Champaign County
Department of
PLANNING & ZONING

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CASE 037-AT-22

SUPPLEMENTAL MEMORANDUM #2
MAY 17, 2022

Petitioner: Zoning Administrator

Request: Amend the Champaign County Zoning Ordinance as follows:

1. Add new paragraph 6.1.4 A.3. regarding Right to Farm Resolution 3425.

2. Amend Sections 6.1.4 C and D regarding WIND FARM TOWER height.

3. Revise paragraph 6.1.4 D.7. regarding Aircraft Detection Lighting Systems (ADLS).

4. Add new Section 6.1.4 R to require conformance to the State of Illinois Agricultural Impact Mitigation Agreement.

5. Revise Section 9 Regarding WIND FARM fees.

Location: Unincorporated Champaign County

Time Schedule for Development: As soon as possible

Prepared by: **Susan Burgstrom**, Senior Planner
John Hall, Zoning Administrator

STATUS

Please see the sections below regarding:

- A recommended revision to the proposed text amendment
- New submittals from Ted Hartke and Mary King
- Updates to the Findings of Fact

RECOMMENDED REVISION TO PROPOSED AMENDMENT

The original proposed amendment removed the minimum setback distance from Sections 6.1.4 C and D. This was done in error, and therefore Zoning Administrator John Hall recommends adding to the text of proposed paragraphs 6.1.4 C.1. and C.2. to not only include a setback as a function of turbine height, but also a minimum distance setback as shown in red text with yellow highlight below:

2. Regarding WIND FARM TOWER height, amend Sections 6.1.4 C and D as follows:
   A. Amend 6.1.4C. 1. and 2. as follows:
      1. ~~At least 1,000 feet~~ The minimum required separation from the exterior above-ground base of a WIND FARM TOWER to any PARTICIPATING DWELLING OR PRINCIPAL BUILDING shall be no less than 2.00 times the maximum allowed total WIND FARM TOWER HEIGHT but not less than 1,000 feet provided that the noise level caused by the WIND FARM at the particular building complies with the applicable Illinois Pollution Control Board regulations.

2. ~~At least 1,200 feet~~ The minimum required separation from the exterior above-ground base of a WIND FARM TOWER to any existing NON-PARTICIPATING DWELLING OR PRINCIPAL BUILDING shall be no less than 2.40 times the maximum allowed total WIND FARM TOWER HEIGHT but not less than 1,200 feet provided that the noise level caused by the WIND FARM at the particular building complies with the applicable Illinois Pollution Control Board regulations and provided that the separation distance meets or exceeds any separation recommendations of the manufacturer of the wind turbine used on the WIND FARM TOWER.

NEW SUBMITTALS

Attachment B includes a list of submittals from Ted Hartke received May 2, 2022:

- Schomer testimony regarding Highland Wind Farm LLC application
- Article: *Big Wind Needs to Address Wind Turbine Syndrome*
- Article: *The Noise from Wind Turbines: Potential Adverse Impacts on Children's Well-being*
- Letter from Bill Mulvaney, Armstrong School Superintendent

Attachment C includes a list of handouts provided by Mary King at the May 5, 2022 ELUC meeting:

- Article: *Enjoying a Windfall*
- Article: *Latest Research on Wind Turbine Health Impacts Brings Unsurprising Results*
- Article: *The link between health complaints and wind turbines: support for the nocebo expectations hypothesis*

REVISED FINDING OF FACT

P&Z Staff revised the Summary Finding of Fact (Attachment E) to include the following:

- a summary of all public comments and testimony received up to and including the April 14, 2022 ZBA meeting;
- a synopsis of the eight exhibits submitted by attorney Brian Armstrong on March 17, 2022;
- Board member Tom Anderson's thoughts regarding Mr. Armstrong's Exhibit 8, Jerry Punch's presentation: *Wind Turbine Noise: Effects on Human Health*; and
- evidence regarding turbine height limits exceeding the current 500 feet in the Zoning Ordinance, as follows:

19. Regarding Part 2.B. of the text amendment regarding the proposed change to maximum WIND FARM TOWER HEIGHT:
    A. Regarding the existing Zoning Ordinance maximum WIND FARM TOWER HEIGHT:
        (1) Existing Zoning Ordinance Section 6.1.4D.5. limits maximum WIND FARM TOWER HEIGHT to less than 500 feet and was adopted in Ordinance No. 848 (Zoning Case 634-AT-08 Part A) on 5/21/09.

        (2) Existing Zoning Ordinance Section 6.1.4D.1.b. requires each Zoning Use Permit Application for a WIND FARM TOWER to include a certification by an Illinois Professional Engineer or Illinois Licensed Structural Engineer that the foundation and tower design of the WIND FARM

TOWER is within accepted professional standards given local soil and climate conditions.

B. The California Ridge Wind Farm was approved by the Champaign County Board on 11/17/2011 with a hub height of 100 meters (328 feet) and a rotor diameter of 100 feet meters (328 feet) for an overall WIND FARM TOWER HEIGHT of 492 feet.

C. The Sapphire Sky Wind Farm was approved by the McLean County Board on 7/14/2021 with a with a hub height of 105 meters (344.4 feet) and a rotor diameter of 150 meters (492 feet) for an overall WIND FARM TOWER HEIGHT of 591 feet. The Harvest Ridge Wind Farm recently approved in Douglas County has a similar height.

D. The National Renewable Energy Laboratory (NREL) Technical Report NREL/TP-5000-73629 titled Increasing Wind Turbine Tower Heights: Opportunities and Challenges dated May 2019 reviewed opportunities, challenges, and potential associated with increasing wind turbine tower heights focused on land-based wind energy and concluded the following:

(1) Wind resource quality (wind speed) improves significantly with height above ground. Over large portions of the country, annual average wind speed doubles and sometimes triples when moving from 80-meter hub heights to 160-meter hub heights. Hub height is the mid-point of the rotor (blades).

(2) Wind speed differences translate to sizable capacity factor (actual power output divided by optimal power output) improvements.

(3) Higher hub heights (110 meter to 140 meter) are often preferred in more moderate wind speed regions. Champaign County is generally considered a moderate wind speed region.

(4) The highest nameplate capacity turbine considered in the study (4.5 megawatts) has a greater preference for 140-meter hub heights than similar 3-megawatt class turbines.

(5) The “business-as-usual” (BAU) turbine considered in the study is expected to be the average turbine installed around the United States by 2030. The BAU turbine has a nameplate capacity of 3.3 megawatts and a rotor diameter of 156 meters and was considered at the hub heights of 110 meters with an overall WIND FARM TOWER HEIGHT of 617 feet; a hub height of 140 meters with an overall WIND FARM TOWER HEIGHT of 715 feet; and a hub height of 160 meters with an overall WIND FARM TOWER HEIGHT of 781 feet.

(6) The analysis found diminishing returns from hub height increases to140 meter and subsequently to 160 meters.

(7) The report notes that the analysis was limited to hub heights of 80 meters, 110 meters, 140 meters, and 160 meters but in many cases the real-world preferred tower heights will likely fall between those points.

(8) To realize taller wind turbine towers, an array of potential concepts remains in play relying on various materials spanning from rolled tubular steel, concrete, lattice steel, and hybrid designs.

