May 2022

Experts Anticipate Larger Turbines and Plants, with Increasing Focus on Grid-Value Enhancement Options

Joseph Rand, Joachim Seel, and Ryan Wiser, Lawrence Berkeley National Laboratory

The design of wind turbines and plants have changed considerably over the past three decades, adapting to changing electric power systems and markets, technological improvements, shifting policy incentives, and increasing constraints on and competition for land and ocean space. Anticipating how wind turbines and plants will continue to evolve over the next 10-15 years can inform today's investment, research, and energy planning decisions. Researchers from Lawrence Berkeley National Laboratory (Berkeley Lab), together with collaborators from the National Renewable Energy Laboratory and the U.S. Department of Energy, elicited opinions from more than 140 of the world's leading experts about their expectations of future wind turbine and plant design in 2035. The research is described in detail in a new article in the journal *Wind Energy.*

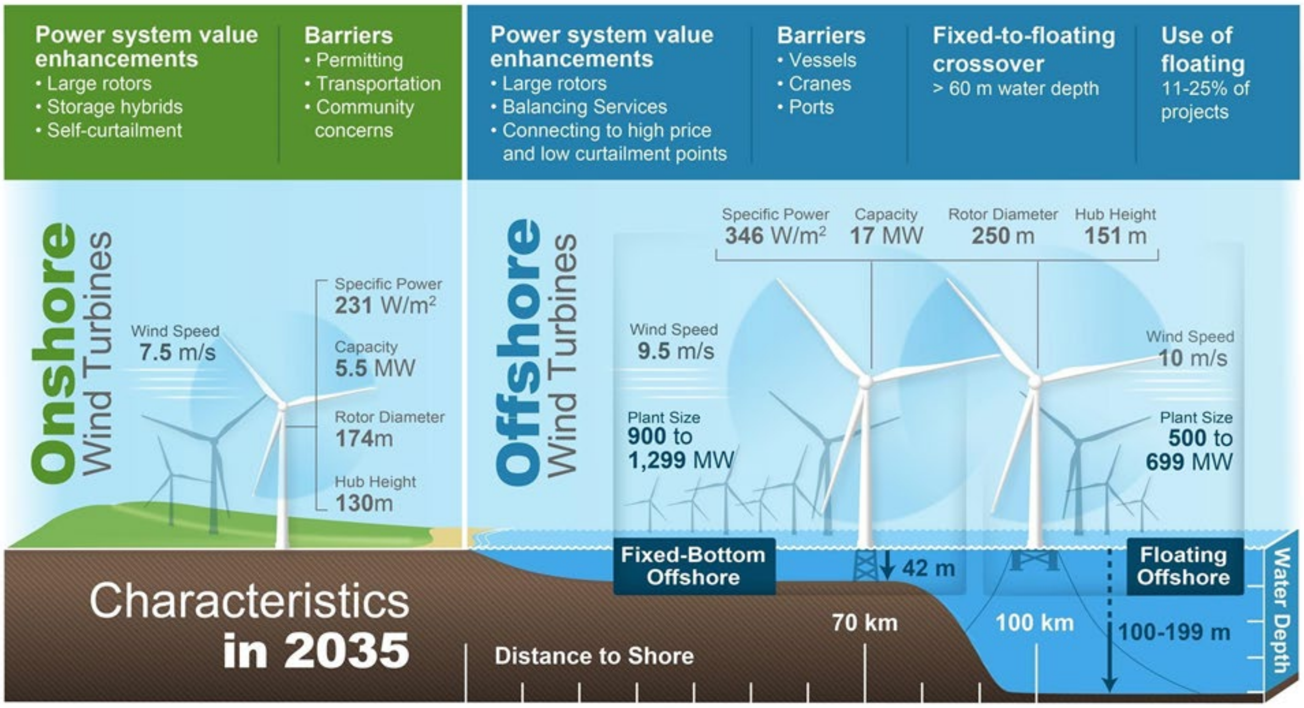
Compared to today, wind turbines and plants are expected to get considerably larger. The experts also highlighted several methods to enhance grid-system value that future wind projects are likely to employ. In additional detail, key findings include:

Future Turbine and Site Characteristics:

- Experts anticipate continued growth in median onshore turbine capacity ratings (5.5 MW in 2035), hub heights (130 m), and rotor diameters (174 m)
- Offshore turbines are expected to grow in size at an even faster rate, with the typical 2035 offshore turbine having a rated capacity of 17 MW, a hub height of 151 m, and a rotor diameter of 250 m.
- Yet, several factors were identified that could constrain future turbine growth: Siting and permitting, transportation limitations, and community concerns are considered the primary constraints for onshore turbines, while logistics (e.g., vessel, crane, and port limitations) are seen as the key limitations for offshore turbine scaling
- For onshore wind, the median annual average wind speed for newly installed projects is expected to decline slightly from 7.9 m/s in 2019 to 7.5 m/s in 2035

