U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

2018 Wind Technologies Market Report: Summary

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2018 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 2018
- Scope focuses on land-based wind turbines over 100 kW
- 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, National Renewable Energy Laboratory

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

Available at: http://energy.gov/windreport

Report Contents

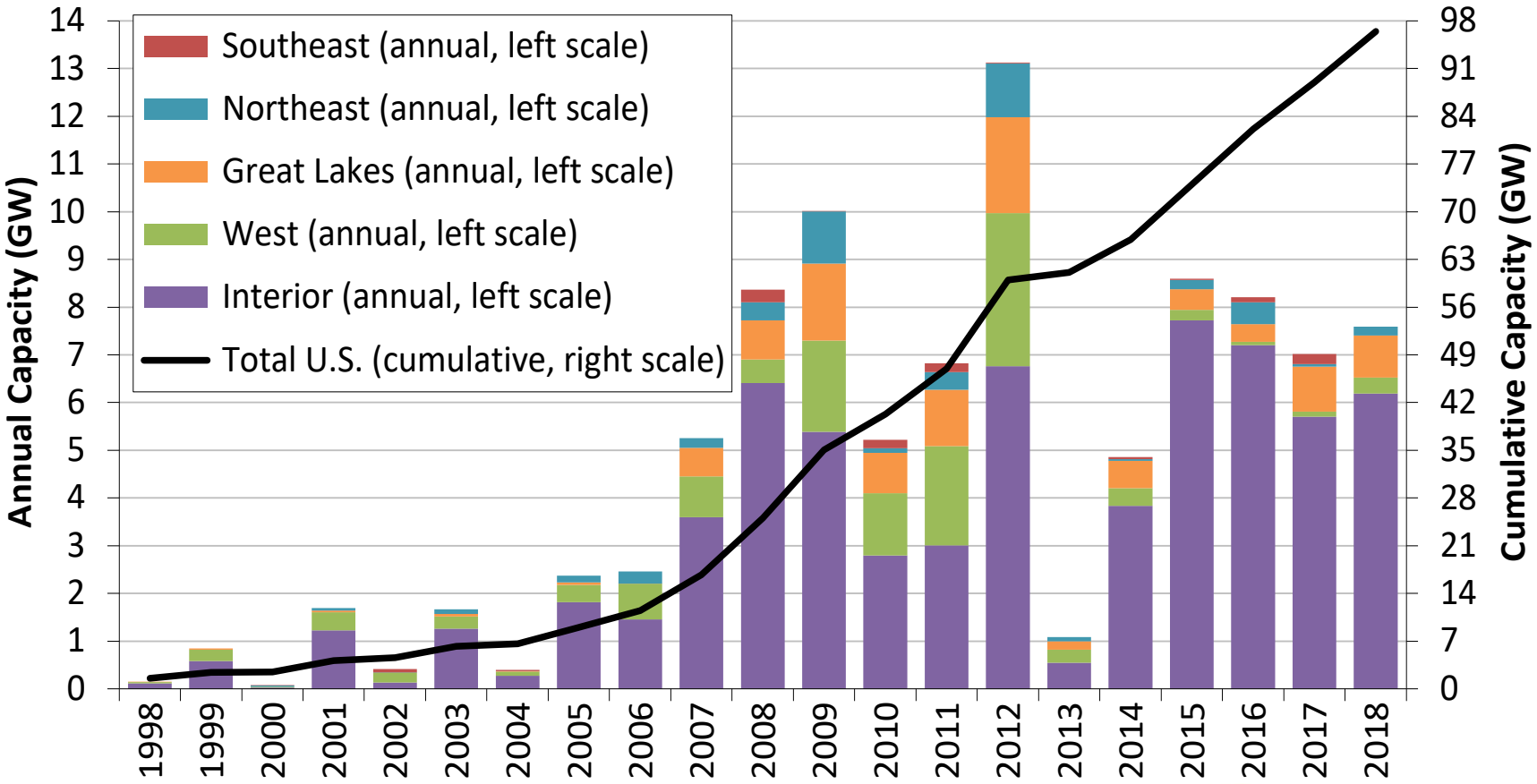
- Installation trends
- Industry trends
- Technology trends
- Performance trends
- Cost trends
- Wind power price trends
- Policy and market drivers
- Future outlook

Key Findings

- Wind capacity additions continued at a robust pace in 2018, with significant additional new builds anticipated in near-term 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 is diverse and multifaceted, with strong domestic content for nacelle assembly, towers, and blades
- Turbine scaling is significantly boosting wind project performance, while the installed cost of wind projects has declined
- Wind power sales prices and levelized cost of energy are at all-time lows, enabling economic competitiveness (with the PTC) despite low 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

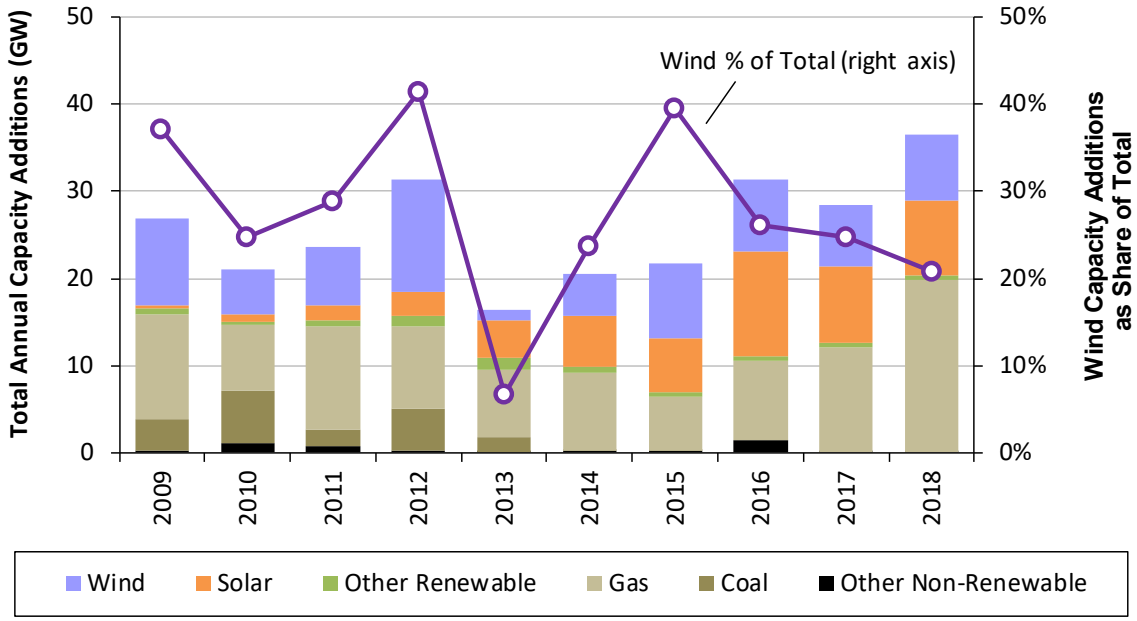
Installation Trends

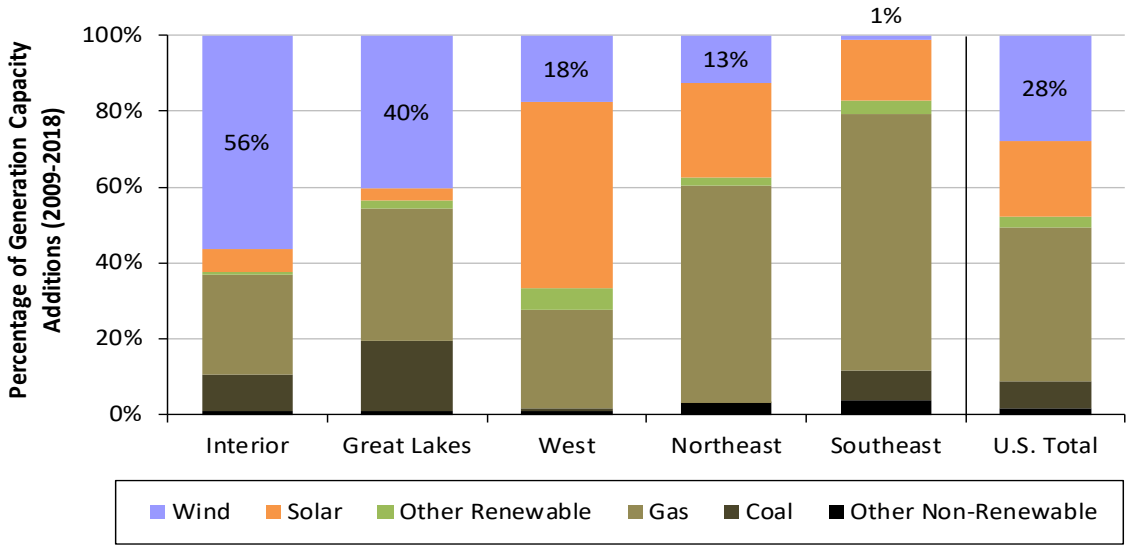
Wind Power Additions Continued at a Robust Pace in 2018, with 7,588 MW of New Capacity, Bringing the Total to 96,433 MW



- $11 billion invested in wind power project additions in 2018
- Over 80% of new 2018 capacity located in Interior region
- Partial repowering trend: 1,312 MW of existing wind plants retrofitted in 2018

Wind Power Represented 21% of Electric-Generating Capacity Additions in 2018, Behind Solar and Natural Gas





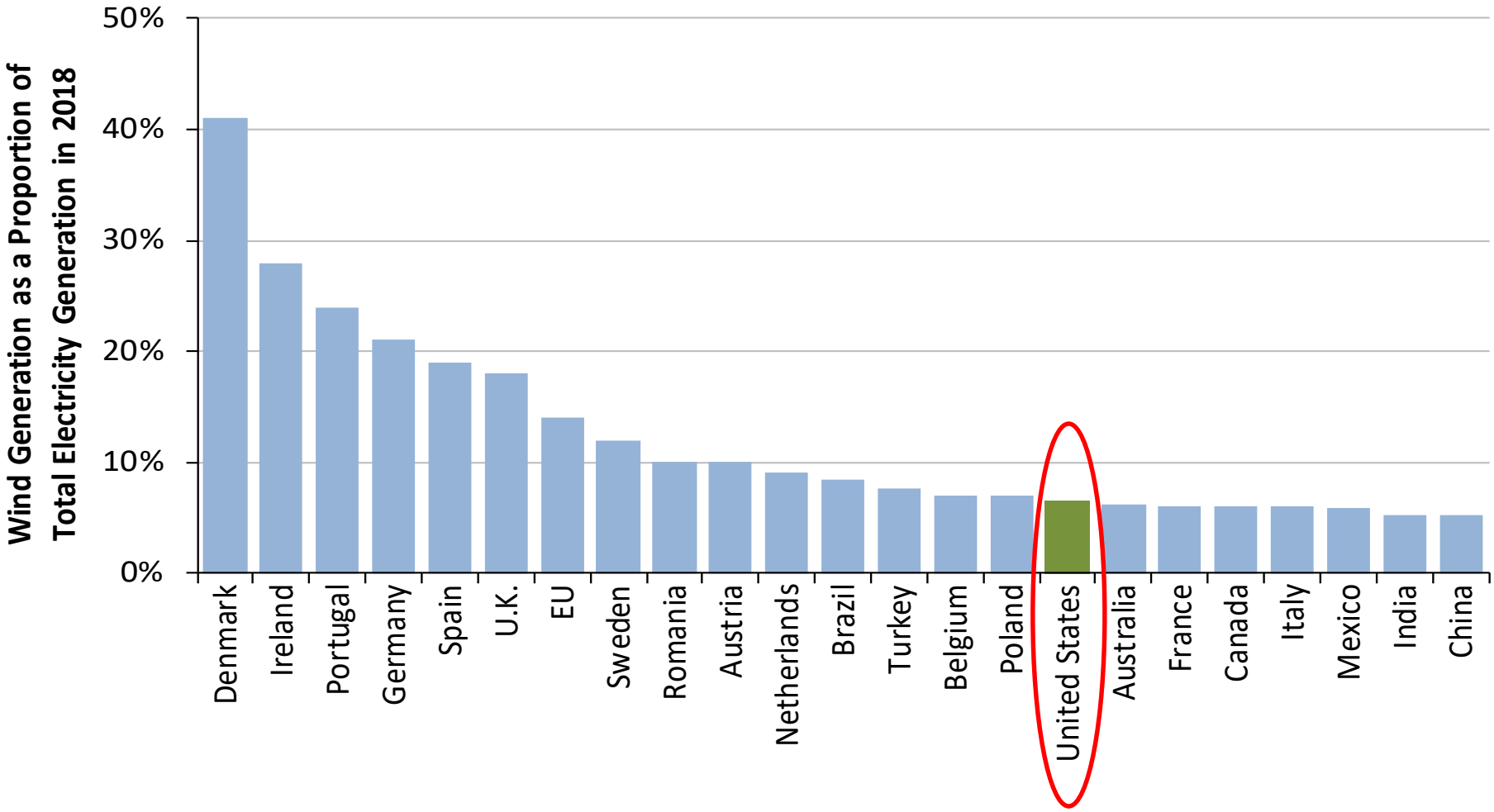
Over the last decade, wind has comprised 28% of total capacity additions nationwide, and a much higher proportion in some regions of the country

Globally, the U.S. Ranked 2nd in Annual Wind Power Capacity Additions in 2018, and in Cumulative Wind Power Capacity

Annual Capacity (2018, MW)		Cumulative Capacity (end of 2018, MW)	
China	23,000	China	211,392
United States	**7,588**	**United States**	**96,433**
Germany	3,371	Germany	59,312
India	2,191	India	35,129
Brazil	1,939	Spain	23,531
United Kingdom	1,901	United Kingdom	20,964
France	1,565	France	15,309
Mexico	929	Brazil	14,707
Sweden	720	Canada	12,816
Canada	566	Italy	9,959
Rest of World	7,545	*Rest of World*	91,518
TOTAL	**51,315**	**TOTAL**	**591,069**

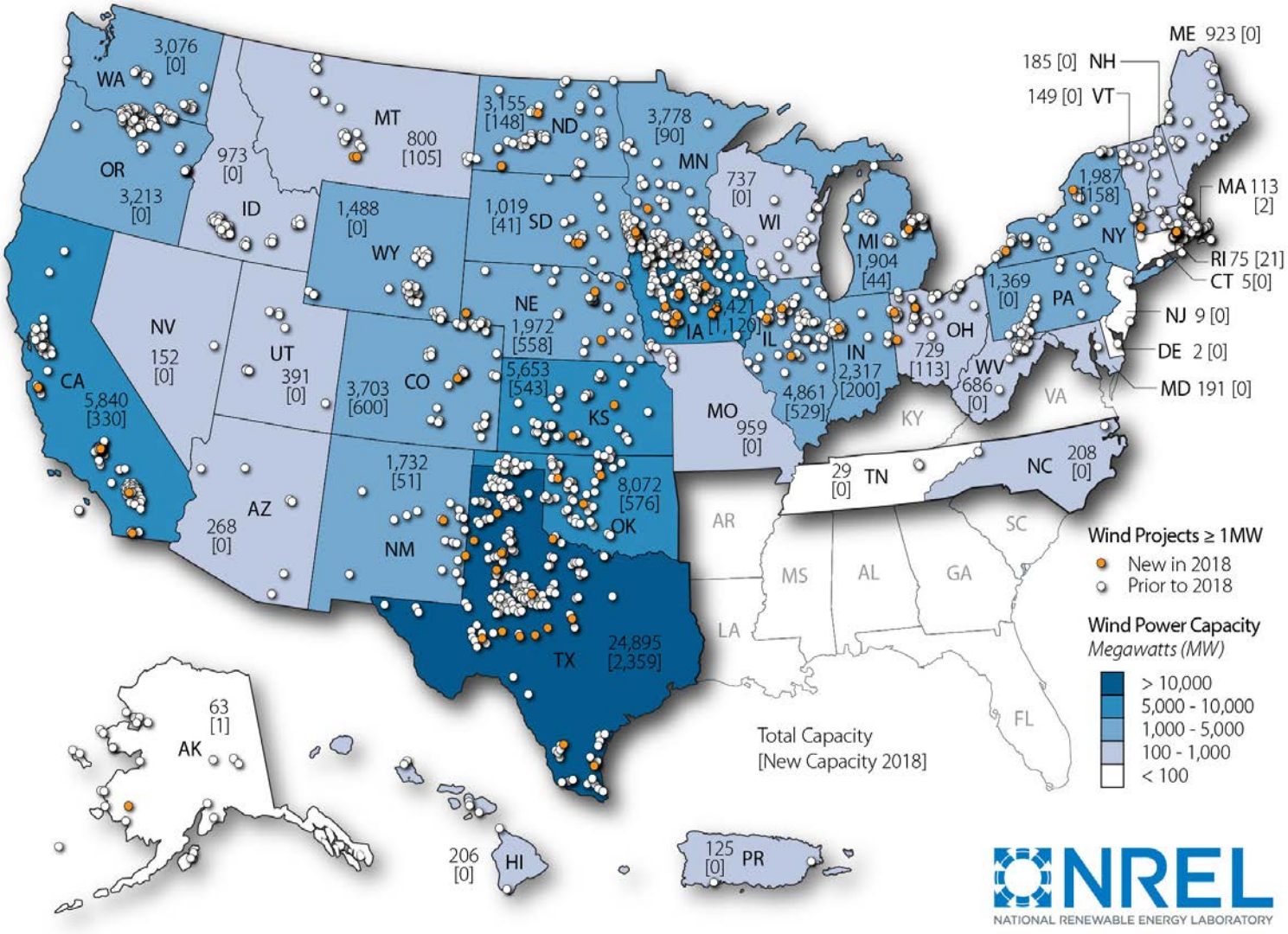
- U.S. remains a distant second to China in annual and cumulative capacity
- Global wind additions in 2018 were below the 53,500 MW added in 2017 and the record level of 63,800 MW added in 2015

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



Note: Figure only includes the countries with the most installed wind power capacity at the end of 2018

The Geographic Spread of Wind Power Projects Across the United States Is Broad, with the Exception of the Southeast



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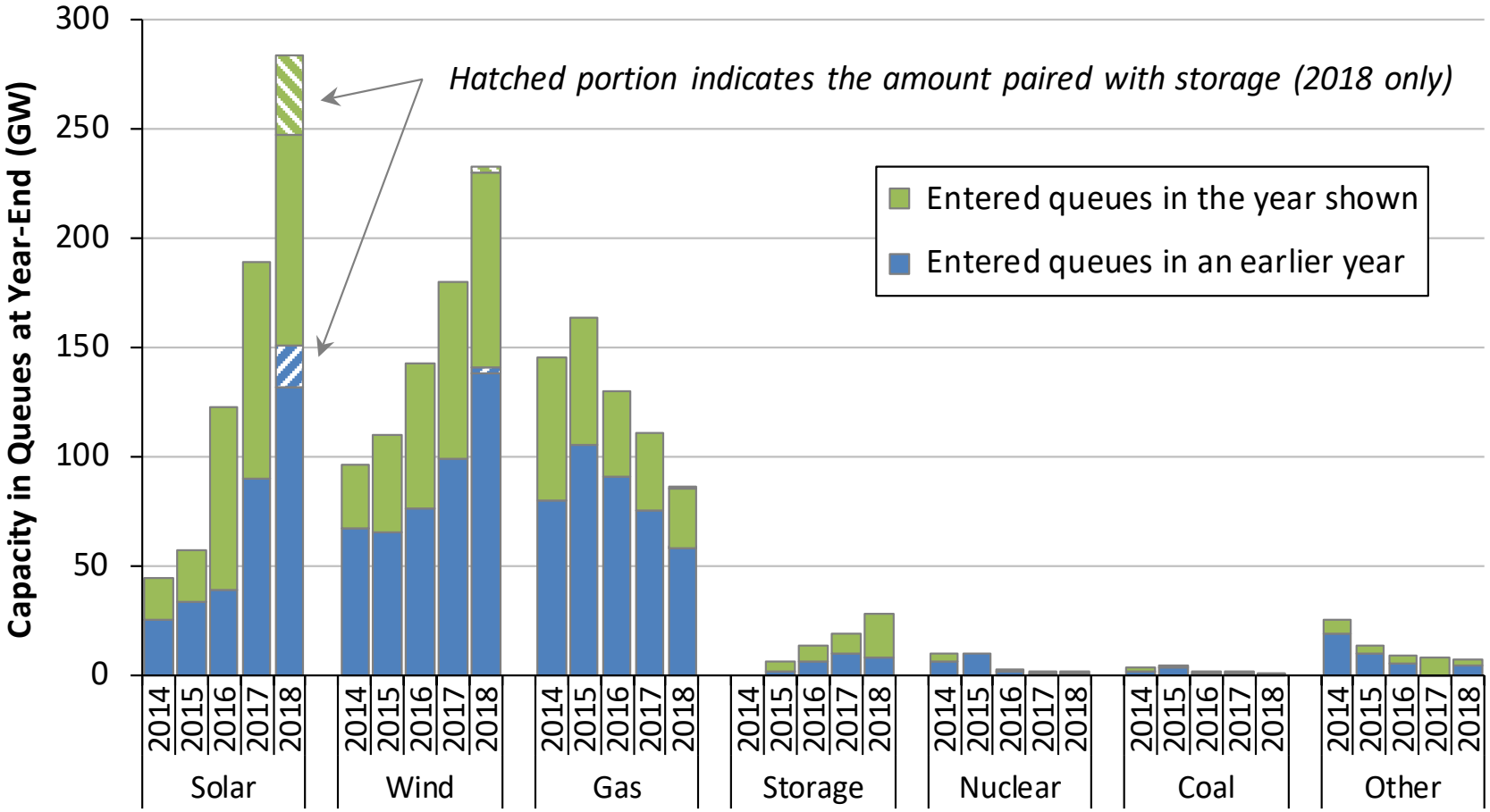
Note: Numbers within states represent cumulative installed wind capacity and, in brackets, annual additions in 2018

Texas Installed the Most Wind Power Capacity in 2018; 14 States Exceed 10% Wind Energy as Percentage of In-State Generation

Installed Capacity (MW)				2018 Wind Generation as a Percentage of:			
Annual (2018)		Cumulative (end of 2018)		In-State Generation		In-State Sales	
Texas	2,359	Texas	24,895	Kansas	36.4%	North Dakota	53.5%
Iowa	1,120	Iowa	8,421	Iowa	33.7%	Kansas	47.1%
Colorado	600	Oklahoma	8,072	Oklahoma	31.7%	Oklahoma	43.4%
Oklahoma	576	California	5,840	North Dakota	25.8%	Iowa	43.2%
Nebraska	558	Kansas	5,653	South Dakota	24.4%	New Mexico	25.6%
Kansas	543	Illinois	4,861	Maine	21.0%	Wyoming	24.9%
Illinois	529	Minnesota	3,778	New Mexico	18.7%	South Dakota	21.7%
California	330	Colorado	3,703	Minnesota	17.9%	Maine	21.0%
Indiana	200	Oregon	3,213	Colorado	17.3%	Texas	18.6%
New York	158	North Dakota	3,155	Texas	15.9%	Colorado	17.5%
North Dakota	148	Washington	3,076	Vermont	15.8%	Minnesota	17.0%
Ohio	113	Indiana	2,317	Idaho	14.7%	Nebraska	16.9%
Montana	105	New York	1,987	Nebraska	14.1%	Oregon	15.0%
Minnesota	90	Nebraska	1,972	Oregon	11.0%	Montana	14.9%
New Mexico	51	Michigan	1,904	Wyoming	9.0%	Idaho	10.8%
Michigan	44	New Mexico	1,732	Montana	7.9%	Illinois	9.1%
South Dakota	41	Wyoming	1,488	Illinois	6.8%	Washington	8.2%
Rhode Island	21	Pennsylvania	1,369	California	6.5%	Vermont	7.1%
Massachusetts	2	South Dakota	1,019	Washington	6.3%	Hawaii	5.8%
Alaska	1	Idaho	973	Indiana	5.0%	Indiana	5.6%
Rest of U.S.	0	*Rest of U.S.*	7,005	*Rest of U.S.*	1.1%	*Rest of U.S.*	1.5%
TOTAL	7,588	TOTAL	96,433	TOTAL	6.5%	TOTAL	7.3%

2018 Wind Penetration by ISO: SPP: 23.9%; ERCOT: 18.6%; MISO: 7.3%; CAISO: 7.3%; ISO-NE: 2.8%; PJM: 2.7%; NYISO: 2.5%

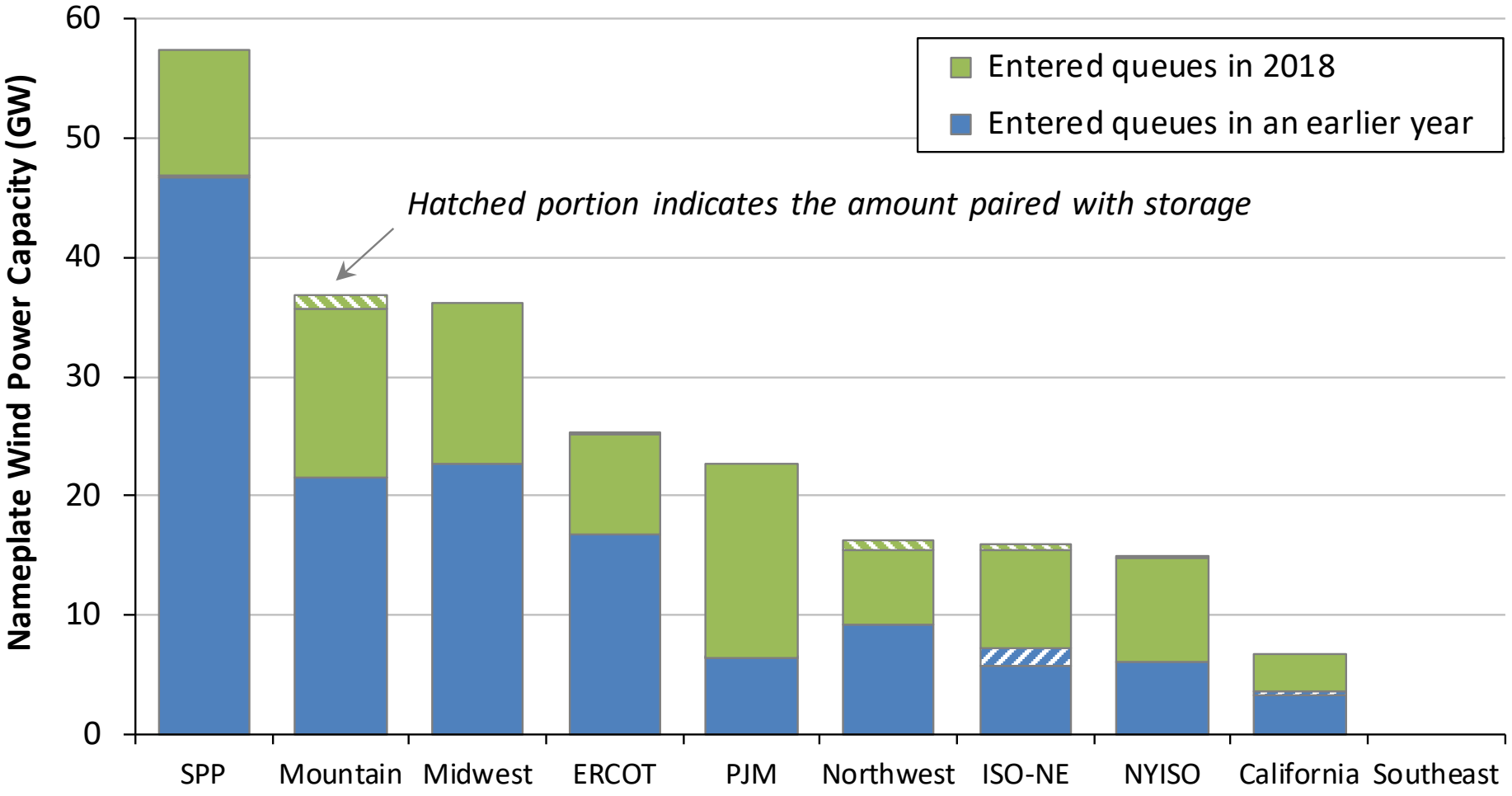
A Record Level of Wind Power Capacity Entered Transmission Interconnection Queues in 2018; Solar and Storage Also Growing