E. Based on current practice in nearby counties and on the National Renewable Energy Laboratory (NREL) Technical Report NREL/TP-5000-73629 titled Increasing Wind Turbine Tower Heights: Opportunities and Challenges, the following seems clear:

(1) Any new wind farm proposed in Champaign County in the next decade will likely have an overall WIND FARM TOWER HEIGHT between 591 feet (the same as the Sapphire Sky and Harvest Ridge wind farms) and 715 feet (assuming a rotor diameter of 156 meters and a hub height of not more than 140 meters).

(2) A height of 715 feet is achievable based on the typical limit of 4.3 meters width for tower base diameter (based on transportation requirements) and using conventional tubular steel tower technology.

(3) Adopting a maximum WIND FARM TOWER HEIGHT of less than 715 feet at this time would result in an artificial limit on WIND FARM development in Champaign County.

F. If the proposed no maximum WIND FARM TOWER HEIGHT is adopted, Champaign County would not be the only Illinois county to not have a maximum WIND FARM TOWER HEIGHT. At least six other Illinois counties (Boone, Fulton, LaSalle, Peoria, Woodford, and Vermilion) have no specific height limit for wind farm towers and Logan County limits wind farm tower height to 750 feet.

G. Adopting a no maximum WIND FARM TOWER HEIGHT is the same as the current Zoning Ordinance approach to tower height in general, in which there is no maximum tower height but any tower height over 100 feet must be approved by the Zoning Board of Appeals in a special use permit, the same kind of approval required for a WIND FARM.

H. Existing Zoning Ordinance Section 6.1.4D.1.b. requires each Zoning Use Permit Application for a WIND FARM TOWER to include a certification by an Illinois Professional Engineer or Illinois Licensed Structural Engineer that the foundation and tower design of the WIND FARM TOWER is within accepted professional standards given local soil and climate conditions. Safety of wind farm towers will always be an issue and will always be certified regardless of WIND FARM TOWER HEIGHT.

I. WIND FARM TOWER HEIGHT is not related directly to noise and Zoning Ordinance Section 6.1.4I. has limits for the allowable noise level from a WIND

FARM. Adopting a no maximum WIND FARM TOWER HEIGHT will have no impact on the allowable WIND FARM noise level.

J. WIND FARM TOWER HEIGHT is directly related to shadow flicker and Zoning Ordinance Section 6.1.4M. has limits for the allowable shadow flicker. Adopting a no maximum WIND FARM TOWER HEIGHT will result in shadow flicker being controlled the same as it is today.

ATTACHMENTS

A Legal advertisement for Case 037-AT-22 dated March 2, 2022

B Submittals from Ted Hartke received May 2, 2022:
- Schomer testimony regarding Highland Wind Farm LLC application
- Article: *Big Wind Needs to Address Wind Turbine Syndrome*
- Article: *The Noise from Wind Turbines: Potential Adverse Impacts on Children's Well-being*
- Letter from Bill Mulvaney, Armstrong School Superintendent

C Handouts from Mary King at the May 5, 2022 ELUC meeting:
- Article: *Enjoying a Windfall*
- Article: *Latest Research on Wind Turbine Health Impacts Brings Unsurprising Results*
- Article: *The link between health complaints and wind turbines: support for the nocebo expectations hypothesis*

D National Renewable Energy Laboratory (NREL) Technical Report NREL/TP-5000-73629 *Increasing Wind Turbine Tower Heights: Opportunities and Challenges dated May 2019*

E Revised Finding of Fact, Summary Finding of Fact, and Final Determination for Case 037-AT-22 dated May 26, 2022, with attachment:
- Exhibit A: Proposed Amendment dated March 17, 2022

LEGAL PUBLICATION: WEDNESDAY, MARCH 2, 2022 CASE: 037-AT-22

NOTICE OF PUBLIC HEARING IN REGARD TO AN AMENDMENT TO THE TEXT OF THE CHAMPAIGN COUNTY ZONING ORDINANCE

CASE 037-AT-22

The Champaign County Zoning Administrator, 1776 East Washington Street, Urbana, has filed a petition to amend the text of the Champaign County Zoning Ordinance. The petition is on file in the office of the Champaign County Department of Planning and Zoning, 1776 East Washington Street, Urbana, IL.

A public hearing will be held **Thursday, March 17, 2022 at 6:30 p.m.** prevailing time in the Shields-Carter Meeting Room, Brookens Administrative Center, 1776 East Washington Street, Urbana, IL, at which time and place the Champaign County Zoning Board of Appeals will consider a petition for the following:

Amend the Champaign County Zoning Ordinance as follows:

1. Regarding Right to Farm Resolution 3425, add new paragraph 6.1.4 A.3. as follows:
    3. The owners of the subject property and the Applicant, its successors in interest, and all parties to the decommissioning plan and site reclamation plan hereby recognize and provide for the right of agricultural activities to continue on adjacent land consistent with the Right to Farm Resolution 3425.

2. Regarding WIND FARM TOWER height, amend Sections 6.1.4 C and D as follows:
    A. Amend Section 6.1.4 C.1. and 2. as follows:
        1. Change the minimum required separation from 1,000 feet to 2.00 times the maximum allowed total WIND FARM TOWER HEIGHT between a WIND FARM TOWER and any PARTICIPATING DWELLING OR PRINCIPAL BUILDING.

        2. Change the minimum required separation from 1,000 feet to 2.40 times the maximum allowed total WIND FARM TOWER HEIGHT between a WIND FARM TOWER and any NON-PARTICIPATING DWELLING OR PRINCIPAL BUILDING.

    B. Amend 6.1.4 D.5. as follows:
        5. Change the maximum WIND FARM TOWER HEIGHT from 500 feet to having no limit, subject to conformance to all FAA requirements including an FAA Determination of No Hazard with or without Conditions.

3. Regarding Aircraft Detection Lighting Systems (ADLS), revise paragraph 6.1.4 D.7. as follows:
    7. Require all WIND FARM TOWERS to use ADLS (aircraft detection lighting system) or equivalent system to reduce the impact of nighttime lighting on nearby residents, communities and migratory birds in accordance with the FAA Advisory circular: 70/7460-IL section 14.1.

4. Regarding the Agricultural Impact Mitigation Agreement, revise Section 6.1.4 as follows:
    A. Add new Section 6.1.4R: Agricultural Impact Mitigation Agreement with the Illinois Department of Agriculture, as follows:

(1) If provided by state law, the Applicant shall enter into an Agricultural Impact Mitigation Agreement with the Illinois Department of Agriculture.

(2) The Applicant shall bear full responsibility for coordinating any special conditions required in the SPECIAL USE Permit in order to ensure compliance with the signed Agricultural Impact Mitigation Agreement with the Illinois Department of Agriculture.

(3) All requirements of the signed Agricultural Impact Mitigation Agreement with the Illinois Department of Agriculture shall become requirements of the COUNTY Board SPECIAL USE Permit.

(4) Champaign County shall have the right to enforce all requirements of the signed Agricultural Impact Mitigation Agreement with the Illinois Department of Agriculture.

B. Add new paragraph 6.1.4A.4 as follows:
All aboveground STRUCTURES and facilities shall be of a type and shall be located in a manner that is consistent with the Agricultural Impact Mitigation Agreement with the Illinois Department of Agriculture as required by paragraph 6.1.4R.