The work described in this report was funded by the U.S. Department of Energy's Wind Technologies Office under Lawrence Berkeley National Laboratory Contract No. DE-AC02-05CH11231. If you have questions or need clarification of any points, please contact Joe Rand, jrand@lbl.gov. Interested in other LBNL Electricity Markets and Policy Group publications? Join our notification list here.

- For fixed-bottom offshore wind, experts anticipate the median project in 2035 to be located farther from shore (70 km [2035] vs. 40 km [2019]) and in deeper water (42 m [2035] vs. 30 m [2019]) but expect average wind speed to remain steady at 9.5 m/s
- Floating offshore wind is expected to become the lower-cost choice (rather than fixed-bottom) at increasingly shallower water depths (>60m [2035] vs. >80m [2019]), due in part to the higher expected wind speeds (10 m/s) for future floating offshore wind sites



Grid System Value Enhancement Options:

- As wind energy's levelized cost declines, additional focus will turn to the value of wind in energy markets
- For onshore wind, a substantial percentage of experts anticipate significant use or even widespread use of many grid-system value-enhancement options: large rotors, hybridization with storage, curtailment for revenue maximization and life extension, and more (see figure)
- For offshore wind, top-rated value enhancement options include: larger rotors, provision of balancing services, interconnection to increase grid value, and hybridization with storage and hydrogen production

Onshore wind: frequency of use of grid-value enhancement options in 2035	Widespread use: *over 50% of projects*	Significant use: *over 10% of projects*
Large rotors: Larger rotors and/or taller towers to increase production when wholesale prices are higher	77%	95%
Storage hybrids: Co-locating wind projects with storage at the plant site or point of interconnection	46%	83%
Curtailment: Self-curtailment when wholesale prices are low to avoid financial losses	45%	79%
Life extension: Operating to reduce mechanical stress when prices are low, to extend project life	38%	71%
Interconnection: Interconnection to locations with higher prices and/or lower levels of curtailment	30%	70%
Balancing services: Using wind plants to provide balancing reserves and/or essential reliability services	29%	81%
Generator hybrids: Co-locating wind projects with other generating sources	26%	80%
Hydrogen: Using wind to produce fuels, such as hydrogen, at the plant site or point of interconnection	22%	56%
Overplanting: Building more wind power capacity than transmission interconnection capacity	17%	65%

Offshore wind: frequency of use of grid-value enhancement options in 2035	Widespread use: *over 50% of projects*	Significant use: *over 10% of projects*
Large rotors: Larger rotors and/or taller towers to increase production when wholesale prices are higher	43%	78%
Balancing services: Using wind plants to provide balancing reserves and/or essential reliability services	35%	87%
Interconnection: Interconnection to locations with higher wholesale and/or lower levels of curtailment	30%	75%
Curtailment: Self-curtailment when wholesale prices are low to avoid financial losses	28%	56%
Storage hybrids: Co-locating wind projects with storage at the plant site or point of interconnection	26%	70%
Life extension: Operating to reduce mechanical stress when prices are low, to extend project life	26%	58%
Hydrogen: Using wind to produce fuels, such as hydrogen, at the plant site or point of interconnection	23%	73%
Overplanting: Building more wind power capacity than transmission interconnection capacity	21%	44%
Generator hybrids: Co-locating wind projects with other generating sources	11%	30%

The paper goes on to identify five economic mechanisms that drive the forecasted design changes: Economies of scale from growing turbines, larger plant size, and greater siting flexibility, as well as grid-system value economies and production efficiencies. In essence, these mechanisms drive design choices because they generate a reduction in costs or a gain in energy production value that exceed the incremental expense to obtain them.

As described in a companion article by the same co-author team published in *Nature Energy*, these and many other design choices can support levelized cost of energy reductions of 27% (onshore) and 17%–35% (floating and fixed-bottom offshore) by 2035 compared to today.

The new *Wind Energy* article can be found here.

The comprehensive global expert survey was made possible through an international research partnership under the auspices of the International Energy Agency's wind energy program, which has a mission of advancing wind energy research, development and deployment in its member countries. The research was funded by the U.S. Department of Energy's Wind Energy Technologies Office.

Disclaimer and Copyright Notice