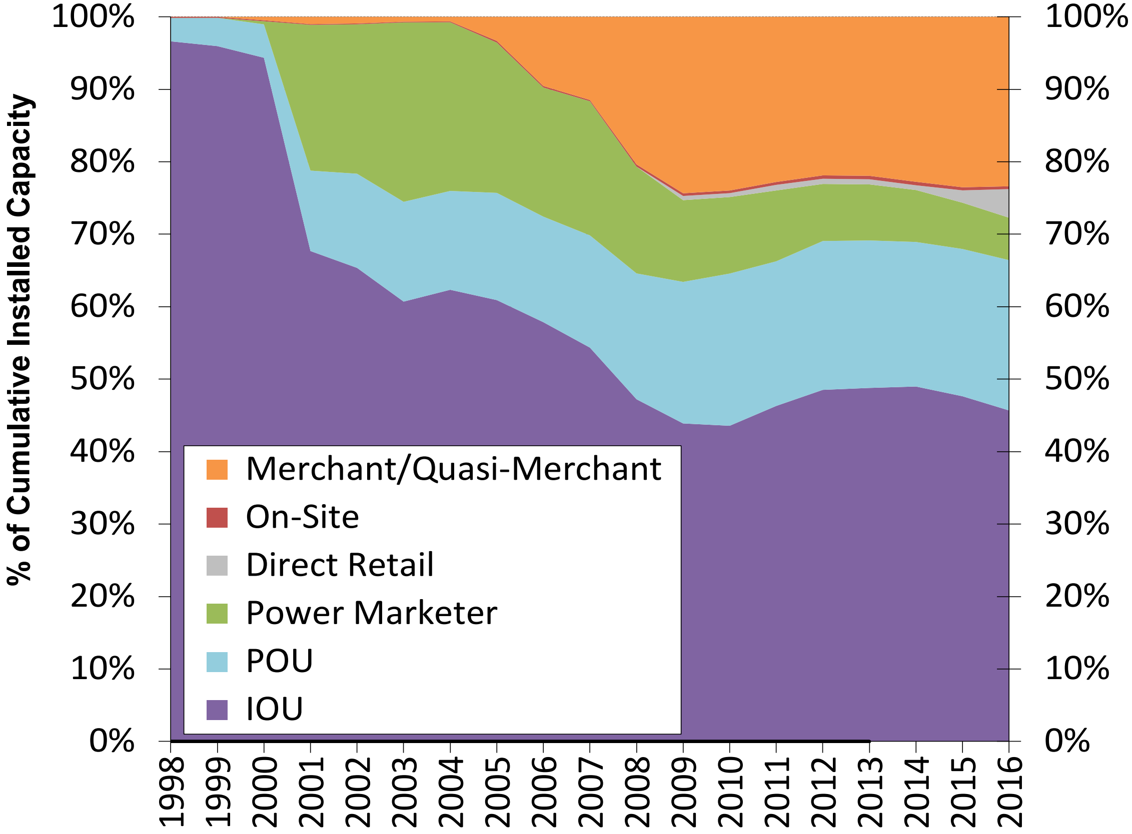
Industry Trends

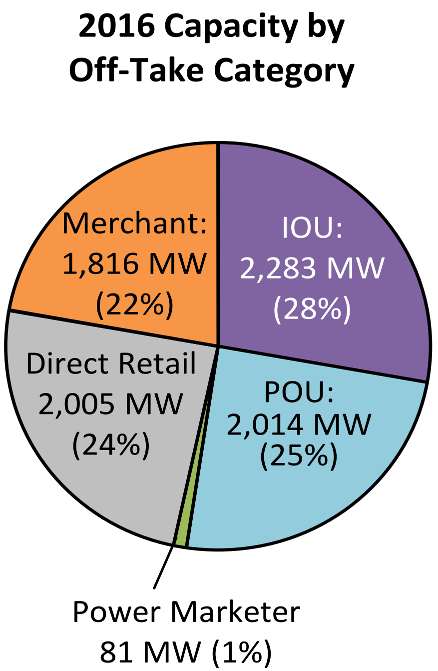
IPPs Own the Majority of Wind Assets Built in 2016



Industry Trends

Long-Term Sales to Utilities Remained the Most Common Off-Take Arrangement, but Direct Retail Sales Gained Ground



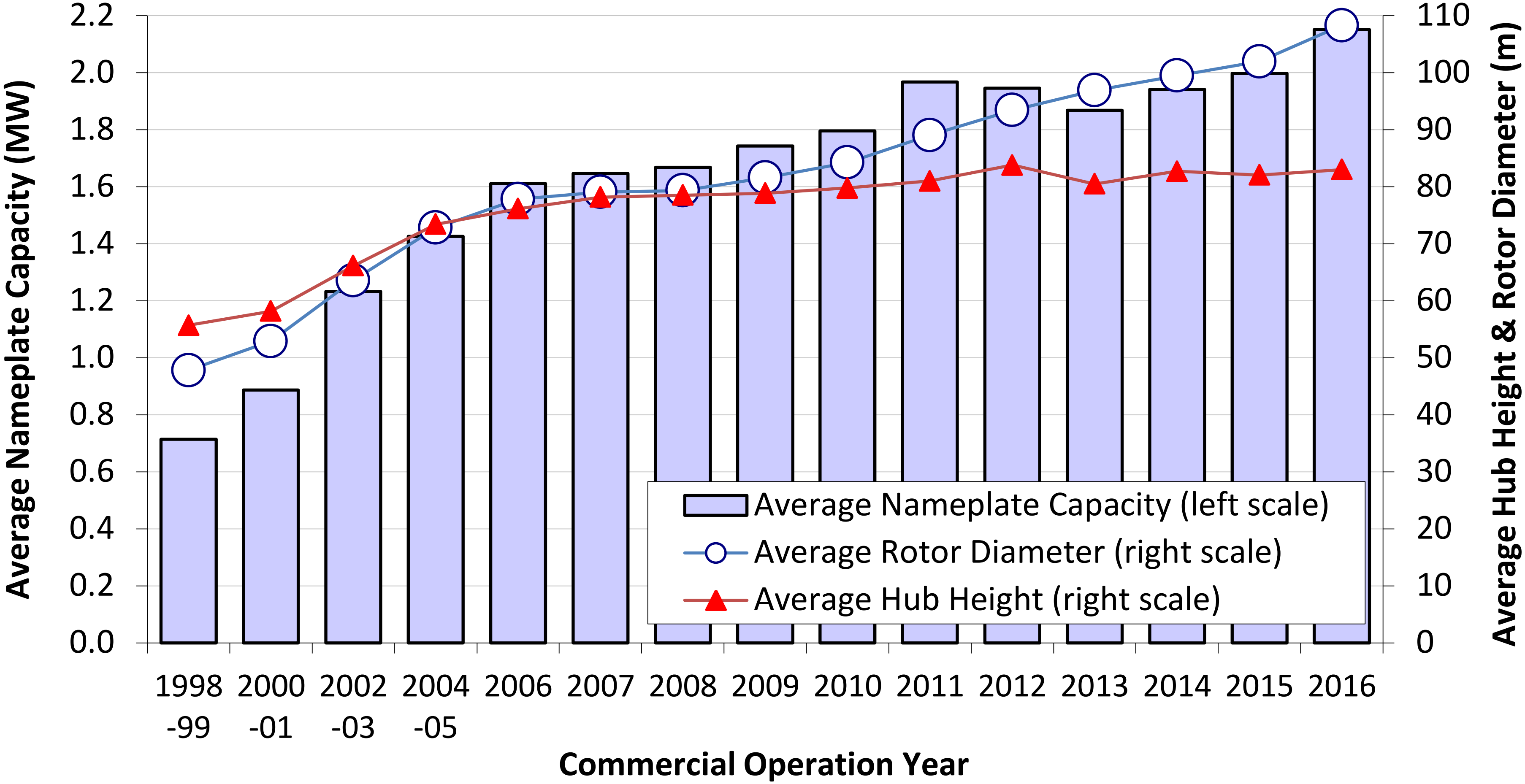


- 24% of added wind capacity in 2016 are from direct retail sales; 39% of total wind capacity contracted through PPAs in 2016 involve non-utility buyers

Technology Trends

Technology Trends

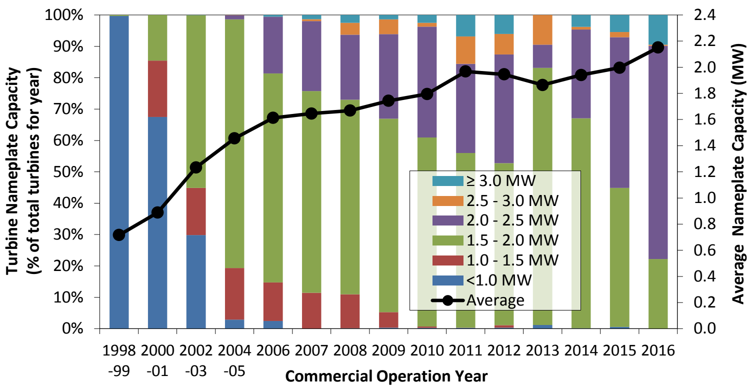
Turbine Nameplate Capacity, Hub Height, and Rotor Diameter Have All Increased Significantly Over the Long Term



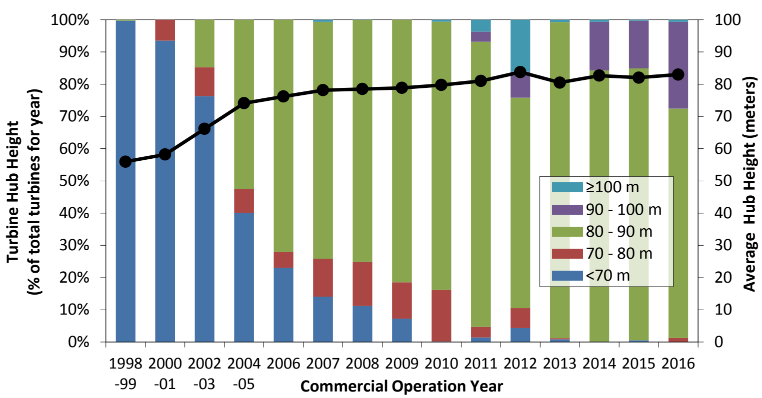
Technology Trends

Growth in Rotor Diameter Has Outpaced Growth in Nameplate Capacity and Hub Height in Recent Years

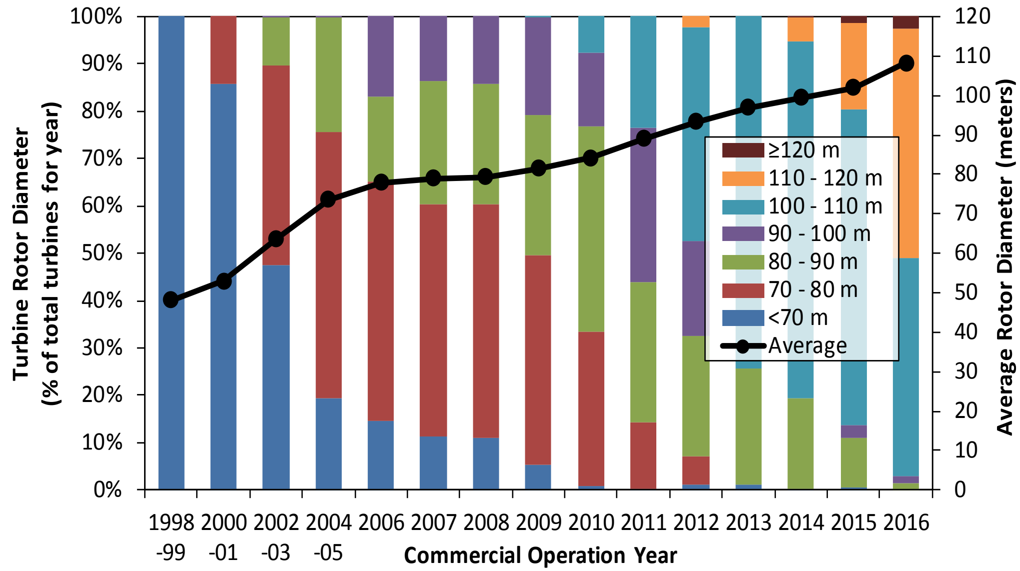
Nameplate Capacity



Hub Height



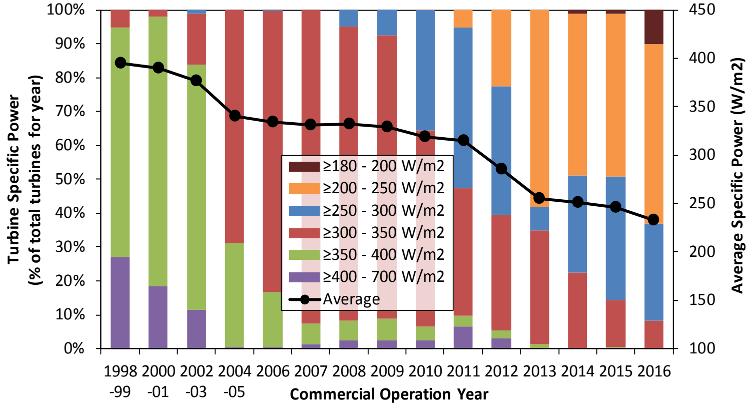
Rotor Diameter



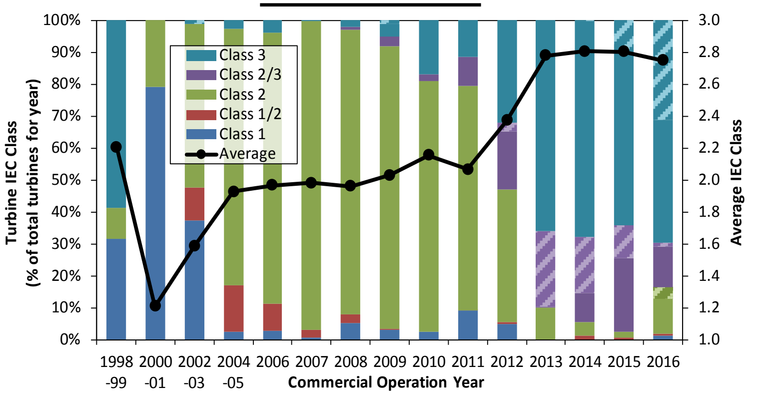
Technology Trends

Turbines Originally Designed for Lower Wind Speed Sites Have Rapidly Gained Market Share

Specific Power

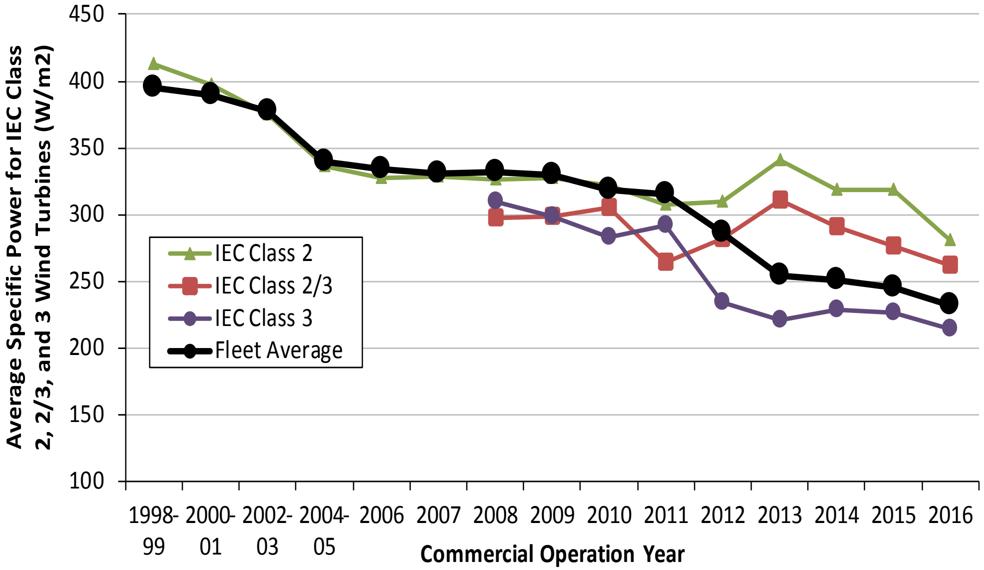


IEC Class



Note: Class S-2, S-2/3 and S-3 turbines are shown with hash marks in their respective bins, which are also used to calculate the average.