C. Revise Section 6.1.4E. to require conformance with the approved Agricultural Impact Mitigation Agreement with the Illinois Department of Agriculture.

D. Add new paragraph 6.1.4P.4.g. as follows:
Any financial assurance required per the Agricultural Impact Mitigation Agreement with the Illinois Department of Agriculture as required by paragraph 6.1.4R. shall count towards the total financial assurance required for compliance with paragraph 6.1.1A.5.

E. Add new paragraph 6.1.4S.1.d. as follows and re-letter subsequent paragraphs:
The Applicant shall include a copy of the signed Agricultural Impact Mitigation Agreement with the Illinois Department of Agriculture with the Zoning Use Permit Application to authorize construction.

5. Regarding WIND FARM fees, revise Section 9 as follows:
A. Revise paragraph 9.3.1H. as follows:
Increase WIND FARM TOWER or BIG WIND TURBINE TOWER fee from $4,500 to $10,000.

B. Revise paragraph 9.3.3B.6. as follows:
Increase the County Board WIND FARM SPECIAL USE Permit from $20,000 to $34,000 and the per WIND FARM TURBINE TOWER from $440 to $760.

All persons interested are invited to attend said hearing and be heard. If you would like to submit comments or questions before the meeting, please call the P&Z Department at 217-384-3708 or email zoningdept@co.champaign.il.us no later than 4:30 pm the day of the meeting. The hearing may be continued and reconvened at a later time.

Ryan Elwell, Chair
Champaign County Zoning Board of Appeals

TO BE PUBLISHED: WEDNESDAY, MARCH 2, 2022, ONLY

Send bill and one copy to: Champaign County Planning and Zoning Dept.
Brookens Administrative Center
1776 E. Washington Street
Urbana, IL 61802
Phone: 384-3708

Our News Gazette account number is 99225860.

OFFICIAL FILING
BEFORE THE
PUBLIC SERVICE COMMISSION OF WISCONSIN

Application of Highland Wind Farm, LLC, for a Certificate of Public Convenience and Necessity to Construct a 102.5 MW Wind Electric Generation Facility and Associated Electric Facilities, to be Located in the Towns of Forest and Cylon, St. Croix County, Wisconsin

Docket No. 2535-CE-100

REHEARING DIRECT TESTIMONY OF PAUL D. SCHOMER

Q. Would you please state your name and address?

A. My name is Paul D. Schomer. My business address is 2117 Robert Drive, Champaign, Illinois 61821.

Q. Have you previously provided testimony in this proceeding?

A. Yes. I evaluated the Highland application for noise level exceedances and testified on the probable adverse impacts to the health and safety of the Town of Forest residents. I also participated in the Shirley Wind infrasound study conducted in December 2012 to evaluate the cause of adverse health effects from the same or similar large wind turbines that are proposed in this docket.

Q. What is the purpose for your testimony?

A. I intend to testify on the new proposal by Highland to mitigate its exceedance of the PSC 128 Nighttime Noise Standards of 45 dBA.

Q. What materials have you reviewed?

A. In addition to the original application materials, exhibits, and testimony from the prior proceedings, I have now reviewed the testimony and exhibits of Tim Osterberg, Michael Hankard, JoAnne Blank, and Jesse Stowell with respect to their proposal to rely on proprietary software of the wind turbine manufacturers to curtail the violation of PSC 128 sound limits. I have also reviewed the recent filings from Mr. Hankard and Mr. Osterberg on the effect of a 40 dBA daytime sound limit and Highland's assurances that all sound limits imposed will be met if the project is built.

Q. Is curtailment a viable strategy to reduce power and sound for wind turbines?

A. Curtailment can be done on a limited, turbine-by-turbine basis for a variety of reasons such as reducing power during low demand periods, performing maintenance on the turbine, and responding to high wind events. Power reduction occurs by simply reducing the speed of the rotor through feathering the blades and spilling wind – much like a sailboat reduces speed by adjusting sails. Reducing rotor speed will tend to reduce sound levels, but there is no guarantee. Under some conditions, feathering the rotors to reduce rotor speed may actually increase sound levels.

Q. To your knowledge has a wind farm ever been designed with a curtailment strategy in the United States?

A. No. Wind turbines and wind farms are designed to operate at maximum capacity. It makes little sense to invest in larger turbines and then reduce power output to comply with noise limit regulations. The solution to Highland's design flaws is to use smaller turbines, which would allow the turbines to operate at full power as they were designed, and comply with all applicable noise regulations. Relying on untested software to predict when noise limits are being exceeded for a particular residence within a large wind farm, and expecting that the software will successfully reduce noise levels to maximum limits for each affected residence, is ludicrous.

Q. Are you familiar with other methods employed to use curtailment as a mitigation strategy for wind turbines?

A. Yes. I consulted with Michael Hankard in his efforts to reduce noise from a 49-turbine wind farm to two "neighboring" residences in Oregon.

Q. How does the Oregon project compare with the proposal now being made by Highland and Mr. Hankard here?

A. They are very different in scope and design. Mr. Hankard presented a paper on this subject to the Acoustical Society of America in Canada this year. His paper has been provided in his July 19, 2013 supplemental direct testimony as Ex.-HWF-Hankard-13 (PSC Ref. # 187658). One principal difference is that Mr. Hankard's proposed solution was designed to mitigate violations of Oregon noise limits at two residences, rather than the far more extensive incorporation of a mitigation plan into the design of the wind farm. Additionally, the mitigation plan in Oregon involved obtaining real time noise data from noise monitors at each of the two residences, wind speed and direction at each of the noise monitors, and wind speed reported by the wind turbines at hub height. Software developed by Mr. Hankard used these various inputs to develop a real time protocol and procedure to initiate the mitigation plan. When conditions indicate that a curtailment is required, a warning is placed on the screen of the operator of the wind farm, who is located in Chicago, IL. Within 30 minutes of such warning, the ten turbines nearest to these two residences are being shut down.

Here, Highland is proposing to use the curtailment function built into each turbine to mitigate predicted noise violations to 30 residences produced by the cumulative noise of an entire wind farm. Highland's mitigation plan would be on a trial and error basis, with no real time noise data at each affected residence. This proposal is infinitely more complex. Yet, Highland proposes to collect no real time data, and instead rely on proprietary turbine software rather than an operator to reduce power and noise to acceptable levels.

Q. In your opinion, is Highland's curtailment mitigation strategy in the public interest?

A. No, absolutely not. To permit this wind farm with mitigation as the principal means of protecting the public would not be in the public interest. The solution is to build the wind farm with smaller, quieter turbines that will run at maximum capacity without requiring curtailment. Highland is proposing a grand experiment with the Town residents as the guinea pigs. The proposed turbines are too big and emit too much noise energy. In the wake of the severe health impacts experienced by some residents in the Town of Glenmore, which has similarly large turbines, it is troubling that Highland refuses to consider a full redesign of this project.

Q. Do you have any criticisms of the proposal suggested by Michael Hankard?

A. Yes. Mr. Hankard and I worked on a project in Oregon in which wind turbine noise exceeded the state noise limits at two "neighboring" residents.[1] These wind turbines were just 1.5 MW, but the noise they produced was in excess of Oregon regulation.

