# Business & Technology Advisory

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# U.S. Department of Energy
# National Renewable Energy Laboratory (NREL) Report: Increasing Wind Turbine Tower Heights: Opportunities and Challenges

**Key Highlights**

- Wind resource quality improves significantly with height above ground which translates to sizable capacity factor improvements. When increasing wind tower hub heights from 80 m to 110 m, capacity factors can increase by an average of over 3 percent; and increasing wind tower heights from 110 m to 140 m, there is an additional average 4 percent or higher increase in capacity factor.
- The most wind-rich regions of the country show an economic preference for the tower heights up to 110 m. Higher hub heights (e.g., 110m and 140m) show an economic preference in more moderate wind speed regions (like the eastern United States, including the Southeast and parts of the western United States typically not known to have much wind potential).
- In addition to wind speeds associated with location, factors that could impact tower height include blade tip clearance requirements, balance-of-station costs, turbine nameplate capacity, specific power, potential FAA or DOD restrictions, etc.
- Currently, large onshore wind turbines are over 3 MW, but marginal costs for capacity further decrease by going to 4.5 MW, which has an economic preference for 140 m to 160 m hub heights. Thus, lower capital costs ($/kW) and lower levelized cost of electricity is anticipated with parallel development and commercialization of increased size of the wind turbine generators and taller towers (resulting in increased capacity factors and lower levelized cost of electricity).
- To achieve economically viable, taller wind turbine towers, tall towers could be built with rolled steel as is used for wind turbine towers today; but also could utilize prestressed concrete (which would eliminate transportation issues in reaching remote sites), latticed steel for space frame designs, etc.
- Assuming more weighted average cost of capital for generation and transmission electric cooperatives, levelized cost of electricity without production tax credits in the Great Plains, from North Dakota to Texas, can range in the future from $18/MWh to $31/MWh; and to $31/MWh to $45/MWh for the eastern United States and a significant amount of area in the western United States in Arizona, Utah, etc., assuming no incremental reduction in costs for new towers designed with prestressed concrete, latticed tower designs, etc.

## Introduction

Recent growth in the wind power industry has been spurred by reductions of costs and state and federal policy support. Further cost reduction is critical to continue its economic competitiveness with other resources, such as low-cost natural gas and solar photovoltaics, and especially since the Production Tax Credit (PTC) is being phased out. One technology that has enabled cost reduction is the use of taller towers to expand energy production and increase capacity factors. Higher hubs are of continued interest, because of the greater wind speeds that are present at higher heights above ground levels, as well as providing more clearance for increasing long blades.

The average wind turbines installed in the United States in 2018 had a nameplate capacity averaging 2.4MW, rotor diameters at about 116m, and hub heights around 88m. Recently, there has been a plateauing of hub height growth in the U.S. which can be attributed to two main reasons. The first, in many areas across the country, is that there are excellent wind resources available at 80m above ground level that have allowed projects to achieve performance levels that support levelized cost of energy (LCOE) values at or below $40/MWh to $45/MWh (excluding the PTC).  In addition, hub height growth has been impacted by transportation and logistical barriers that restrict the sectional roles steel towers to fit under highway and railway underpasses.

The U.S. Departments of Energy (DOE) National Renewable Energy Laboratory (NREL) recently completed a research report to analyze factors associated with increasing wind turbine tower heights. Their goal is to share the opportunities and potential of higher above ground hubs, as well as explore conditions and locations where taller towers offer the most significant potential to increasing performance and reducing costs.

## Tower Opportunities

In order to compare different hub heights, NREL utilized data and models from their Wind Integration National Dataset (Wind) toolkit. They looked at the incremental wind speed change in accordance with increasing altitude. Then, they quantified the impact of the change in wind speed on the turbine's power capacity. This allowed them to further estimate the change in energy production and capacity factor for four wind turbine configurations, and then derived their respective levelized cost of electricity (LCOE) with various heights and locations.