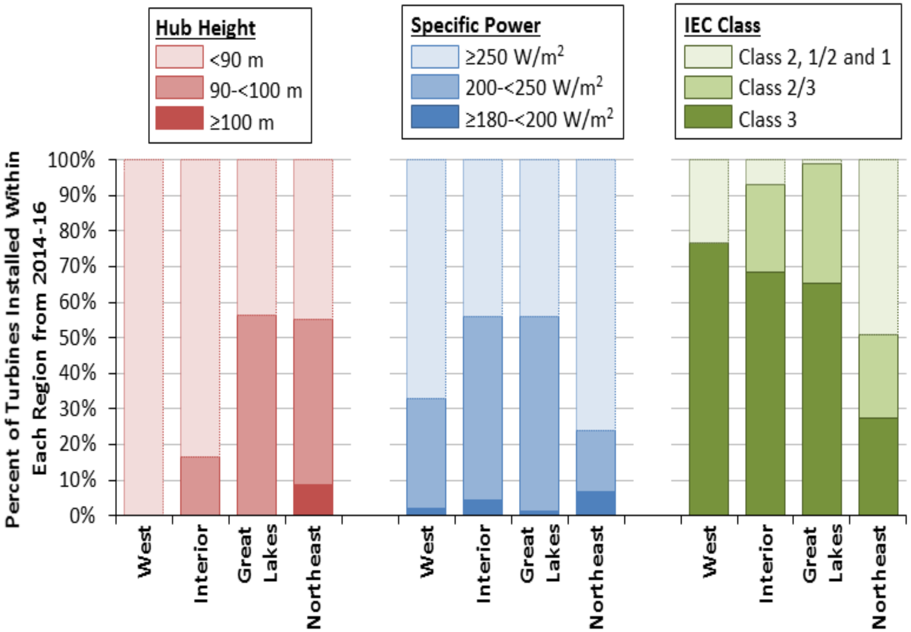
Specific Power by Selected IEC Class



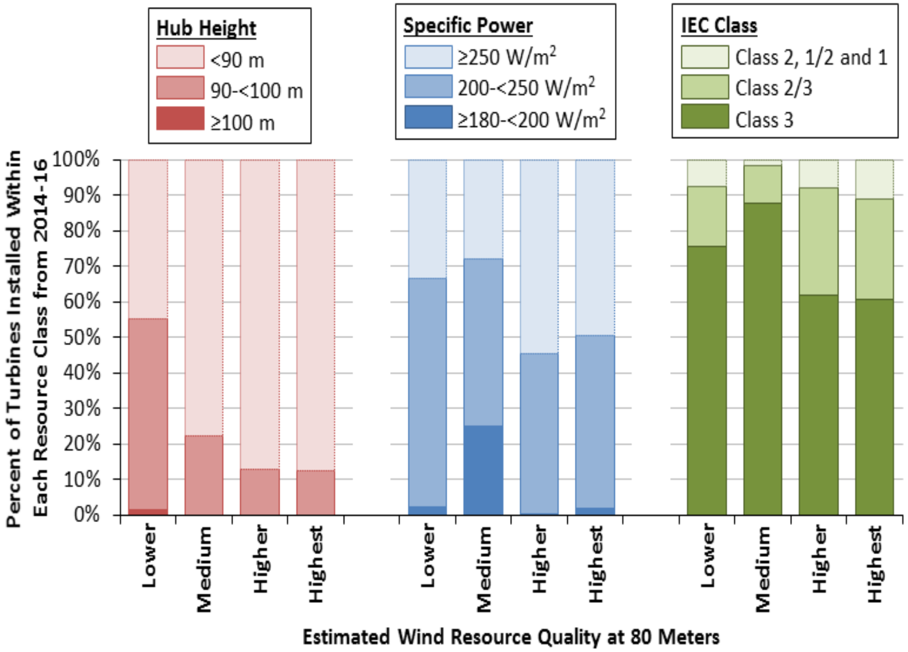
Technology Trends

Turbines Originally Designed for Lower Wind Speeds Regularly Used in Lower & Higher Wind Sites; Taller Towers Mostly in Great Lakes and Northeast

By Region

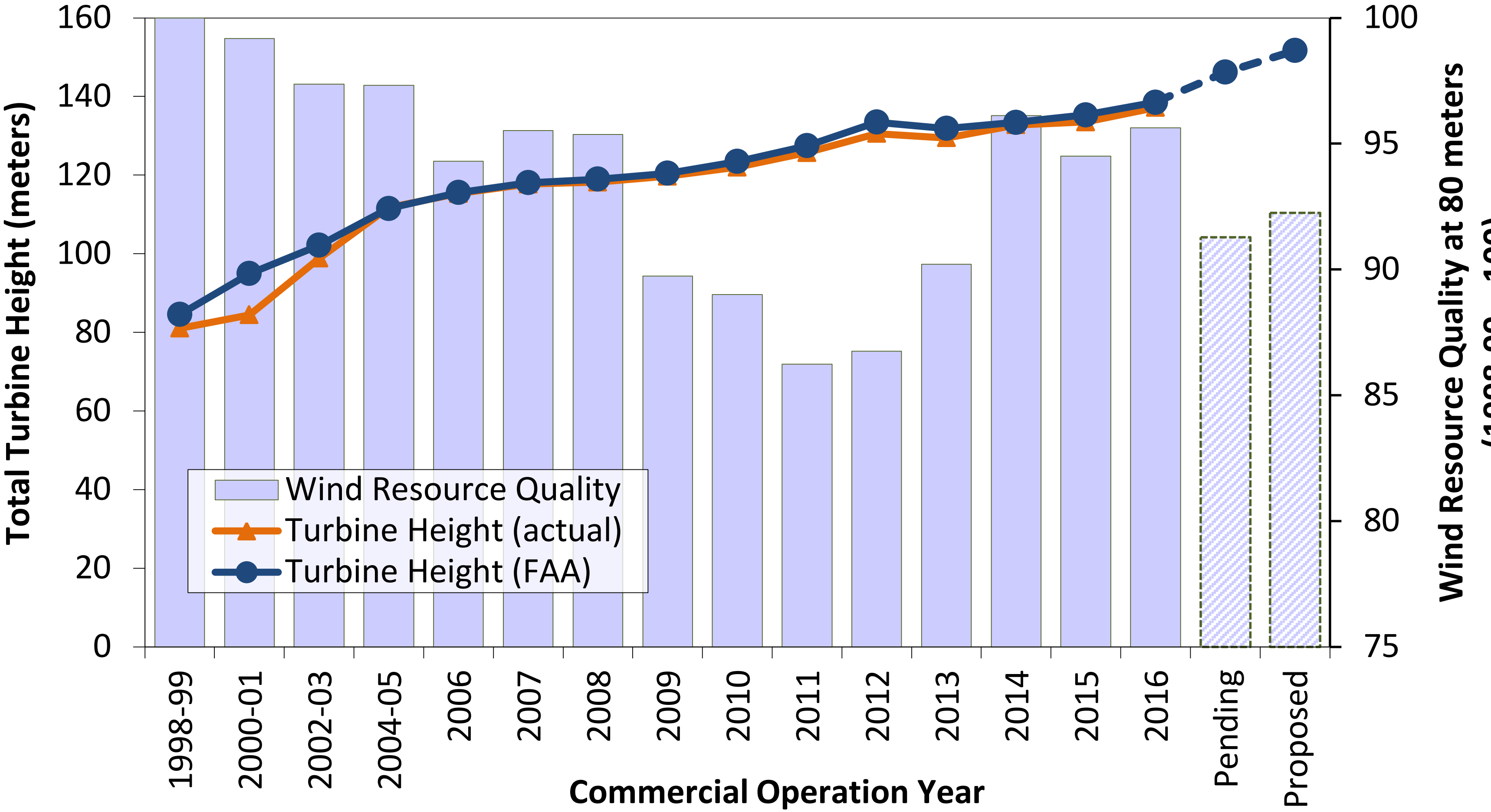


By Wind Resource Quality



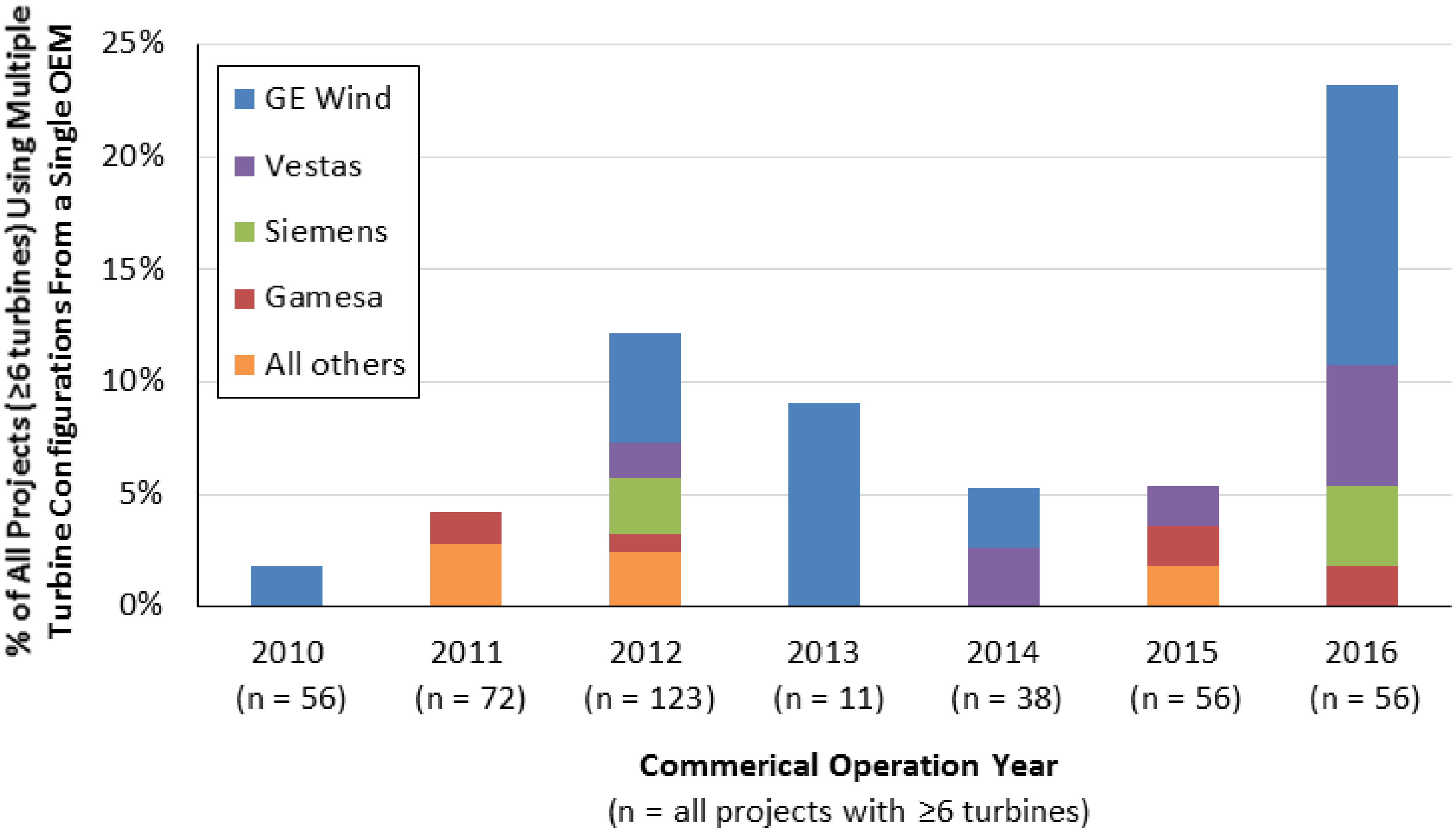
Technology Trends

Pending & Proposed Projects Continue Trend of Even-Taller Turbines as Lower Wind Sites Appear to Be Targeted



Technology Trends

A Large Number of Projects in 2016 Employed Multiple Turbine Configurations from a Single OEM

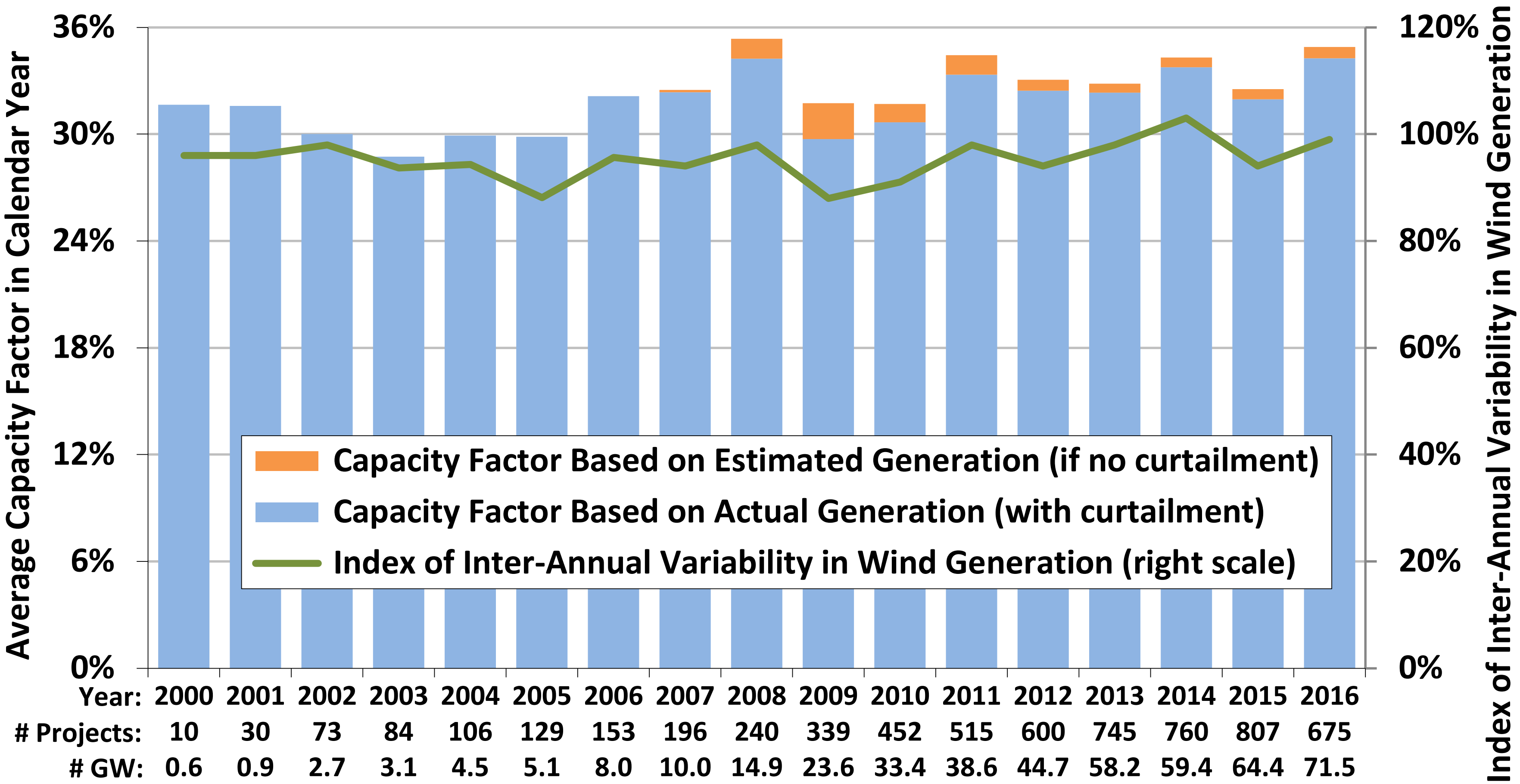


Note: Turbine configuration = unique combination of hub height, rotor diameter, and/or capacities