In order to mitigate the noise problems with these turbines, Mr. Hankard developed a clever mitigation strategy to shut down the ten nearest turbines to these houses. The on-site data, which includes the acoustic levels, the wind speed and direction at each residence, and specific turbine operating parameters, are all transferred in real time to the central office in Chicago. There, software determines the conditions

[1] There are only five houses within many miles of this wind farm. Two of the five houses are the two discussed above; two of the houses are not in violation of the Oregon regulation; and the fifth house is owned by the landowner who sold all the land for development of the wind farm. He uses this house for some of his farm help.

under which the sound is predicted to be too high, and issues a warning to the operator that he should initiate a shutdown of the ten turbines.

Q. How does the curtailment mitigation strategy purposed by Mr. Hankard in the Highland farm differ from the system he created in Oregon?

A. The starkest difference is that the Highland curtailment proposal relies exclusively on automated programming of proprietary software. There is no ground truth of noise levels at each residence. As I understand it, the only data relied upon by the software would be from the wind speed anemometer on each turbine, which would then be programmed to reduce power output at 8 meters per second. There would be no ground truth, such as real time microphones collecting data, to determine whether the curtailment is effective at all residential facilities. Mr. Hankard does propose limited ground truth in three locations accumulating data sporadically. However, this is not nearly as effective as continuously accumulating data through all seasons and wind conditions. Additionally, none of these data are going directly to a wind farm operator that can immediately adjust the wind turbines to maintain acceptable noise levels.

Q. Do you believe that Mr. Hankard's suggestion of using curtailment as a strategy to bring Highland into conformance PSC 128 noise limits is in the public interest?

A. In my opinion, no. The current proposal simply tries to squeeze a square peg into a round hole. As I have testified previously, the wind turbines suggested in this proceeding are simply too large for the layout of the Project, producing too much noise.

Q. Is the proposed mitigation plan workable?

A. Anything is possible, but the real question here is whether it is worth the long-term risk to area residents – who will have to live with this experiment for the next 30 years. Since there will be no real time noise data collected at each residence as the experiment unfolds, the burden will shift to the residents to prove that the noise limits are being exceeded. The problem is that the turbines proposed by Highland are too big, and their acoustic emission levels are too high, to meet current PSC regulations. Highland proposes a complex solution to a problem with a simple solution: the use of smaller turbines that produce less noise and require no curtailment.

Q. Are you still concerned about the health impacts of large mega turbines such as those proposed in the Town of Forest?

A. Yes. There is significant evidence from all over the world that large turbines placed too close to residences cause very serious health problems. While the research is underway, there is continuing focus on balancing the size and output of wind turbines with public health. I do not believe that the right balance has yet been struck. The wind industry continues to claim that there is no known link between wind turbine noise and health effects.

In a recent paper, which is being submitted as Ex.-Forest-Schomer-20, I show that for a small group of specially selected people, the probability that motion sickness-like symptoms experienced by wind farm residents are unrelated to wind turbine noise is less than two in a million. This analysis proves that it is virtually certain that these individuals are adversely affected with serious health effects that result from the acoustic emission of nearby wind turbines. This changes the dynamic of the situation. Since it can no longer be said that there are no known health effects related to wind farms, it follows that the industry must prove that there will be no adverse health effects from what they plan to do, or that the industry must state what the adverse health effects will be.

Q. Is there a sound scientific basis for imposing a 40 dBA noise limit for day and night, as proposed by the PSC, for the six homes that are identified as "sensitive"?

A. Yes. George and David Hessler have coauthored an article that recommended a noise limit of 40 dBA for wind farms, which has been shown to virtually eliminate noise related complaints and health problems. I have done independent work and concluded that 39 dBA should be the maximum limit to avoid annoyance and health impacts from wind turbine noise. A recent paper that George Hessler and I coauthored, which is being submitted as Ex.-Forest-Schomer-21, explains how we independently arrived at these limits of 40 and 39 dBA.

Q. Where was your article presented?

A. It was presented at the Acoustical Society of America/International Congress of Acoustics that occurred in Montreal in June of 2013. Michael Hankard presented his paper in the same technical session at this conference.

Q. Have some jurisdictions adopted the 39 or 40 dBA maximum limit?

A. Jurisdictions all over the world have adopted a wide range of limits. Europe and South Australia tend to have limits in the range of 35 dBA, sometimes even as low as 30 dB. On the other extreme, some jurisdictions have a limit of 55 dBA. George Hessler and I wrote this paper together because we thought it was important to show to the scientific community that we arrived at essentially the same answer, even though we used different methods and approaches to get there.

Q. Did the Massachusetts wind turbine study, upon which the environmental assessment relied, support these noise limits?

A. Yes. It supported the same 40 dBA limit at night.

Q. Have the Massachusetts study's conclusions on adverse health effects from wind turbines held up to recent scrutiny?

A. No. In a paper to be presented and to be published in December 2013, which is being submitted as Ex.-Forest-Schomer-22, we show that the Massachusetts study's conclusions about the lack of connection between human health and infrasound and wind turbine noise are flat out wrong.

Q. Do you believe that a 40 dBA limit is needed to avoid adverse health effects from audible and infrasound?

A. Yes. All the experts in this proceeding agree that the louder the turbines are in audible noise and the larger the turbines are in structure, the more infrasound will be produced. The larger mega turbines seem to correlate very starkly with health impacts. It is significant that in a wind farm with only eight turbines, three families have left their homes in the Town of Glenmore. As I testified earlier, if this farm is built as designed, it is likely that the same result will occur – with or without curtailment.

Q. Without ground truth to accurately measure sound levels at all locations, how would the wind turbine operator or the PSC be informed that noise limits are exceeded?

A. Without ground truth data, no one will know whether noise levels are exceeded. The burden of proof would shift to property owners to prove the cause of their problems.

Q. What is your reaction to Mr. Hankard's suggestion to use wind speed and direction to calculate the wind turbine noise emission levels?

A. To my knowledge, it has never been used anywhere for wind turbine noise assessment, and is completely untested in practical use. It introduces a new form of average levels where 50% or more could end up not meeting the limit – at least part of the time. The noise model used in this case, ISO 9613-2, already takes directionality into account by requiring a downwind prediction in all directions. Reducing predicted sound levels further with a directivity analysis makes any prediction model less conservative.

This proposal institutes averages that change with direction, but otherwise have the same effect as the averaging inherent in the use of impedance coefficients greater than 0,0,0 in ISO 9613-2. It recreates a situation where many residences exceed the limit for large percentages of the time. Also, this novel approach immeasurably complicates the noise impact analysis for each home. Not all the residences will have the same juxtaposition to the wind at any given wind speed and direction. When the wind shifts, these directivity analyses will change. Given the infinite number of variables concerning wind speed and direction, predicting noise levels at each residence will become very complex. Additionally, the conservative value of ISO 9613-2 always predicting the "downwind" solution will be lost if Mr. Hankard's directivity analysis is adopted.

Q. Does Mr. Hankard's directivity analysis assure that the Highland mitigation curtailment plan will work?

A. No. Mr. Hankard's statement that the radiation pattern of the wind turbines is a dipole is an over simplification and does not appear to be justified by his own data.