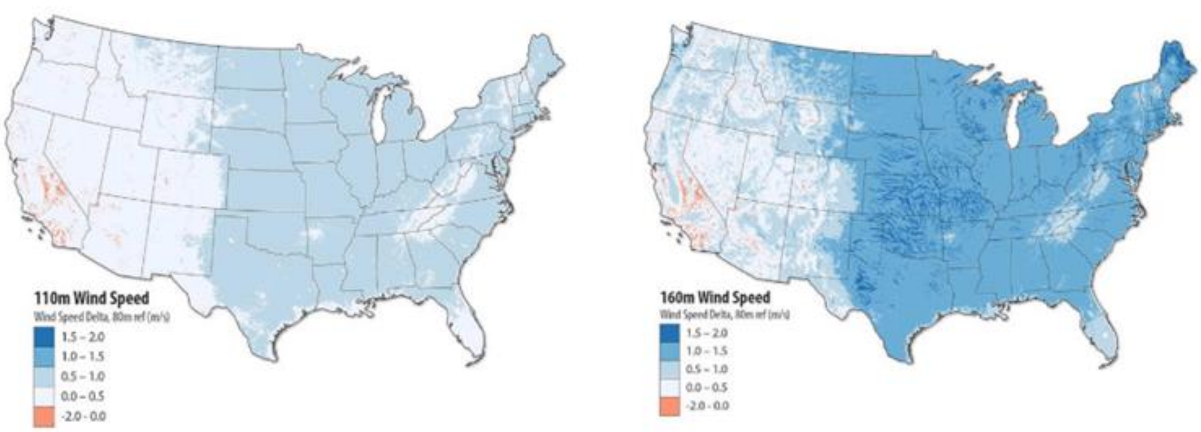


**Figure 1. Difference in Mean Annual Wind Speed at 110m and 160m Above Ground Level Relative to 80m**

For the analysis, hub height of 80m, 110m, 140m, and 160m above ground level were considered. In Figure 1, it is evident, based on the Wind Toolkit Dataset, that almost all regions of the country experience wind speed increases when moving up to 140m to 160m. Exceptions in this regard are in small pockets in the Southwest and in California, due to their rare topographical and meteorological patterns.  Note a significant improvement in wind speed in the eastern United States, including northern Florida.

| | Today | BAU | Low-SP 3.25 MW | Low-SP 4.5 MW |
|---|---|---|---|---|
| **Nameplate CapacitTy (MW)** | 2.32 | 3.30 | 3.25 | 4.50 |
| **Rotor Diameter (m)** | 113 | 156 | 166 | 194 |
| **Specific Power (W/m²)** | 231 | 173 | 150 | 152 |

**Figure 2. Configurations Used to Estimate Capacity Factors at Higher Hub Heights**

The four turbine configurations used, as shown in Figure 2, varied in nameplate capacity, rotor diameter, and specific power (SP). The "Today Turbine" design was calculated using average values of turbines installed in the U.S. in 2017.  The business as usual (BAU) was intended to reflect the expected average turbine installation in 2030. The two additional configurations represent potential future 3MW and 4-5MW turbine with low specific powers (SP).

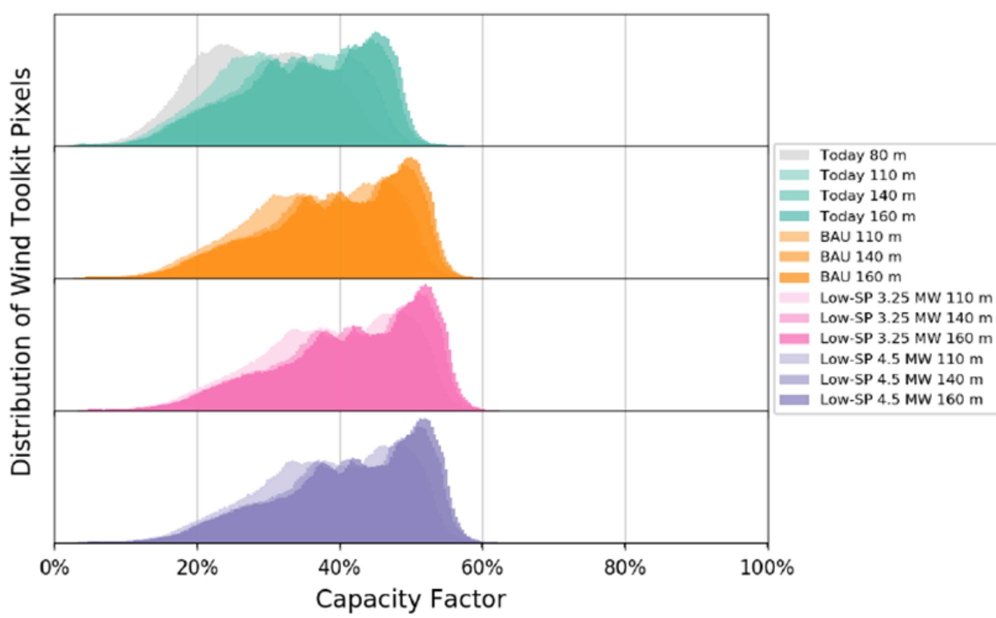


**Figure 3. Estimated Net Capacity Factor, All Turbines and Hub Heights**

The wind speed data, along with wind turbine power curves, were used to estimate potential energy generation and capacity factors for the four turbines at multiple hub heights. The highest capacity factors were observed at 160m with the Low-SP turbines. Even with higher specific power, as with the Today and BAU turbines, the 160m hub height increases the number of sites with 40 percent or greater capacity factors, which may become economically attractive especially in the eastern United States and portions of the western United States.