- Hybrid plants with storage represent 20% of solar in queue in 2018, but just 2% of wind in queue is proposed to include storage
- AWEA reports 39 GW of capacity under construction or in advanced development at end of 1Q2019

Note: Not all of this capacity will be built

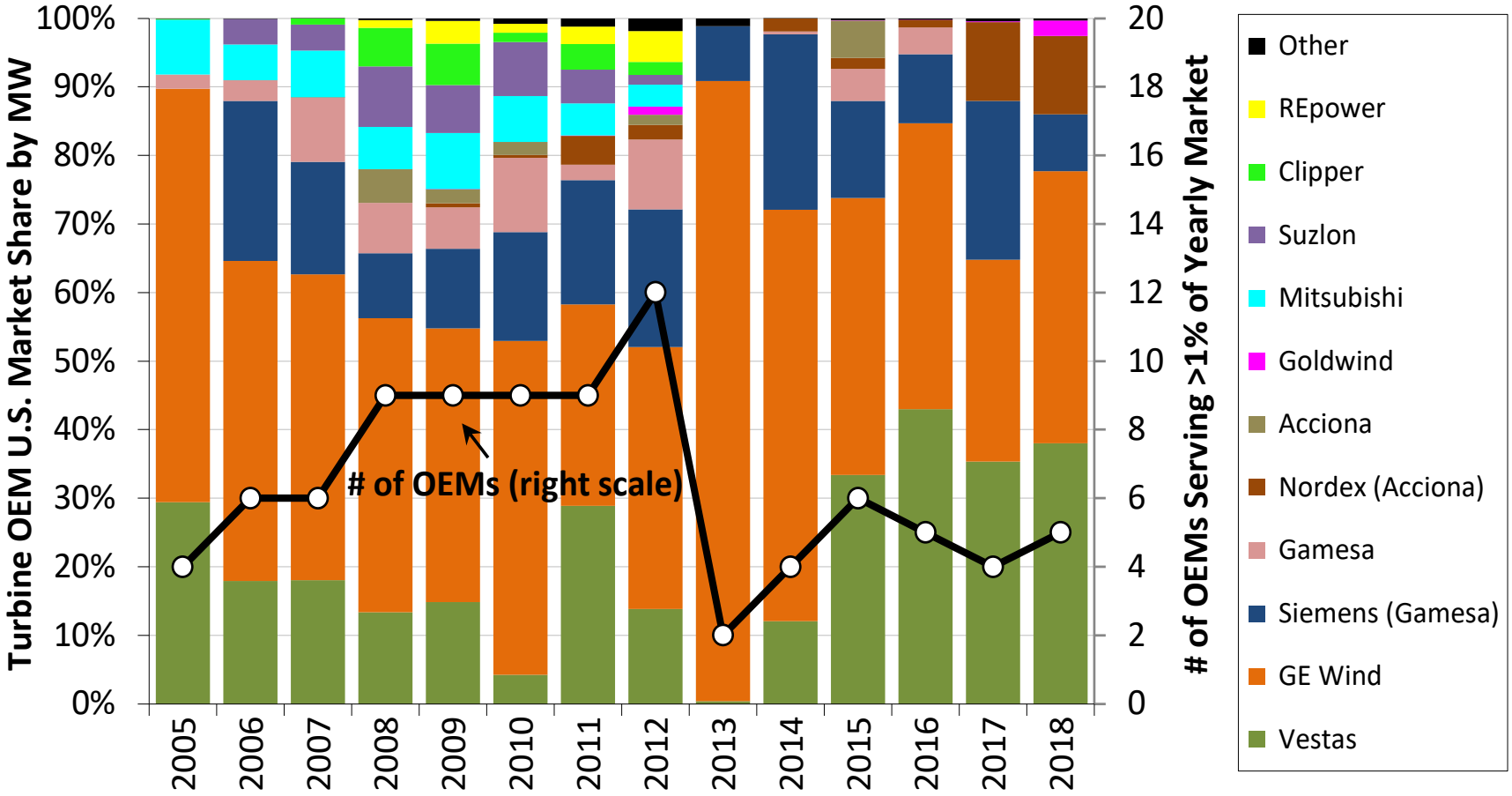
Larger Amounts of Wind Power Capacity Planned for Southwest Power Pool, Mountain & Midwest Regions; Major Growth in PJM



Note: Not all of this capacity will be built

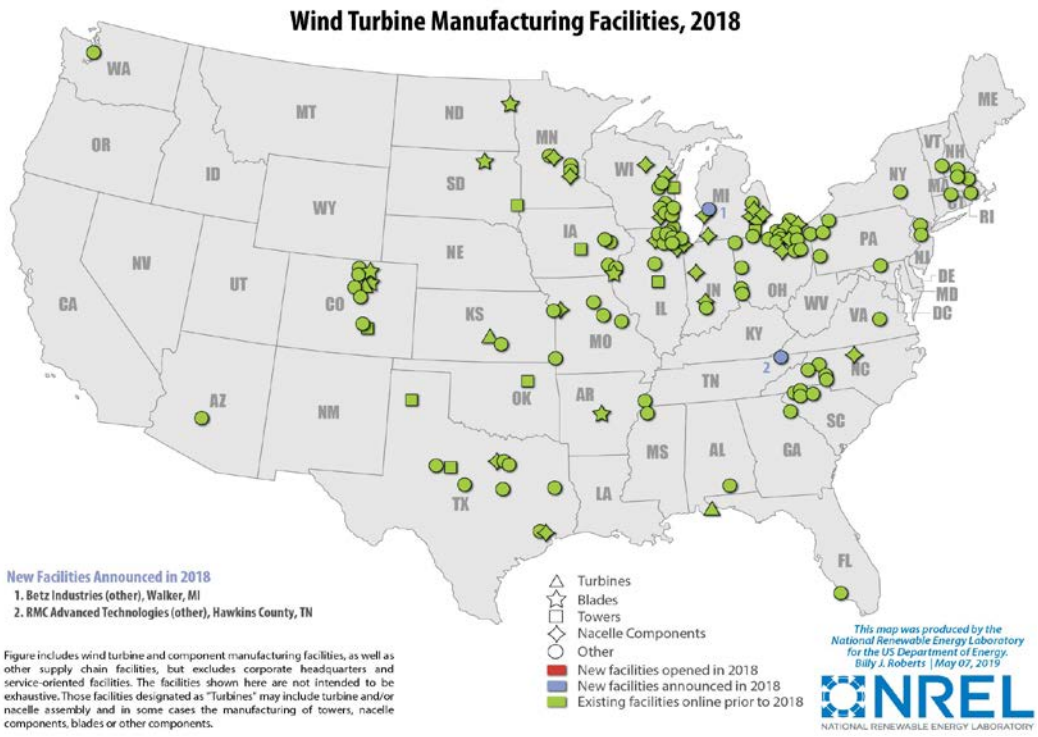
Industry Trends

GE and Vestas Captured 78% of the U.S. Market in 2018



- Globally, Vestas, Goldwind, Siemens Gamesa, and GE were the top suppliers of wind turbines in 2018
- Chinese suppliers occupied 8 of the top 15 spots in the global ranking, based primarily on sales within their domestic market

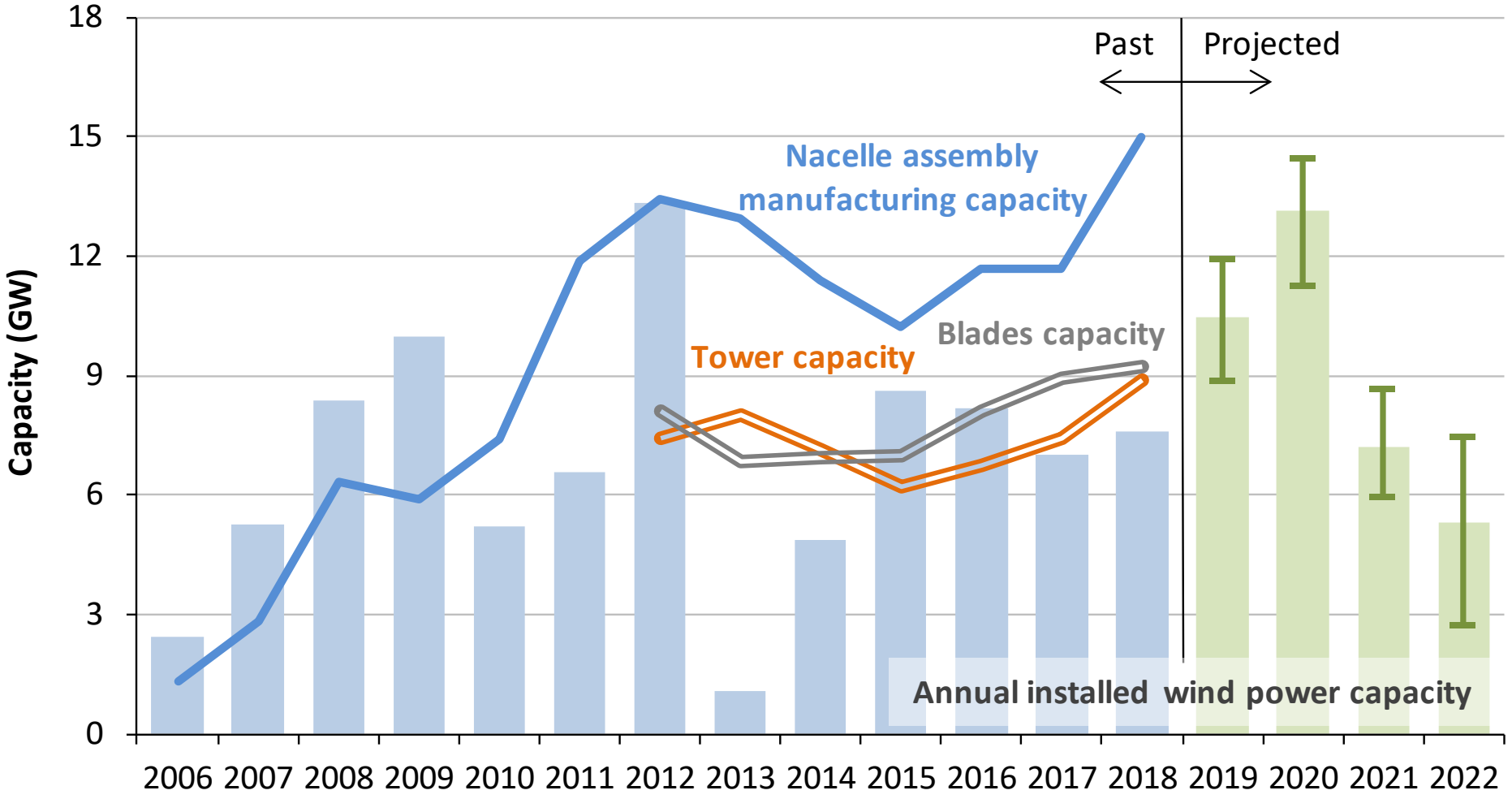
The Domestic Supply Chain for Wind Equipment is Diverse



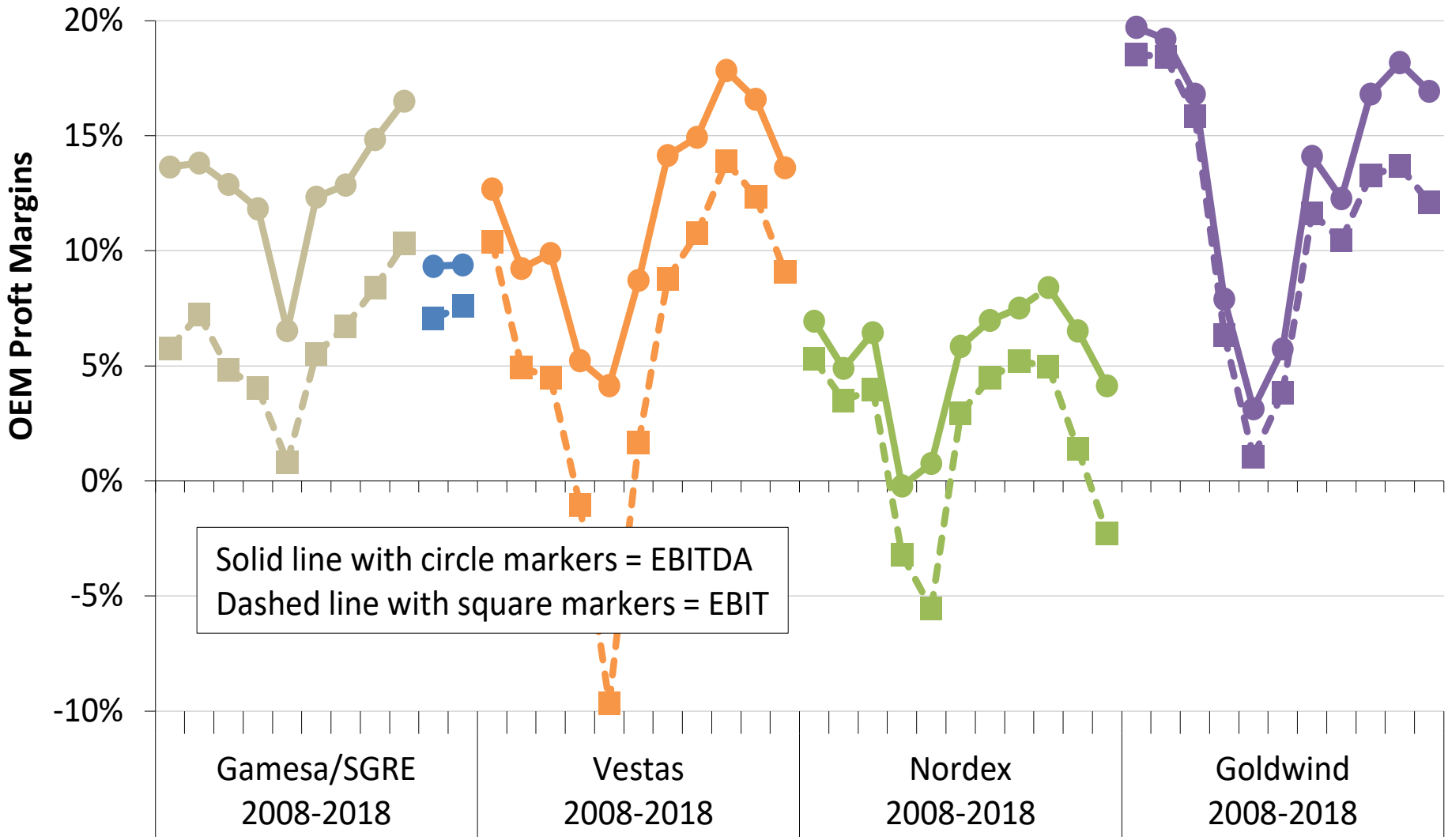
Note: map not intended to be exhaustive

- Some manufacturers increased the size of their U.S. workforce in 2018 and/or expanded existing facilities, but expectations for significant additional supply-chain expansion have become less optimistic
- Continued near-term expected growth, but strong competitive pressures and expected reduced demand as PTC is phased out
- Two new manufacturing facilities announced with expected online dates in 2019; four facilities stopped serving industry
- Many manufacturers remain; three of the largest OEMs serving U.S. market all have at least one facility
- Wind-related jobs reached a new all-time high, at 114,000

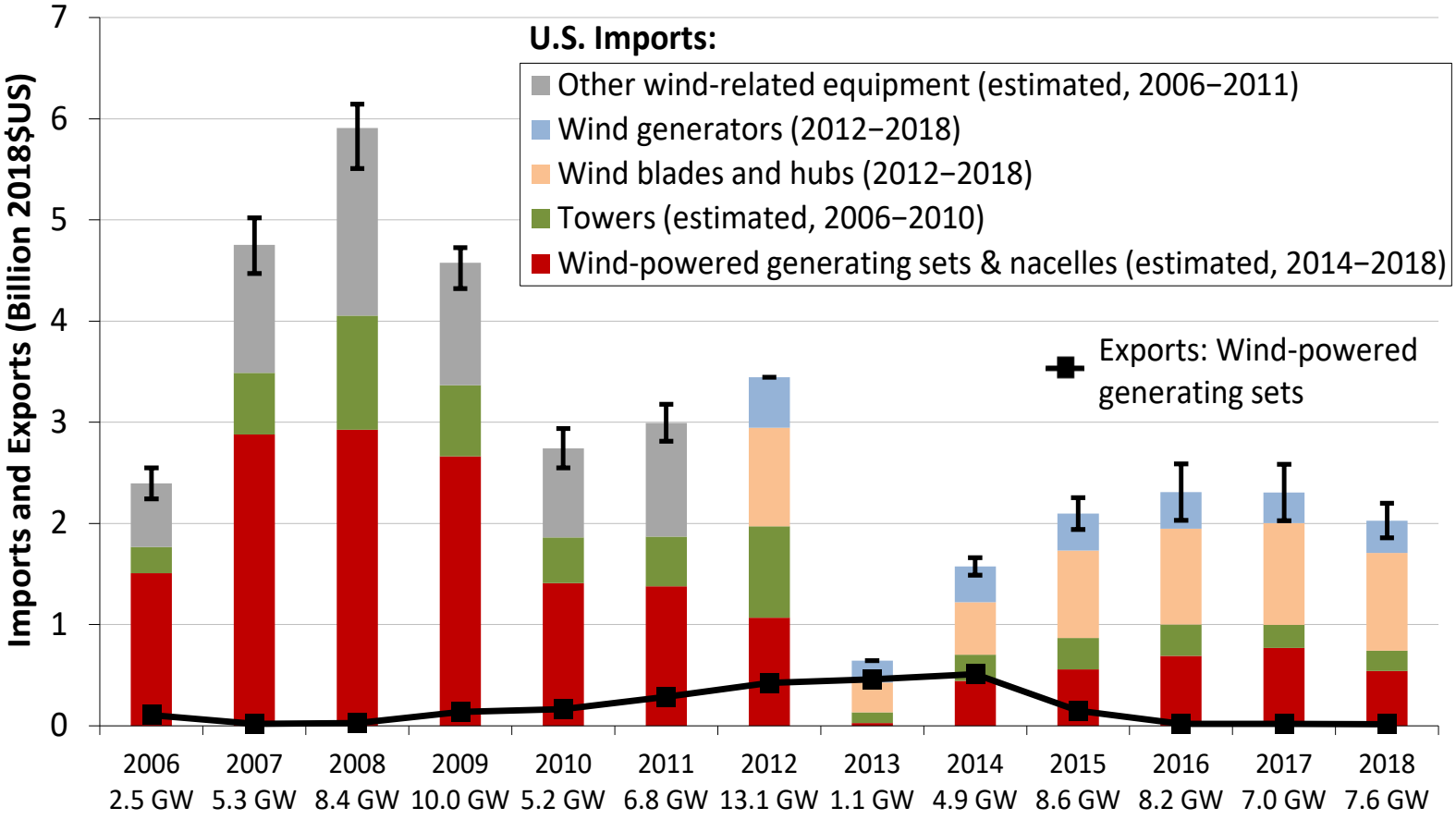
Domestic Manufacturing Capability for Nacelle Assembly, Towers, & Blades Reasonably Well Balanced Against Historical Demand



Turbine OEM Profitability Has Generally Declined in Most Recent Years, Following Several Years of Recovery Since Low in 2012



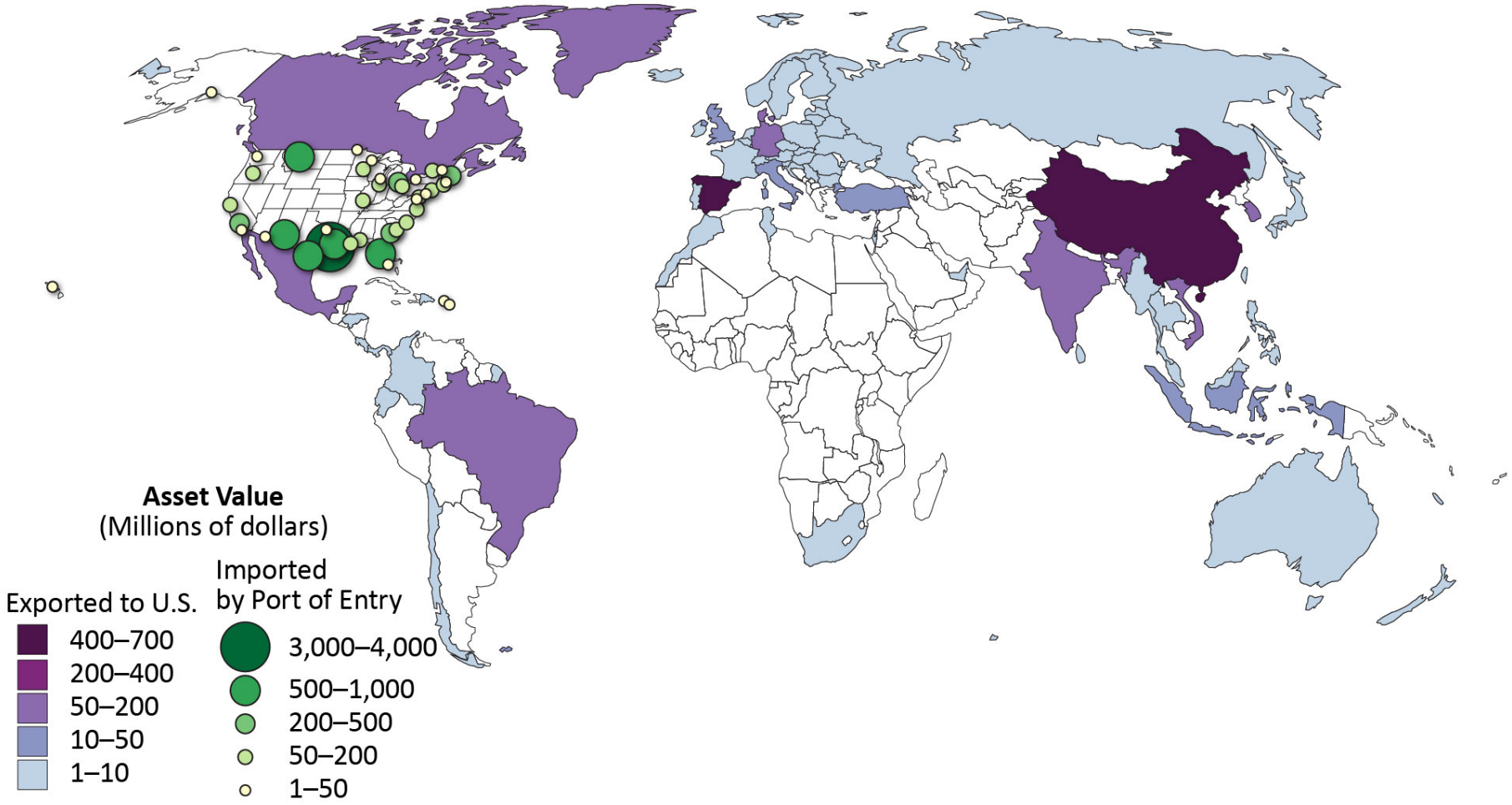
U.S. Is a Net Importer: Imports of Wind Equipment into the United States Are Sizable; Exports Remained Low in 2018



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

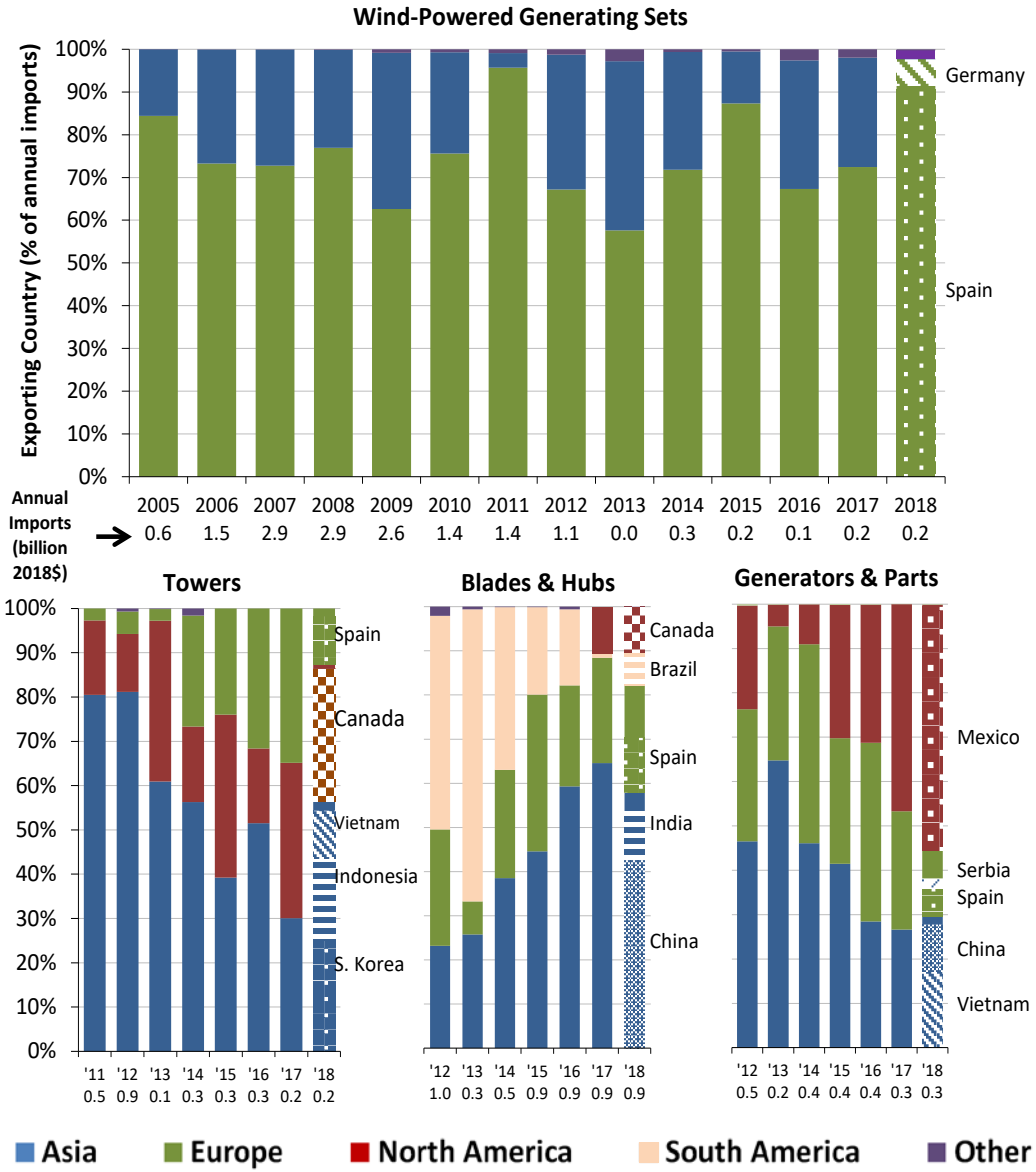
- **Exports of wind-powered generating sets = $13 million in 2018**
- **No ability to track other wind-specific exports, but total 'tower and lattice mast' exports equaled $29 million**

Tracked Wind Equipment Imports in 2018: 44% from Asia, 35% from Europe, 20% from the Americas



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

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



- Majority of imports of wind-powered generating sets historically from home countries of OEMs, dominated by Europe
- Decline in imports of towers from Asia over time, in part due to tariffs, but rebound in 2018
- Majority of imports of blades & hubs from Asia (especially) China
- Mexico becoming a dominant supplier of generators and parts