For instance, Ex.-HWF-Hankard-9 (PSC Ref. # 186229) does little to support Mr. Hankard's assertion that he can apply a directivity pattern without introducing significant new uncertainty. According to the data in Ex.-HWF-Hankard-9 (PSC Ref. # 186229), the most common "directivity" value for the first study listed is -3 dB, which occurs at 45°, 135°, 180°, and 270° with -4 dB at 90°. Yet the first study in Ex.-HWF-Hankard-9 (PSC Ref. # 186229) indicates virtually no change in sound with wind direction and does not support Mr. Hankard's assertion. If any of the wind turbines in Forest operate in a similar fashion to Ex.-HWF-Hankard-9 (PSC Ref. # 186229), then the measured levels would be smaller than predicted. In contrast, if some of the turbines at Forest follow the second study presented in Ex.-HWF-Hankard-9 (PSC Ref. # 186229), then noise levels at two of the turbines would be under predicted by 1 dB. This directivity factor needs substantial research to demonstrate that it will not increase uncertainty and error. No persuasive data are shown that the individual turbines in the Town of Forest will instantaneously respond to wind direction and take on this pattern in all directions.

The second study Mr. Hankard presents in Ex.-HWF-Hankard-9 (PSC Ref. # 186229) has directivity values of 0,0,+1, and +1 dB at the 45°, 135°, 235°, and 315° angles to the wind. Mr. Hankard's method would subtract 1 dB at each of these directions, when according to the second study 1 dB should be added, yielding a net error of 2 dB. If this directivity pattern is so prevalent, and the wind turbine manufacturers want to report the loudest direction per IEC 61400-11, why does the IEC 61400-11 standard call for measurements in four directions instead of just one? This proposed change by Mr. Hankard makes no practical sense. Subtracting some generalized average can only introduce new error.

Q. Does Mr. Hankard's proposal to assess wind direction to determine sound levels at each residence assure that the problems encountered at Shirley will not be repeated?

A. No. While this directivity effect might reduce audible sound in some cases, infrasound flows in all directions and its amplitudes are not reduced by which direction the sound originates. Adverse health effects from infrasound will not be abated by directivity. This is another reason to stick with ISO 9613-2 and IEC 61400-11, each as is, and not venture into the unknown.

Q. Mr. Hankard treats the inputs to and predictions from ISO 9613-2 as absolute maximum noise levels. Is this the case?

A. No, it is not the case. I have closely examined the data presented in Ex.-HWF-Hessler-3 (PSC Ref. # 172233) in this matter, which attempted to measure the accuracy of noise level predictions made by using ISO 9613-2. The Hessler data show that turbine noise tends to be louder at night. These data result from two weeks of continuous measurements at 1000 feet in three directions (north, south and east) from the east end of an east-west line of wind turbines in 10-minute intervals. Averaging the daytime data (7 AM to 10 PM) reveals values of 31, 30, and 30 dB for the three directions. During the night (11 PM to 5AM) the average noise levels increase by 6 dB to 37, 37, and 36 dB from the same three locations. This same "nighttime" effect is likely to occur in the Town of Forest. Although data collection of turbine noise levels during various times of the year would likely produce different average sound levels, the important point is that there is a significant increase in noise levels at night which is between 3 and 6 dB.

Q. How does this relate to the requirement that nighttime levels not exceed 45 dBA?

A. What this means is that it would be misleading to use a 24 hour noise prediction for a wind farm to calculate the nighttime levels. The 24 hour prediction averages lower daytime levels with higher sound levels at night. The reality is that the night-only levels will be on the order of 3 dB louder than the 24 hour prediction.

Q. How does all of this apply in the current matter?

A. This means that Highland must take into account the "nighttime" effect revealed in the Hessler data by developing mean values and standard deviations empirically in the Town of Forest area in sufficient quantity for the sources and receivers to generalize to the entire wind farm. In the alternative, Highland must assume a conservative stance by predicting that the effective nighttime emissions will be 4 dB greater than those currently stated.

Q. Has Mr. Hankard adequately explained the procedure used to reduce the turbine noise levels to verify the reliability of his calculations?

A. No. Ex.-HWF-Hankard-11 (PSC Ref. # 186231) fails to include critical information necessary to understand its reliability. Ex.-HWF-Hankard-11 (PSC Ref. # 186231) shows turbine noise levels dropping by up to 6 dBA with no explanation of how the reductions were selected, how long they will be in effect and why these turbines were curtailed while others were not. Eight solution sets are reported to exist for the eight compass wind directions, north through northwest, but only one of the eight solution sets is given. Also it is stated that these eight solution sets are sufficient for all wind directions.

But, once again, no data are provided to substantiate this assertion. Further, the rate at which the solution set is changed is not explained. Is it updated once per second? Once per minute? Once per hour? What triggers a change? How long does a change take to effect? The unanswered questions are almost limitless. It is impossible to judge the veracity of a procedure when we are not told what the procedure is.

Q. Are there issues with any of the other testimony?

A. Yes. Mr. Stowell testified that this mitigation scheme is not stable, and is therefore not suitable for the long term. Specifically, he reports that the curtailment scheme will slip in and out of compliance. A system that slips in and out of compliance is unsatisfactory.

Q. Are bigger wind turbines better for people?

A. The history of wind turbines, as young as they are, is one of ever increasing size. Current units go from 1.5 to 3.5 MW, and bigger units can be expected in the future. Larger turbines may have the advantages of greater efficiency and net profit but they create more problems for people living close by. There is strong evidence that the very low infrasound frequencies produced by large wind turbines are the sources of acoustic emission that are adversely affecting people. As the power generated by wind turbines grows, the blades grow and hence the tip's speed is reduced to avoid too high an advancing blade tip Mach number.

According to a paper by van den Berg (2004), which is being submitted as Ex.-Forest-Schomer-22, the increase due to a typical nighttime wind profile (the change in velocity with altitude) was 5 dB for a wind turbine with a 58 m hub height, and up to 15 dB for a turbine with a 98 m hub height. That is, the increase in low frequency energies in size and magnitude may be substantial because of this blade-loading, wind-gradient effect, much greater than what is predicted for constant blade loading. The conclusion is that unless mitigation methods and strategies can be developed and implemented, bigger turbines are not necessarily better. They may actually be much worse for people.

Q. Have all your opinions been given to a reasonable degree of professional certainty?

A. Yes

Q. Does this conclude your testimony?

A. Yes.

NEW REPUBLIC

ENERGY JUNE 15, 2014

Big Wind Is Better Than Big Oil, But Just as Bad at P.R.

By Alex Halperin

Photo: Scott Olson/Getty Images

Nancy Shea didn't learn about the wind farm until after she moved to northwest Massachusetts to enjoy a quiet country life. The news didn't bother her. Shea, who describes herself as "green" and "crunchy," favors clean and renewable energy. But just days after the 19-turbine project went online Shea sensed something wrong. She "felt kind of queasy," one day in the kitchen. Later she woke up feeling like she had bed spins.

Shea's husband did some research and learned about wind turbine syndrome (WTS), a condition said to be caused by "infrasound," an inaudible low-frequency sound produced by the turbines. Sufferers complain about symptoms like insomnia, vertigo, headaches and disorientation. "It's a hard to describe sensation, you just want to crawl out of your skin," Shea says.