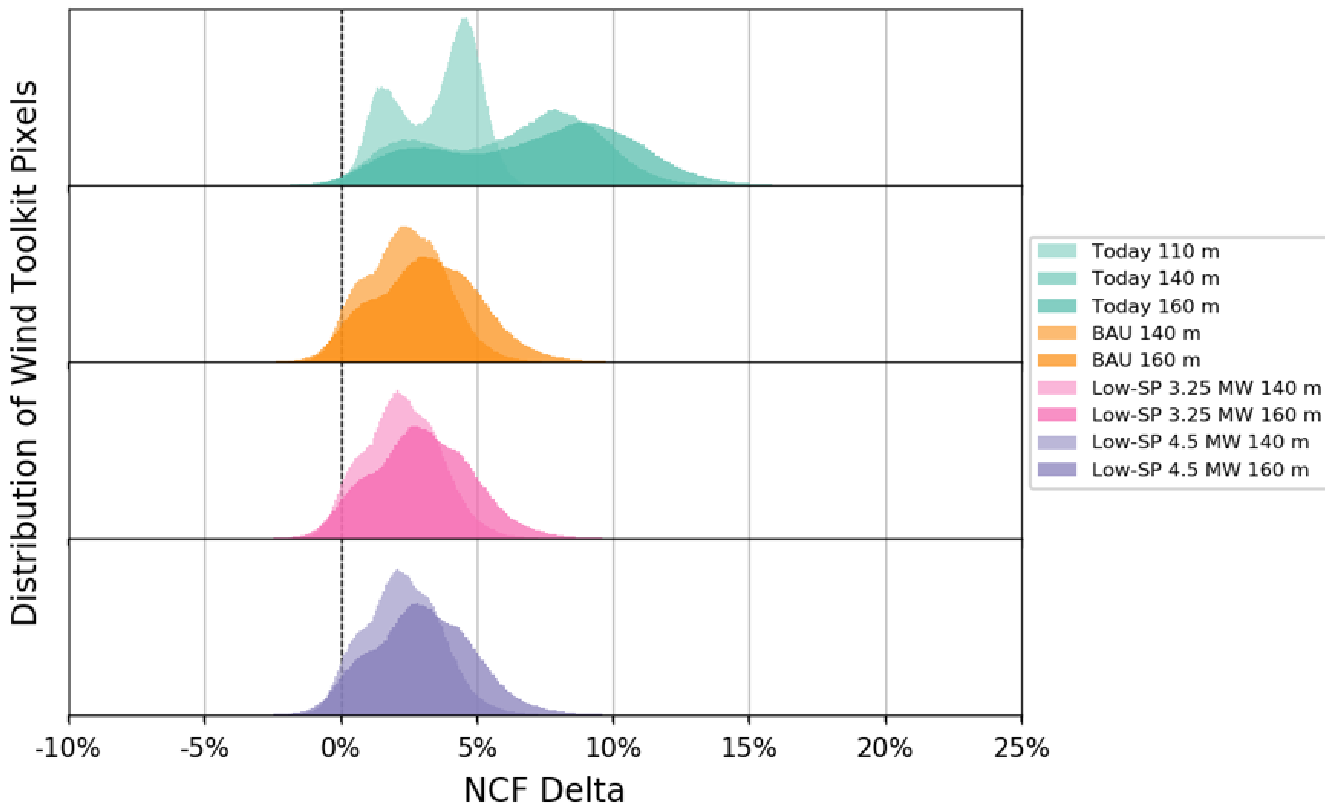


**Figure 4. Estimated Difference in Net Capacity Factor, All Turbines and Hub Heights Relative to the Lowest Hub High Available per Platform Relative to 80 m Hub Height**

Figure 4 shows the change and difference in net capacity factor for Today turbines, business as usual turbines (BAU), low specific power 3.25 MW turbines, and low specific power 4.5 MW turbines for varying hub height relative to 80m hub height. It shows with Today Turbine technologies that going to higher towers can significantly increase capacity factors, increase annual energy production, and lower levelized cost of electricity. On the average, it appears that the 110m towers can increase capacity factors by about 3 percent, and going to 140 m towers can increase capacity factors an average of 7 percent.