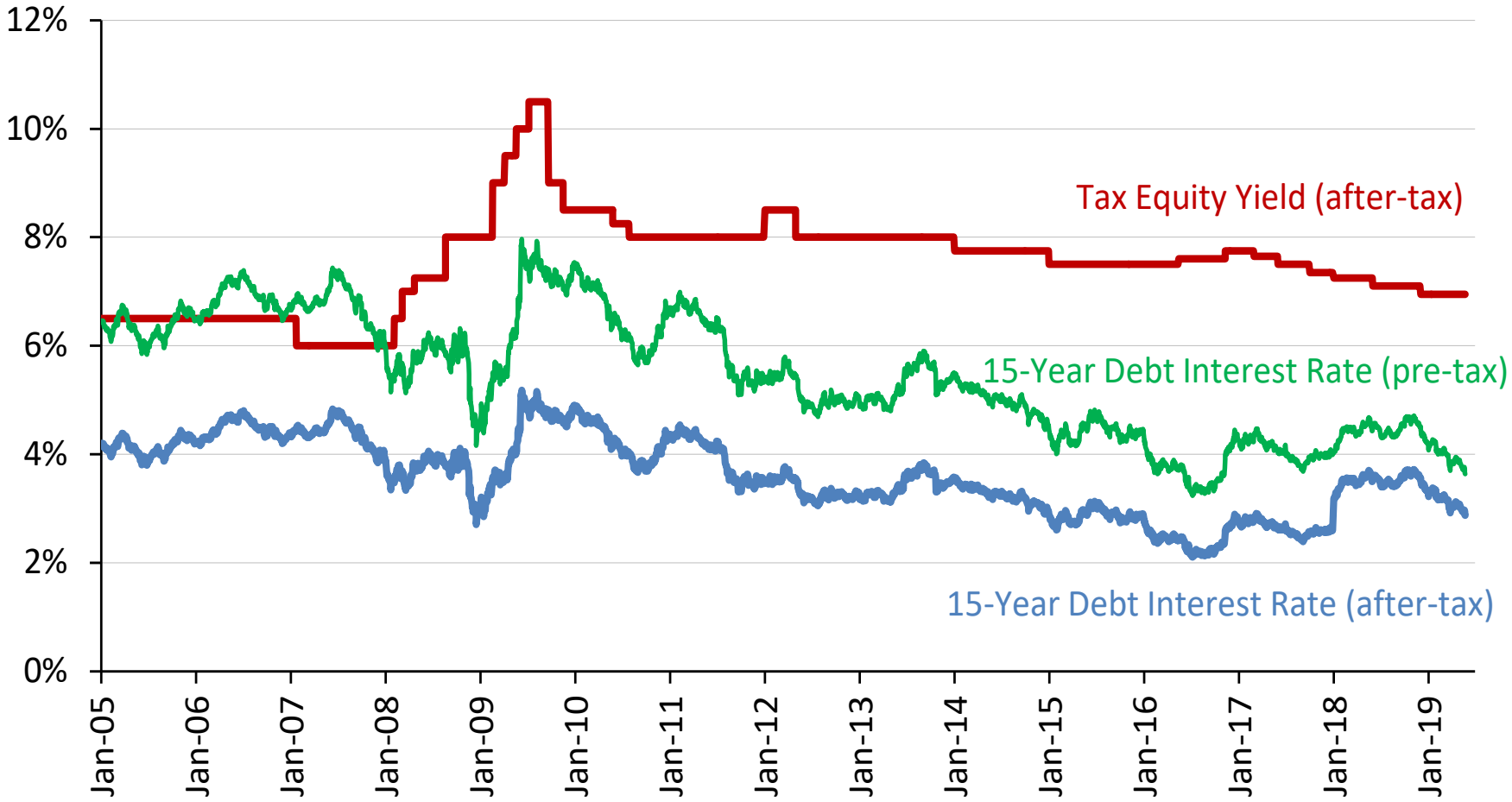
Domestic Manufacturing Content is Strong for Nacelle Assembly, Towers, and Blades, but not Equipment Internal to the Nacelle

Domestic Content for 2018 Turbine Installations in the United States:

Towers	Blades & Hubs	Nacelle Assembly
75–90%	50–70%	> 85%

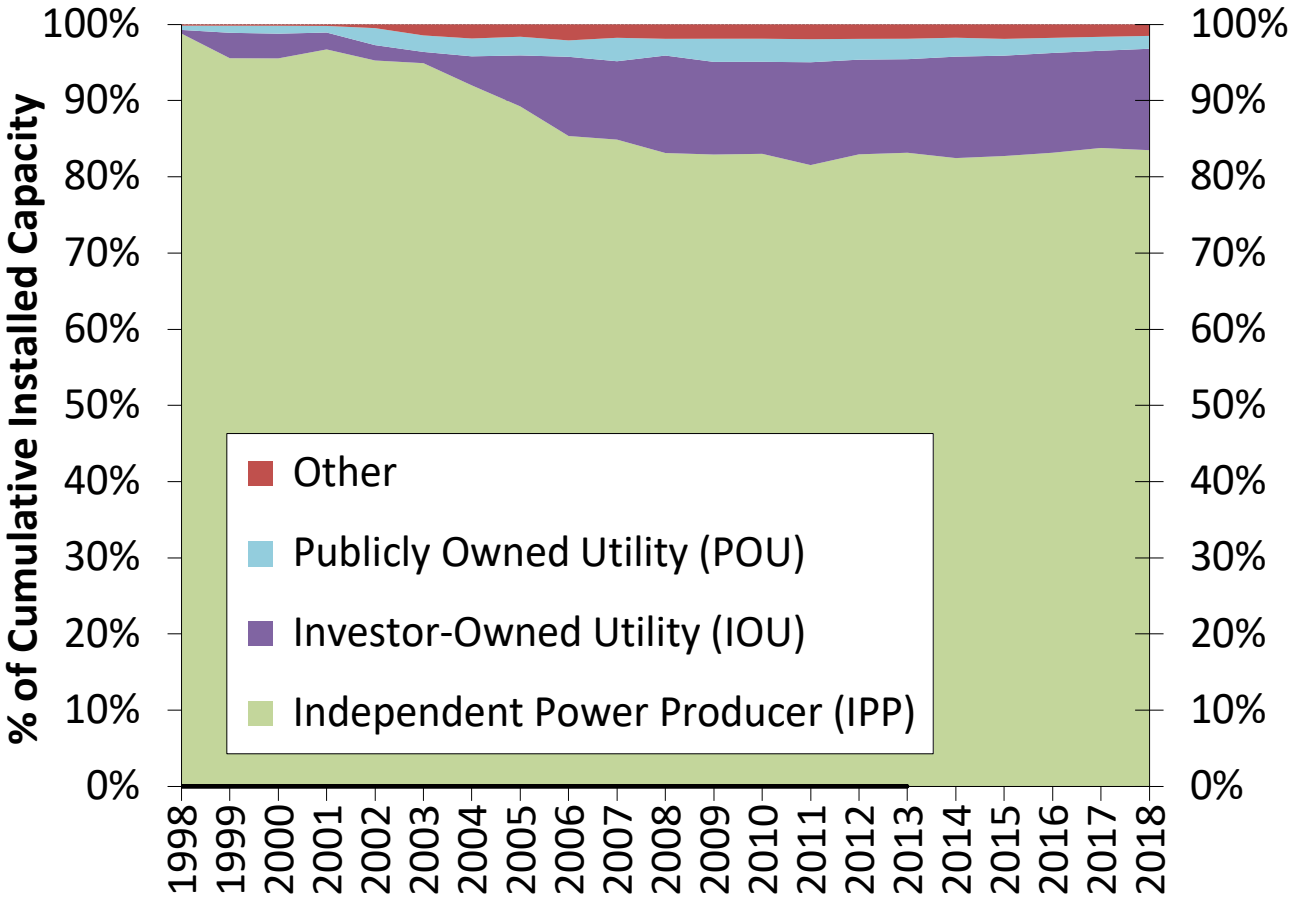
- Imports occur in untracked trade categories, including many nacelle internals; nacelle internals generally have domestic content of < 20%

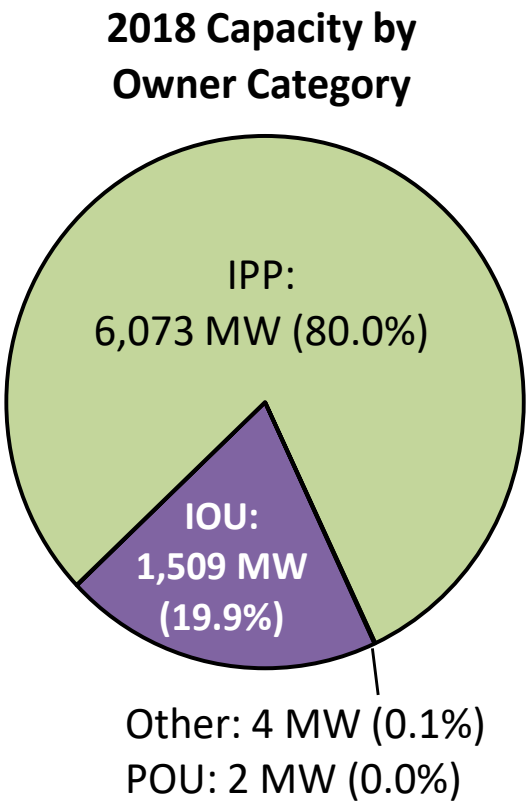
The Project Finance Environment Remained Strong in 2018



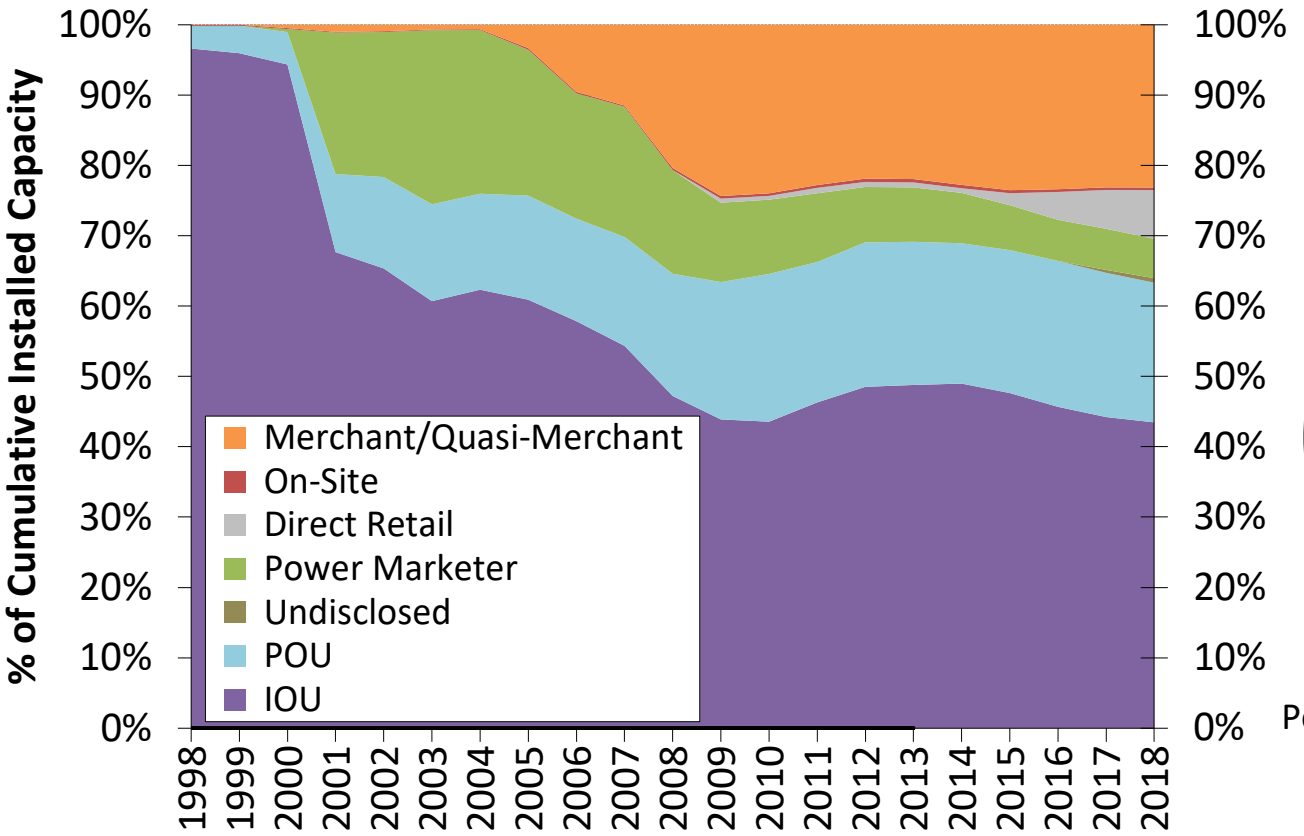
- Sponsors raised $6-7 billion of tax equity in 2018
- Tax reform legislation contained a number of provisions with implications for wind finance, but in general those implications have been modest

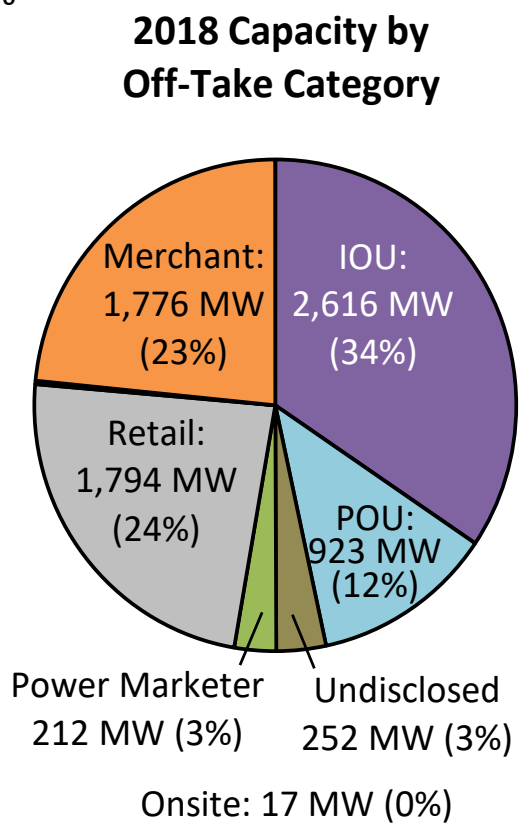
Independent Power Producers Own the Majority of Wind Assets Built in 2018





Long-Term Sales to Utilities Remained Most Common Off-Take, but Direct Retail Sales and Merchant Were Significant

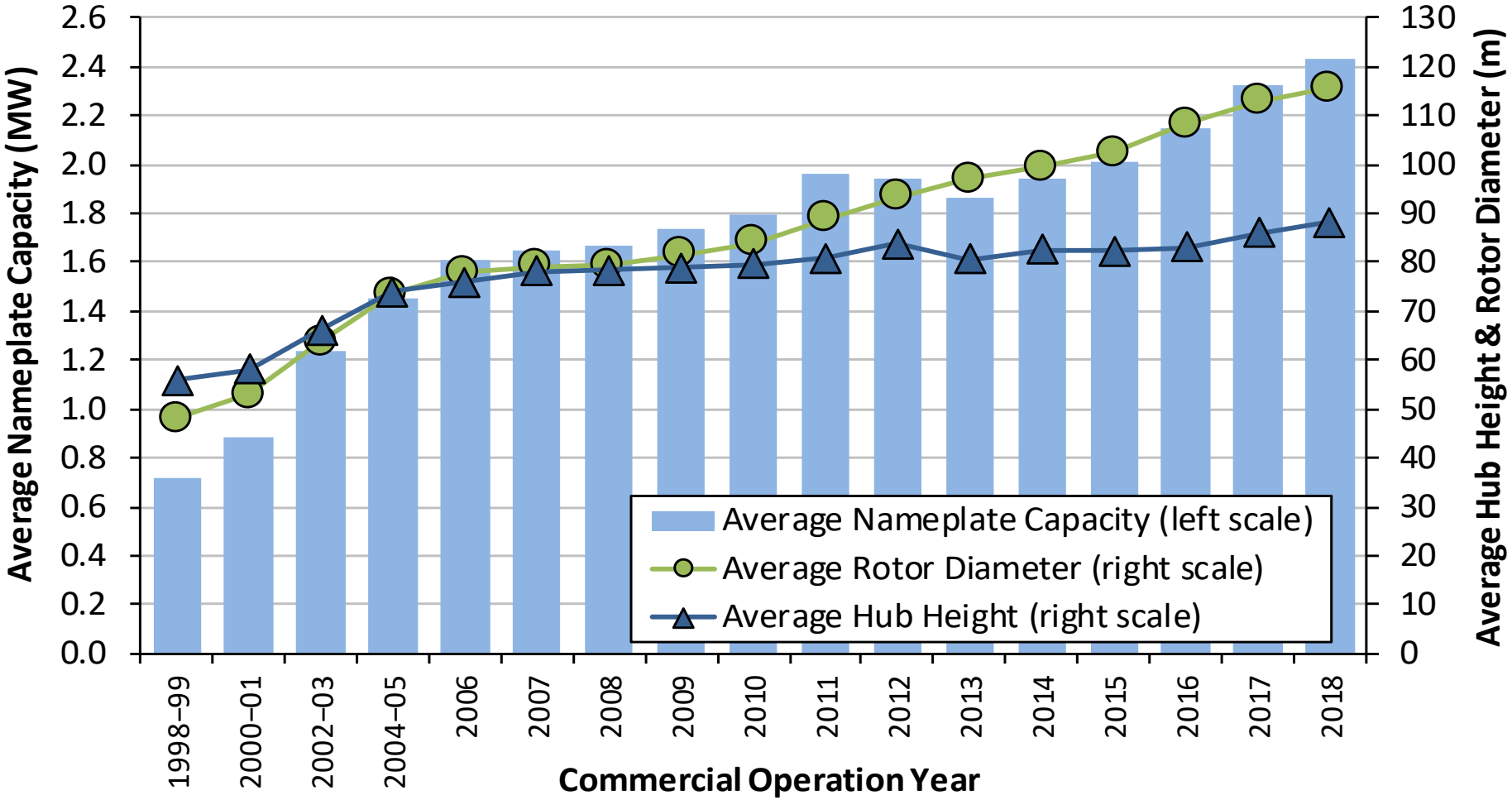




- 24% of added wind capacity in 2018 are from direct retail sales; 49% of total wind capacity contracted through PPAs in 2018 involve non-utility buyers

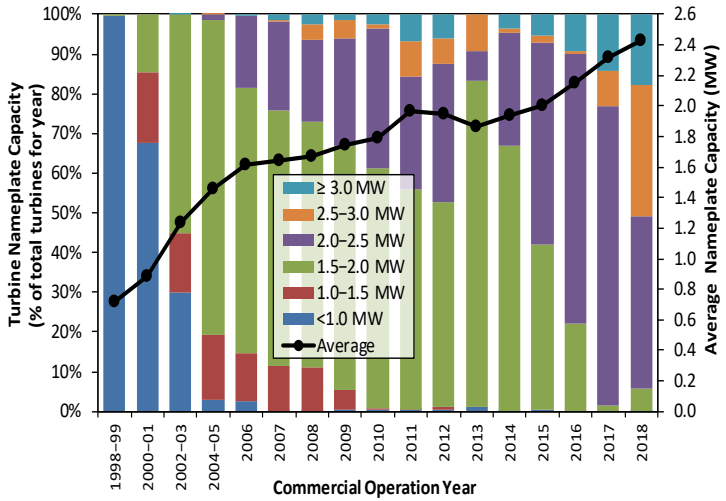
Technology Trends

Turbine Capacity, Rotor Diameter, and Hub Height Have All Increased Significantly Over the Long Term, and in 2018

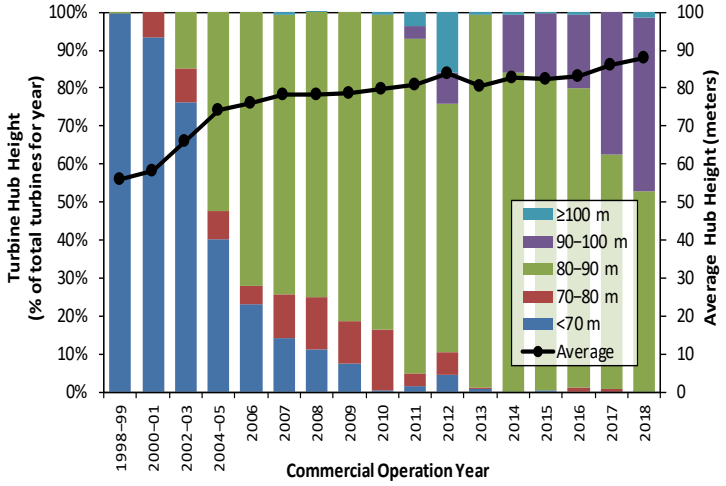


Growth in Rotor Diameter and Nameplate Capacity Have Outpaced Growth in Hub Height over the Last Two Decades