A few nights later, the couple could hear the turbines spinning—the closest is 2,200 feet away. It sounded, Shea says, like a jet repeatedly flying over their cabin. Neither of them could sleep and they drove through a snowstorm to another property they have several miles away. Shea felt better immediately. Similar symptoms have been reported worldwide by people who live near wind turbines. But America's wind industry says their condition is psychological.

There's a great deal to like about wind power. It's a domestic, renewable power source that doesn't produce greenhouse gasses. It doesn't require digging anything out of the ground and, unlike nuclear energy, doesn't create any risk of catastrophic accidents. According to the American Wind Energy Association (AWEA), more than 70 percent of the public view wind energy favorably. Following President Obama's recent push to reduce greenhouse gas emissions, there's every reason to believe that these giant pinwheels will become more familiar sights on the American landscape. (The towers alone are hundreds of feet high.)

Clean energy, however, is not the same thing as flawless energy. Producing power on a large scale involves processes and infrastructure which disrupt ecosystems and have other unintended consequences. Dams, for example, remain the most important source of renewable power in this country and environmentalists hate them.

Wind farms have raised objections for ruining views and being noisy. But the fight over WTS presents a more difficult challenge for the industry. And while wind power advocates like to think of it as a forward looking and pragmatic fix for America's energy needs, when it comes to managing this mysterious phenomenon, they're foolishly borrowing from the bad old energy playbook.

Earlier this year, two physiologists at Washington University in St. Louis published a paper in the journal *Acoustics Today* detailing several mechanisms by which infrasound from wind turbines could have detrimental effects. One, for example, is "excitation" of nerve fibers in the inner ear that are related to tinnitus and "aural fullness." The article concludes that more study of infrasound is needed and pointedly states:

> If, in time, the symptoms of those living near the turbines are demonstrated to have a physiological basis, it will become apparent that the years of assertions from the wind industry's acousticians that "what you can't hear can't affect you"… was a great injustice.

Last year the same journal published an article by an England-based acoustician named Geoff Leventhall who argues that wind turbines don't produce infrasound at sufficient levels to cause health problems. When I called Leventhall, whose clients have included wind power developers, he said he doesn't believe WTS exists. Leventhall doesn't dispute that infrasound can distress people. His disagreement with the Washington University scientists, grossly simplified, is in how the infrasound produced by wind turbines should be measured.

In written responses to questions, AWEA says that waves on the seashore, a child's swing, a car and even a human heartbeat expose people to higher levels of infrasound than wind turbines do. AWEA relied heavily on Leventhall's work and calls him "the most cited and referenced acoustician regarding wind energy in the world." The organization cited two studies, one from Australia, one from New Zealand, which suggest that WTS results from a "nocebo" effect, essentially that if people are told wind turbines make them sick, they will feel sick around wind turbines. Leventhall endorses this view.

In an email, one AWEA manager wrote that "Independent, credible studies from around the world have consistently found that sound from wind farms has no direct impact on human physical health." AWEA also cites a 2012 report - http://www.mass.gov/eea/docs/dep/energy/wind/turbine-impact-study.pdf)%20regarding - prepared for two Massachusetts state agencies by an independent panel which found no evidence of the existence of WTS. (Activists who oppose situating turbines near homes have numerous objections to the report.)

Anyone who has ever played the NIMBY game knows the power of a scientific imprimatur. But the two sides are wielding their science to achieve asymmetrical goals. In the Washington University paper, Alec Salt and Jeffrey Lichtenhan write:

> Whether it is a chemical industry blamed for contaminating groundwater with cancer-causing dioxin, the tobacco industry accused of contributing to lung cancer, or athletes of the National Football League (NFL) putatively being susceptible to brain damage, it can be extremely difficult to establish the truth when some have an agenda to protect the status quo.

In these cases, industry's primary goal isn't to be right on the merits, though that would be nice, but to continue operating. As long as it's planting turbines, the wind industry is winning. But as long as it's simply dismissing WTS, the industry is putting itself at risk of losing its sympathetic, clean image.

Dr. Steven Rauch, an otologist at the Massachusetts Eye and Ear Infirmary and a professor at Harvard Medical School, believes WTS is real. Patients who have come to him to discuss WTS suffer from a "very consistent" collection of symptoms, he says. Rauch compares WTS to migraines, adding that people who suffer from migraines are among the most susceptible to turbines. There's no existing test for either condition but "Nobody questions whether or not migraine is real."

"The patients deserve the benefit of the doubt," Rauch says. "It's clear from the documents that come out of the industry that they're trying very hard to suppress the notion of WTS and they've done it in a way that [involves] a lot of blaming the victim."

In fact, the inconstant nature of symptoms can compound WTS. Even when someone doesn't feel the effects, they're always conscious of wind speed and direction as they try to sense when their symptoms might return. (Turbines produce infrasound independently of audible noise.)

Massachusetts governor Deval Patrick aims to increase the state's wind energy capacity to 2000 megawatts by 2020, a total equal to roughly 15 percent of the state's current electricity production. In a densely populated state that means more people are inevitably going to feel affected by WTS, even if it doesn't exist.

As wind power has become more prominent, so have complaints. Scores of residents of Herkimer County, N.Y. are suing the Spanish wind power company Iberdrola over a wind farm. A judge has ordered that two wind turbines in Falmouth, Mass. can only be operated 12 hours a day and not on Sundays.

The wind industry might take a lesson from Nancy Shea: People are generally reasonable, maybe more reasonable than they should be. Shea refuses to spend any more nights in the house she and her husband bought. She calls it a "dead asset." Nonetheless, she still considers herself pro-wind.

In the annals of corporate public relations debacles, WTS is a relatively minor one, at least for now. It would be self-defeating if the industry squanders this promising moment by failing to candidly address WTS concerns. Not doing so invites further attacks from Fox News - http://mediamatters.org/blog/2013/02/26/fox-news-wind-power-hypochondria/192808 - and National Review - http://www.nationalreview.com/articles/289920/wind-energy-noise-pollution-robert-bryce - and other conservative groups looking for an excuse to bash clean energy.

The best advice might come from the Salt and Lichtenhan article. Big Wind, it argues, should "acknowledge the problem and work to eliminate it."

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The Noise From Wind Turbines: Potential Adverse Impacts on Children's Well-Being

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The Noise From Wind Turbines: Potential Adverse Impacts on Children's Well-Being

Arline L. Bronzaft[1]

Abstract

Research linking loud sounds to hearing loss in youngsters is now widespread, resulting in the issuance of warnings to protect children's hearing. However, studies attesting to the adverse effects of intrusive sounds and noise on children's overall mental and physical health and well-being have not received similar attention. This, despite the fact that many studies have demonstrated that intrusive noises such as those from passing road traffic, nearby rail systems, and overhead aircraft can adversely affect children's cardiovascular system, memory, language development, and learning acquisition. While some schools in the United States have received funds to abate intrusive aircraft noise, for example, many schools still expose children to noises from passing traffic and overhead aircraft. Discussion focuses on the harmful effects of noise on children, what has to be done to remedy the situation, and the need for action to lessen the impacts of noise from all sources. Furthermore, based on our knowledge of the harmful effects of noise on children's health and the growing body of evidence to suggest the potential harmful effects of industrial wind turbine noise, it is strongly urged that further studies be conducted on the impacts of industrial wind turbines on their health, as well as the health of their parents, before forging ahead in siting industrial wind turbines.