Performance Trends

Performance Trends

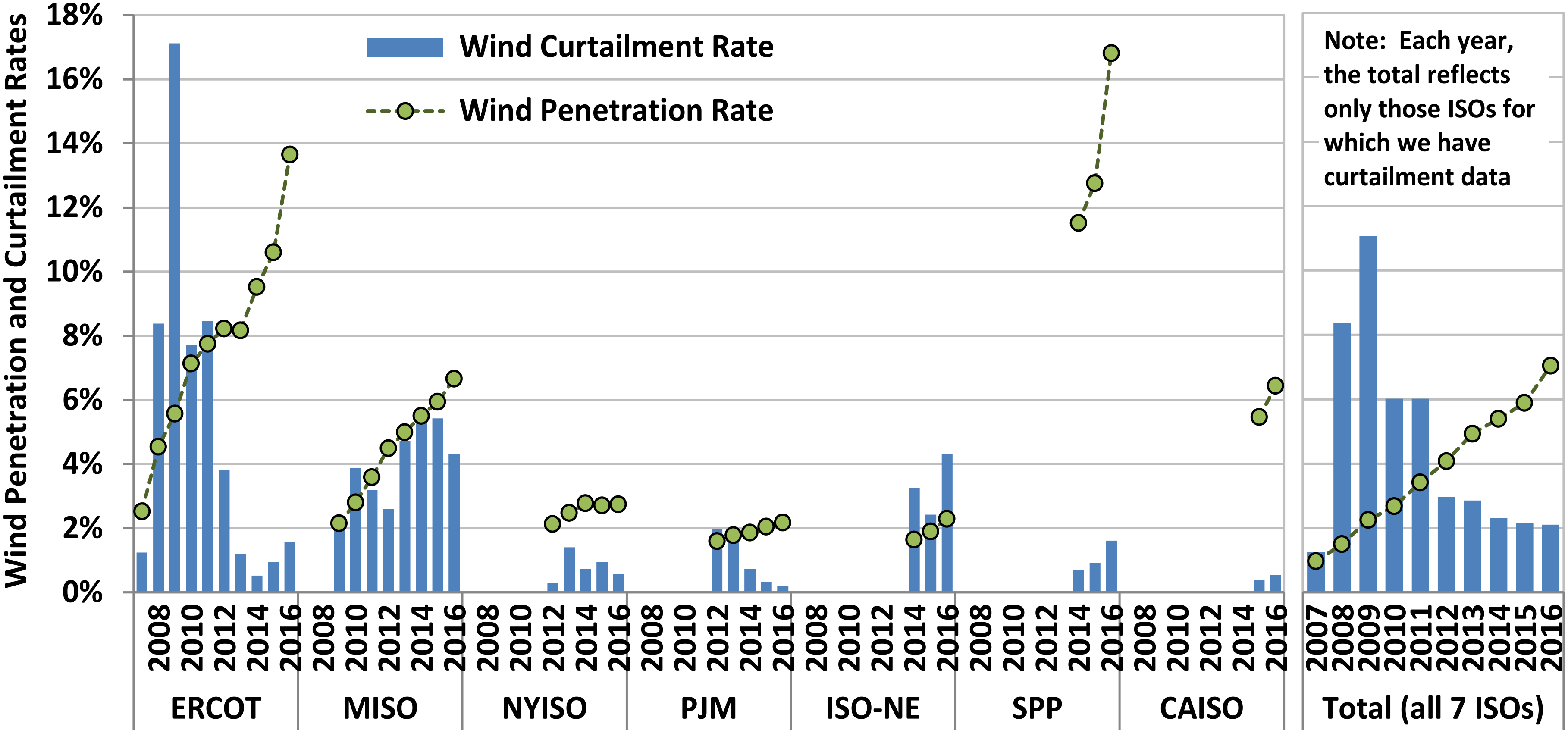
Sample-Wide Capacity Factors Have Increased, but Impacted by Curtailment and Inter-Year Wind Resource Variability



Note: The wind resource index is compiled from NextEra Energy Resources reports

Performance Trends

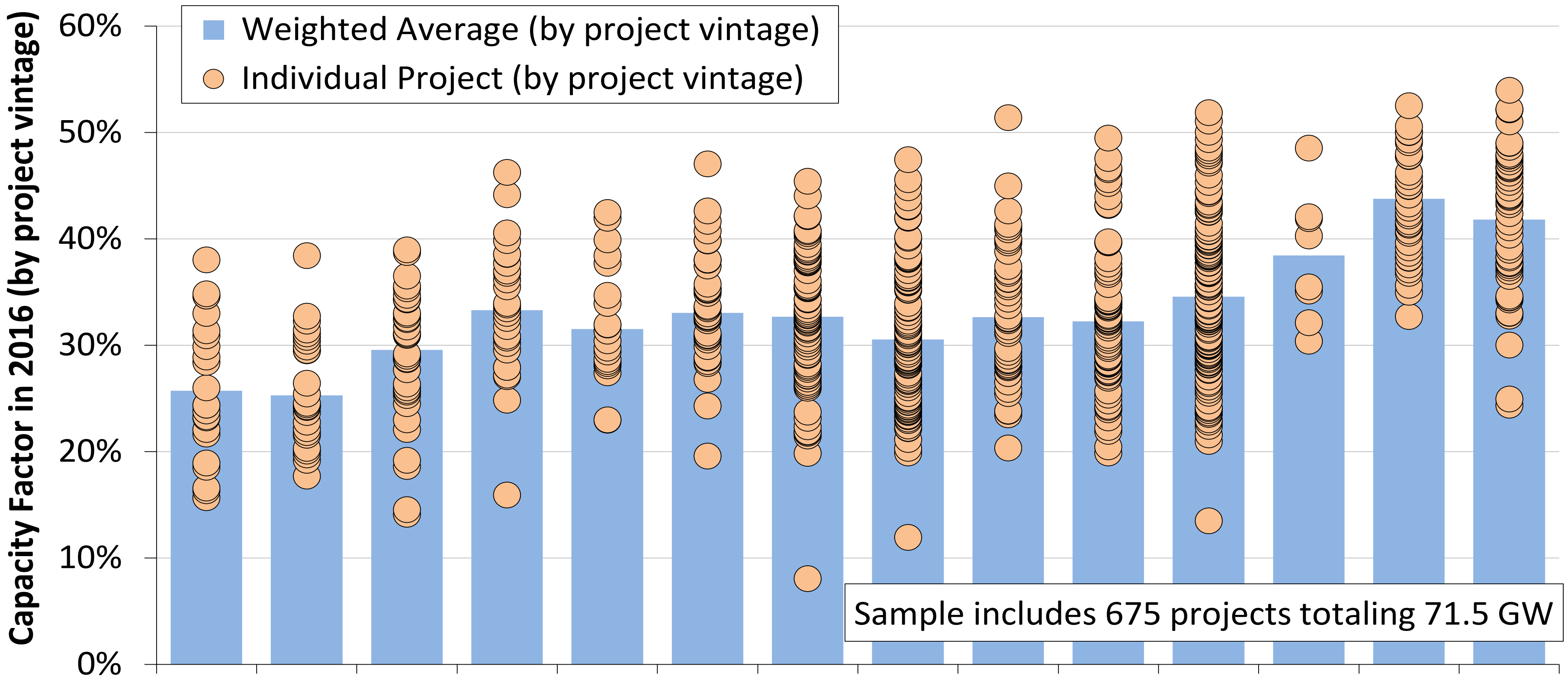
Wind Curtailment Has Generally Declined in Recent Years; Higher in MISO & ISO-NE



- In areas where curtailment has been particularly problematic in the past – principally in Texas – steps taken to address the issue have born fruit

Performance Trends

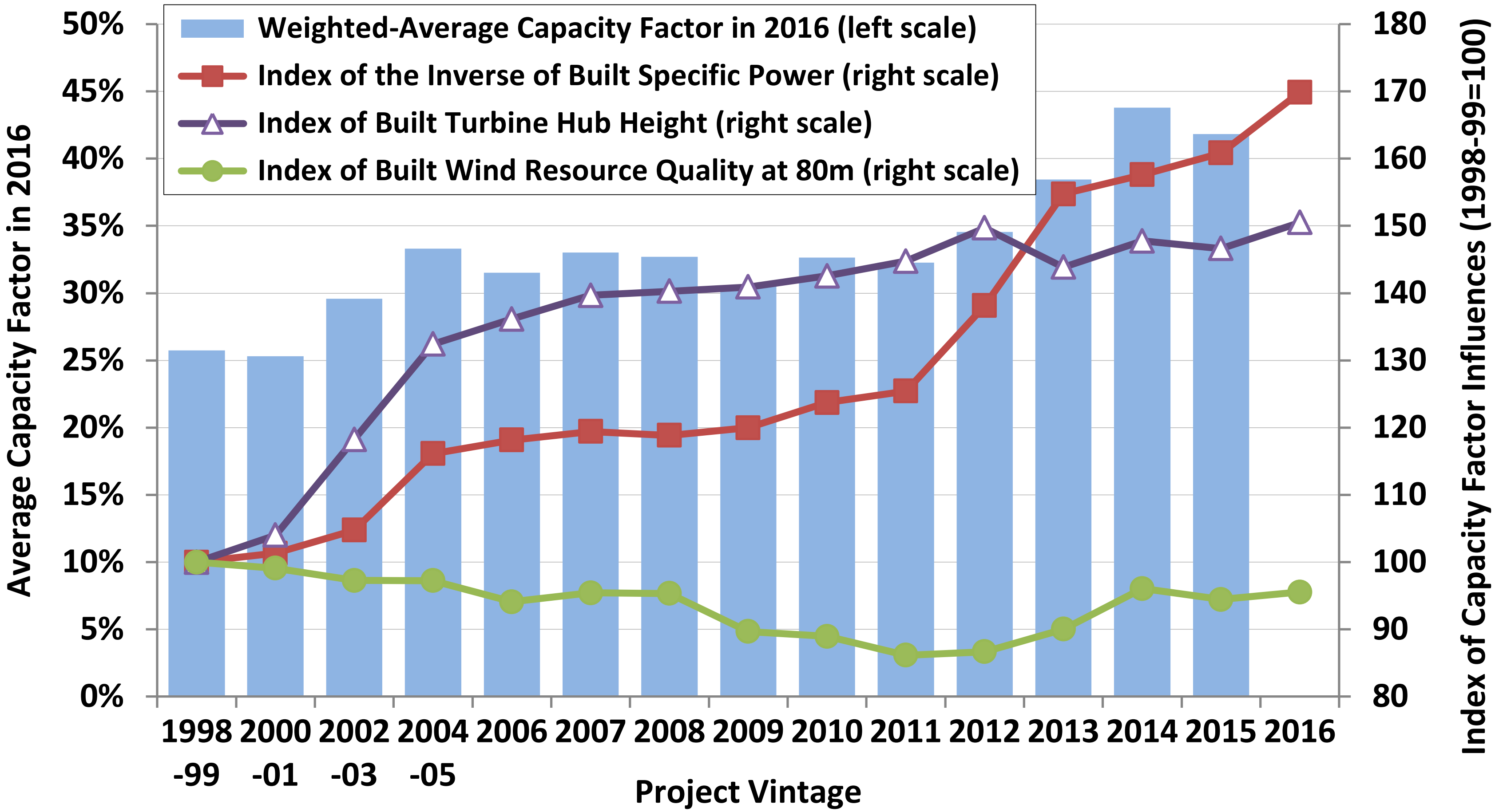
Impact of Technology Trends on Capacity Factors Becomes More Apparent When Parsed by Project Vintage



Vintage:	'98-99	'00-01	'02-03	'04-05	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
# projects:	23	26	34	27	20	37	79	96	47	69	121	8	35	53
# MW:	894	1,750	1,979	3,634	1,738	5,282	8,498	9,578	4,632	5,904	13,672	969	4,917	8,063

Performance Trends

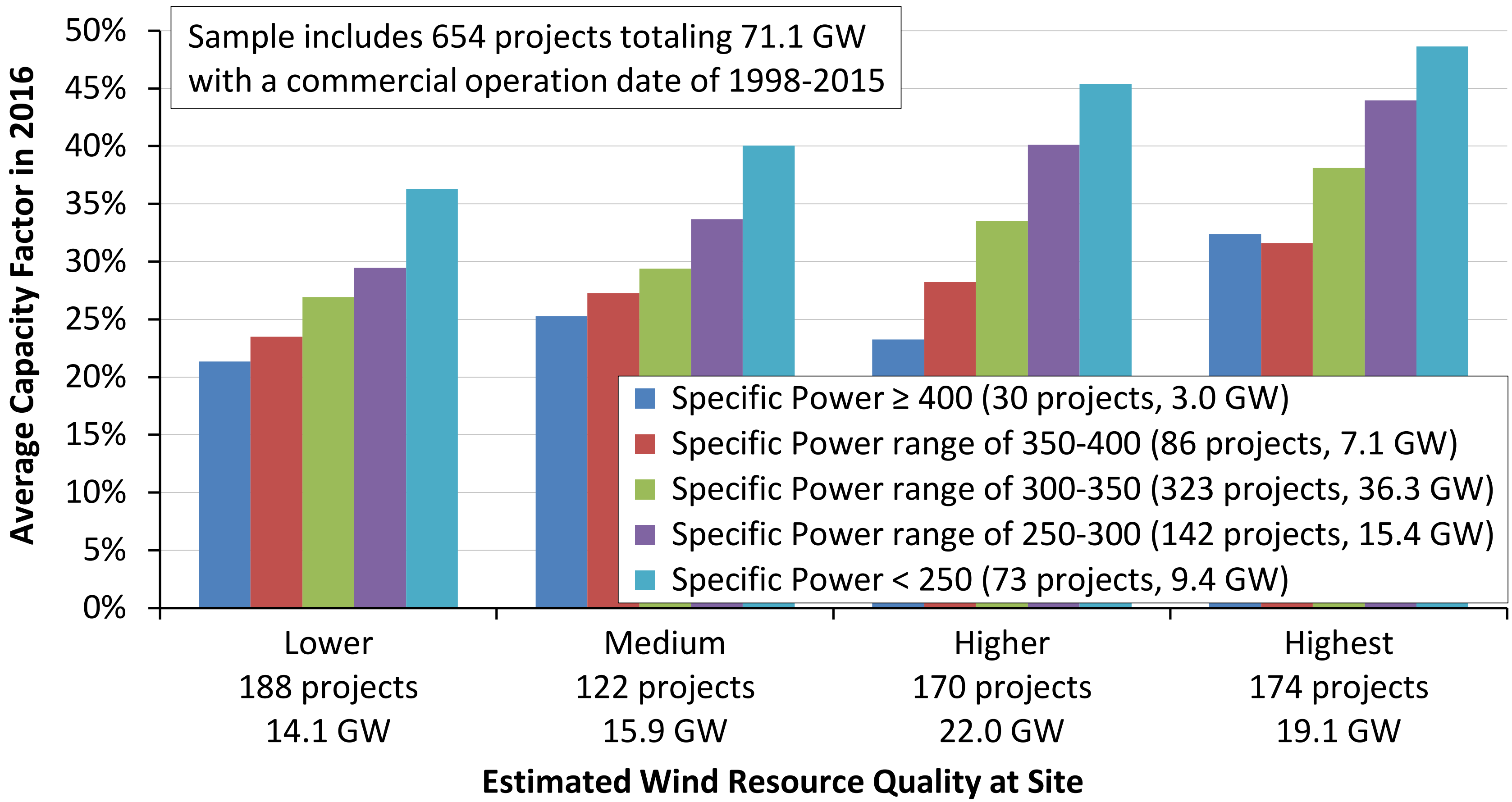
Trends Explained by Competing Influence of Lower Specific Power and Higher Hub Heights vs. Build-Out of Lower Quality Wind Resource Sites through 2012