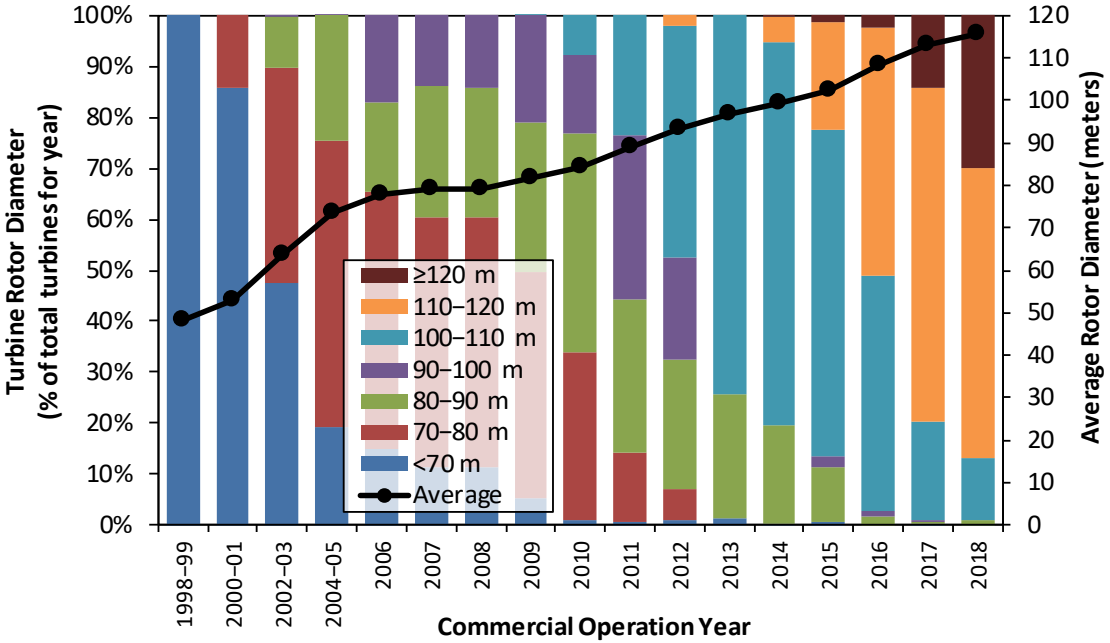
Nameplate Capacity



Hub Height

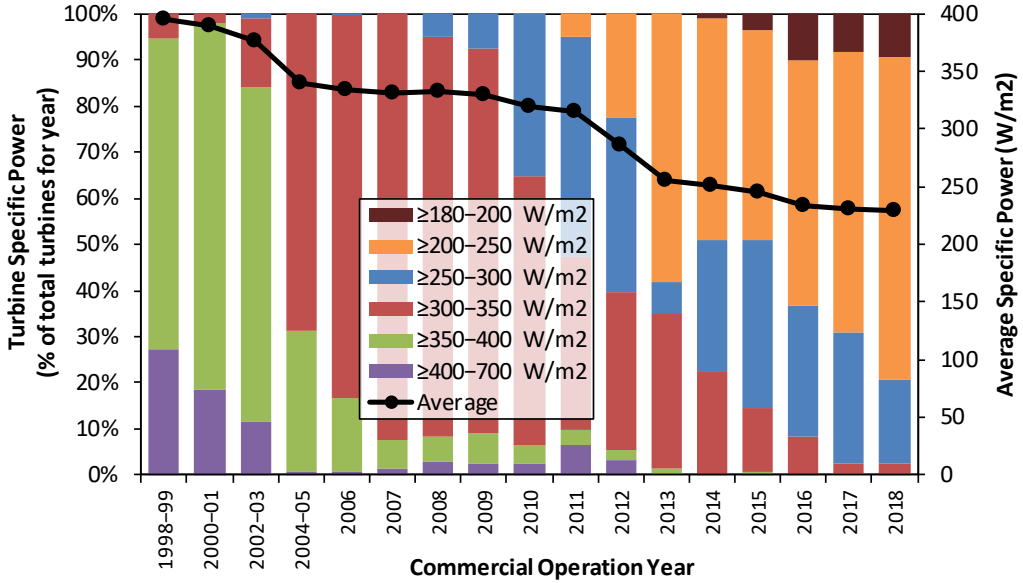


Rotor Diameter

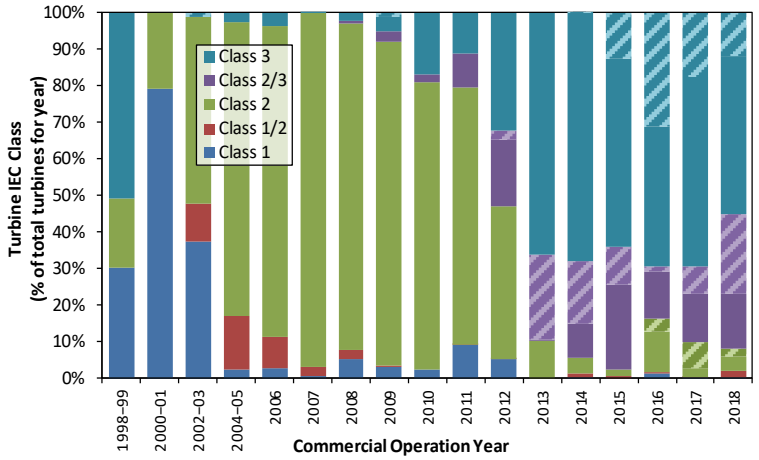


Turbines Originally Designed for Lower Wind Speed Sites Dominate the Market

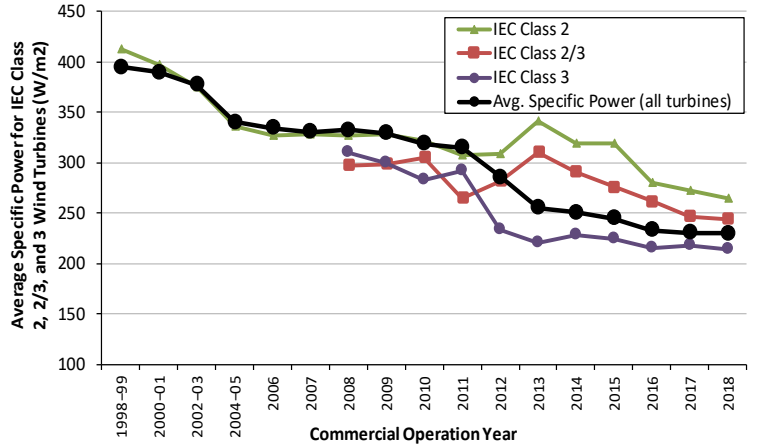
Specific Power



IEC Class

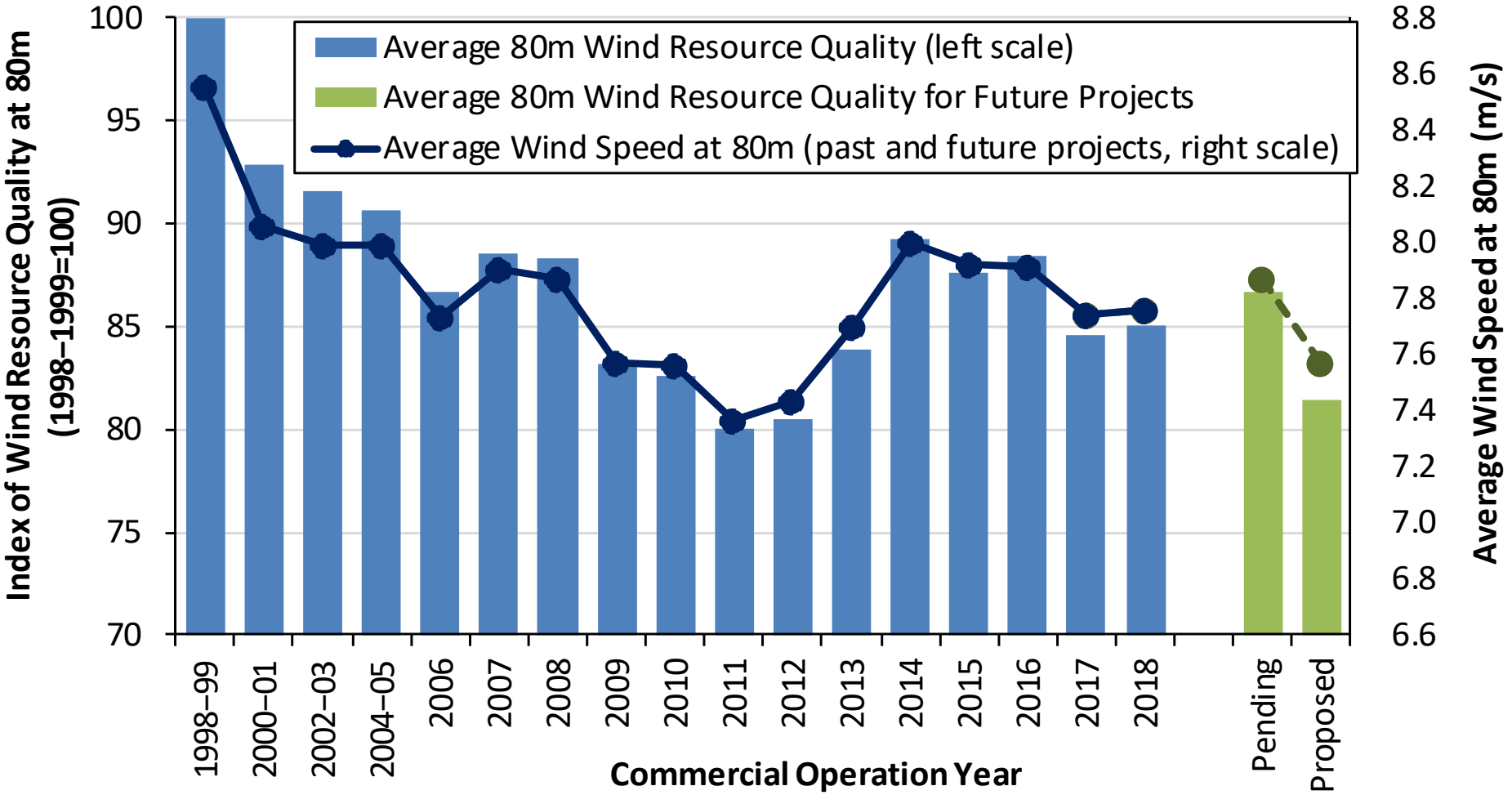


Specific Power by Selected IEC Class

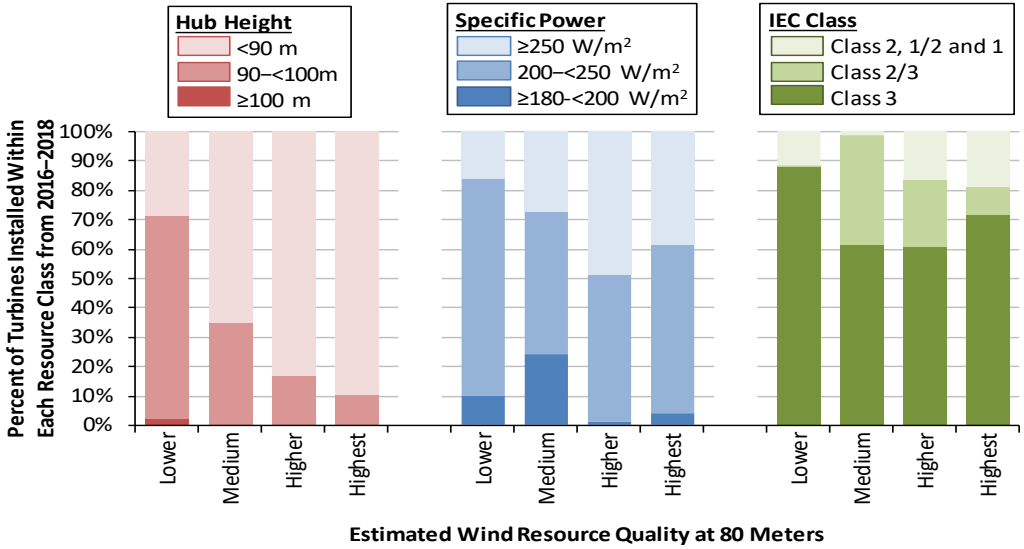


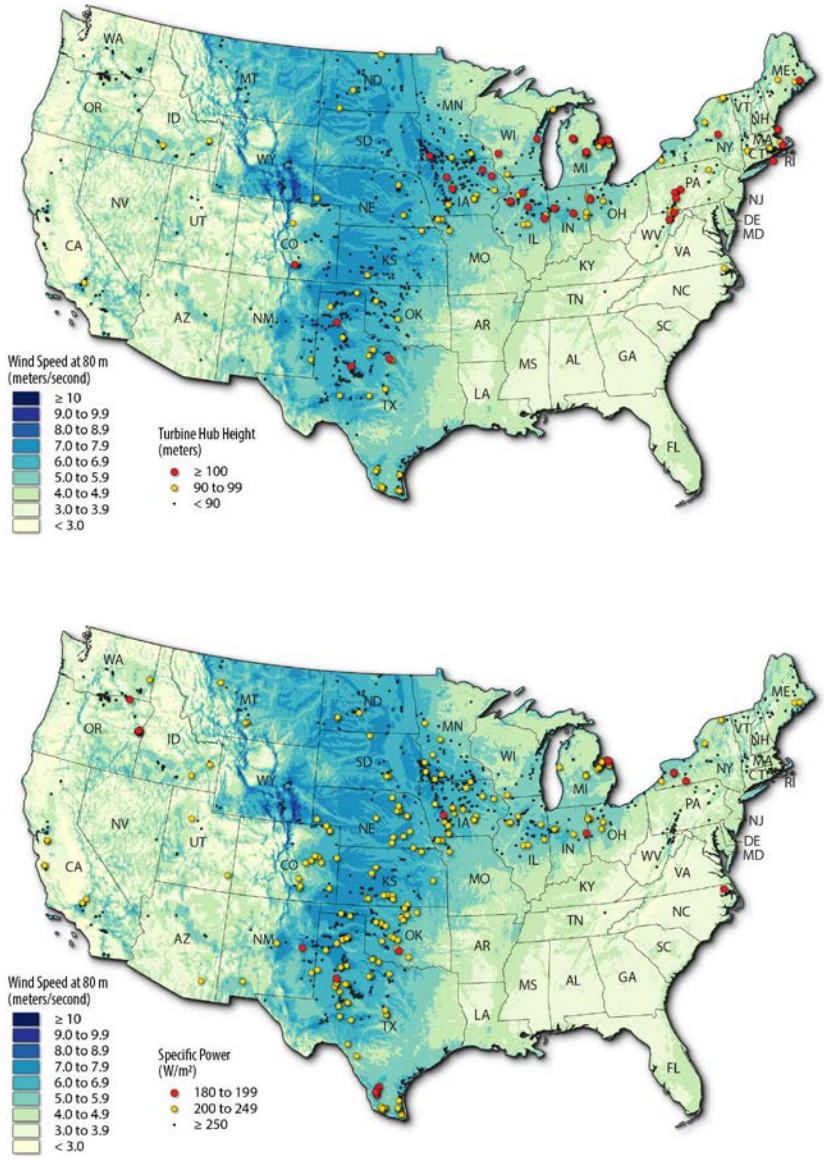
- **Specific power:** turbine nameplate capacity divided by swept rotor area; lower specific power leads to higher capacity factors, as shown later
- **IEC Class 1/2/3** represent turbines designed originally for high, medium, and low wind speed, respectively

Wind Turbines Continued to be Deployed in Somewhat Lower Wind-Speed Sites in 2018

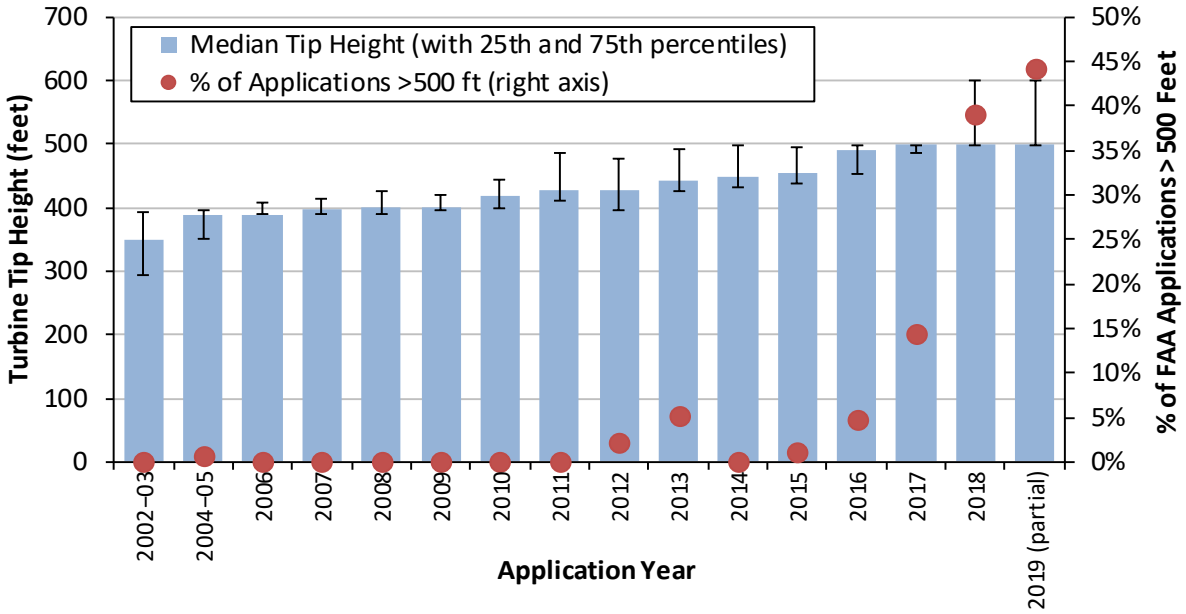


Low Specific Power Turbines Are Deployed in Low & High Wind Speeds; Taller Towers More Common in Great Lakes & Northeast



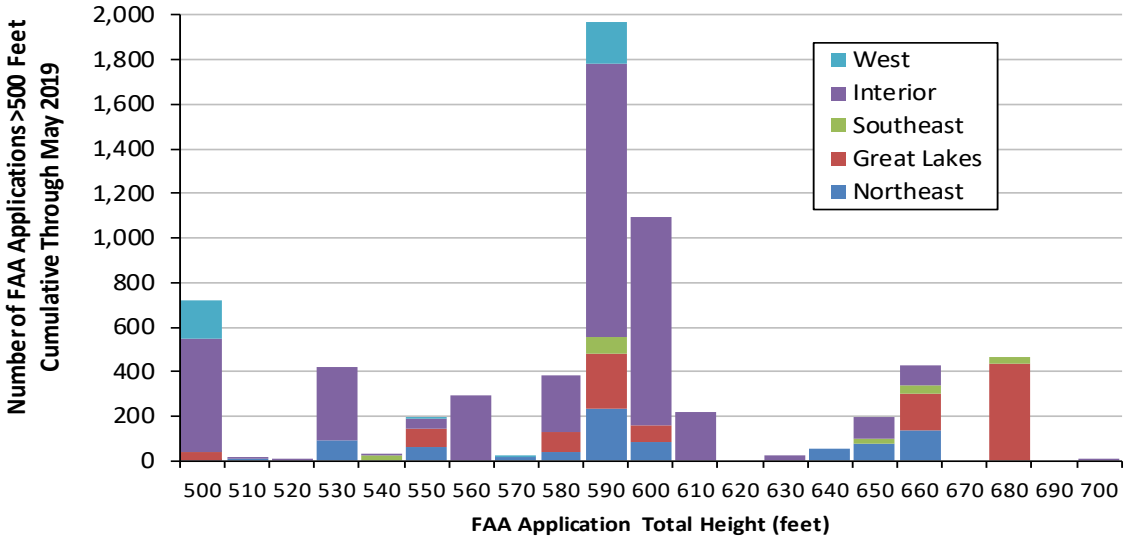


Wind Power Projects Planned for the Near Future Are Poised to Continue the Trend of Ever-Taller Turbines

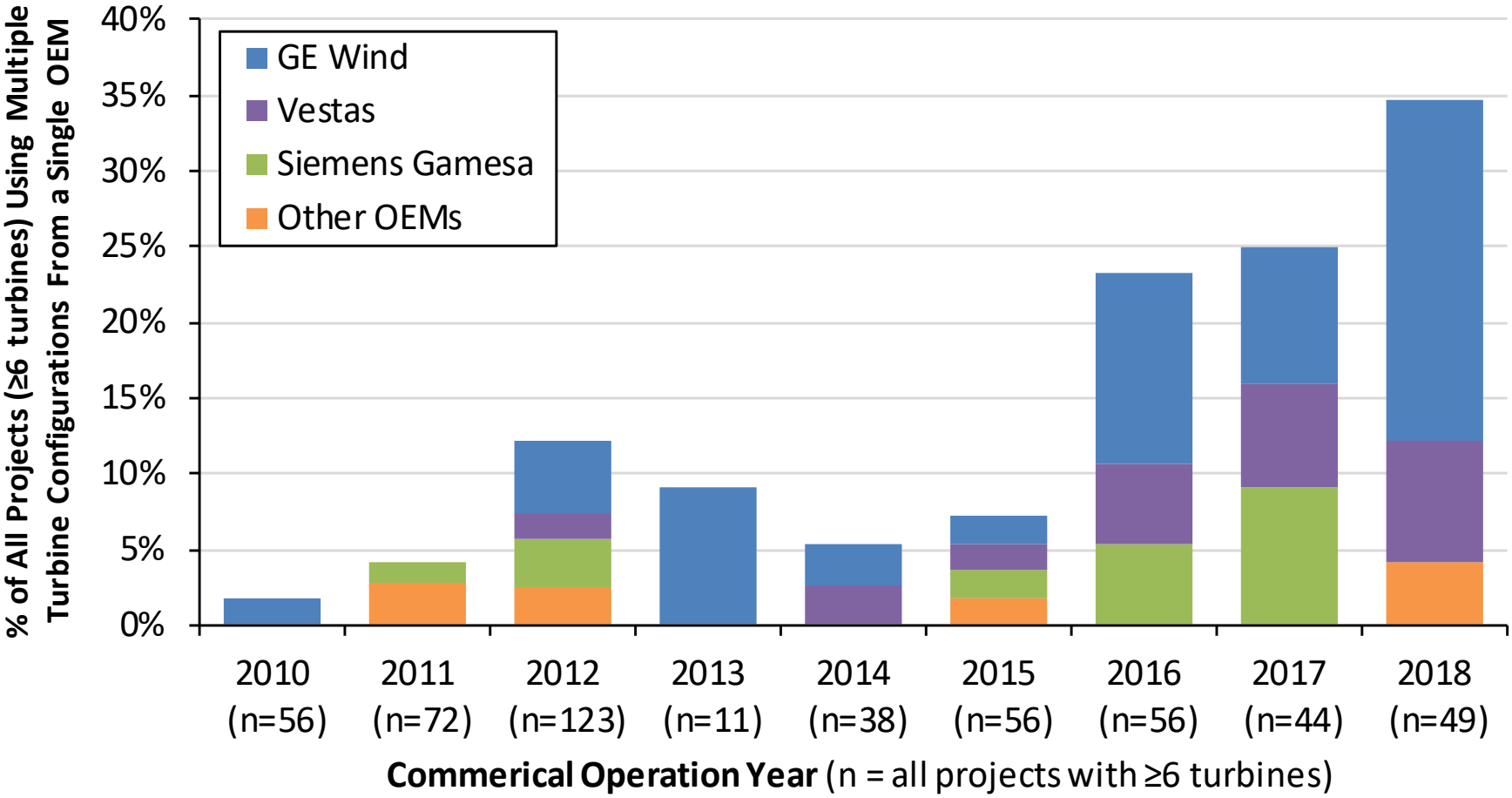


Total turbine heights proposed in FAA applications, over time

Histogram of cumulative FAA applications through May 2019 greater than 500 feet

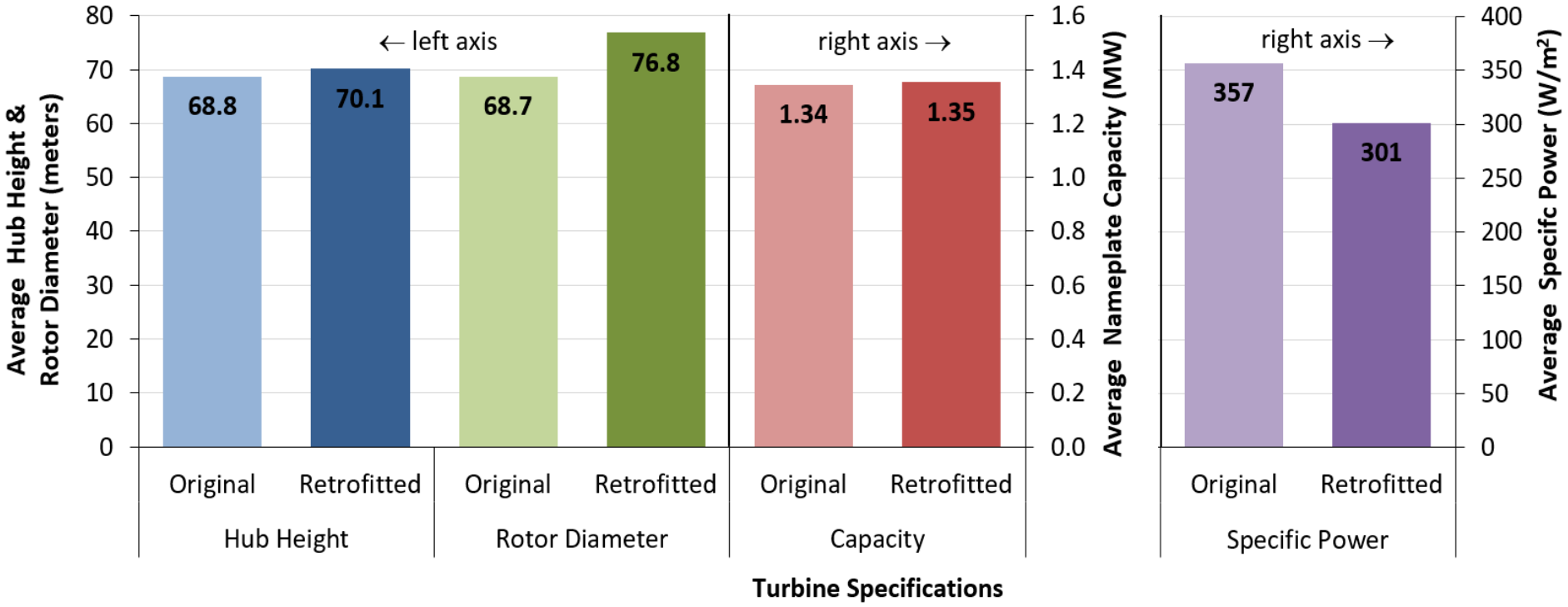


A Large Number of Projects Continued to Employ Multiple Turbine Configurations from a Single Turbine Supplier



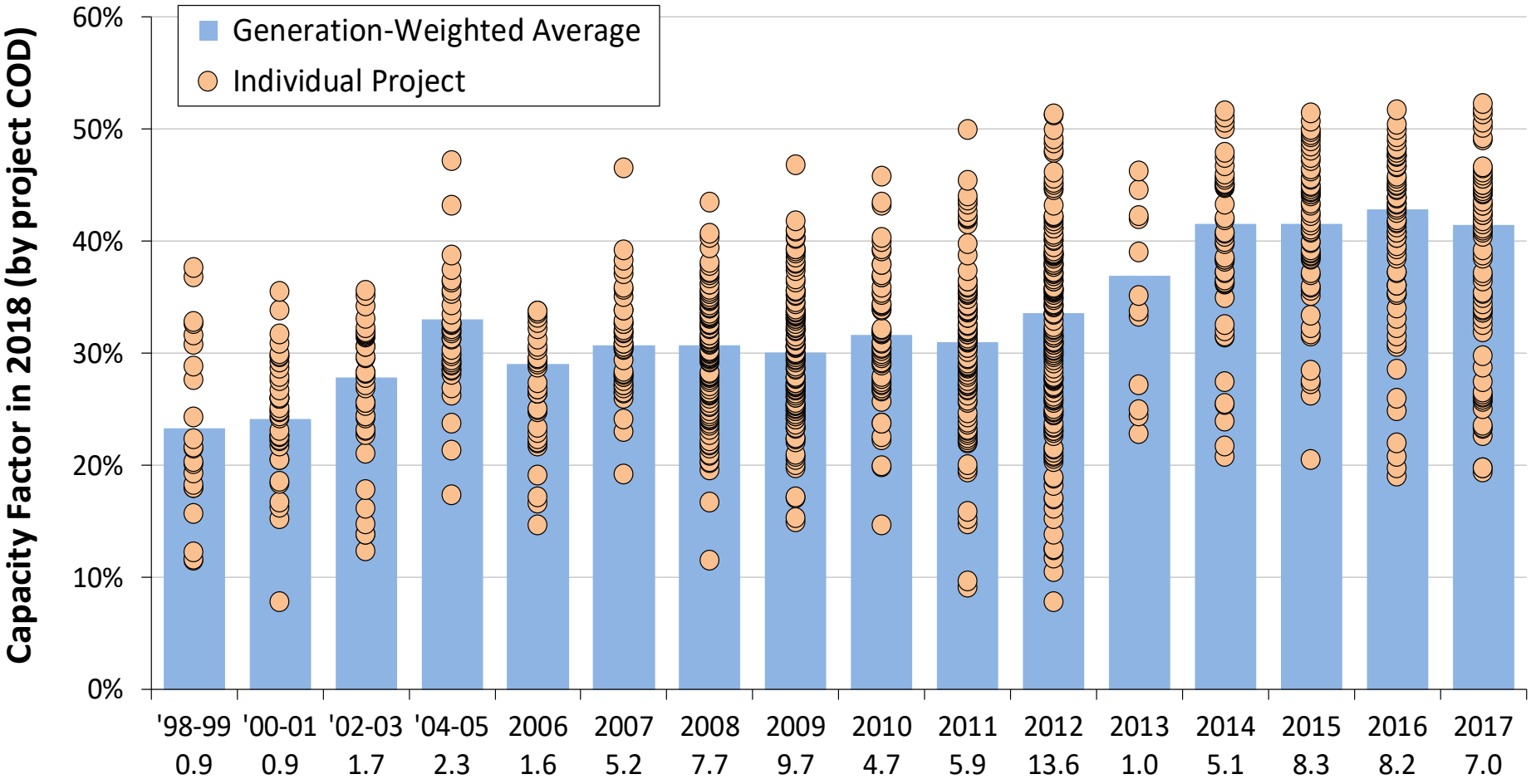
Note: Turbine configuration = unique combination of hub height, rotor diameter, and/or capacities

Through 2018, 23 Projects Have Been Partially Repowered, most of which Feature Larger Rotors and Lower Specific Power

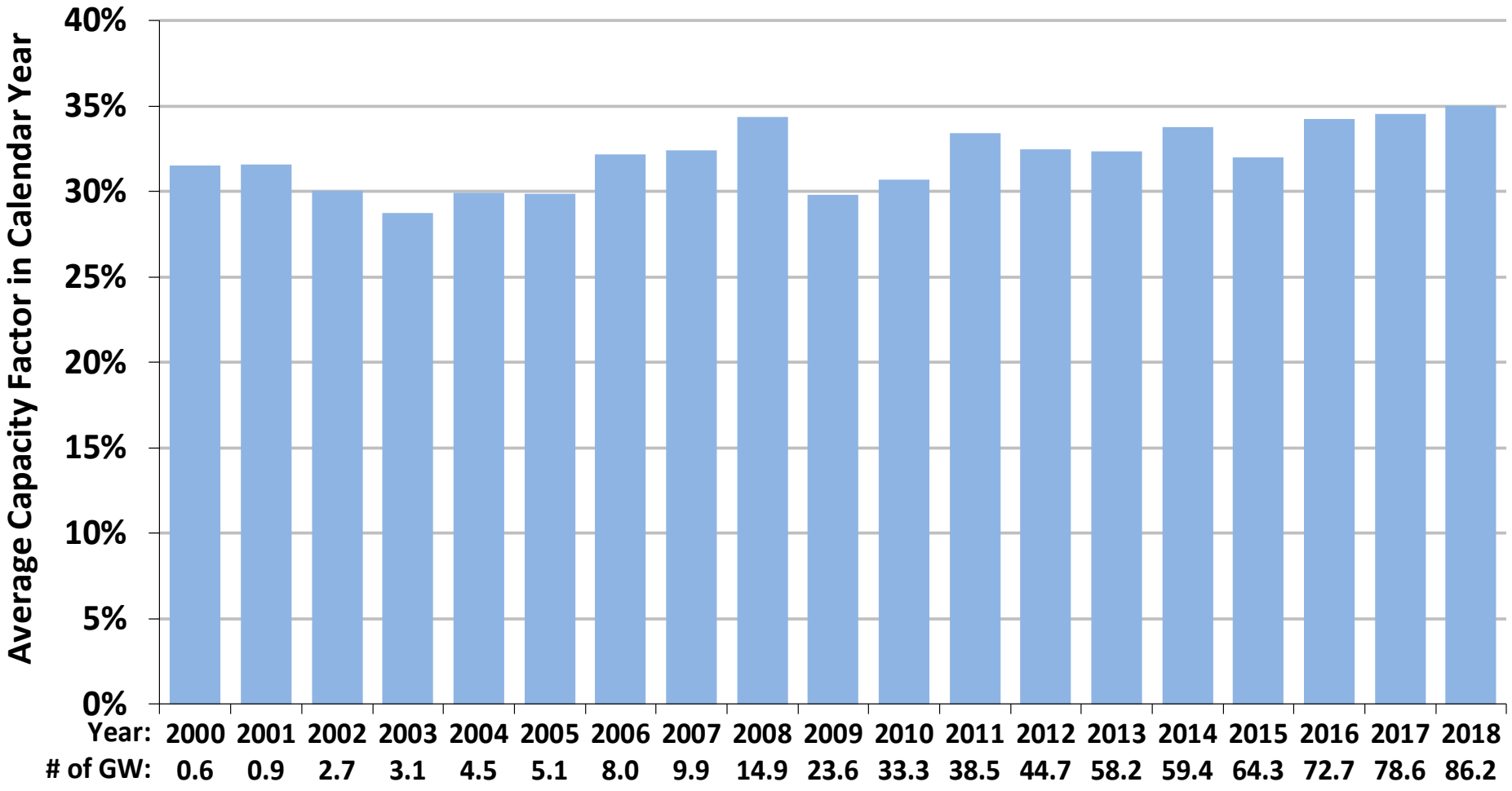


Performance Trends

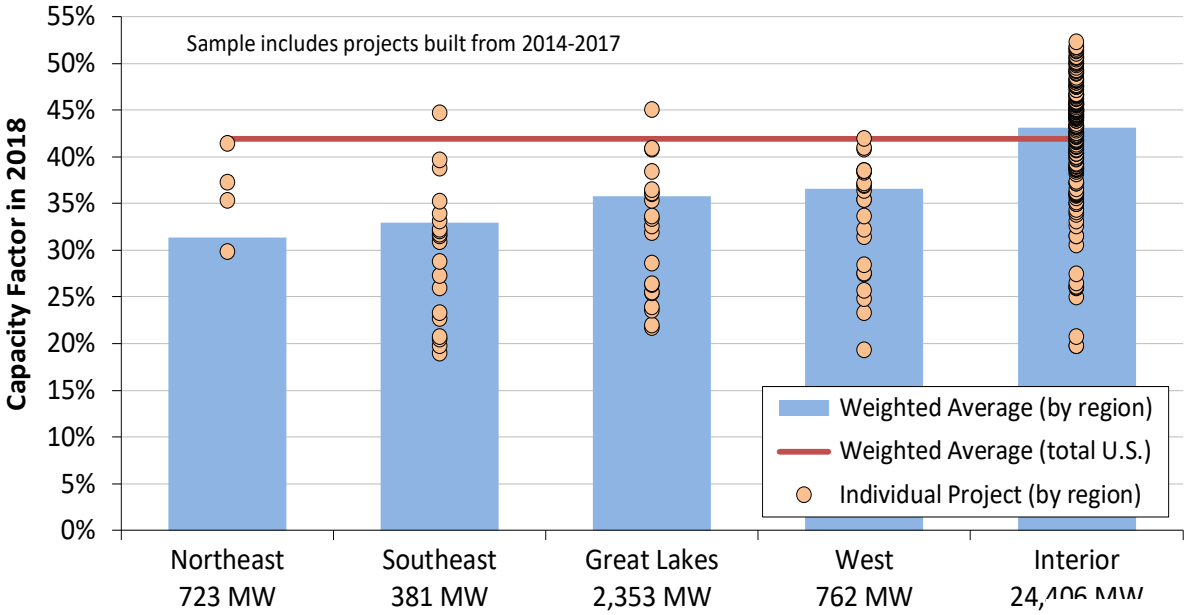
Capacity Factors Have Increased Significantly Over Time, by Online Date (i.e., Commercial Online Date, COD)