Keywords

health, cognition, language, learning, wind turbines, transportation, well-being

Introduction

Thirty-six years ago, when my then 8-year-old daughter learned I was looking at the impact of passing train noise on children's classroom learning, she asked me why I was conducting this study because it seemed obvious to her that passing train noise disrupting children's learning every 4 to 5 minutes for 30 seconds would affect their learning ability. I responded that someone had to demonstrate the impact of the noise on classroom learning with solid data, explaining the meaning of data to my daughter.

Assessing the Impacts of Noise on Children's Learning

My initial study on noise/learning link examined the impact of elevated train noise on reading ability in a school situated 220 feet from an adjacent elevated train structure. Eighty trains passed the school during the hours between 9 a.m. and 3 p.m. each weekday and disrupted the classes on the side of the building facing the tract every 4½ minutes for 30 seconds. The sound level in a classroom rose to 89 dBA from 59 dBA when the train passed, forcing the teacher to scream to be heard or to stop teaching until the train passed. In 1973, the New York Department of Air Resources reported that 11% of classroom teaching time was lost because of passing trains.

Reading scores were examined for 4 years comparing the scores of the children in the classrooms exposed to train noise with children attending classrooms on the quiet side of the building. Reading scores of children on the noisy side of the building lagged behind their peers on the quiet side from 3 months in the lower grades to as much as 1 year in the sixth grade. Whether the cause was the lost teaching time, the distraction of the trains, or the fact that the children took the tests in the noisy rooms, the fact remains that children in the noisy classrooms demonstrated poorer reading scores than children on the quiet side of the building. My results were published in a article in 1975 in the *Journal of Environment and Behavior* (Bronzaft & McCarthy, 1975).

Responding to Effects of Noise on Learning

The reaction to this study in New York City was overwhelming. Newspaper accounts of the study plus statements by public officials highlighted the findings broadly. This reaction made

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it easier for me to approach the Transit Authority and ask the agency to select the tracks adjacent to P.S. 98 to test the effectiveness of rubber padding in quieting noisy elevated trains. When the pads were in place, the principal of the school and I asked the Board of Education to install noise abatement materials in three of the noisiest classrooms at P.S. 98. The noise reduction as a result of the two abatement techniques was 6 to 8 dBA. When asked to return to the school by a public official to conduct a study after the installation of noise abatement materials, I did so nervously. However, when I compared the reading scores of children in classrooms facing the tracks with those on the quiet side of the building, children on both sides of the building were reading at comparable levels. This study clearly demonstrated that when you correct a noise problem, children benefit (Bronzaft, 1981).

Research on Effects of Noise on Children's Learning Expands

Subsequent years saw additional research on the effects of noise on children's learning. Wachs and Gruen (1982) noted that noisy households can disrupt a child's development and warned parents about shouting and playing televisions and stereo systems too loudly. The U.S. Federal Interagency Committee on Aviation Noise (FICAN) concluded, after summarizing the findings of 20 studies, including my study in 1975, that aircraft noise can interfere with reading, speech acquisition, and noise (FICAN, 2000). Lercher, Evans, and Meis (2003) examined ambient neighborhood noises and found that chronic noise exposure was significantly related to poor incidental and intentional memory in children. S. A. Stansfeld et al. (2005) reported that an investigation of school children in the Netherlands, Spain, and the United Kingdom indicated that aircraft noise could impair cognitive development, especially reading comprehension. Recent studies by Matheson et al. (2010) and S. Stansfeld, Hygge, Clark, and Tamuno (2010) add to our knowledge of the adverse effects of road traffic and aircraft noise exposure on children's learning abilities, particularly in the school setting.

In my book *Top of the Class*, published in 1996, which examined the lives of high academic achievers, I learned from these high academic achievers that they were reared in homes that respected quiet (Bronzaft, 1996). Quiet areas were provided for them to read, study, and learn. Their parents tended not to discipline them with shouting and loud voices but rather used lowered, stern voices to correct their behavior. We could say that a quieter environment served these high academic achievers well.

Greater Awareness of Noise/Learning Link?

U.S. President Obama understands that noise can affect classroom learning. In a speech before Congress in February 2009, the President identified a young woman in the audience named Ty'Sheoma Bethea who attended a school in Dillon, South Carolina. In identifying the elements impeding on the learning in her classroom, he noted that "they have to stop teaching six times a day because the train barrels by their classroom." The American National Standards Institute in 2002 set acoustical standards for classrooms, stressing the importance of a proper acoustical school environment. In 2009, the House Education and Labor Committee of the U.S. Congress passed a bill that would introduce measures designed to reduce or eliminate exposure to classroom noise, as part of the Green High Performing School Facilities Act, but this legislation has not yet become law.

My daughter, now 44 years old, wonders why after years of research demonstrating a link between noise and children's learning, we need to conduct further research as suggested by the U.S. Federal Aviation Administration's (FAA) proposed study on the effects of aircraft noise on classroom learning (Airport Cooperation Research Program, Project Number 02-26). She believes there is enough research demonstrating an adverse effect of noise on learning and we should move, without hesitation, to creating quieter classroom environments rather than using funds to conduct further studies. Despite the fact that I serve on the Transportation Research Board committee that is overseeing the FAA-funded research on airport noise and children's schoolroom learning, I tend to agree with my daughter's conclusion. In 2011, there definitely is sufficient research linking noise to impaired learning and we should work toward improving the school learning environment.

Impacts on Children Beyond Learning

It should be pointed out even if the child were able to overcome the adverse effect of noise in the classroom, the need to do so may create stress and discomfort for the child, which in the long run can have an adverse effects on his or her health. In my 1974 study, the children interviewed expressed their unhappiness at the passing trains. One child, when interviewed for television, said, "I wish the trains wouldn't run anymore."

Noise has been associated with physiological problems in children. Studies on the adverse effects of loud sounds and noise on children's hearing have been well documented. Yet youngsters continue to expose themselves to loud video games, loud concerts, and so on. An example of the effects of long-term exposure to loud music is Pete Townshead, a member of the rock band "The Who," who has experienced hearing problems himself because of his exposure. Yet hearing loss is not the only physiological impact of noise. Evans and Lapore (1993) reviewed the nonauditory effects of noise and concluded that children living near or attending a school near a major airport were more likely to experience elevated blood pressure. Passchier-Vermeer and Passchier (2000) wrote that road traffic and aircraft noise have been found to affect children's cardiovascular system. The U.S. government over

30 years ago in its "Noise: A Health Problem" pamphlet stated that children in homes and schools exposed to aircraft noise had higher blood pressure than children in quieter environments (U.S. Environmental Protection Agency, 1978). Although this booklet pointed out back then that more studies were needed to strengthen this finding, it concluded with the statement that "this finding is cause for concern."

When Parents Are Stressed, Children May Suffer!