- ***Reversal*** of build-out in lower wind speed sites in 2013-2016

Performance Trends

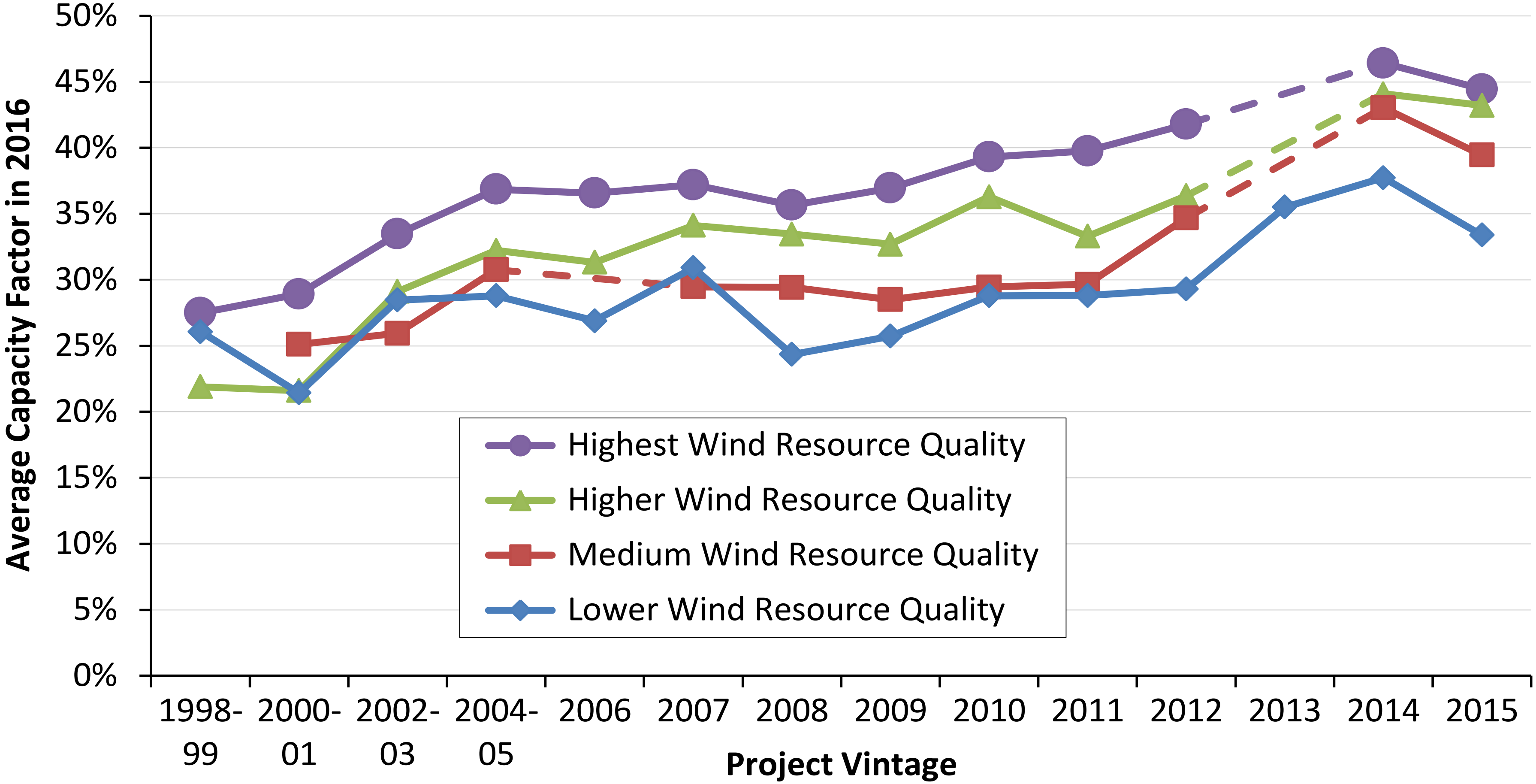
Controlling for Wind Resource Quality and Specific Power Demonstrates Impact of Turbine Evolution



- Turbine design changes are driving capacity factors higher for projects located in given wind resource regimes

Performance Trends

Controlling for Wind Resource Quality and Commercial Operation Date Also Illustrates Impact of Turbine Evolution



Performance Trends

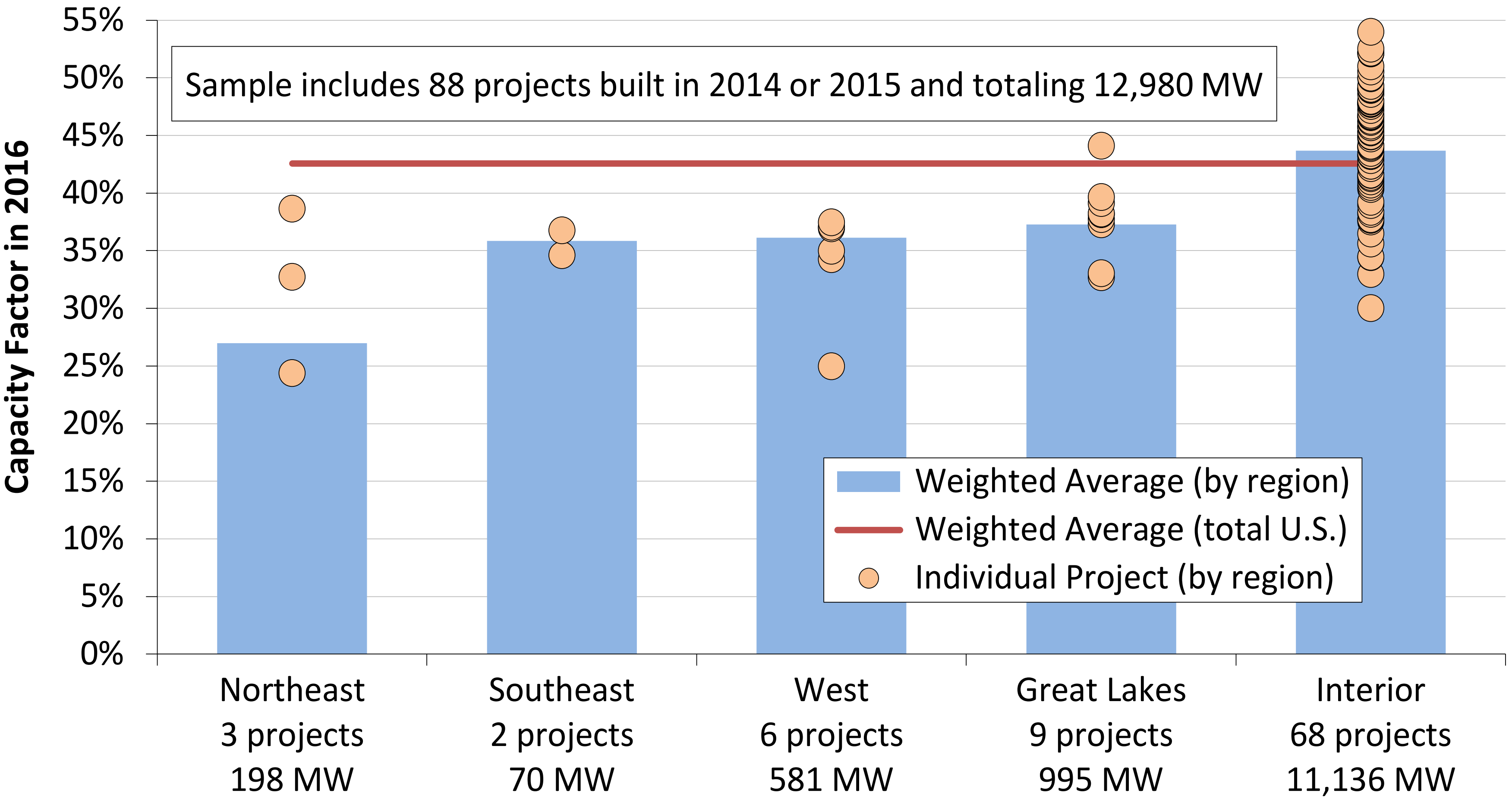
Change in Performance as Projects Age Also Impacts Overall Trends

Years post-COD:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Sample GW:	71.9	63.7	58.7	57.7	44.0	37.9	33.2	23.5	15.1	9.7	8.0	4.9	4.3	2.8	2.3	0.6	0.6
Sample projects:	819	754	715	681	545	462	400	282	200	141	118	91	83	61	36	12	9

Note: See full report for caveats associated with this figure

Performance Trends

Regional Variations in Capacity Factors Reflect the Strength of the Wind Resource and Adoption of New Turbine Technology

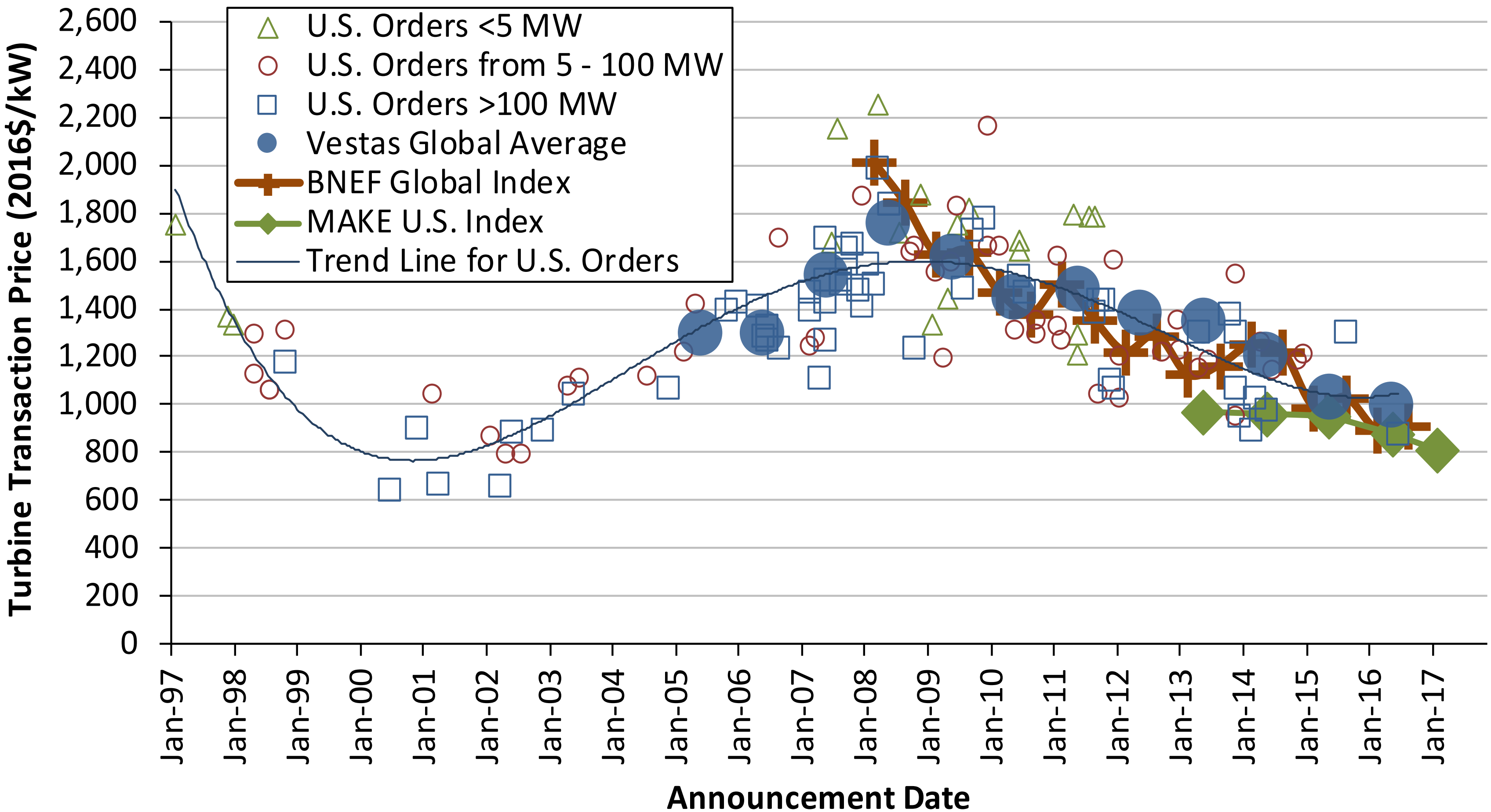


Note: Limited sample size in some regions

Cost Trends

Cost Trends

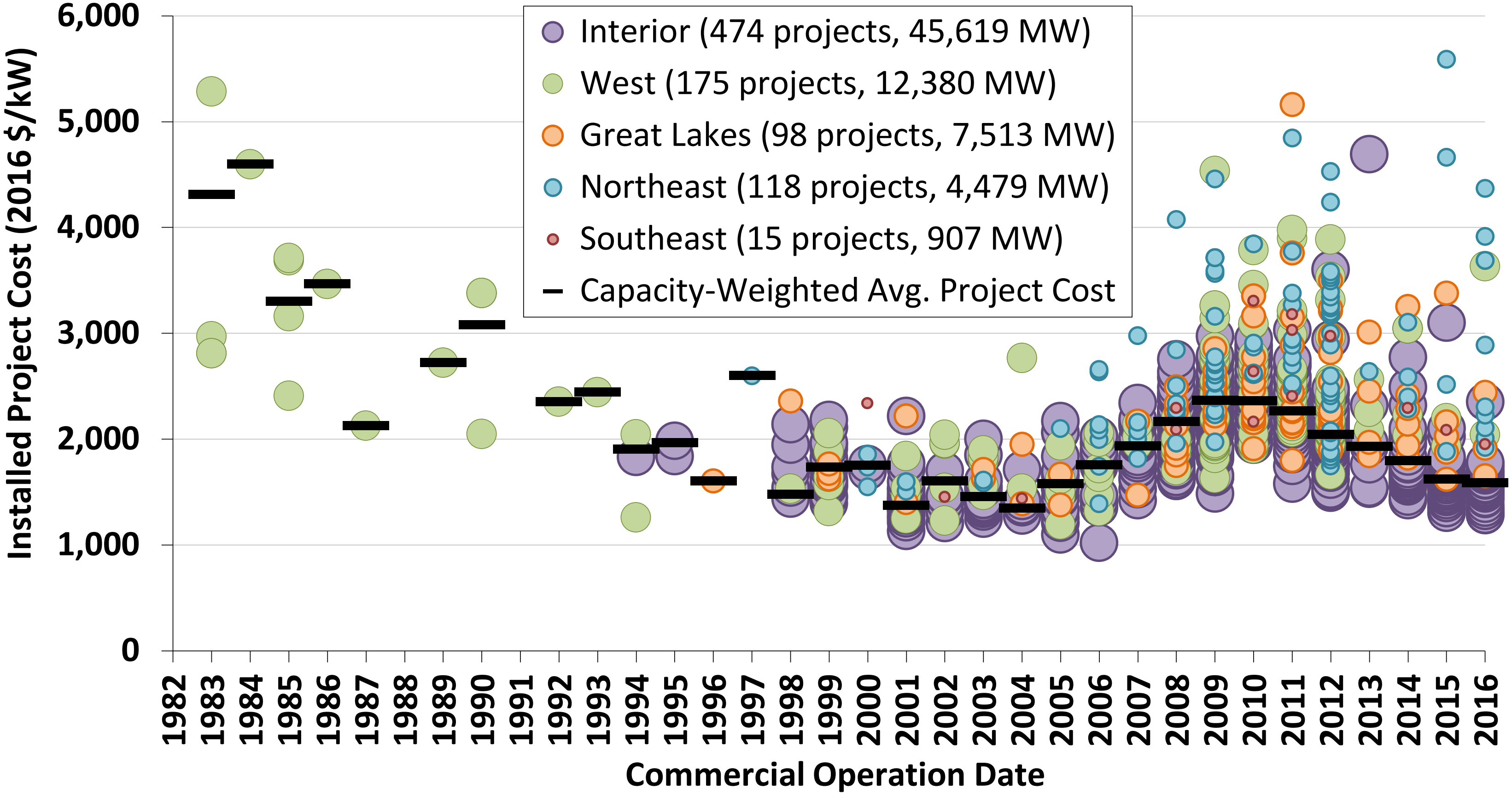
Wind Turbine Prices Remained Well Below the Levels Seen Several Years Ago