Of course, to achieve these higher capacity factors and taller tower heights requires increased capital costs as shown in Figure 5 on the following page.

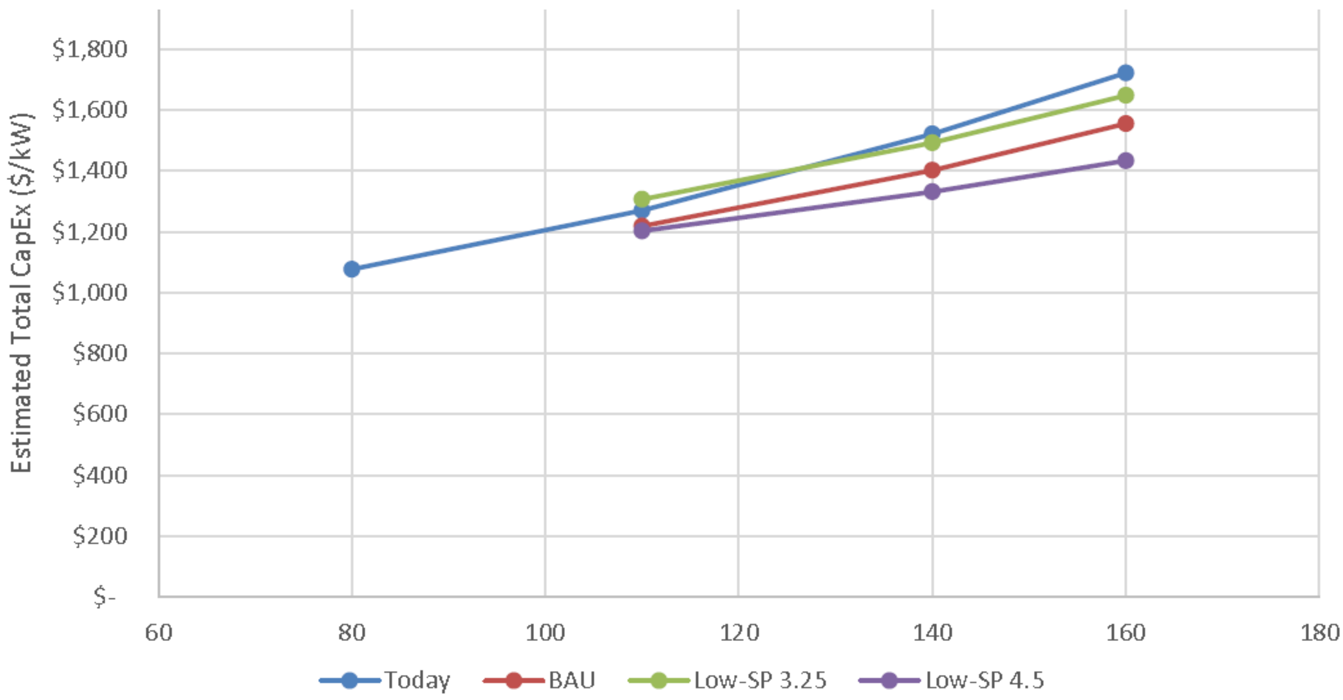


**Figure 5: Estimated Total Installed Capital Cost by Turbine and Hub Height**

Note that with today turbines, increasing the hub height from 80m to 140m will increase capital costs from t $1100/kW to $1500/kW or 36 percent increase, assuming no improvement in technology to go to higher hub heights like lattice construction, prestressed concrete slip form, etc. By increasing hub height from 80m for a Today Turbine to 140 m for a low specific power 4.5 MW turbine the capital cost only increases by 18 percent.

## Cost Estimation

It is the trade-off between incremental energy production and incremental capital cost expenditure that ultimately determines the hub heights for commercial wind farms. Combined with the power capacity findings, NREL's LCOE results are based on a first-order set of assumptions and, therefore, should not be viewed as the final value, but more of an indicator. If we calculate the levelized cost of electricity using a typical generation and transmission electric cooperative financing of 2.4 percent weighted interest rate, 100 percent debt financing, and a 30 year life, then the LCOE for the 4.5 MW low specific power turbine will be $25/MWh at 140 m hub height, assuming a 7 percent increase in capacity factor over a Today Turbine at 80m with levelized cost of electricity of $26/MWh, or at least $1/MWh more expensive than the 4.5 MW low specific power turbine at 140m hub height, assuming no significant reduction in costs for taller towers using advanced technologies. This geographic dependency can be observed in Figure 6 for the Today Turbine.