Fleet-Wide Average Capacity Factors Have Gradually Increased, Reaching 35% for the First Time in 2018

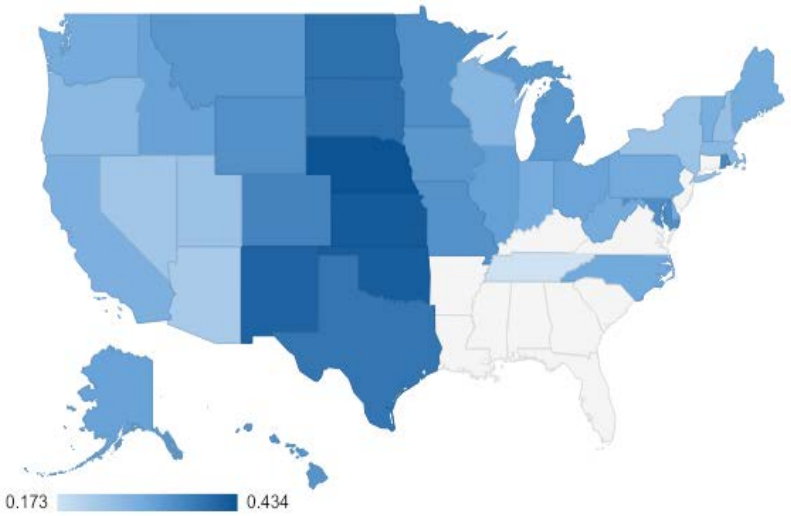


The Interior Region Features the Highest Capacity Factors, in Part Reflecting the Strength of the Wind Resource

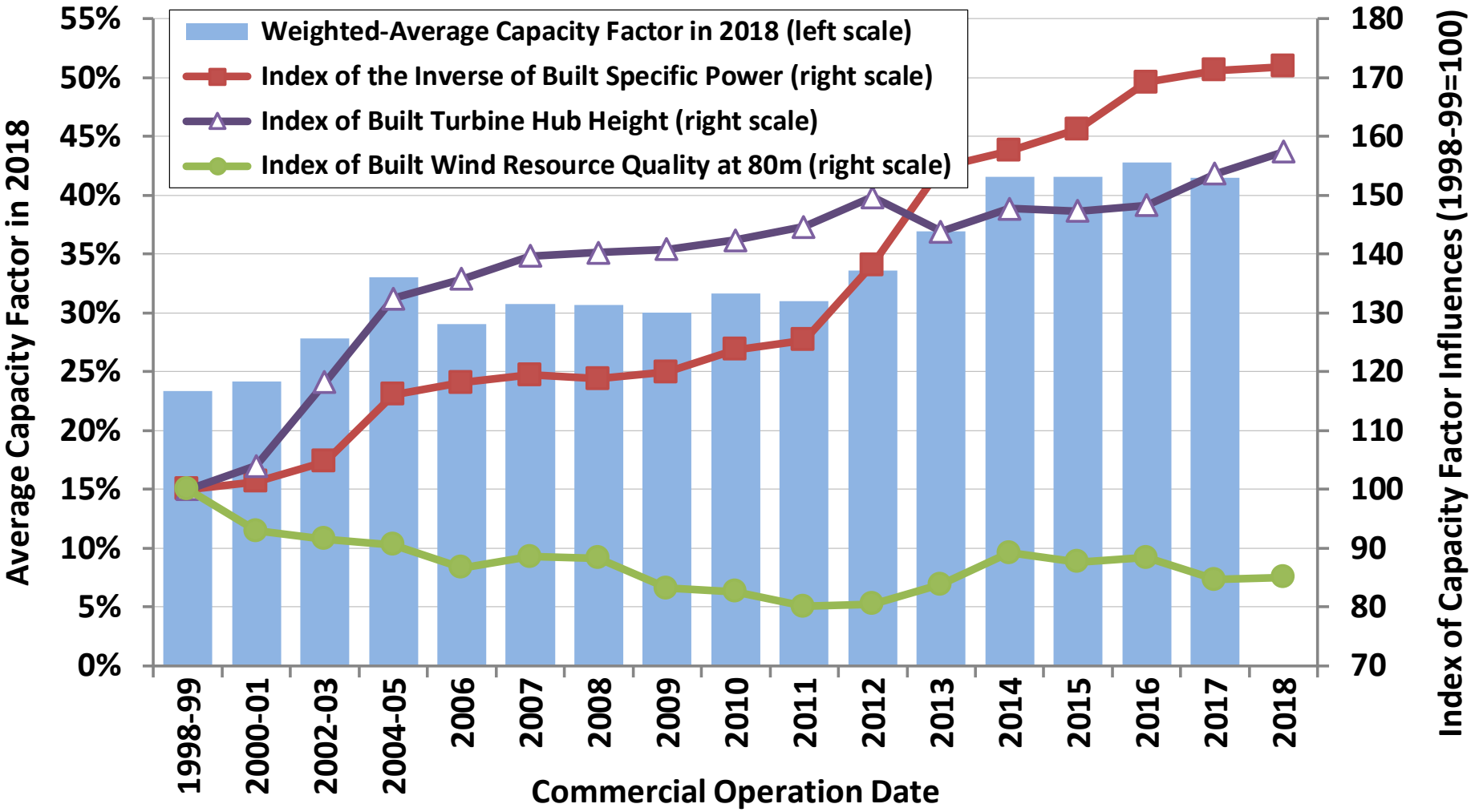


Only projects built from 2014-2017

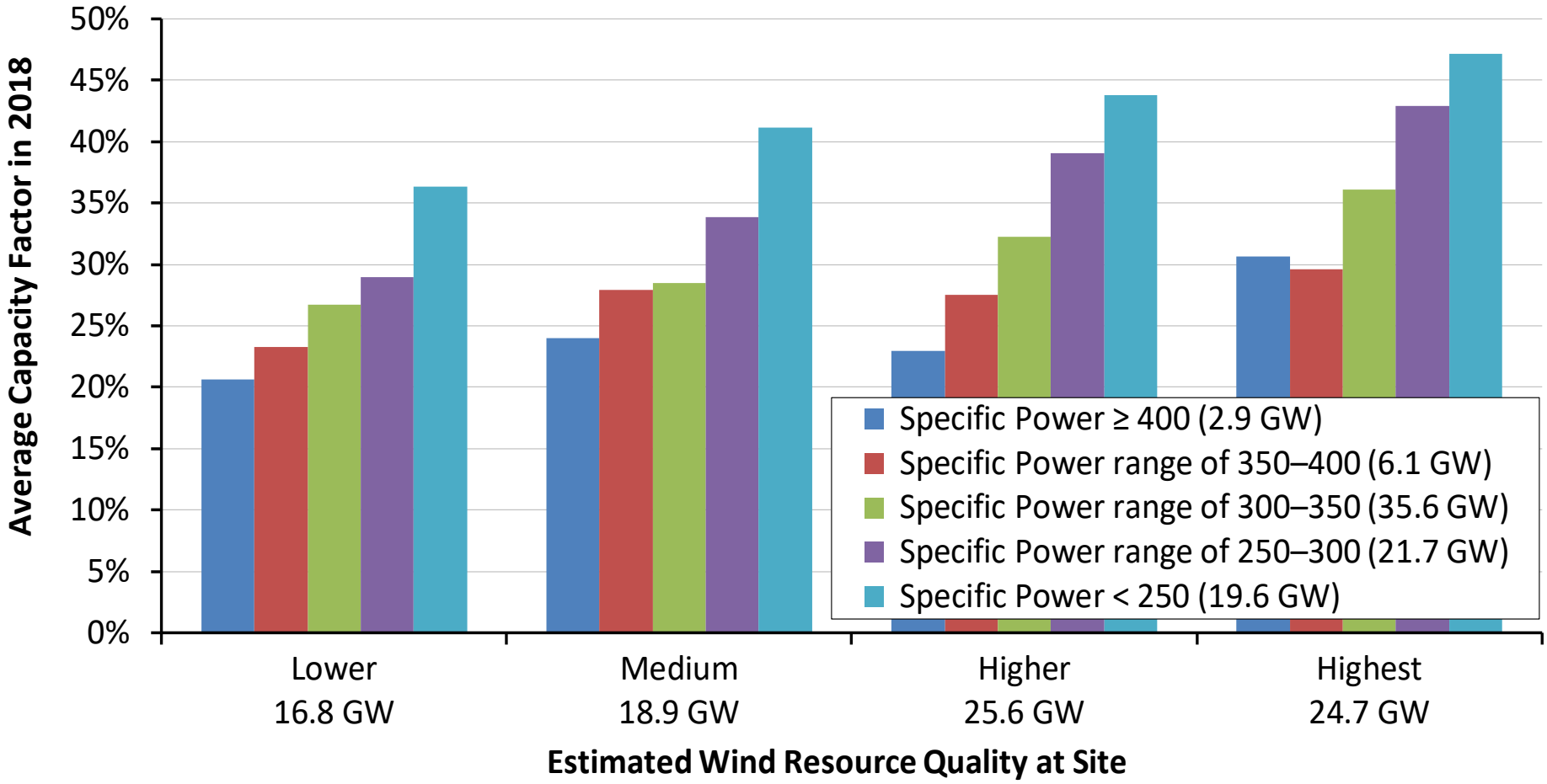
Projects built from 1998-2017



Time Trends Explained by Competing Influences of Lower Specific Power, Higher Hub Heights, Varying Quality Wind Resource Sites

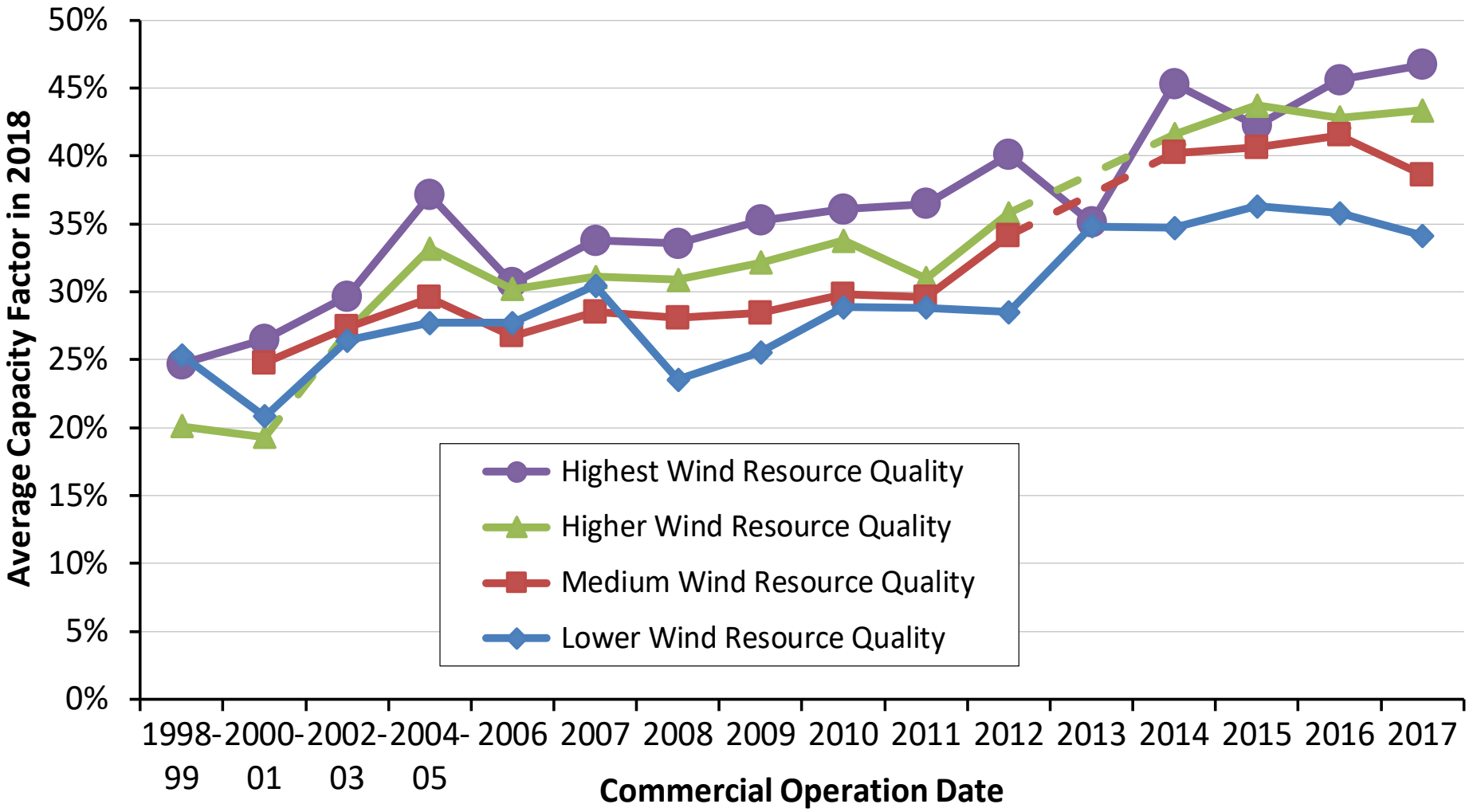


Controlling for Wind Resource Quality and Specific Power Demonstrates Impact of Turbine Evolution

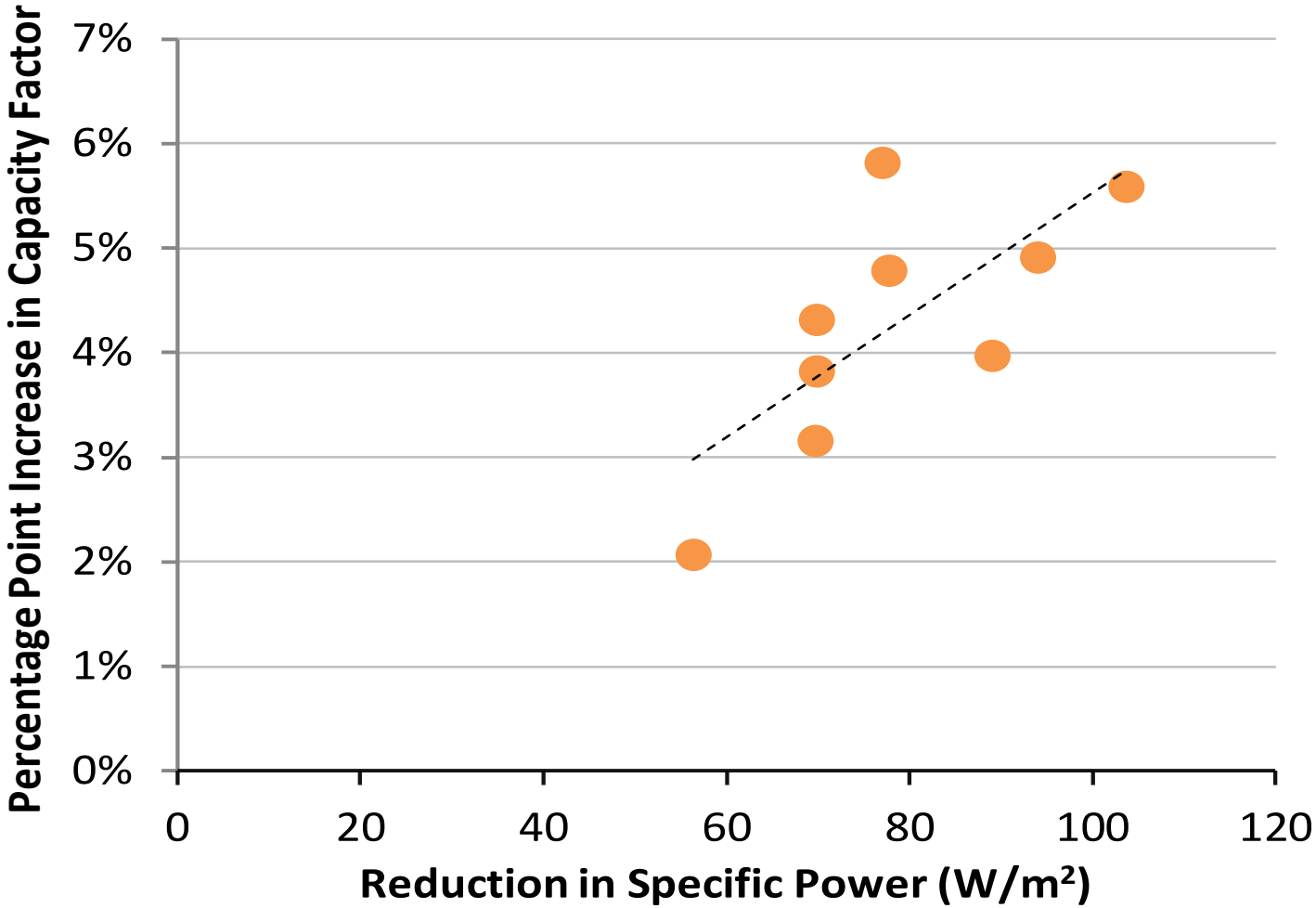


- Turbine design changes are driving capacity factors higher for projects located in given wind resource regimes

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

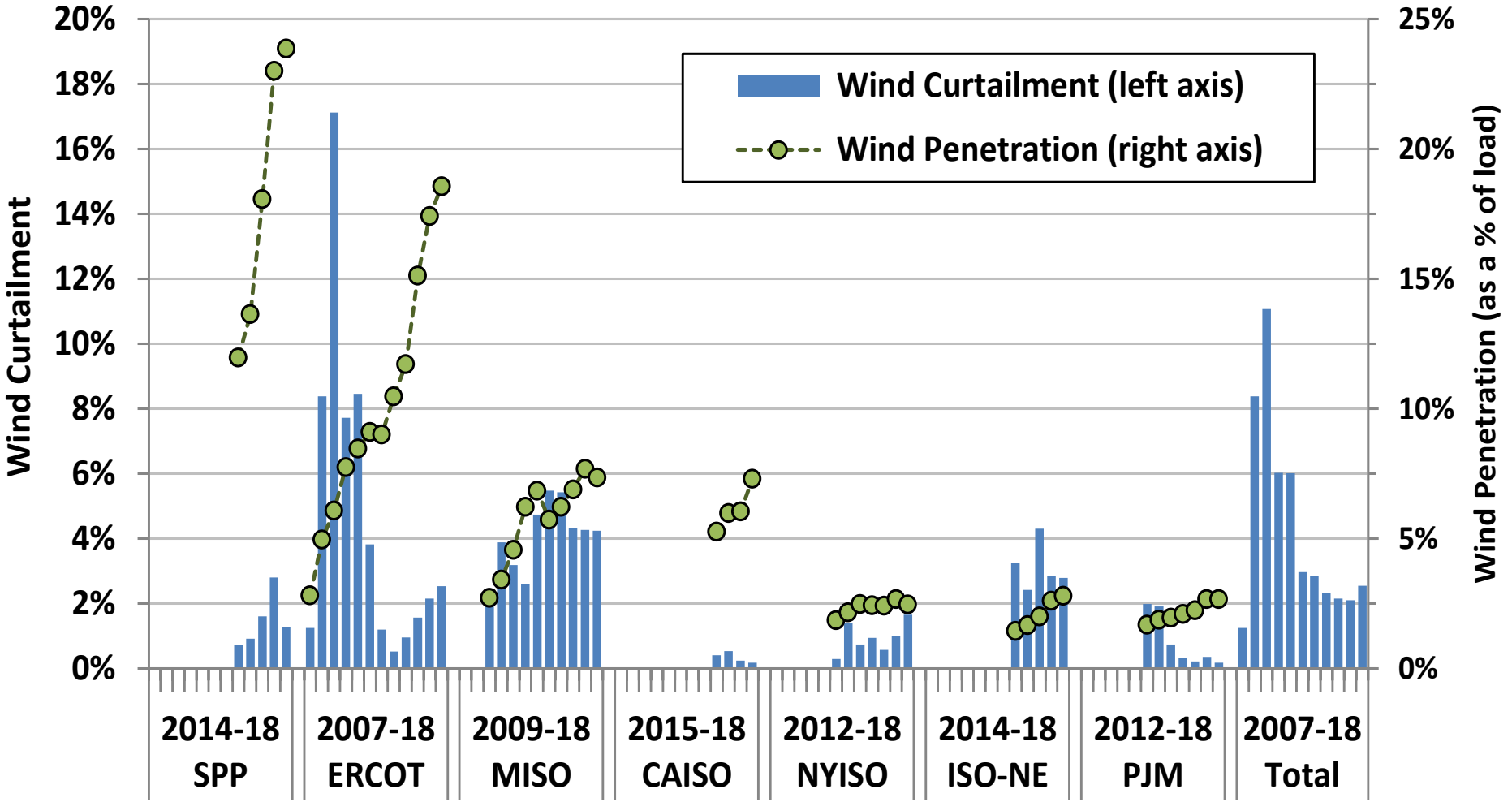


First Wave of Partial Repowering Demonstrates Higher Capacity Factors from Lower Specific Power



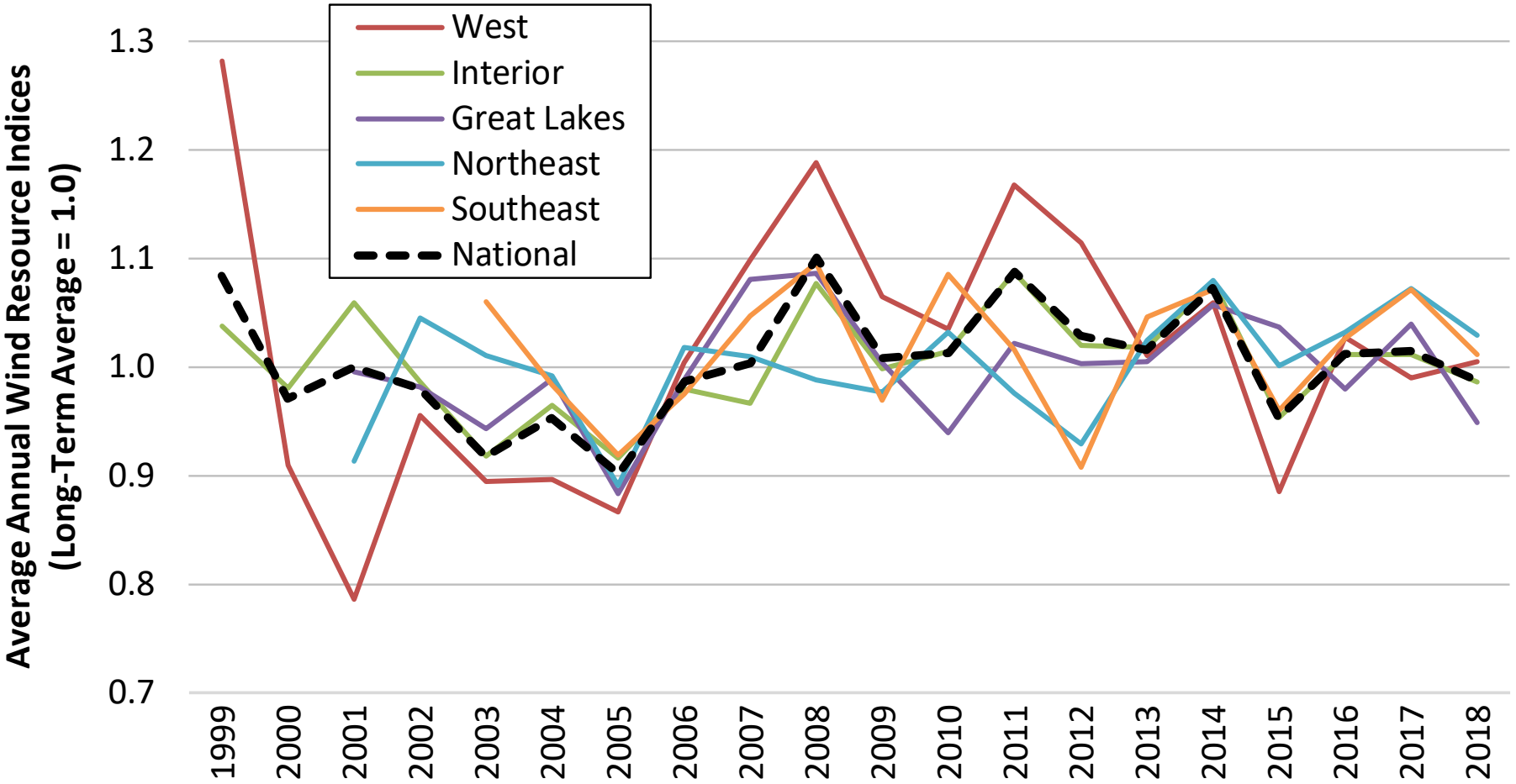
- Graphic includes 9 projects totaling 2.2 GW that partially repowered their turbines in 2017, and shows the increase in capacity factor in 2018 (relative to the 4-year average from 2013-2016) as a function of the reduction in average specific power

Wind Curtailment Varies by Region; Was Highest in MISO in 2017, but Highest-Ever in ERCOT in 2009