- Recent turbine orders in the range of $800-1,100/kW

Cost Trends

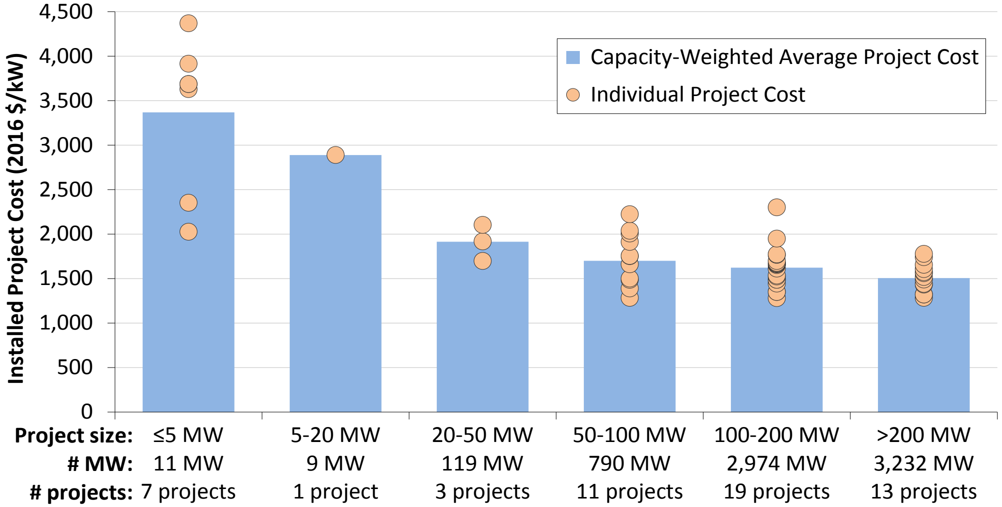
Lower Turbine Prices Drive Reductions in Reported Installed Project Costs

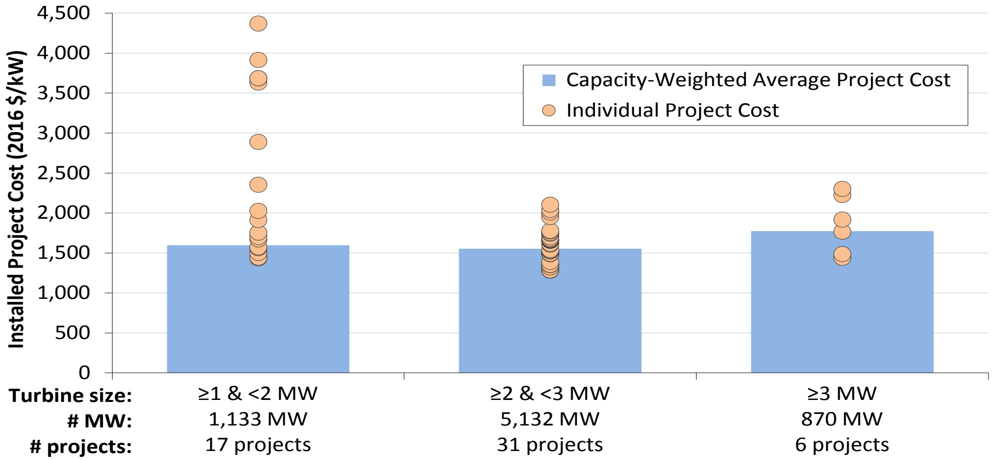


- 2016 projects had an average cost of $1,590/kW, down $780/kW since 2009 and 2010; limited sample of under-construction projects slated for completion in 2017 suggest no material change in costs

Cost Trends

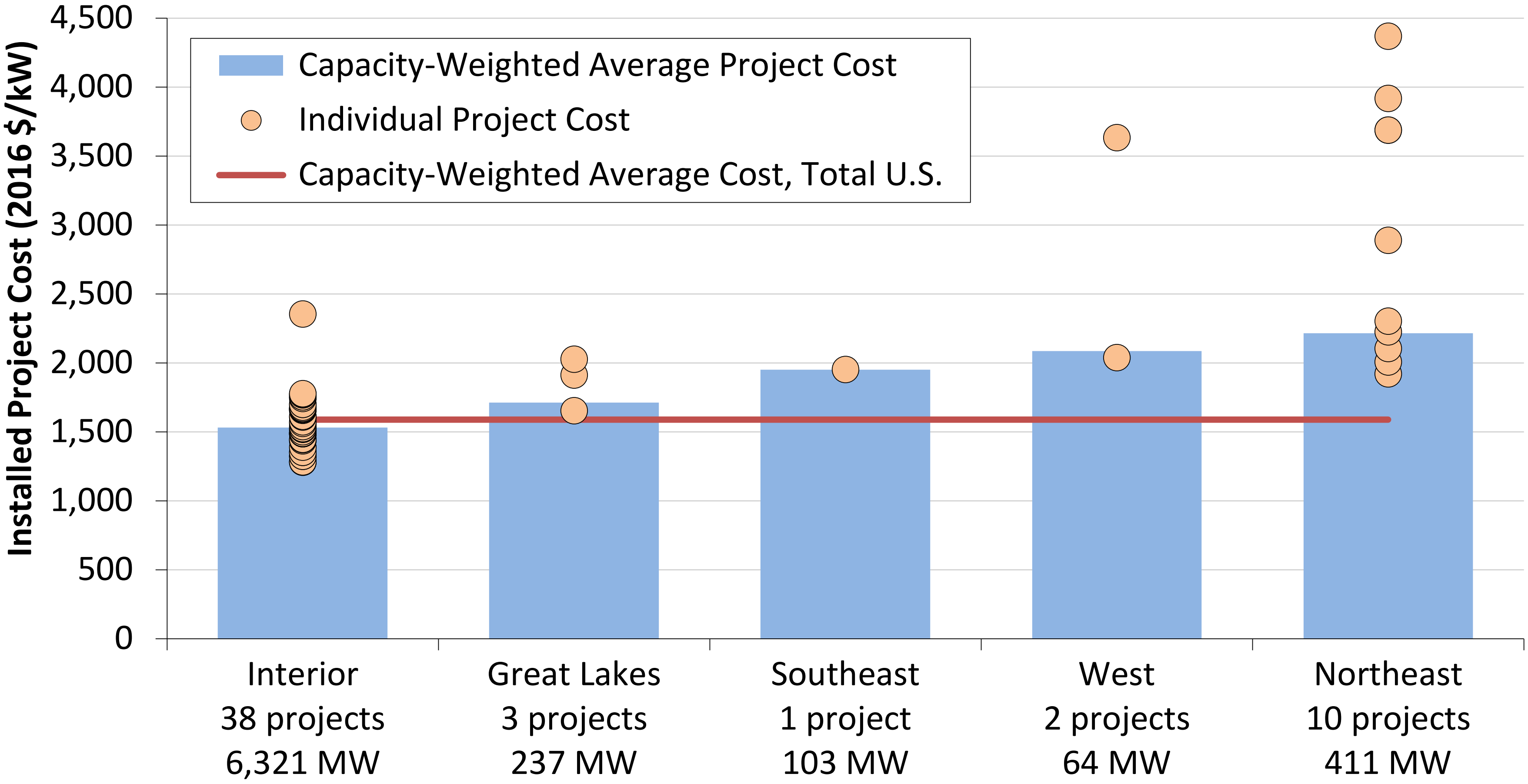
Economies of Scale, Especially at Lower End of Project Size Range





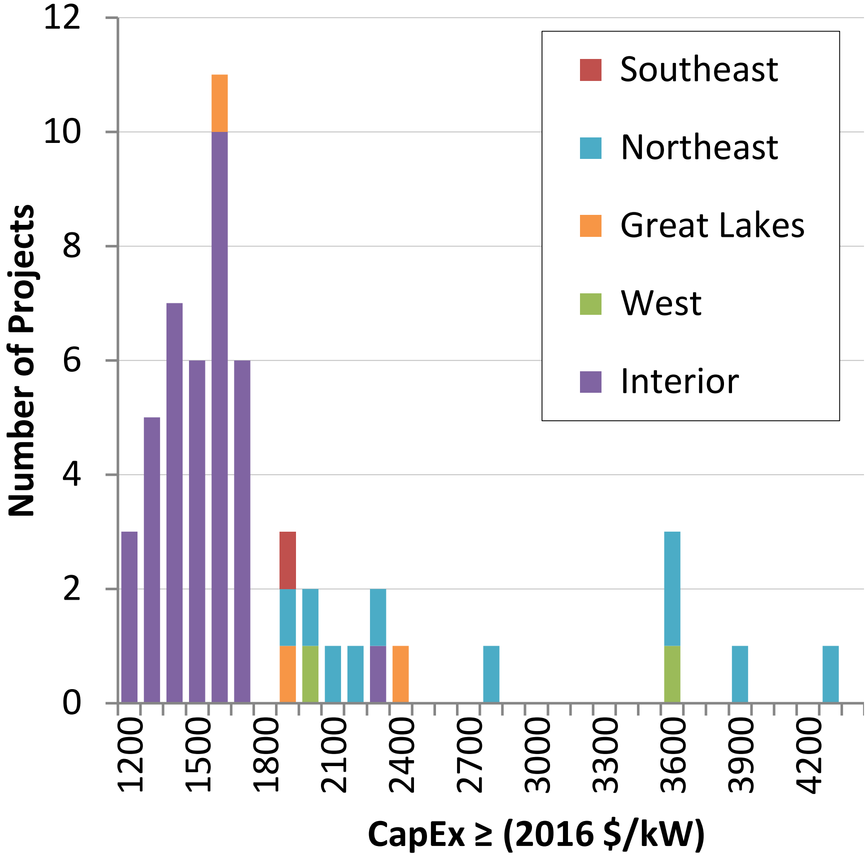
Cost Trends

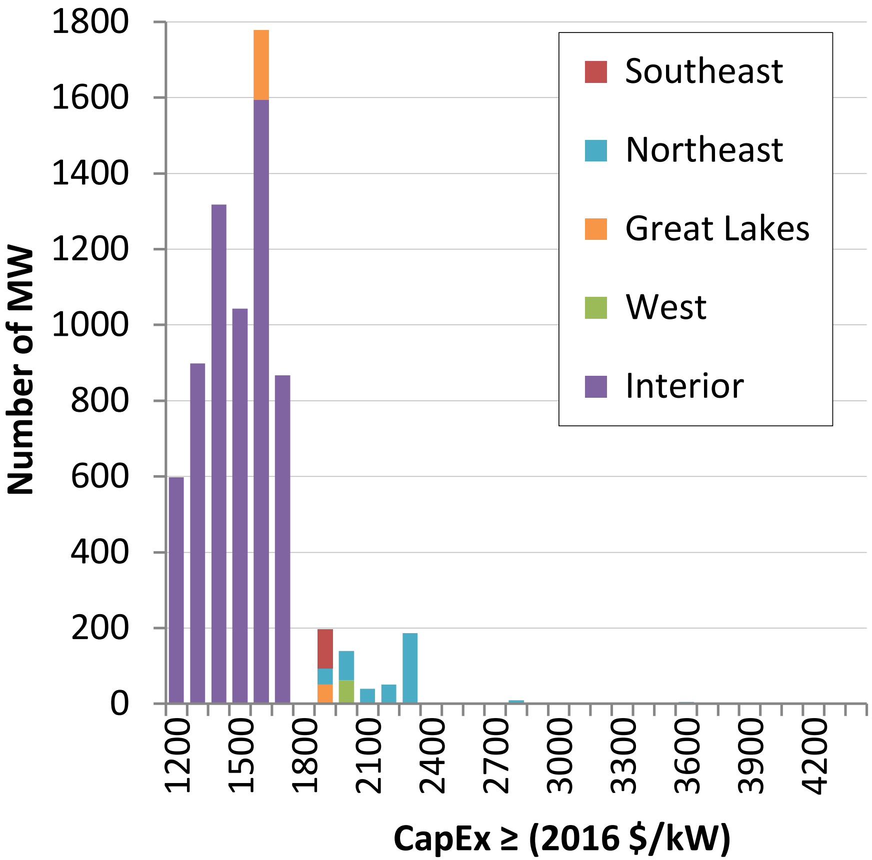
Regional Differences in Average Wind Power Project Costs Are Apparent, but Sample Size Is Limited