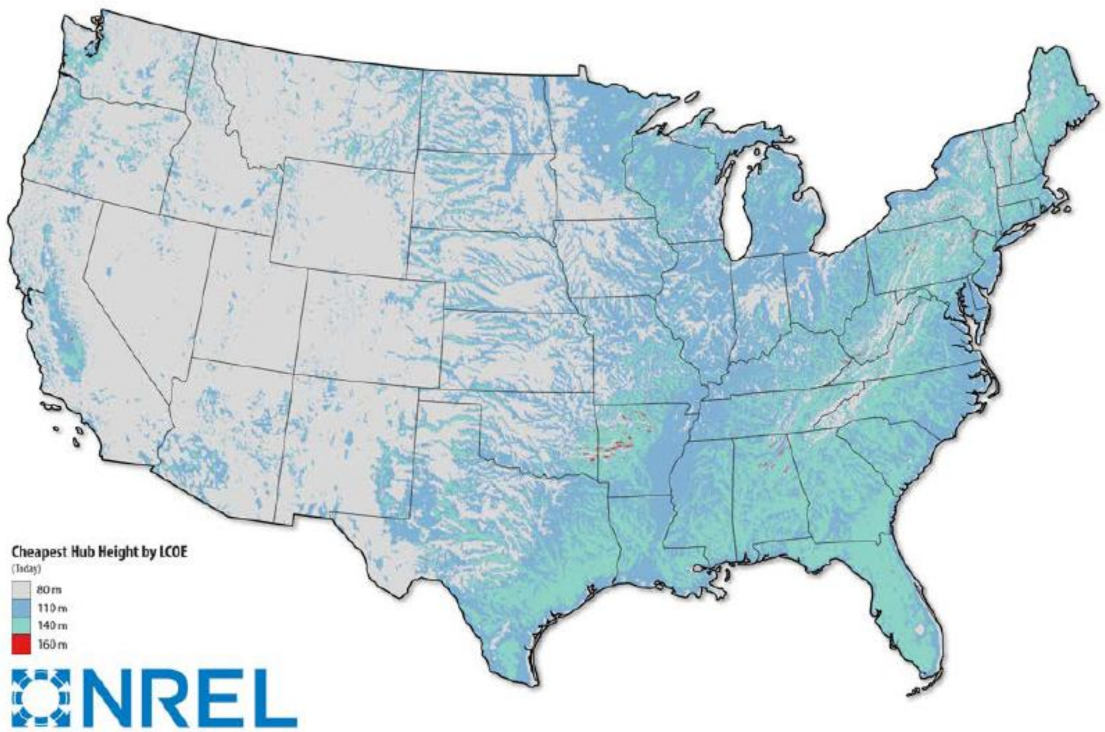


**Figure 6. Calculated Economically Preferred Hub Heights for the Today Turbine (Wind Turbine Technology Available Today), Based on Estimated Costs and Performance**

It can be seen from Figure 6 that the optimal tower height for much of the eastern United States, and especially in the southeastern United States, is 110m to 140m assuming no improvement in tower design and construction.