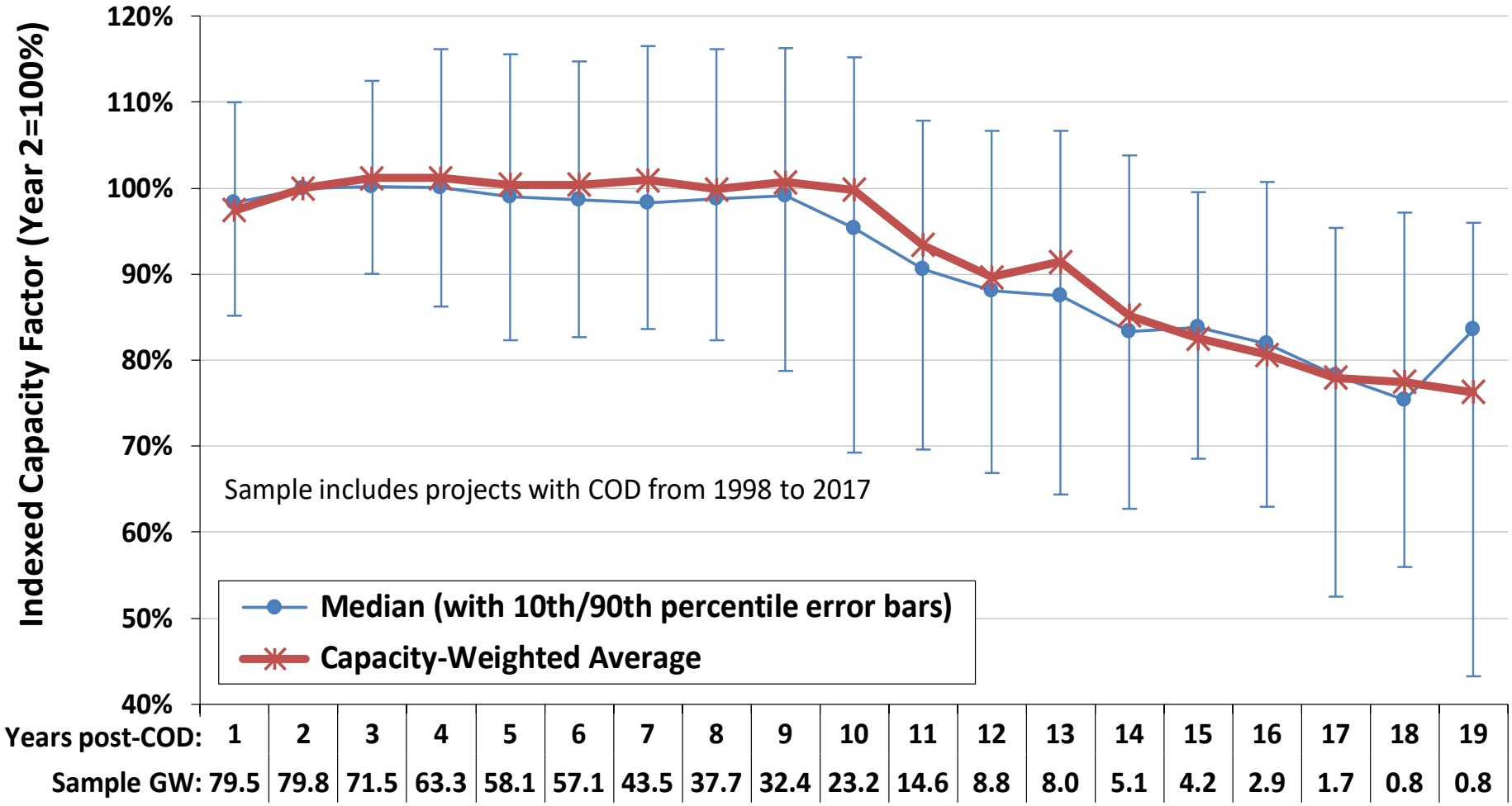


- In areas where curtailment has been particularly problematic in the past—principally in Texas—steps taken to address the issue have born fruit

Yearly Variations in Average Wind Speed Also Impact Project Performance, but 2018 Was a Reasonably Normal Wind Year

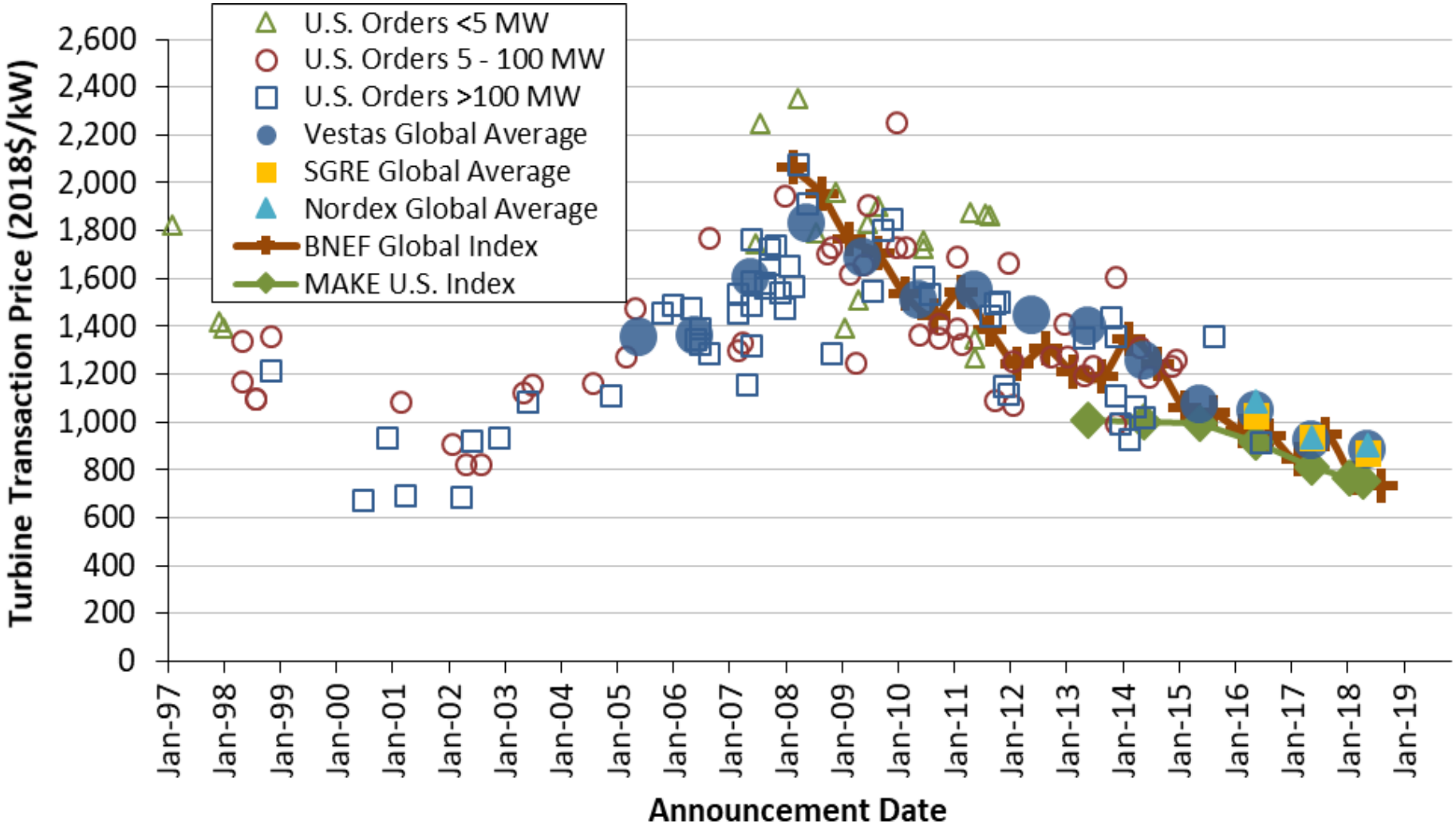


Change in Performance as Projects Age Also Impacts Overall Trends; Performance Degradation Shown After Year 10



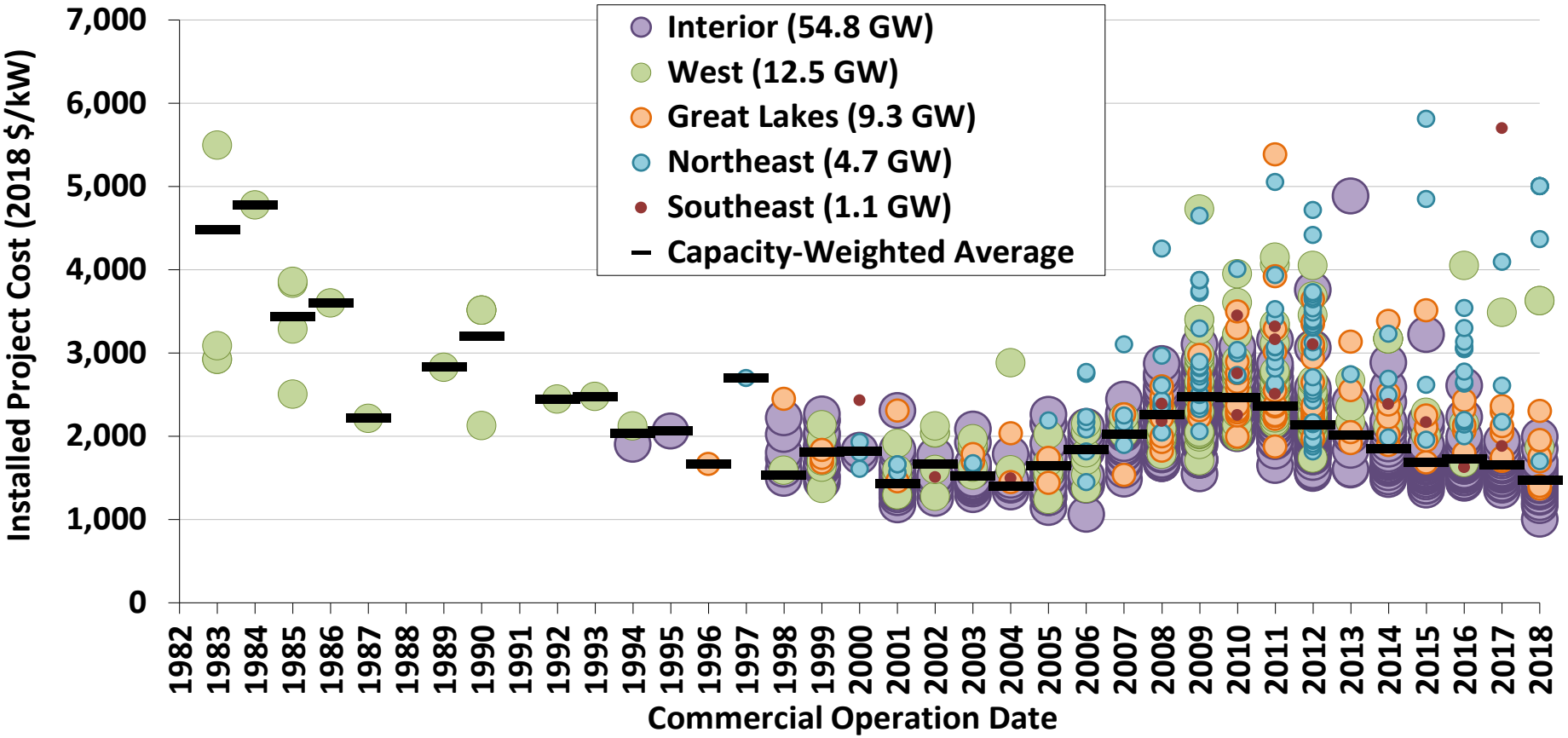
Cost Trends

Wind Turbine Prices Remained Well Below the Levels Seen a Decade Ago



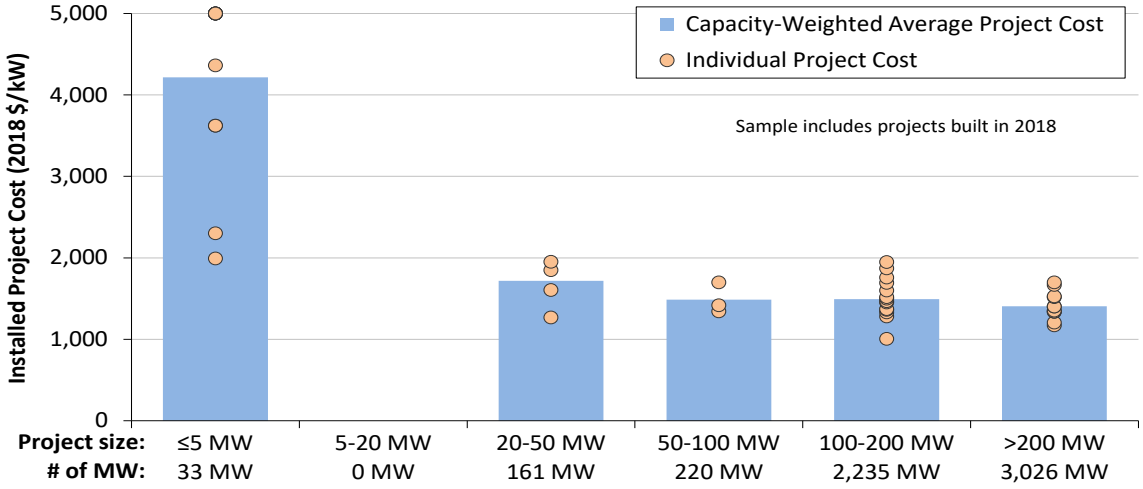
- Recent turbine orders in the range of $700-900/kW

Lower Turbine Prices Have Driven Reductions in Total Installed Project Costs

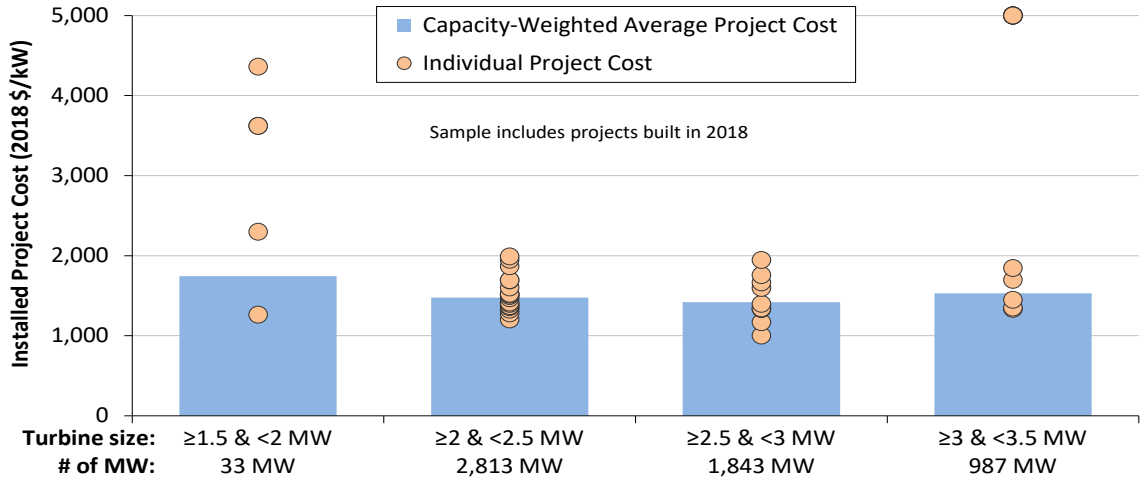


- 2018 projects had average cost of $1,470/kW, down ~$1000/kW since 2009-2010
- Limited sample of under-construction projects suggest somewhat lower costs in 2019

Economies of Scale Are Apparent, Especially when Moving from Small- to Medium-Sized Projects

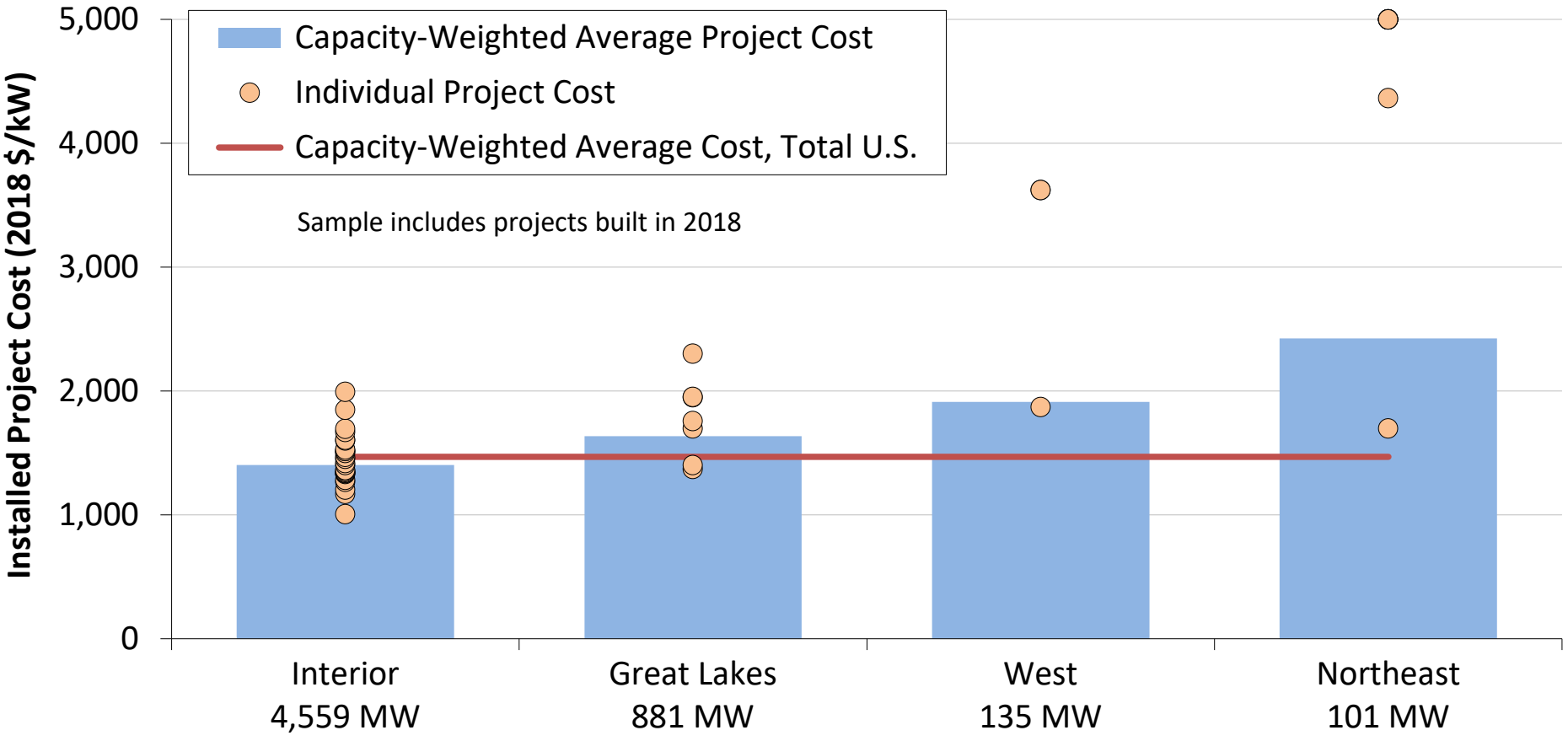


Project Size

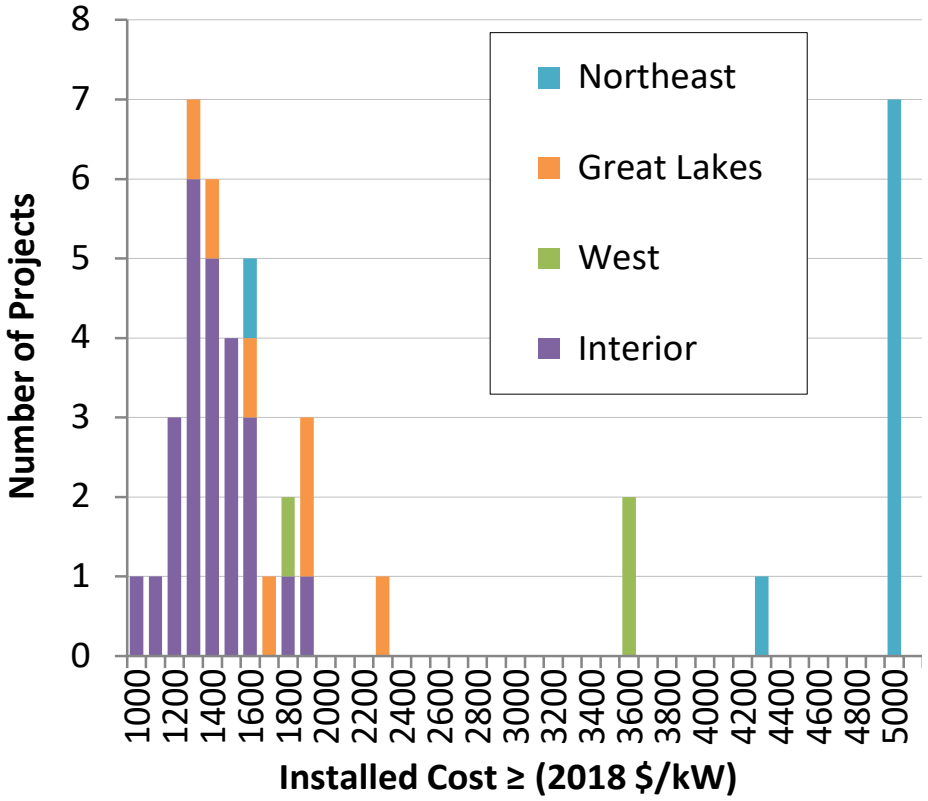


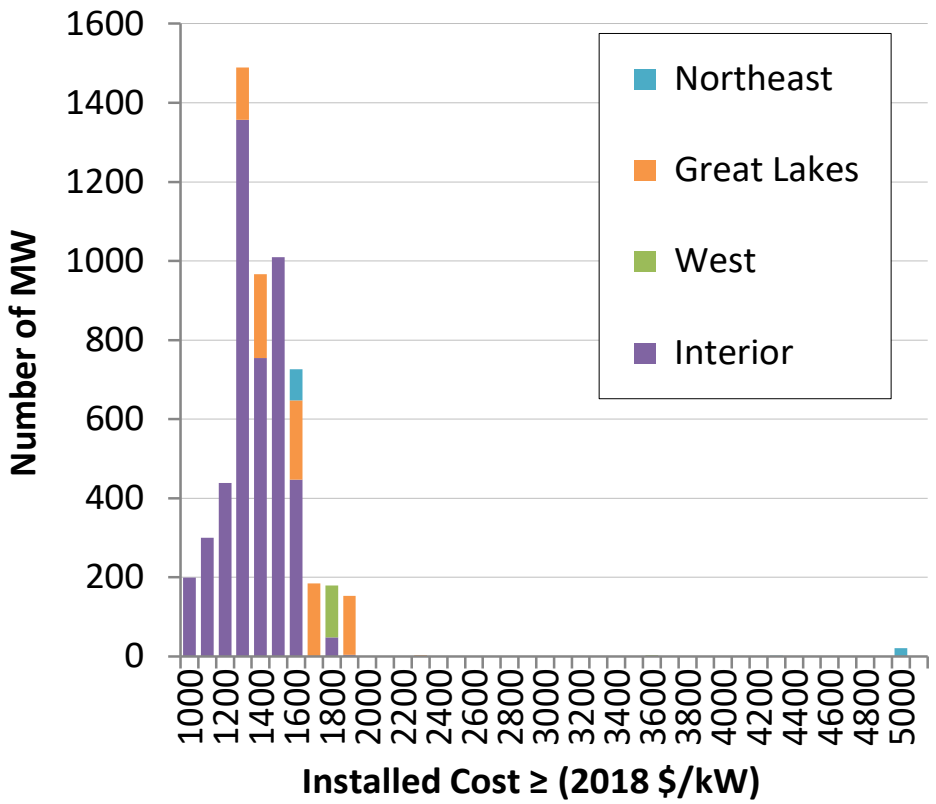
Turbine Size

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



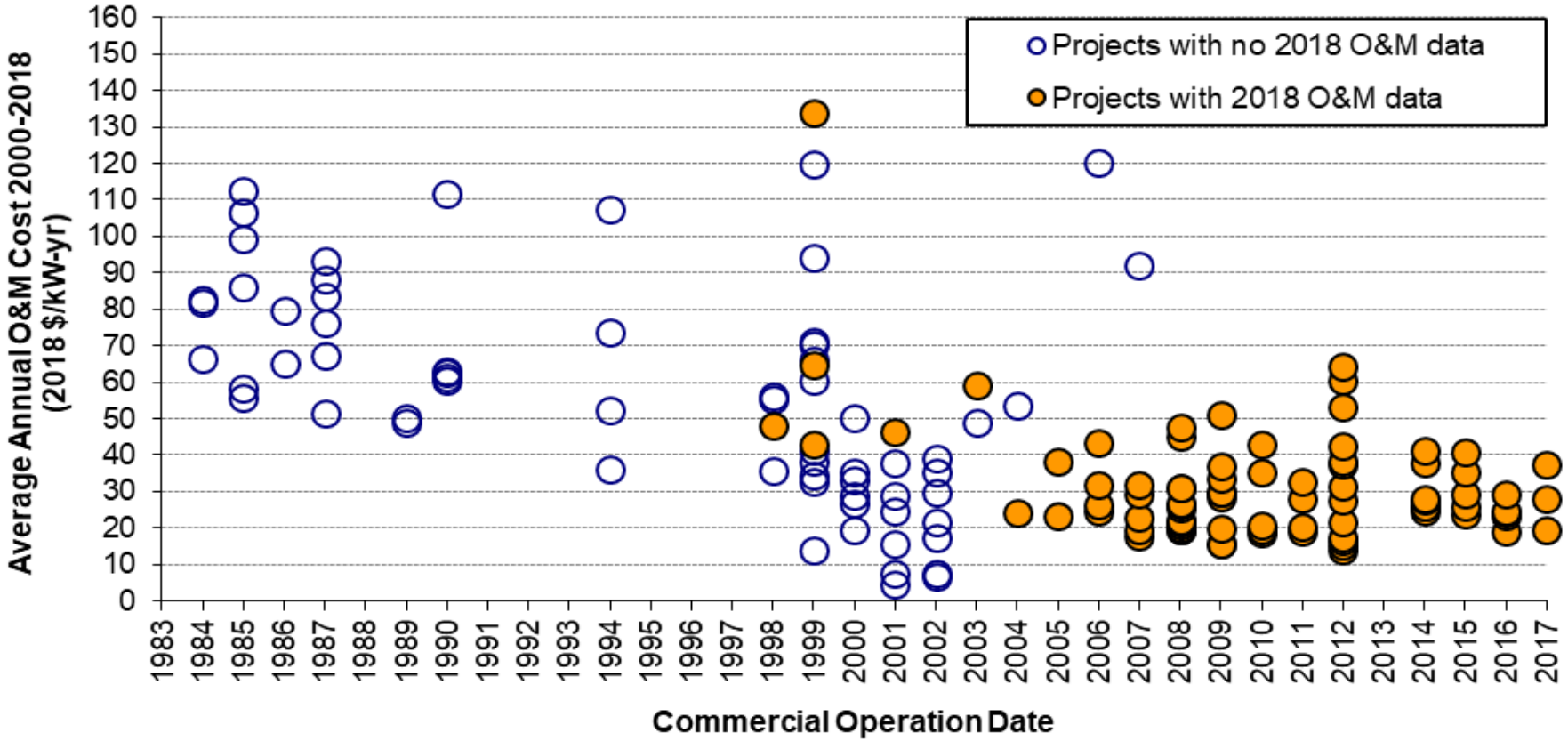
Most Projects—and All of the Low-Cost Projects—Are Located in the Interior; Other Regions Have Higher Costs