Cost Trends

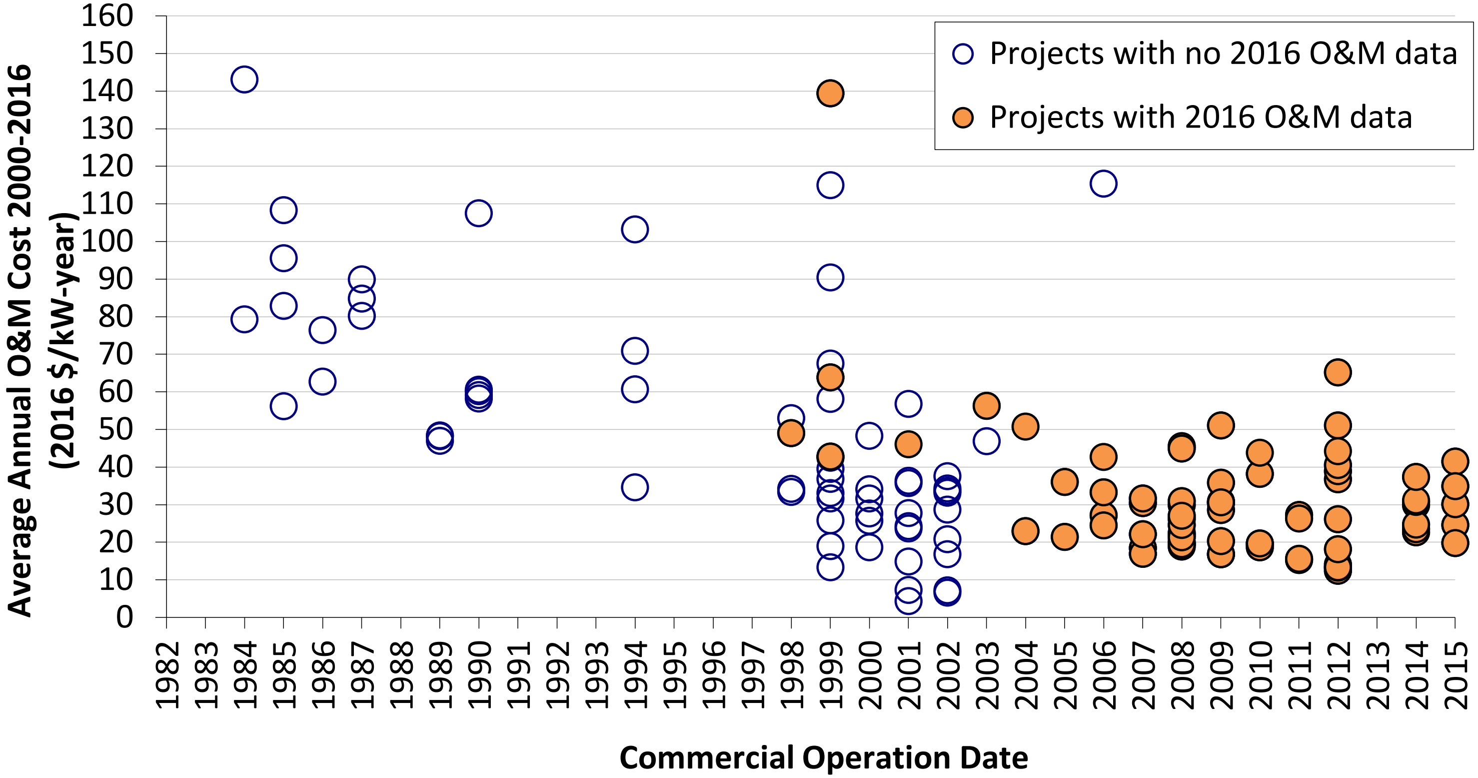
Most 2016 Projects—and All of the Low-Cost Projects—Are Located in the Interior; Other Regions Have Higher Costs





Cost Trends

O&M Costs Varied By Project Age and Commercial Operations Date

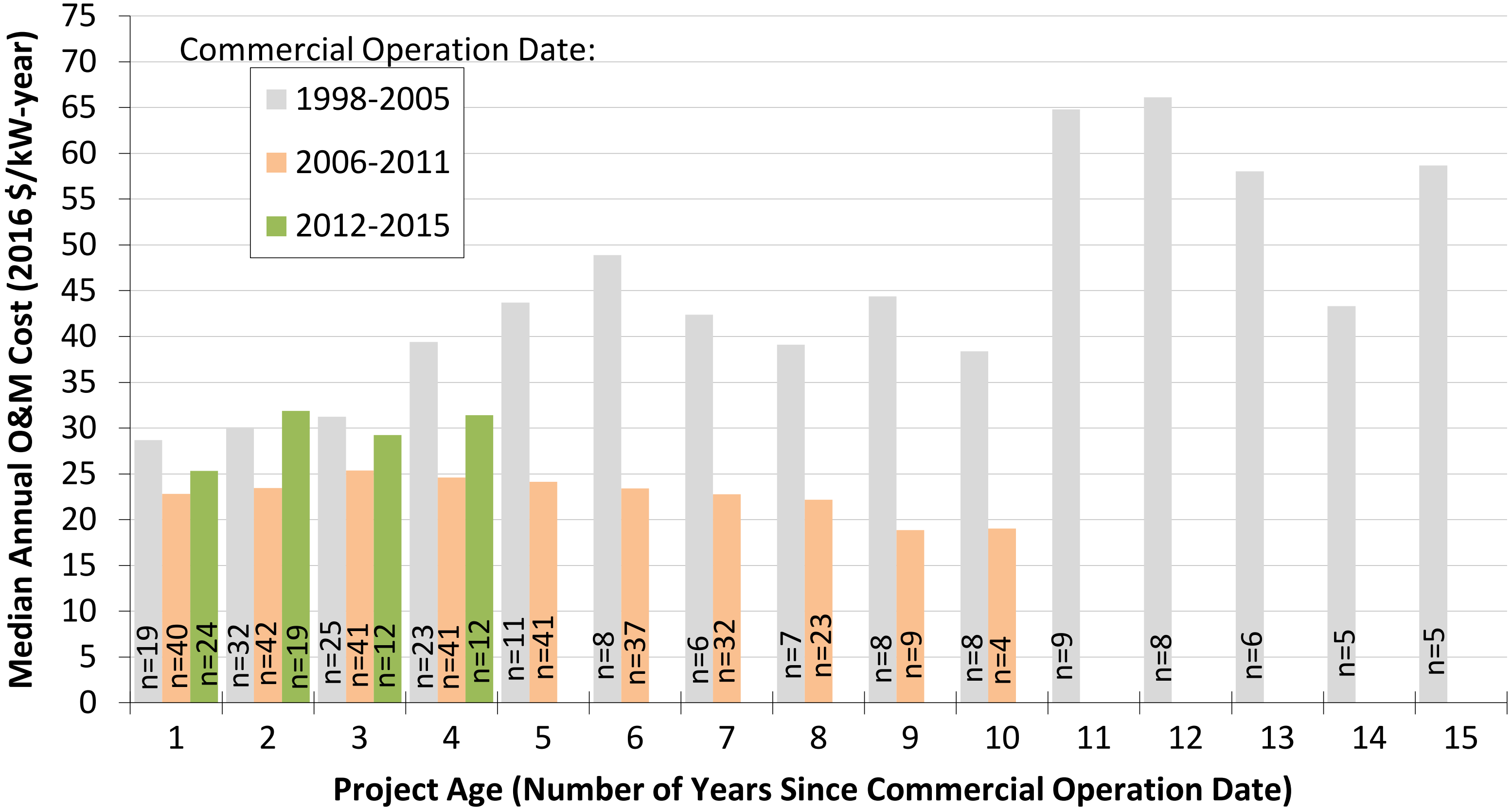


Note: Sample is limited; few projects in sample have complete records of O&M costs from 2000-16; O&M costs reported here DO NOT include all operating costs

- Capacity-weighted average 2000-16 O&M costs for projects built in the 1980s equal **$69/kW-year**, dropping to **$57/kW-year** for projects built in 1990s, to **$28/kW-year** for projects built in the 2000s, and to **$27/kW-year** for projects built since 2010

Cost Trends

O&M Costs Varied By Project Age and Commercial Operations Date



Note: Sample size is limited

- **O&M reported in figure <u>does not</u> include all operating costs:** Statements from public companies with large U.S. wind portfolios report ***total*** operating costs in 2016 for projects built in the 2000s of ~$55/kW-year

Wind Power Price Trends

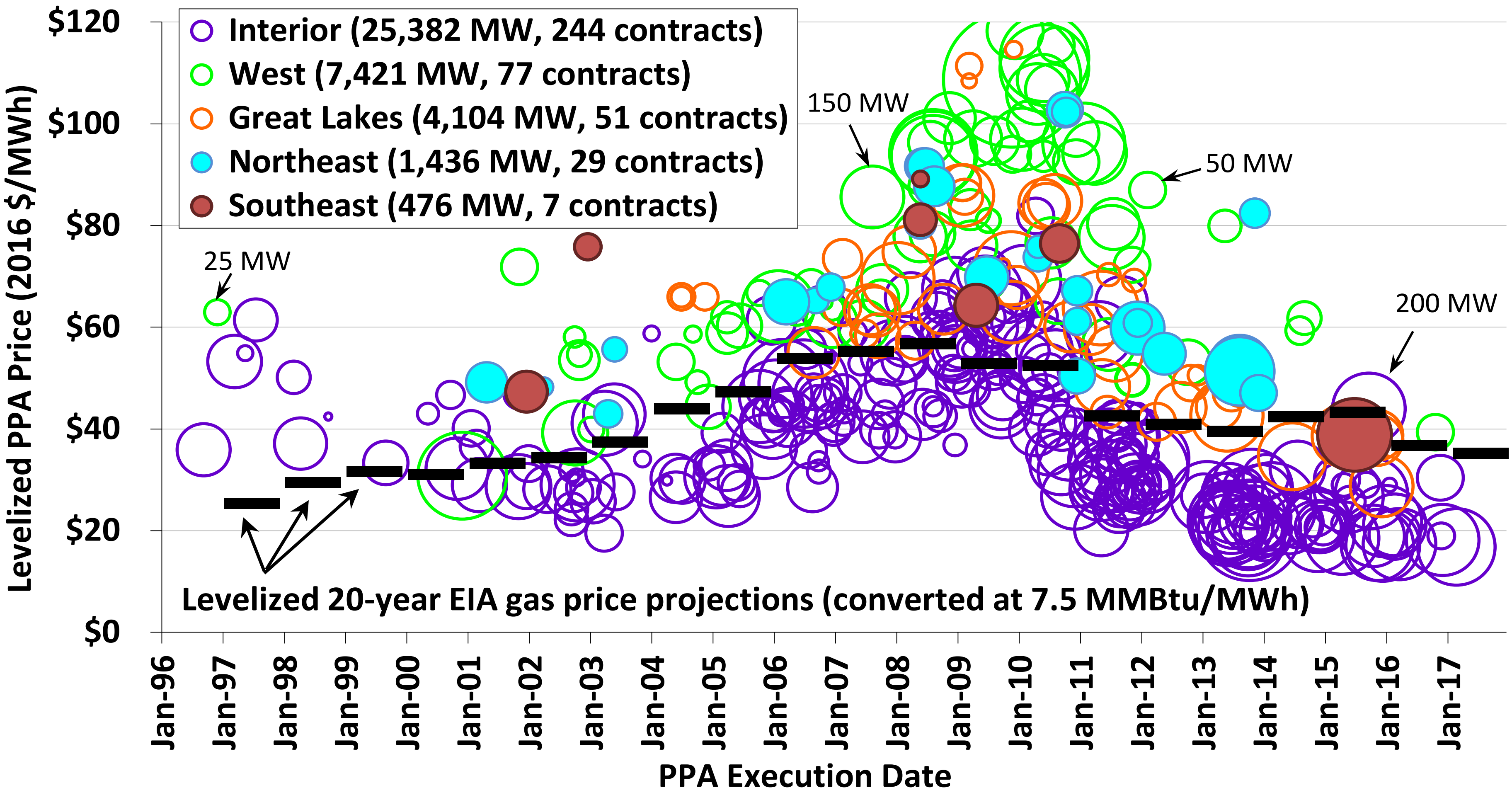
Wind Power Price Trends

Sample of Wind Power Prices

- Berkeley Lab collects data on historical wind power sales prices, and long-term PPA prices
- PPA sample includes 414 contracts totaling 38,819 MW from projects built from 1998-2016, or planned for installation in 2017 or beyond
- Prices reflect the bundled price of electricity and RECs as sold by the project owner under a PPA
  - Dataset excludes merchant plants, projects that sell renewable energy certificates (RECs) separately, and direct retail sales
  - Prices reflect receipt of state and federal incentives (e.g., the PTC or Treasury grant), as well as various local policy and market influences; as a result, prices do not reflect wind energy generation costs