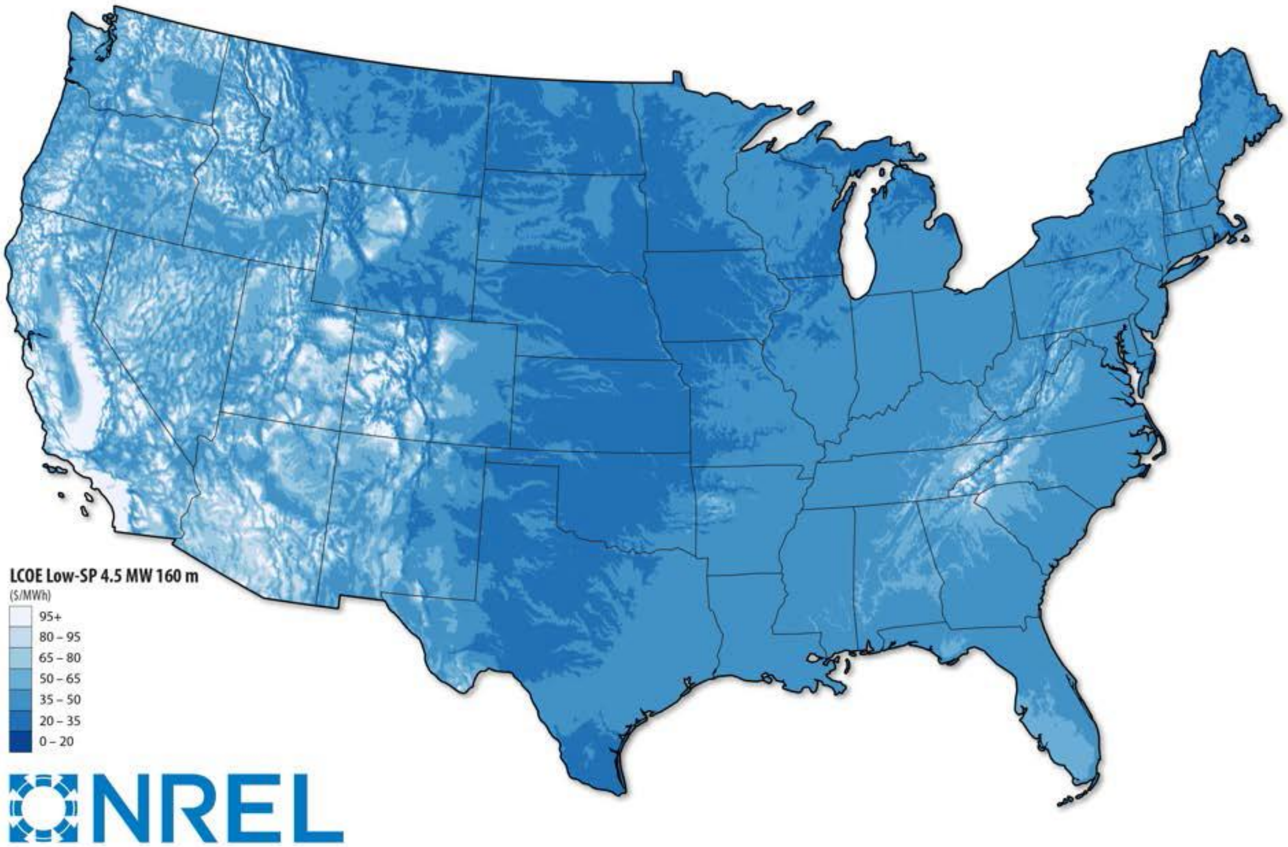


**Figure 7: Estimated Levelized Cost of Electricity**
**Assuming a Low Specific Power 4.5 MW Turbine and a 140m to 160m Hub Height**

DOE NREL calculated the levelized cost of electricity for Figure 7 using an after-tax weighted average cost of capital of about 3.9 percent, which is at least 1.6 percent higher than the weighted average cost of capital for generation and transmission electric cooperative financing. They show that in the Great Plains in the central part of the United States, from North Dakota all the way to Texas, that the levelized cost of electricity ranges from $20/MWh to $35/MWh, and in most of the eastern United States, the cost ranges from $35/MWh to $50/MWh without production tax credits. Assuming more weighted average cost of capital for generation and transmission electric cooperatives, these costs would drop by another 11 percent to $18/MWh to $31/MWh for the Great Plains, and to $31/MWh to $45/MWh for the eastern United States and a significant amount of area in the western United States in Arizona, Utah, etc.

## Conclusion

There is sufficient, additional wind resource in the United States at higher above ground levels to warrant the pursuit of technology enabling higher hub heights. After analysis using data from NREL's Wind Toolkit, it was found that hub heights of 110m to 140m have the potential to offer some LCOE advantages relative to today's typical turbines in most of the eastern region of the United States (especially in the southeastern United States), as well as parts of the western United States typically not known for their wind potential.

In addition, future tower innovations that can overcome costs due to transportation and material limitations could make higher hub heights more attractive than shown in the DOE NREL report. Other future drivers of higher wind turbines include land constraints and a desire to further increase rotor size, increase size of wind turbine generators, reduced specific power, and therefore, increase hub height to provide sufficient ground clearance.

## Additional Resources:

- *Increasing Wind Turbine Tower Heights: Opportunities and Challenges*: https://www.energy.gov/eere/wind/downloads/increasing-wind-turbine-tower-heights-opportunities-and-challenges

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