Note: Only includes 2018 projects

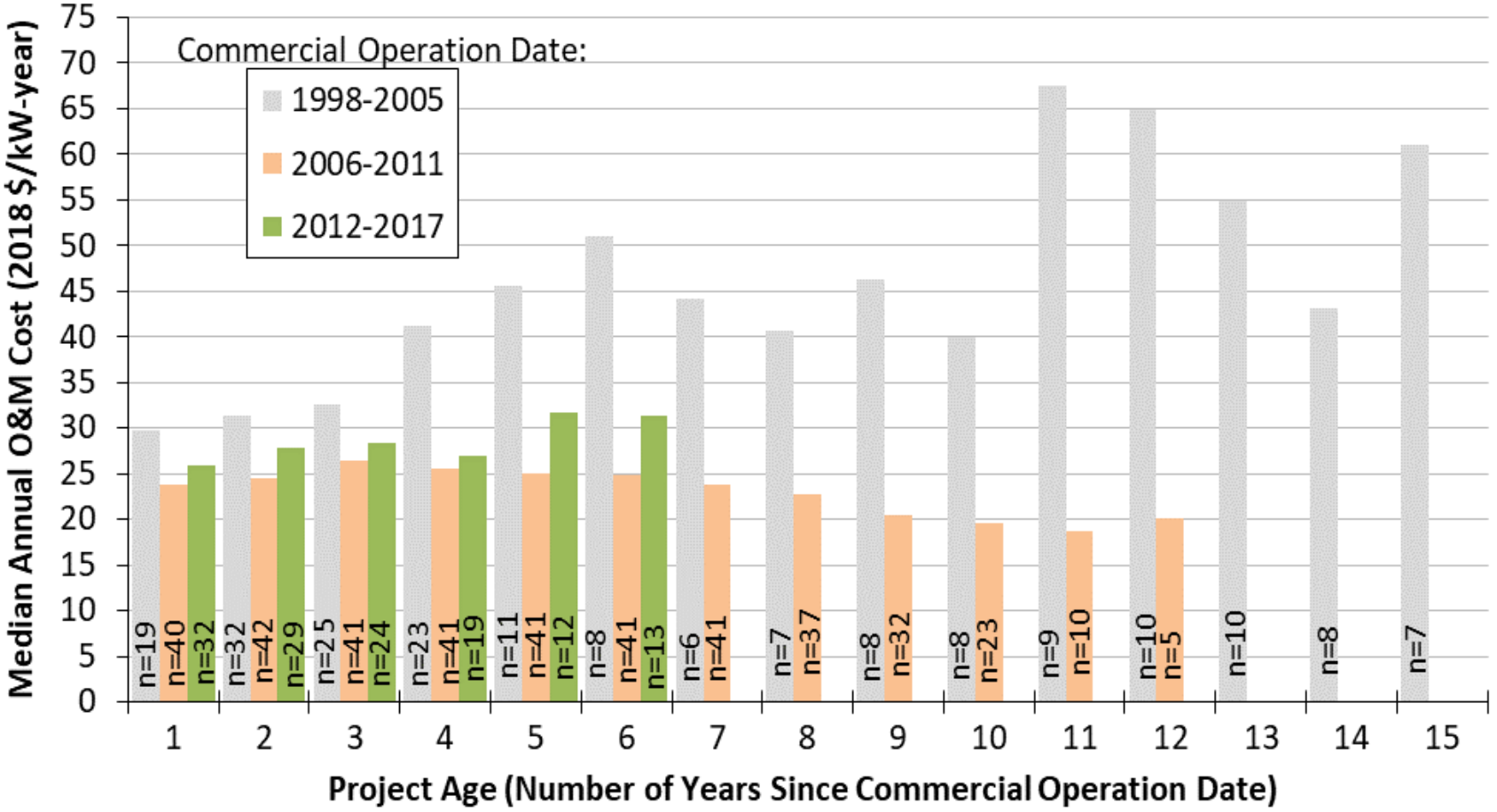
O&M Costs Vary By Project Age and Commercial Operations Date



Note: Sample is limited; few projects in sample have complete records of O&M costs from 2000-18; O&M costs reported here DO NOT include all operating costs

- **Capacity-weighted average 2000-2018 O&M costs for projects built in the 1980s equal $72/kW-year, dropping to $60/kW-year for projects built in the 1990s, to $29/kW-year for projects built in the 2000s and since 2010**

O&M Costs Are Lower for More-Recent Projects, and Increase with Age for the Older Projects



Note: Sample size is limited

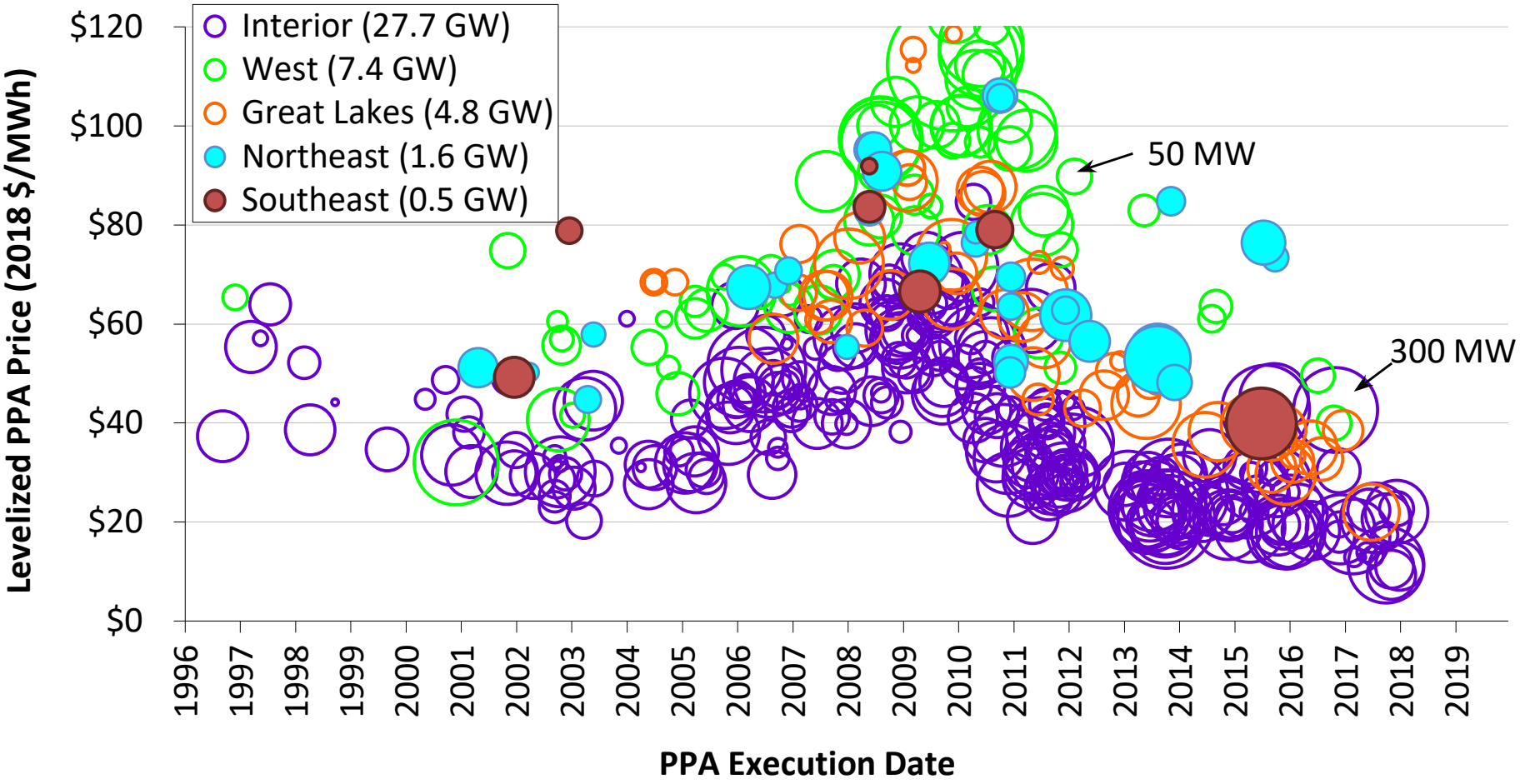
- O&M reported in figure does not include all operating costs: recent work by Berkeley Lab suggests all-in operating costs for the most recent wind projects in the United States of ~$40/kW-yr

Wind Power Price Trends

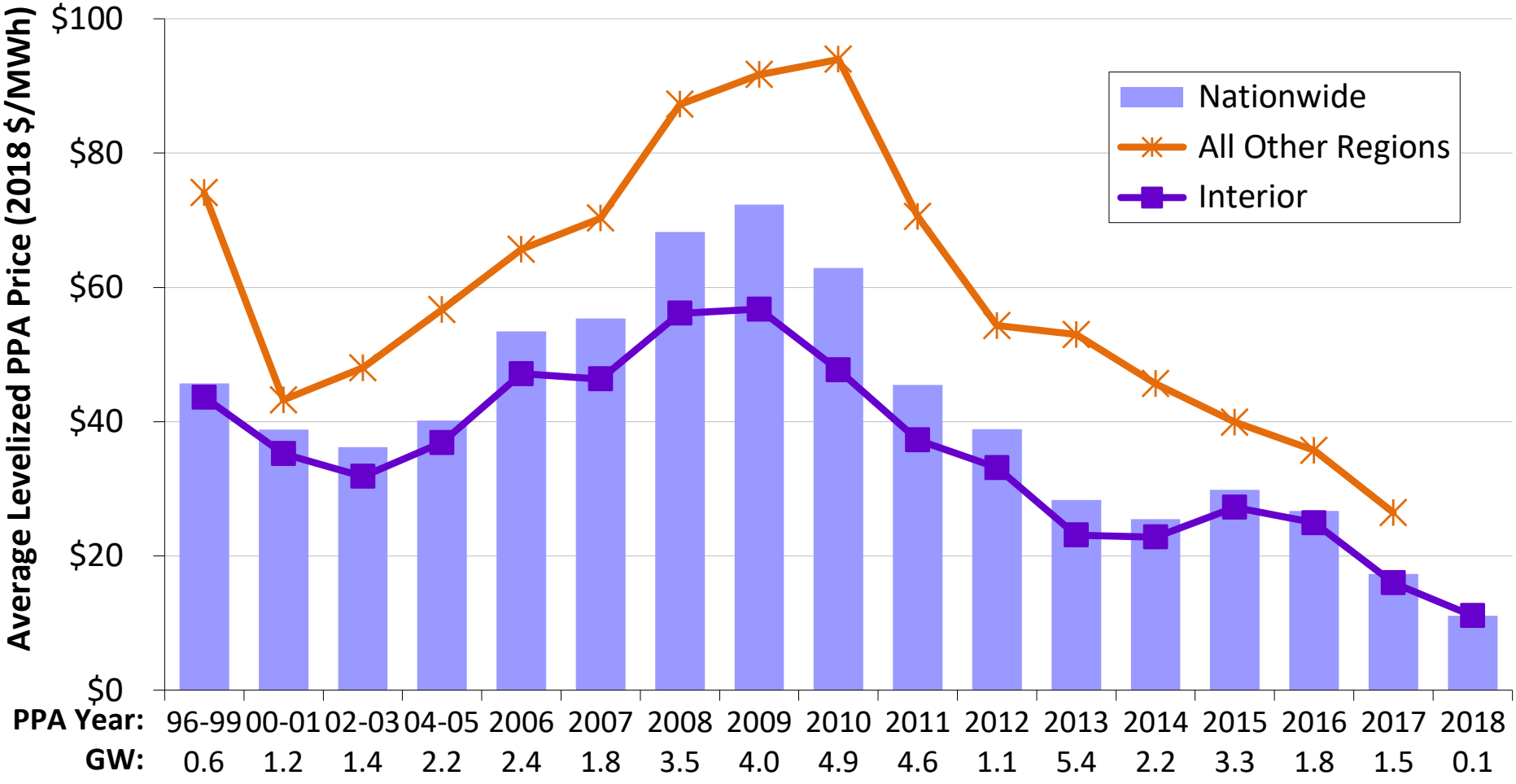
Sample of Wind Power Sales Prices

- **Berkeley Lab collects data on historical wind power sales prices, and long-term power purchase agreement (PPA) prices**
- **PPA sample includes 448 contracts totaling 42,018 MW from projects built from 1998 to the present, or planned for installation in 2019 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

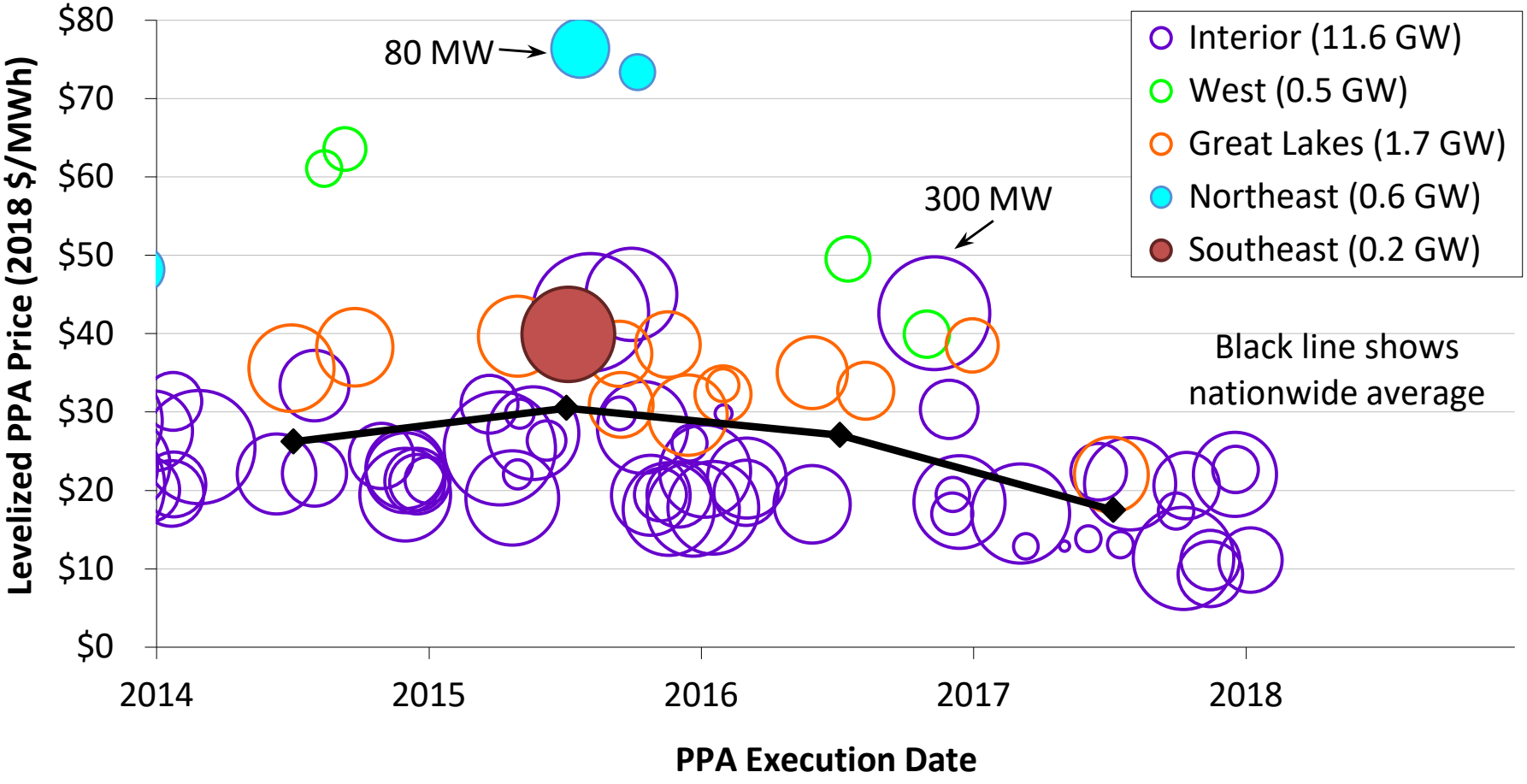
Wind PPA Prices Are at Historical Lows



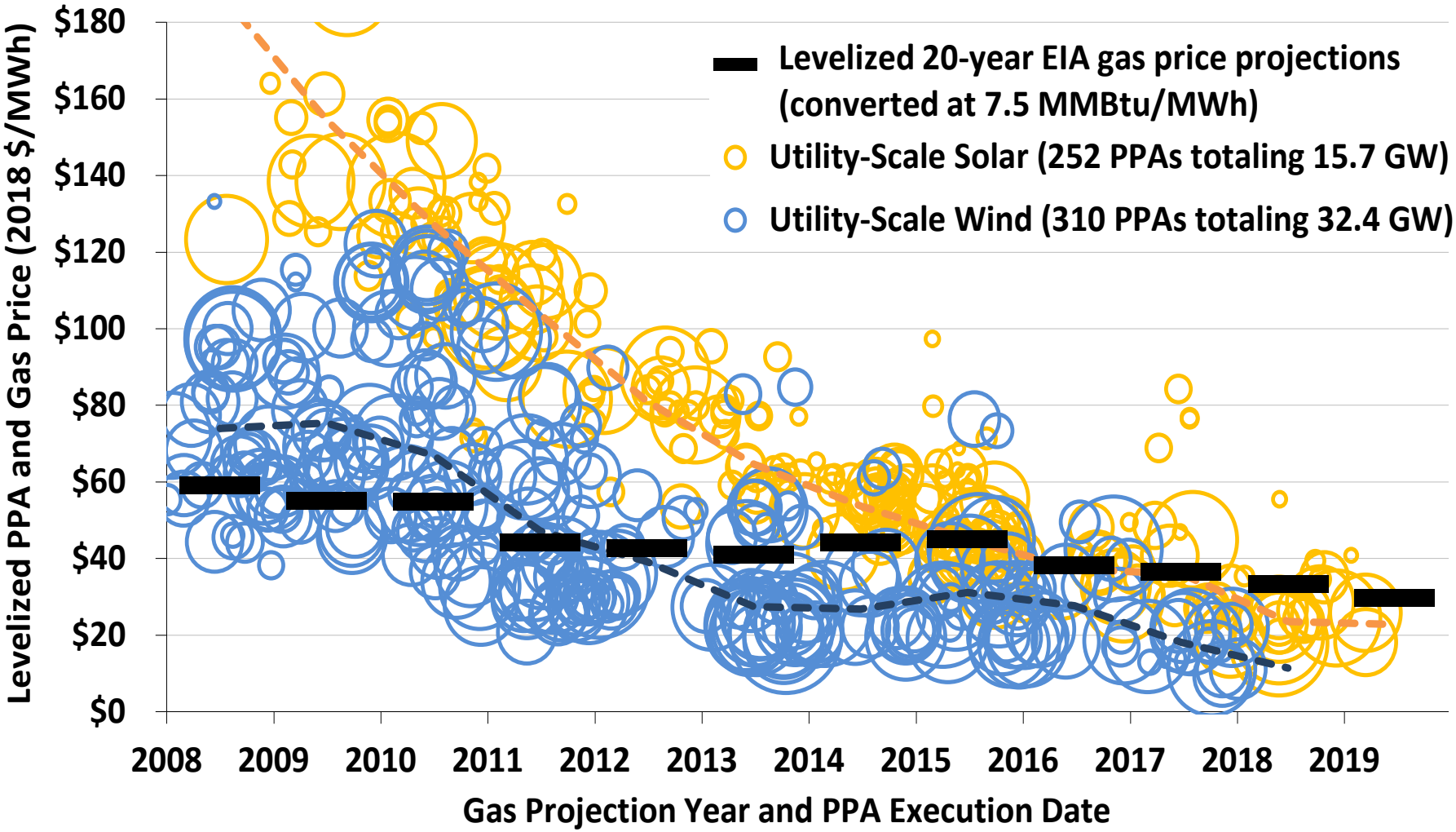
A Smoother Look at the Time Trend Shows a Steep Decline in Pricing Since 2009; Prices Below $20/MWh in Interior Region



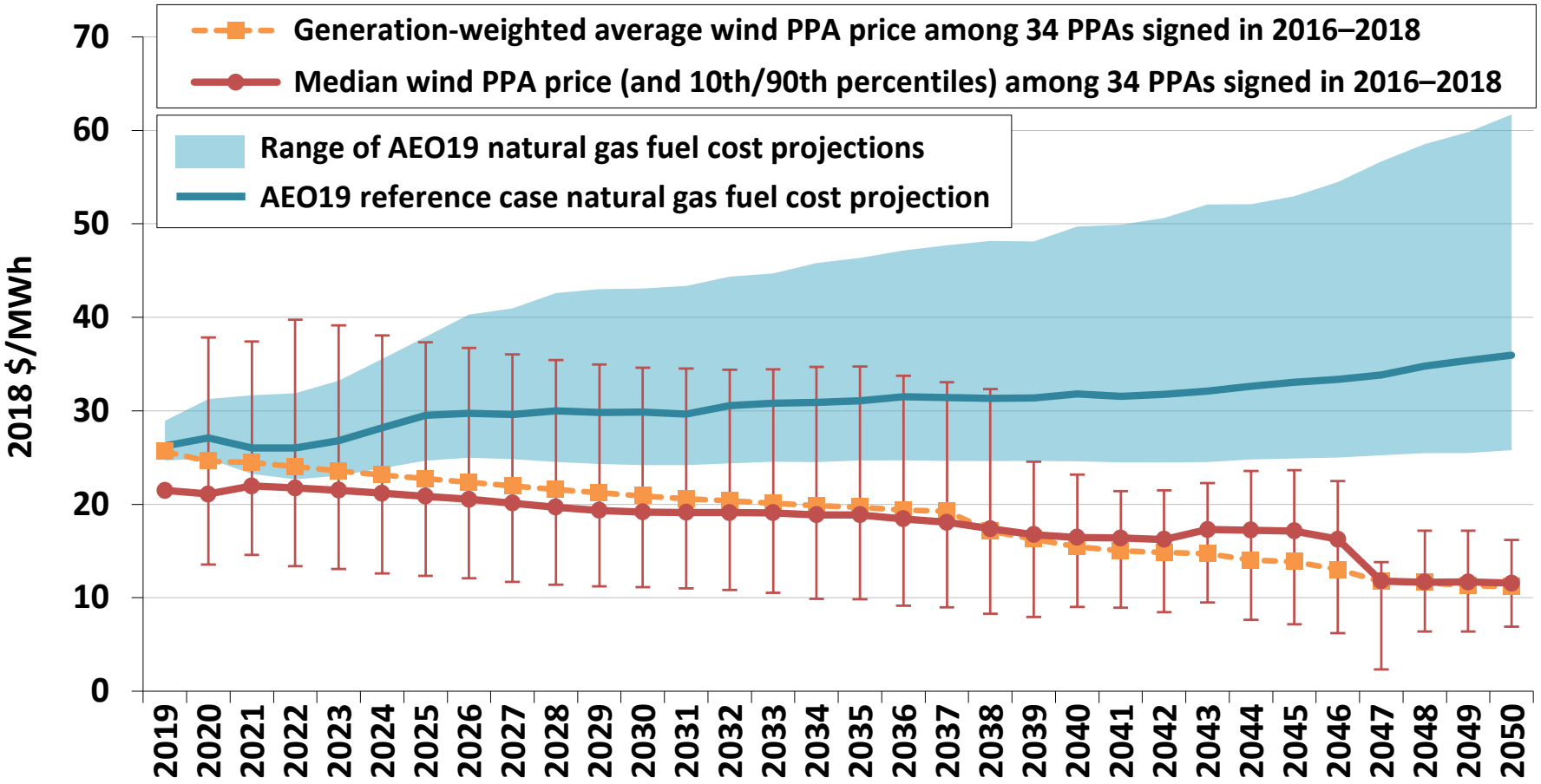
Recent Wind PPAs Are Priced in the Mid-Teens in Some Cases



Despite Recent Low PPA Prices, Wind Faces Competition from Solar and Natural Gas

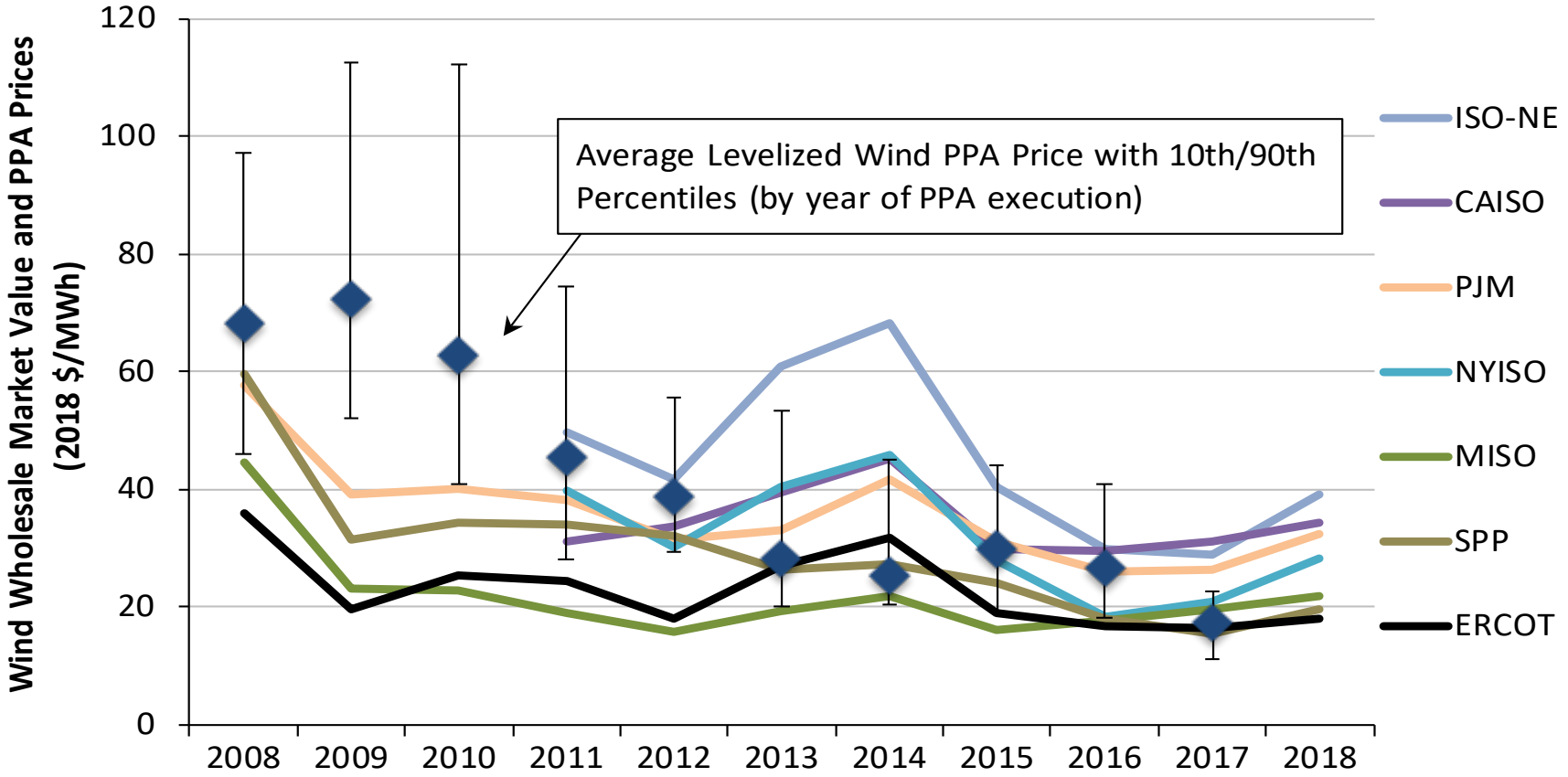


Recent Wind Prices Are Competitive with the Expected Future Cost of Burning Fuel in Natural Gas Plants