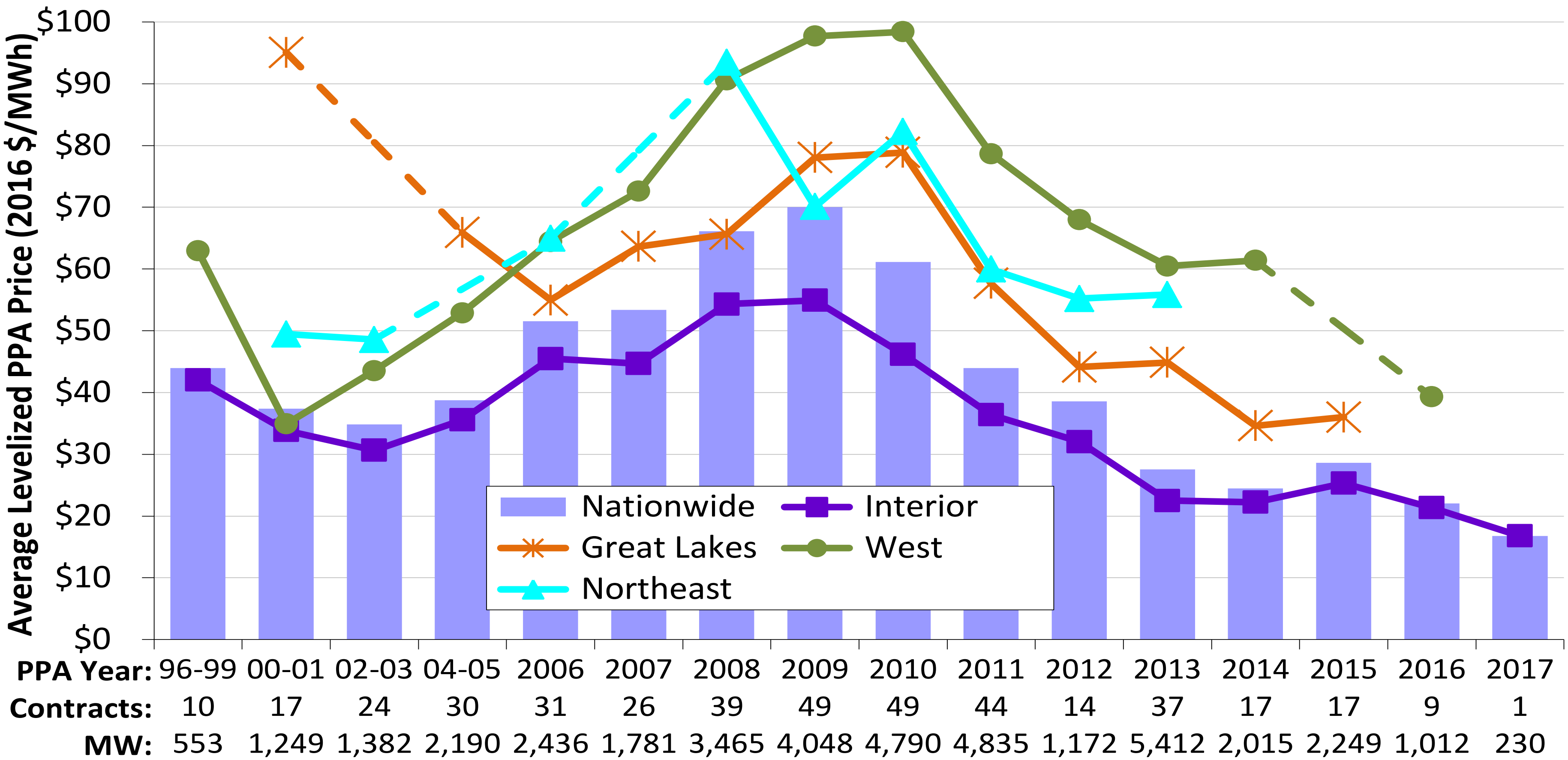
Wind Power Price Trends

Wind PPA Prices Very Low, Competitive with Levelized Fuel Cost of a Gas Plant



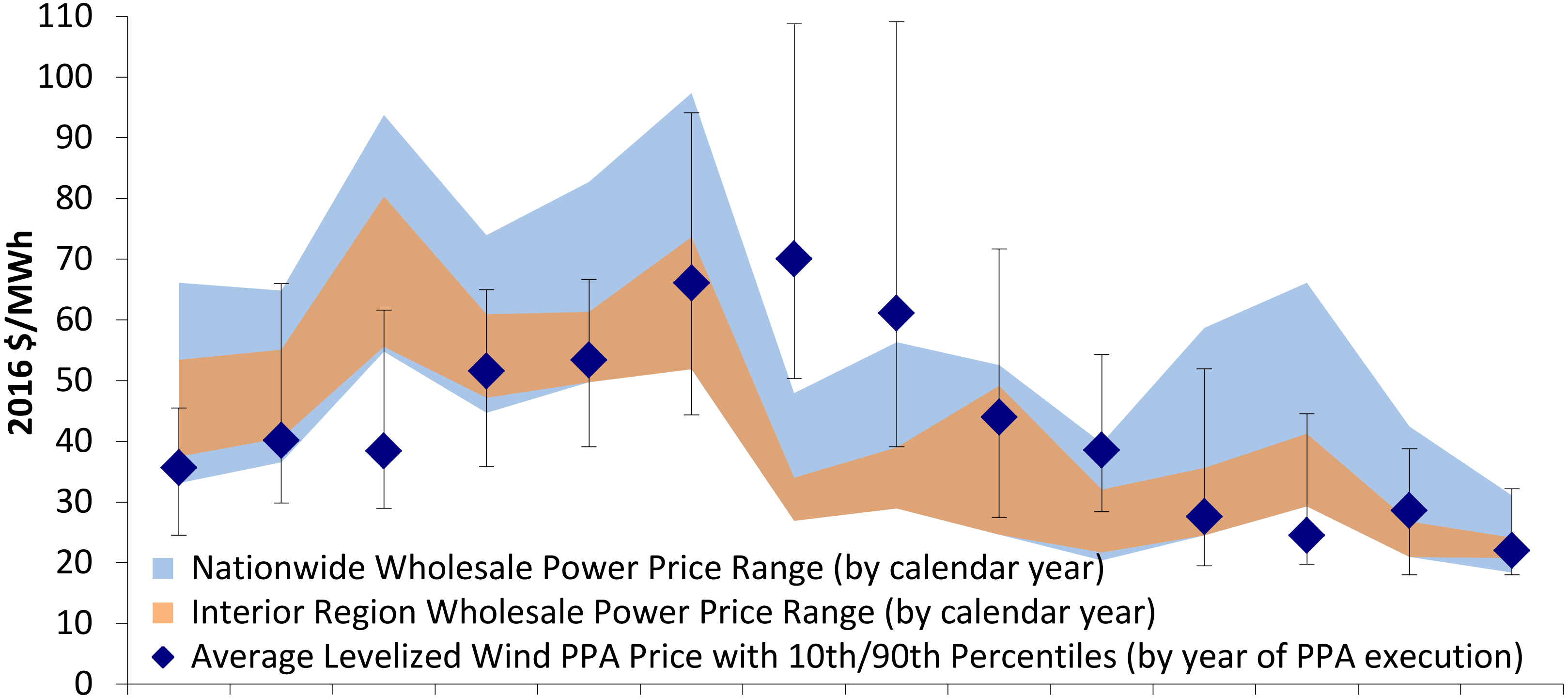
Wind Power Price Trends

A Smoother Look at the Time Trend Shows Steep Decline in Pricing Since 2009; Especially Low Pricing in Interior Region



Wind Power Price Trends

Relative Competitiveness of Wind Power Has Been Affected by the Continued Decline in Wholesale Power Prices

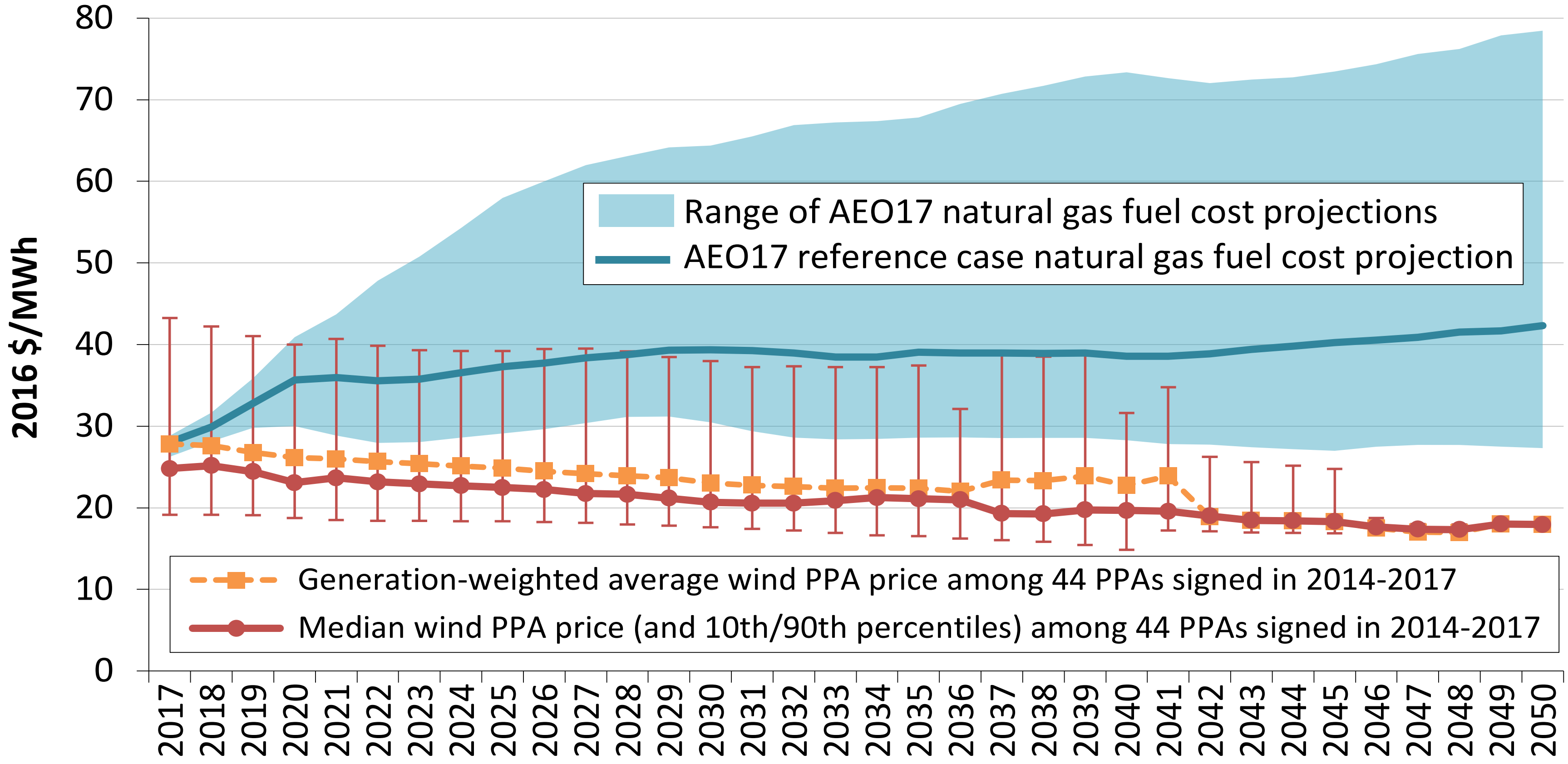


Year:	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Contracts:	9	13	17	31	26	39	49	49	44	14	37	17	17	9
MW:	570	547	1,643	2,436	1,781	3,465	4,048	4,790	4,835	1,172	5,412	2,015	2,249	1,012

- Wholesale price range reflects flat block of power across 23 pricing nodes across the U.S. (and Interior)
- Price comparison shown here is far from perfect – ***see full report for caveats***

Wind Power Price Trends

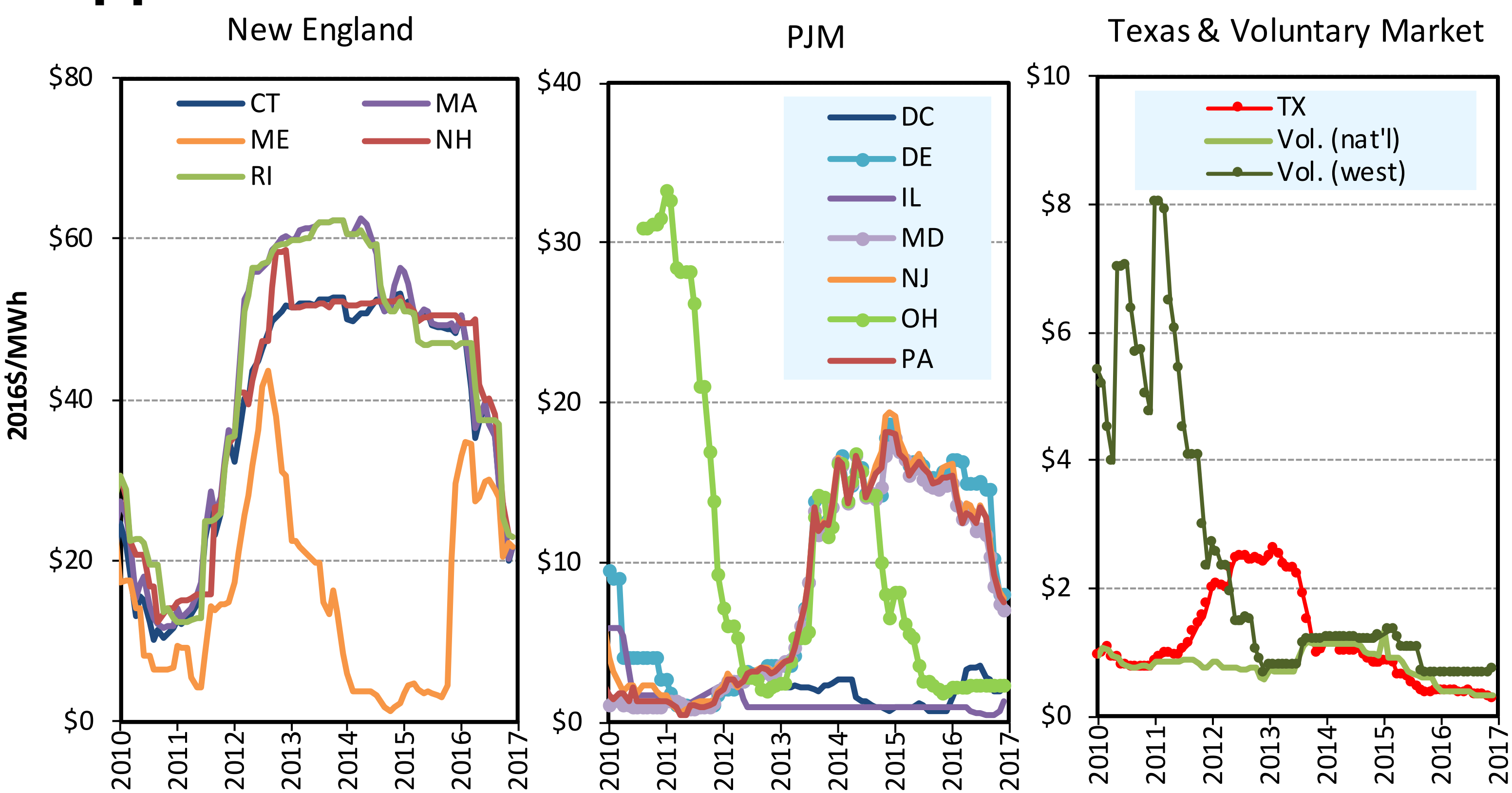
Recent Wind Prices Are Hard to Beat: Competitive with Expected Future Cost of Burning Fuel in Natural Gas Plants



- Price comparison shown here is far from perfect – ***see full report for caveats***

Wind Power Price Trends

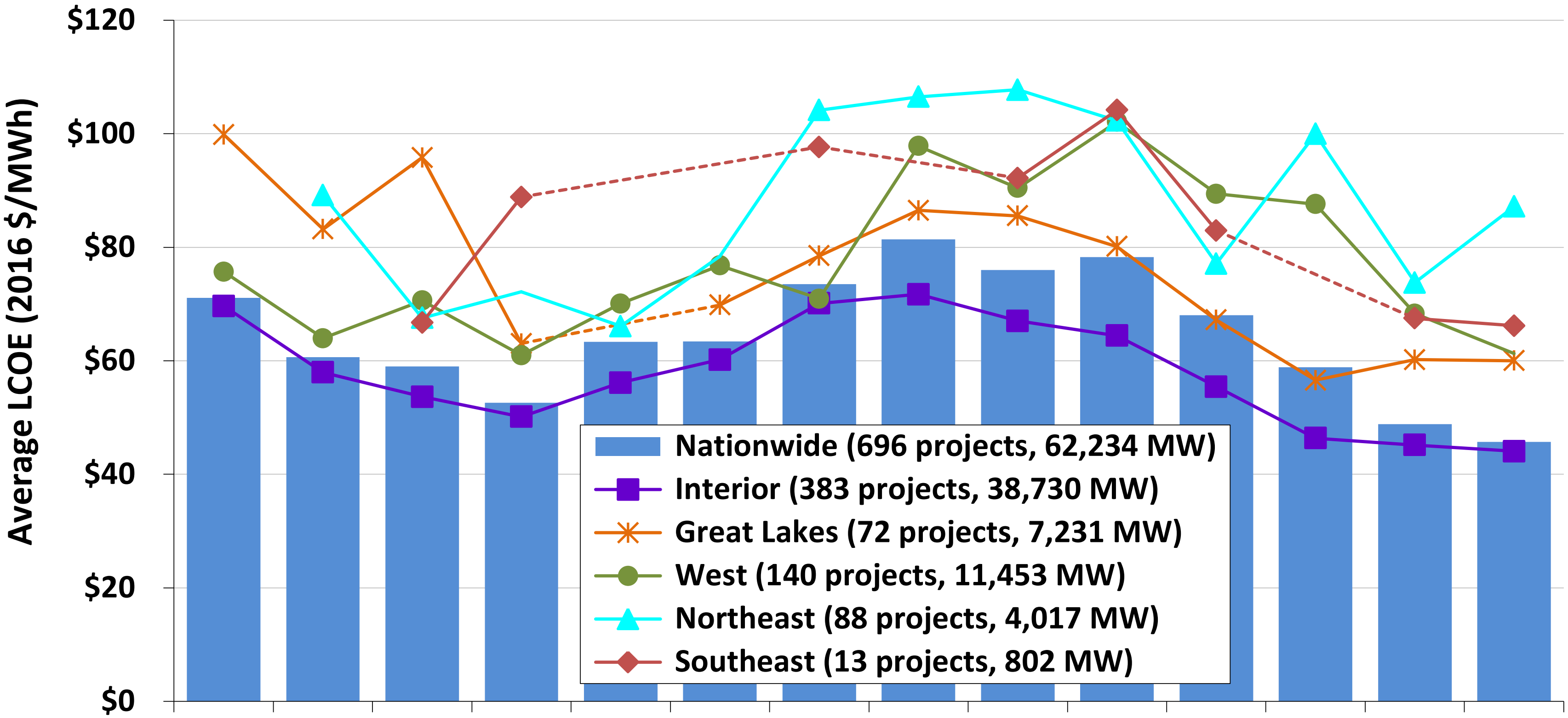
Renewable Energy Certificate (REC) Prices in Key RPS Markets Fell Significantly in 2016, Reflecting Growing Supplies



- REC prices vary by: market type (compliance vs. voluntary); geographic region; specific design of state RPS policies

Wind Power Price Trends

Levelized Cost of Wind Energy Is at an All-Time Low



COD Year:	98-99	00-01	02-03	04-05	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Projects:	26	26	30	29	23	30	64	103	63	85	109	12	46	50
MW:	849	1,694	1,885	2,005	1,820	3,597	6,305	9,575	5,129	6,281	9,378	852	5,100	7,763