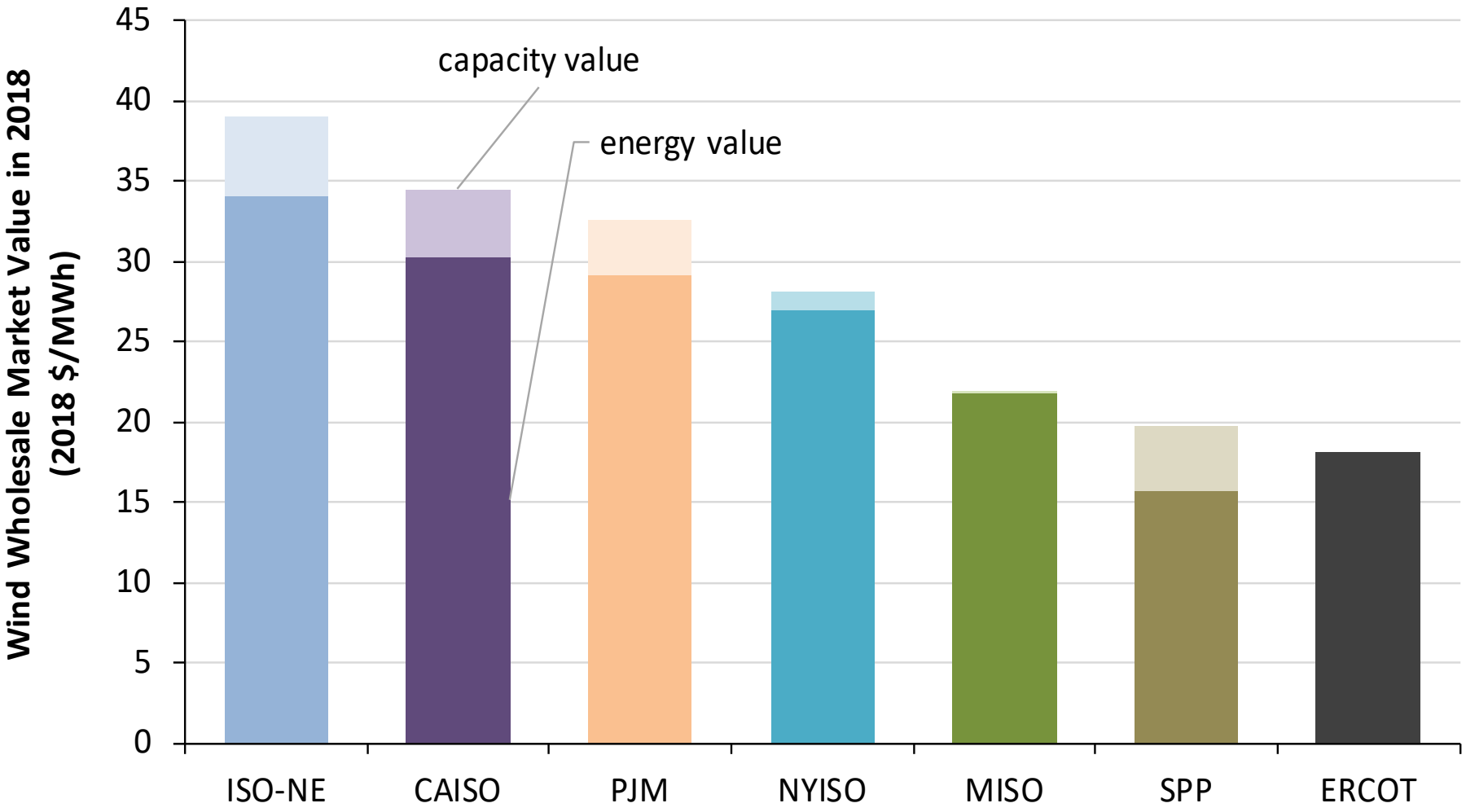
- Price comparisons shown are far from perfect—see full report for caveats

The Economic Competitiveness of Wind Power Is Affected by Its Grid-System Value (Energy & Capacity) in Wholesale Markets

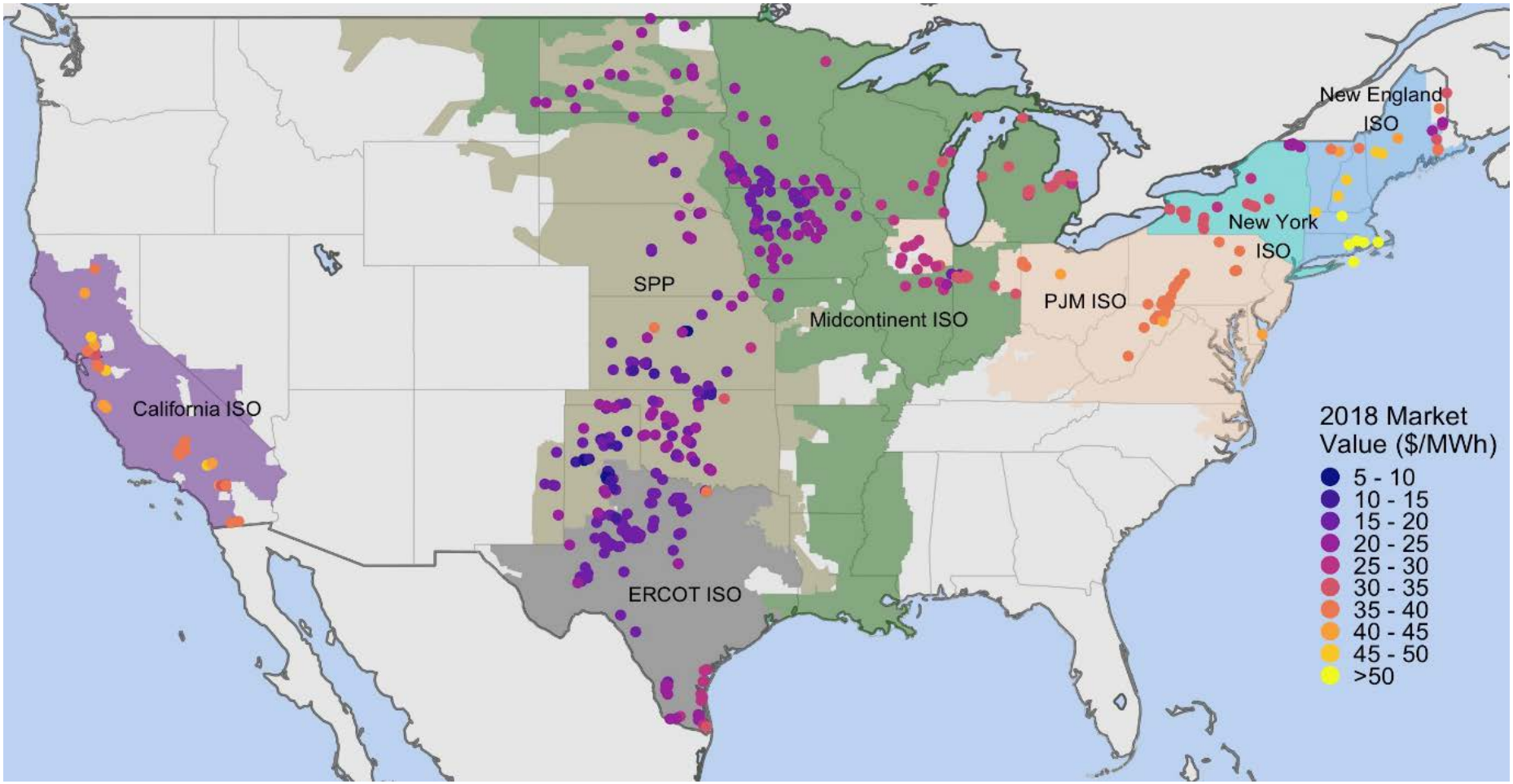


- Wholesale market value considers hourly local wholesale energy price and hourly wind output, along with capacity value where available
- Wholesale market value has declined over last decade, but increased in last couple years
- Recent wind PPAs are comparable to grid-system market value, with a number of recent PPAs coming in at a discount relative to wholesale market value estimates

The Wholesale Market Value of Wind Energy in 2018 Varied by Region: Lowest in ERCOT, Highest in ISO-NE

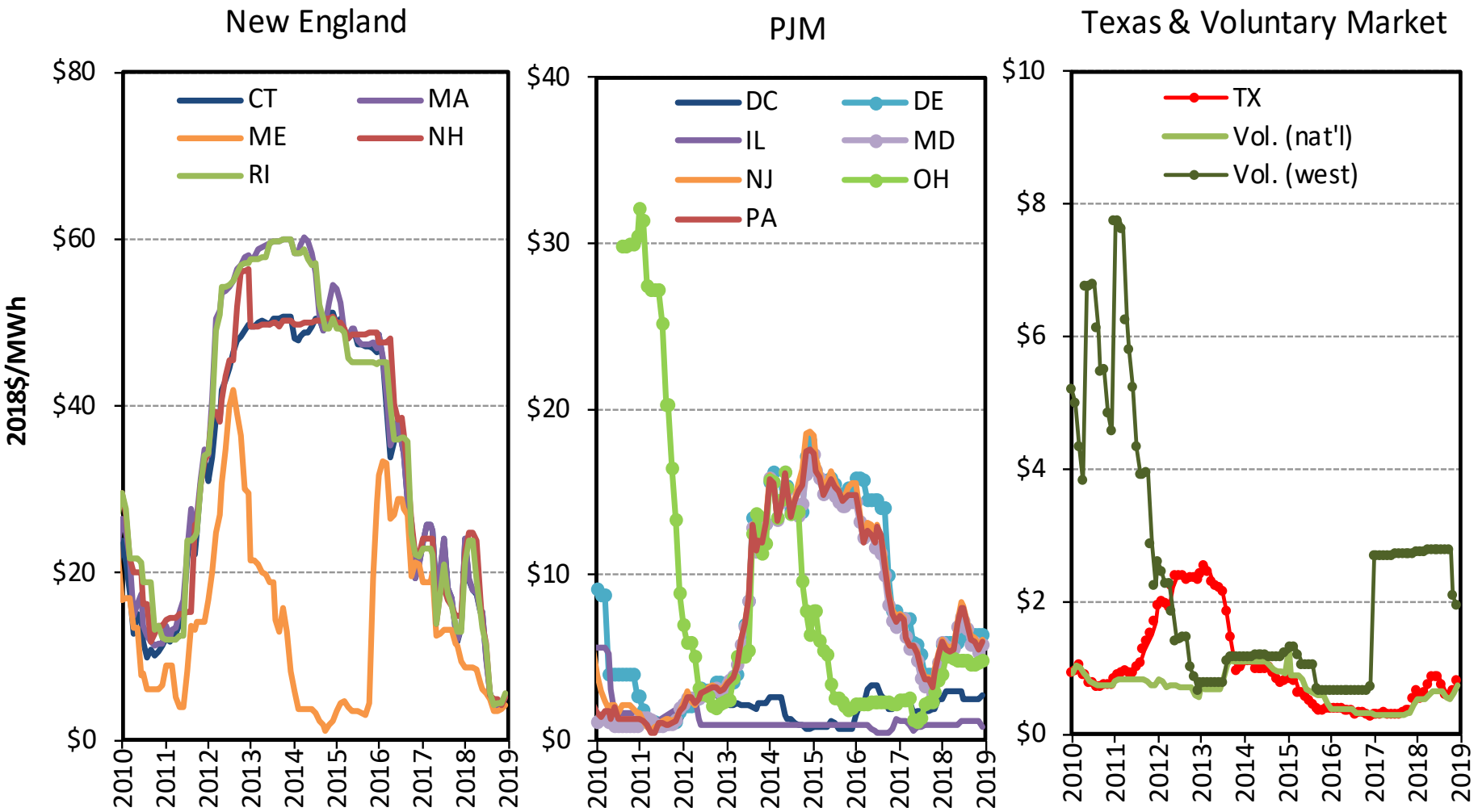


The Wholesale Market Value of Wind Energy in 2018 Varied by Region: Lowest in ERCOT, Highest in ISO-NE



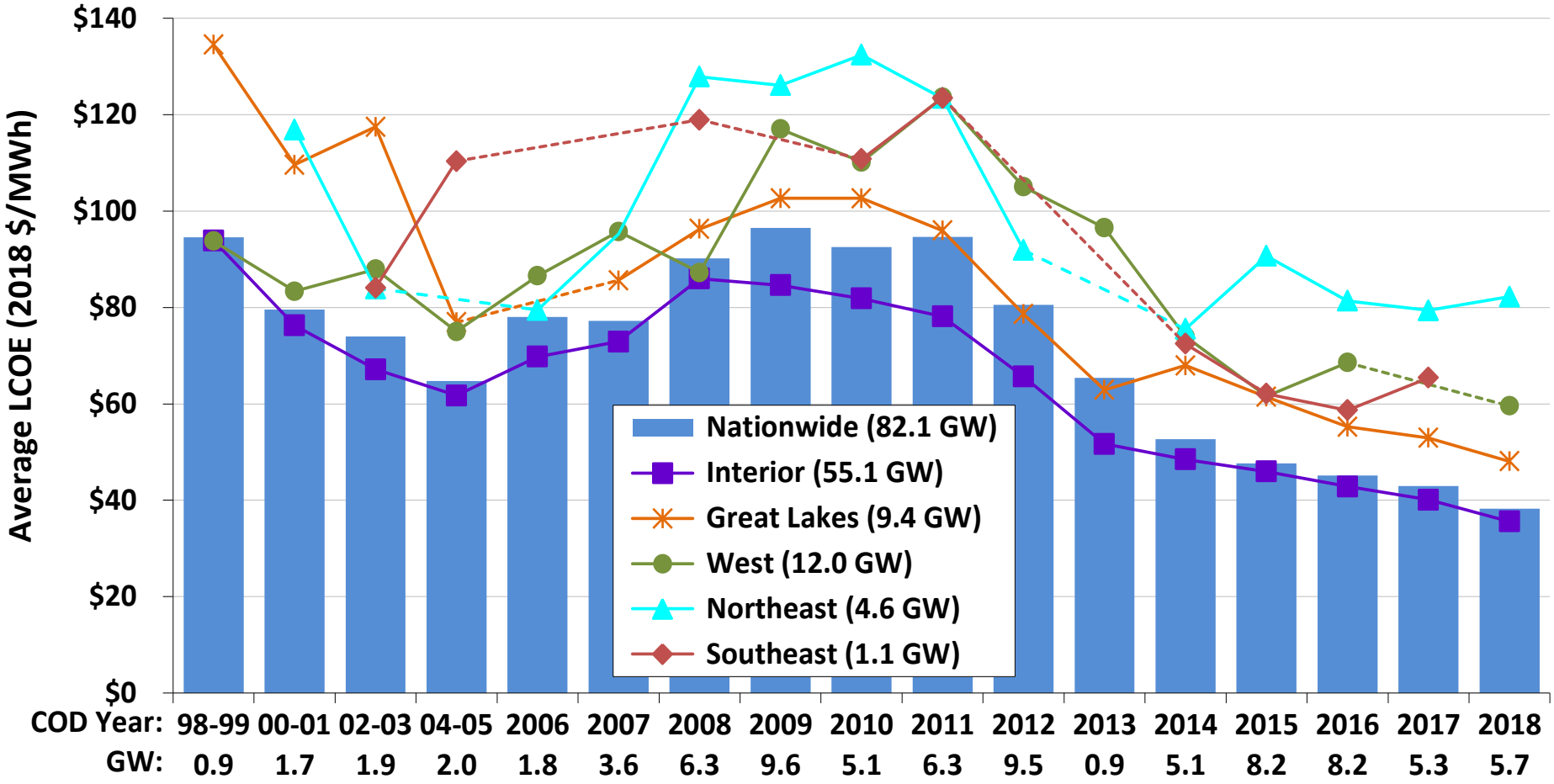
- Market value estimates in 2018 at project level span a wide range, from a low of $7/MWh to a high of $72/MWh, with a median value of $22/MWh

Renewable Energy Certificate (REC) Prices in RPS Compliance Markets Remained Low in 2018



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

The Levelized Cost of Wind Energy Is at an All-Time Low: Nationwide Average of $38/MWh for Projects Built in 2018



- Estimates reflect variations in installed cost, capacity factors, operational costs, cost of financing, and project life; include accelerated depreciation but exclude PTC

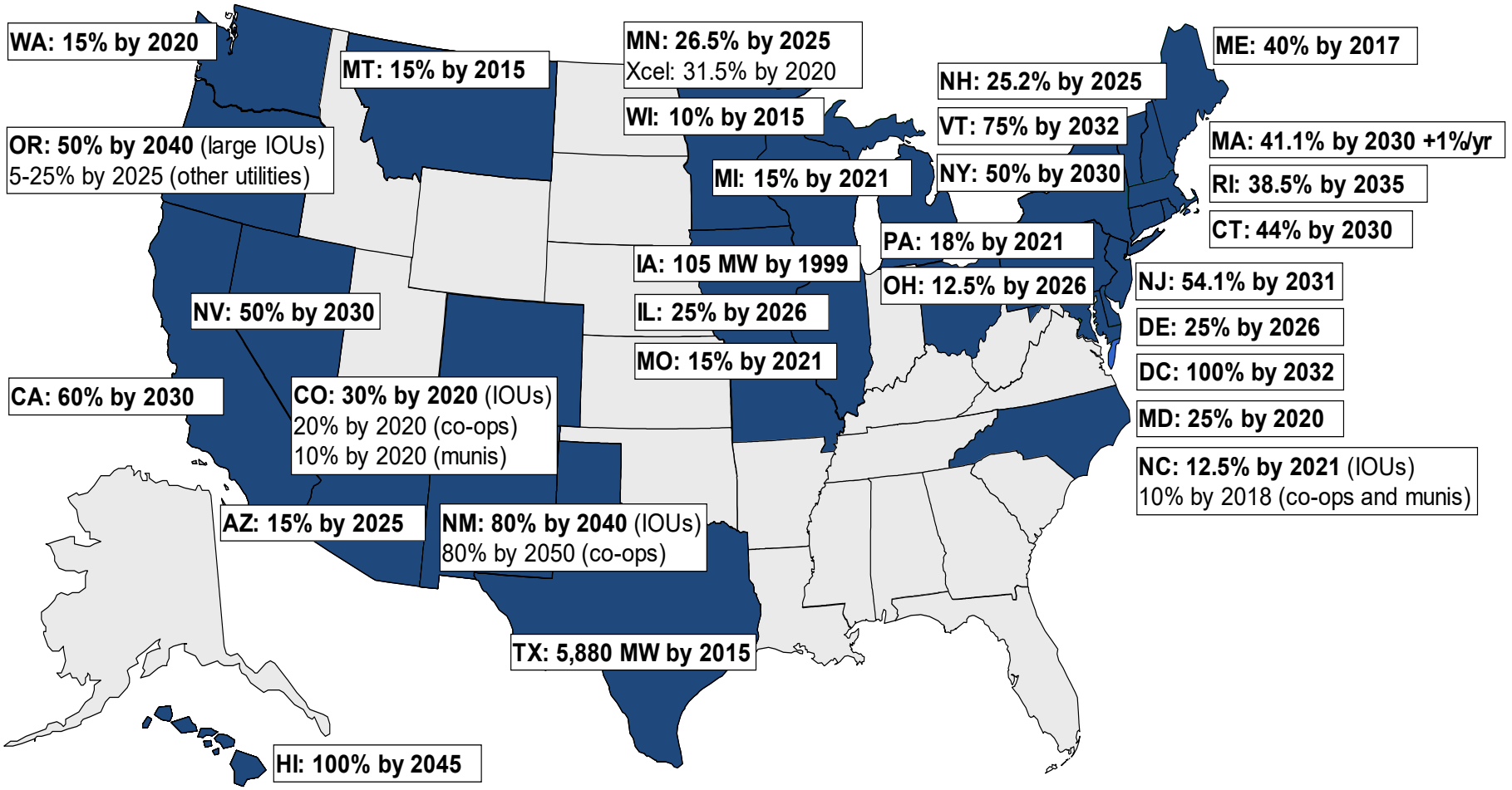
Policy and Market Drivers

The Federal Production Tax Credit (PTC) Remains One of the Core Motivators for Wind Power Deployment

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

- 5-year extension of PTC in 2015, plus 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 out in 20%-per-year increments for projects starting construction in 2017 (80% PTC value), 2018 (60%), 2019 (40%)

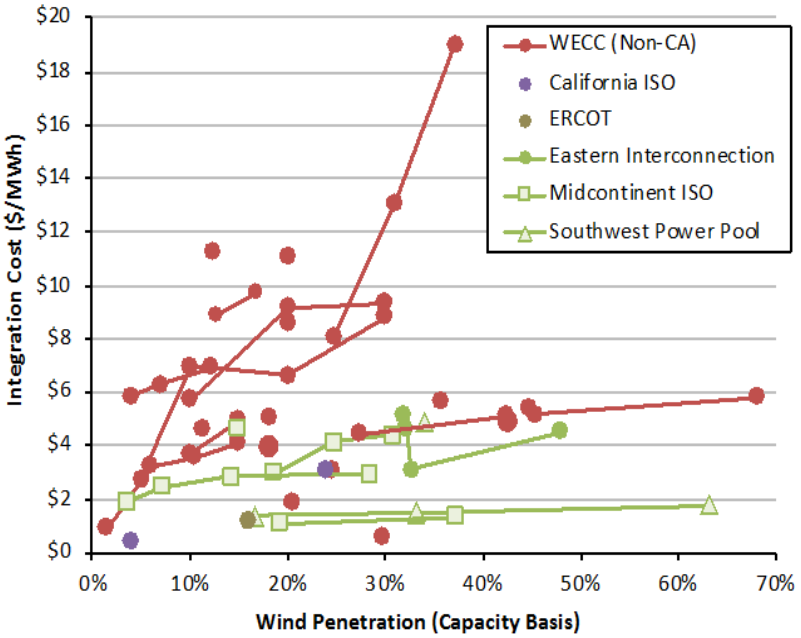
State Policies Help Direct the Location and Amount of Wind Development, but Wind Growth is Outpacing State Targets



- 29 states and D.C. have mandatory RPS programs, which can support ~5 GW/yr of renewable energy additions on average through 2030 (less for wind specifically)

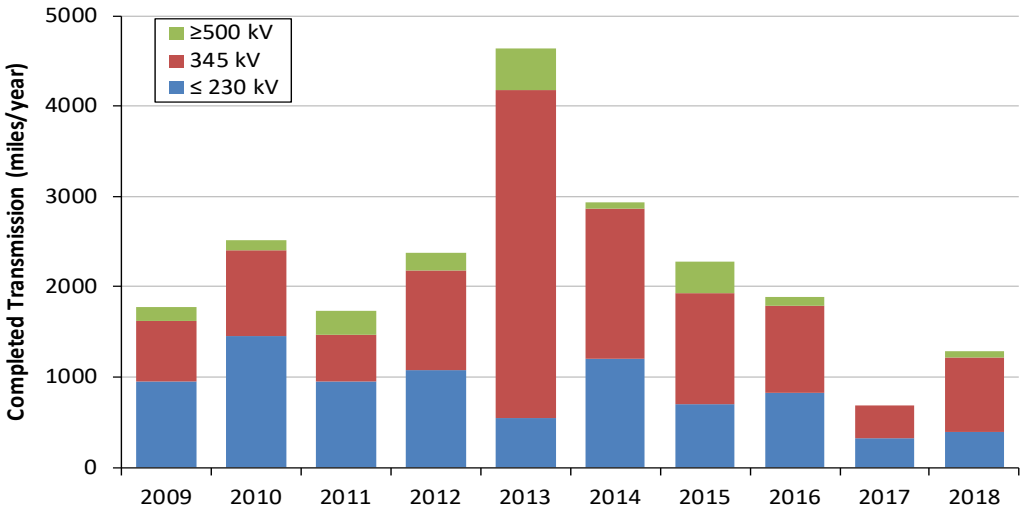
System Operators Are Implementing Methods to Accommodate Increased Penetrations of Wind

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



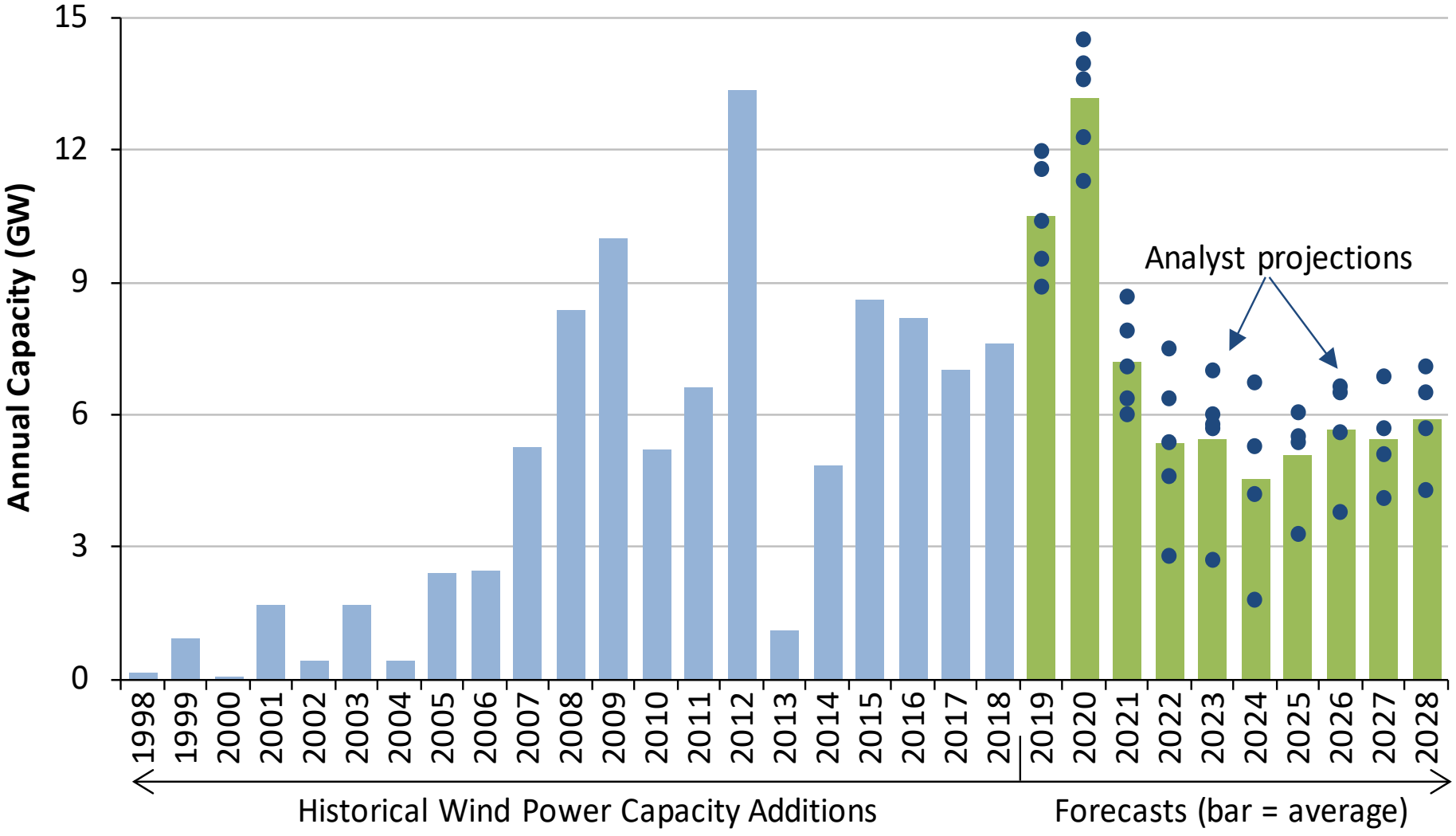
Notes: Because methods vary and a consistent set of operational impacts has not been included in each study, results from the different analyses of integration costs are not fully comparable.

Transmission Barriers Remain



Future Outlook

Sizable Wind Additions Anticipated for 2019–2020 Given Federal Tax Incentives; Downturn and Greater Uncertainty Beyond 2020



Future Outlook, Beyond Current PTC Cycle, is Uncertain

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

- Phase-out of federal tax incentives
- Continued low natural gas and wholesale electricity prices
- Potential decline in market value as wind penetration increases
- Modest electricity demand growth
- Limited near-term demand from state RPS policies
- Limited transmission infrastructure in some areas
- Growing competition from solar in some regions

Conclusions

- Wind capacity additions continued at a robust pace in 2018, with significant additional new builds anticipated in near-term 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 is diverse and multifaceted, with strong domestic content for nacelle assembly, towers, and blades
- Turbine scaling is significantly boosting wind project performance, while the installed cost of wind projects has declined
- Wind power sales prices and levelized cost of energy are at all-time lows, enabling economic competitiveness (with the PTC) despite low 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.:

- windreport.lbl.gov

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