- Estimates only reflect variations in installed cost and capacity factors; include accelerated depreciation but exclude PTC

Policy and Market Drivers

Policy and Market Drivers

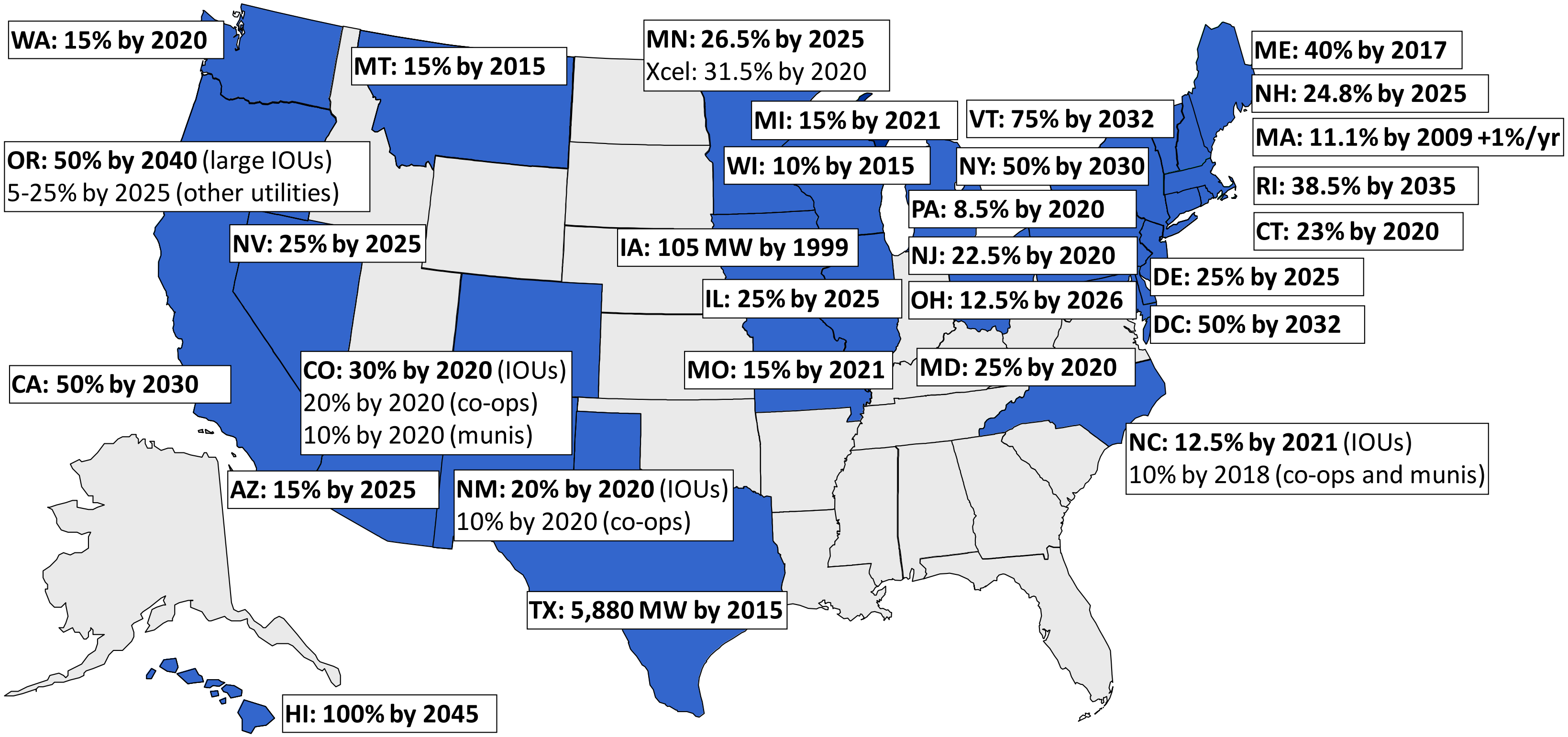
Federal Production Tax Credit (PTC) Remains a Core Motivator for Wind Power Deployment

- 5-year extension of PTC, plus favorable guidance allowing 4 years for project completion after the start of construction
- PTC phase-out, with progressive reduction in the value of the credit for projects starting construction after 2016
- PTC phases down in 20%-per-year increments for projects starting construction in 2017 (80% PTC value), 2018 (60%), and 2019 (40%)

Legislation	Date Enacted	Start of PTC Window	End of PTC Window	Effective PTC Planning Window (considering lapses and early extensions)
Energy Policy Act of 1992	10/24/1992	1/1/1994	6/30/1999	80 months
>5-month lapse before expired PTC was extended				
Ticket to Work and Work Incentives Improvement Act of 1999	12/19/1999	7/1/1999	12/31/2001	24 months
>2-month lapse before expired PTC was extended				
Job Creation and Worker Assistance Act	3/9/2002	1/1/2002	12/31/2003	22 months
>9-month lapse before expired PTC was extended				
The Working Families Tax Relief Act	10/4/2004	1/1/2004	12/31/2005	15 months
Energy Policy Act of 2005	8/8/2005	1/1/2006	12/31/2007	29 months
Tax Relief and Healthcare Act of 2006	12/20/2006	1/1/2008	12/31/2008	24 months
Emergency Economic Stabilization Act of 2008	10/3/2008	1/1/2009	12/31/2009	15 months
The American Recovery and Reinvestment Act of 2009	2/17/2009	1/1/2010	12/31/2012	46 months
2-day lapse before expired PTC was extended				
American Taxpayer Relief Act of 2012	1/2/2013	1/1/2013	Start construction by 12/31/2013	12 months (in which to start construction)
>11-month lapse before expired PTC was extended				
Tax Increase Prevention Act of 2014	12/19/2014	1/1/2014	Start construction by 12/31/2014	2 weeks (in which to start construction)
>11-month lapse before expired PTC was extended				
Consolidated Appropriations Act of 2016	12/18/2015	1/1/2015	Start construction by 12/31/2016	12 months to start construction and receive 100% PTC value
			Start construction by 12/31/2017	24 months to start construction and receive 80% PTC value
			Start construction by 12/31/2018	36 months to start construction and receive 60% PTC value
			Start construction by 12/31/2019	48 months to start construction and receive 40% PTC value

Policy and Market Drivers

State Policies Help Direct the Location and Amount of Wind Development, but Current Policies Cannot Support Continued Growth at Recent Levels

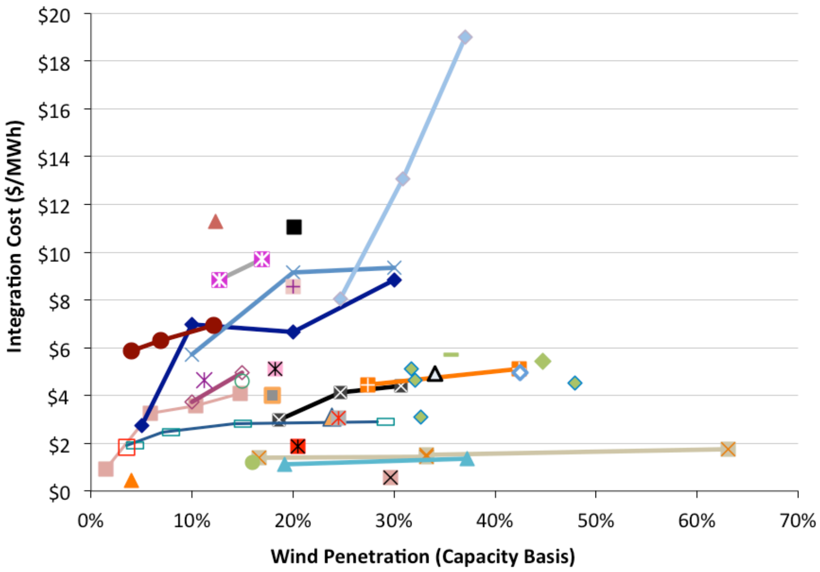


- 29 states and D.C. have mandatory RPS programs
- State RPS' can support ~3.9 GW/yr of renewable energy additions on average through 2030 (less for wind specifically)

Policy and Market Drivers

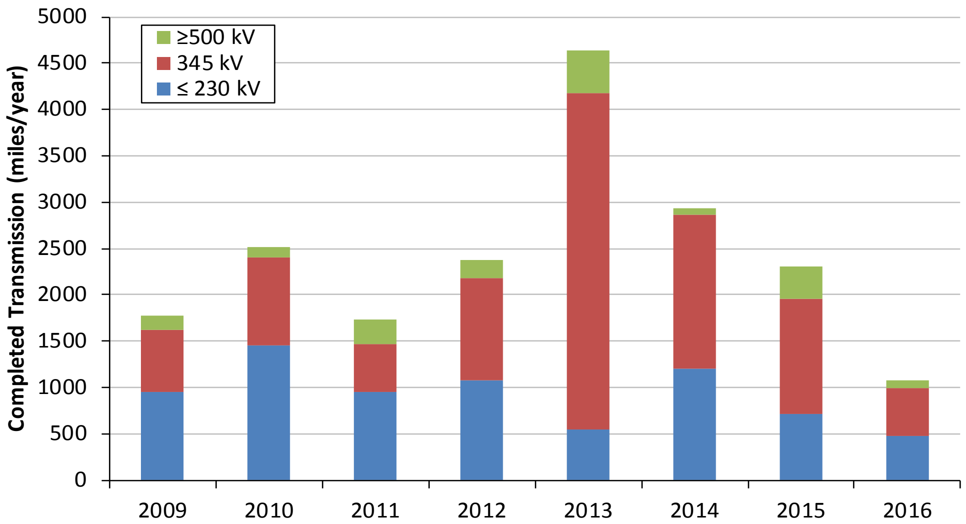
System Operators Are Implementing Methods to Accommodate Increased Penetrations of Wind

Integrating wind energy into power systems is manageable, but not free of additional costs



Notes: Because methods vary and a consistent set of operational impacts has not been included in each study, results from the different analyses of integration costs are not fully comparable.

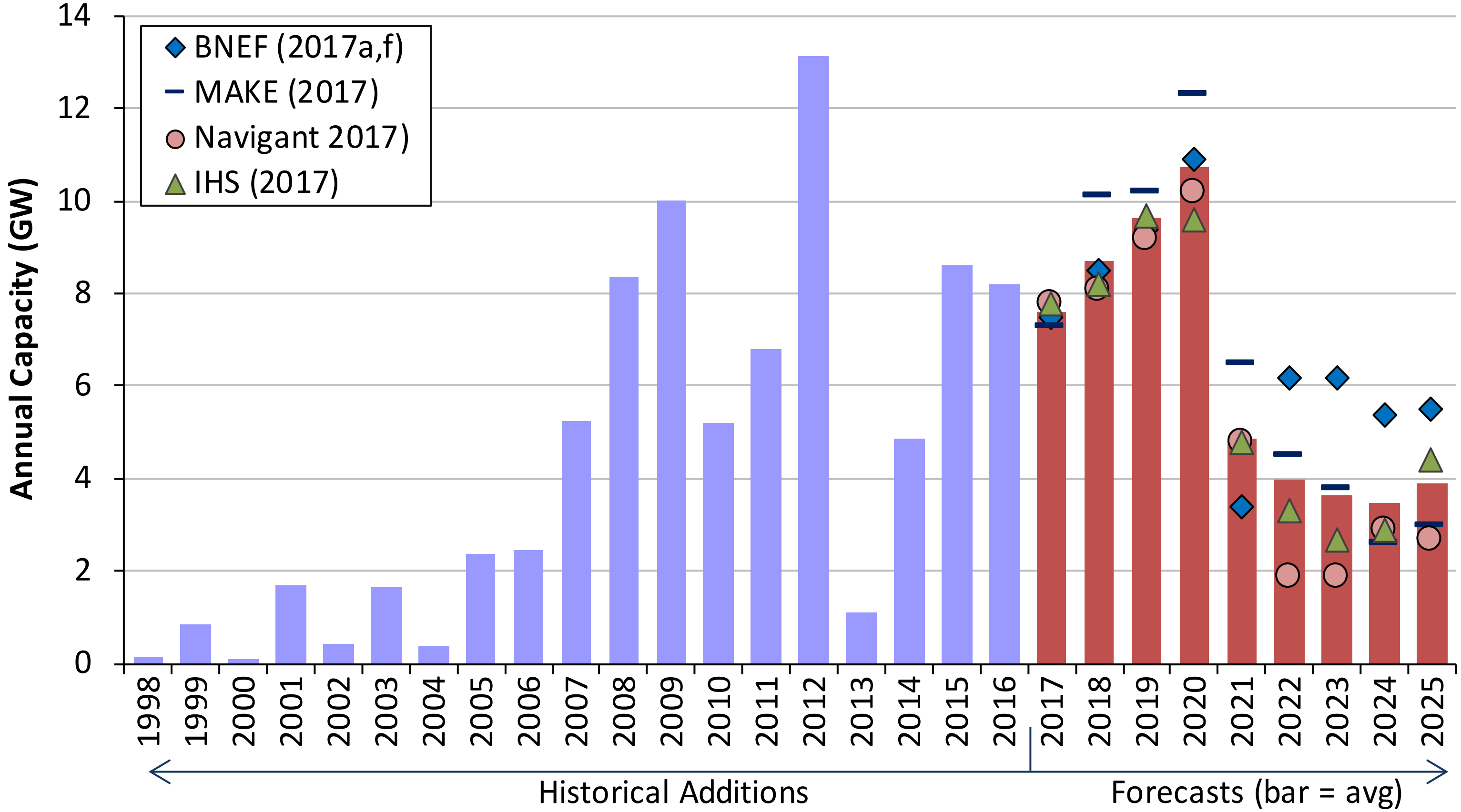
Transmission Barriers Remain



Future Outlook

Future Outlook

Sizable Wind Additions Anticipated for 2016-2020 Given PTC Extension; Downturn and Uncertainty Beyond 2020



- Wind additions through 2020 consistent with deployment trajectory analyzed in DOE's *Wind Vision* report; not so after 2020

Future Outlook

Current Low Prices for Wind, Future Technological Advancement, and Direct Retail Sales May Support Higher Growth in Future, but Headwinds Include:

- Phase-down of federal tax incentives
- Continued low natural gas and wholesale electricity prices
- Modest electricity demand growth
- Limited near-term demand from state RPS policies
- Inadequate transmission infrastructure in some areas
- Growing competition from solar in some regions

Conclusions

- Wind capacity additions continued at a rapid pace in 2016, w/ significant additional new builds anticipated over next four years in part due to PTC
- Wind has been a significant source of new electric generation capacity additions in the U.S. in recent years
- Supply chain continued to adjust to swings in domestic demand, but domestic content for nacelle assembly, towers, and blades is strong
- Turbine scaling is significantly boosting wind project performance, while the installed cost of wind projects has declined
- Wind power sales prices are at all-time lows, enabling economic competitiveness despite low natural gas prices
- Growth beyond current PTC cycle remains uncertain: could be blunted by declining federal tax support, expectations for low natural gas prices and solar costs, and modest electricity demand growth

For More Information

See full report for additional findings, a discussion of the sources of data used, etc.:

- https://energy.gov/eere/wind/downloads/2016-wind-technologies-market-report

To contact the primary authors:

- Ryan Wiser, Lawrence Berkeley National Laboratory
  510-486-5474, RHWiser@lbl.gov
- Mark Bolinger, Lawrence Berkeley National Laboratory
  603-795-4937, MABolinger@lbl.gov

Berkeley Lab's contributions to this report were funded by the Wind Energy Technologies Office, Office of Energy Efficiency and Renewable Energy of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231. The authors are solely responsible for any omissions or errors contained herein.