Another point that I would like to make concerning the impacts of noise on children's lives deals with the effects noise has on their parents. There are sufficient studies linking noise to adverse health effects (Bronzaft & Hagler, 2010) in adults. Even if we were to argue that the best data linking noise to well-being centers on a diminished quality of life rather than specific health ailments, as noted by the World Health Organization, then living near a noisy source would most likely diminish quality of life. Good health is not merely the absence of symptoms; it is the ability to experience a decent quality of life. Parents experiencing this poorer quality of life, or suffering from a noise-related ailment, may have less patience with their children and, as a result, express more anger at their misdeeds. I need not illustrate further how good parent-children relationships affect the health and well-being of children. If noise prevents a parent from getting a good night's sleep because of overhead aircraft, then one could expect this tired parent to be less able to deal with the obligations of parenthood.

Going Beyond Existing Findings on Noise Impacts

How does my discussion of the impacts of noise, largely measured on the dbA scale, on children's mental and physical health relate to the topic of wind turbine noise, including sound levels measured on the A scale as well as potential impacts from low-frequency sound. What I think we can learn from the research on the effects of noise on children is that before changes are made based on research findings, authorities demand solid data with huge samples. Occasionally, there are exceptions, as I experienced in the case of the New York Transit Authority and the New York City Board of Education actions to abate the noise at the school in which I had conducted my research on noise and learning. Although studies such as mine did influence the U.S. FAA to abate noise at schools lying within a designated noise area, it is difficult for schools to receive this abatement, largely because the noise metrics used by the FAA limit the numbers of schools that may be eligible. Thus, far too little has been done in the United States to lessen the effects of intruding noises from traffic, trains, and aircraft, despite a growing body of literature linking noise to adverse impacts on children's mental and physical health. With respect to wind turbine noise, the solid data we now have regarding the noise/health link in children should serve to warn about the potential harm of wind turbine noise and caution should be exerted before building industrial wind turbines near people's homes.

How Valid Are the Data in Support of Wind Turbines?

Before the academically reviewed journal articles are written and published, researchers explore problems employing observations and interviews. Before I conducted my research as noted above, parents of the children at P.S. 98 had long complained about the noise from the trains but no action was taken until after the findings of my research were published. However, I want to add that many public officials in New York City joined in our efforts to quiet the tracks next to the school and that hastened the abatement. Similarly, Dr. Pierpont (2009) was responding to resident complaints when she undertook her observations and interviews of residents living with wind turbine noise. Dr. Pierpont's observations, and those of other speakers who presented at the recent First International Symposium on the Global Wind Industry and Adverse Health Effects held in Ontario, Canada, are being questioned because they appear to be based on small numbers of residents. The validity and reliability of these observations are also being criticized because they lack comparisons with control groups. In the early days of psychology, Dr. Freud took careful notes on his patients' complaints and he relied on observations and interviews as he formulated his theory of human behavior. In time Dr. Freud, one of the great minds of the 20th century, developed a theory of human behavior, as well as a method to treat psychological problems. More traditional studies of his theories followed afterwards. Observations and interviews generally proceed questionnaires and testing that result in correlative data to be analyzed and evaluated.

The dismissal of the adverse effects of noise on residents living with wind turbine noise has largely come from the wind power industry, which has supported this claim with reports by acousticians, doctors, and engineers whom they have hired to write on the noise/health relationship. Yet there exist reports written by researchers that suggest that both the wind industry and governments in favor of wind turbine energy have erred in concluding that noise from wind turbines cannot affect physical and mental well-being. Dr. Frits van den Berg (2004), a Dutch physicist, claims that the methods used to predict the noise from large turbines are inappropriate and, thus, the conclusions drawn from findings based on these methods have to be questioned. Dr. van den Berg believes that the measurements of wind turbine noise near people's homes in quieter environments at night may be underestimated by as many as 10 dBA. Dr. van den Berg's conclusions have been supported earlier by Pedersen and Halmstad (2003). Studies such as these deserve to be examined more closely and, at the very least, suggest that additional studies be conducted to evaluate the impacts of wind turbine noise, including the low-frequency sounds, on individuals.

A Growing Interest in the Impacts of Wind Turbine Noise

Garret Keizer in his book *The Unwanted Sound of Everything We Want* (2010) states that while he is not an expert on wind turbine noise, he can still write as an individual who personally researched the issue of noise and wind power, including the works of van den Berg and Pedersen, for his book. He also personally visited residents in Maine who described how the wind turbine noise affected their lives. Mr. Keizer concluded that "wind turbines produce a devilishly complex form of noise that, combined with the imprudent siting of certain wind installations, is making some people sick." (p.221) Additionally, Mr. Keiser, in thinking about future environmental debates, states that "in debates over wind energy, noise will be front and center." (p.221)

In a *New York Times* article (Zeller, 2010), Mr. Zeller gives voice to residents who have had their quality of life diminished by nearby wind turbines, but then adds that "for the most extreme claims, there is little independent backing." Unfortunately, the only studies he cites are those from American Wind Energy Association, a trade group, and its Canadian counterpart, which concluded that "there is no evidence that the audible and sub-audible sounds emitted by wind turbines have a direct adverse physiological effects." The *New York Times* published two additional articles shortly afterwards (Wald, 2010; Wald & Zeller, 2010) on wind power energy. Additionally, President Barack Obama mentioned wind power as an alternative energy source that we must pursue in his State of the Union address in early January 2011. That Mr. Keizer's noise book, and the soon to be published book *Why Noise Matters* (Stewart, 2011), contain sections on wind turbine noise and that several stories on wind power have recently appeared in the *New York Times* indicate a both a growing interest in wind power as an alternative energy source as well as a source for potential harm from noise.

A Call for More Research

Yet this interest in harnessing wind power must be accompanied by research to resolve the issues of the potential harm of wind turbine noise on individuals living nearby. Research should also be conducted on the cost-effectiveness of harnessing the wind among other concerns. From past experience, I would venture to guess that the eagerness to move to wind power on the part of industry and governments internationally will result in a reluctance to support research that may conclude that caution is required when locating wind turbines close to residential communities. Of course, I speak from an American perspective where history has demonstrated how quickly Americans adopt new products, without requisite research on harmful effects, and how reluctantly they relinquish these products when evidence proves that they may be harmful. Similarly, when it comes to environmental concerns, the United States often errs on the side of industry, as noted by a *New York Times* editorial ("Questions About Fracturing," 2010), and proceeds with activities that might be harmful to the environment. In this editorial, the concern is hydraulic fracturing, which has been implicated in a number of water pollution cases. The drilling industry, like the wind power industry, states that its technology is "fundamentally sound" but the editorial adds: "We need more credible assurances this time." Yet the United States is most likely not alone in requiring *overwhelming* evidence to remove dangerous products or to proceed with dangerous technology.

Enough Evidence to Issue Warnings About the Hazards of Wind Turbine Noise

The U.S. Environmental Protection Agency released a booklet in 1978 that contained a section entitled "Special Effects on Children" and cited my research on the impacts of noise on children's classroom learning. The booklet in its final word section concludes: "It is finally clear that noise is a significant hazard to public health. Truly, noise is more than an annoyance." In 2009, the U.S. Environmental Protection Agency (http://www.epa.gov/air/noise.html) issued a pamphlet entitled "Say What" for middle school students, which states, "Noise can not only harm your hearing—it can also make it hard to concentrate while reading or doing homework, make you frustrated, prevent you from falling asleep, and make it hard to communicate with your family and friends."

Yet, despite declarative statements in government publications, and I could have added others to those cited above, the U.S. government is still assessing the impact of aircraft noise on children's learning and still thinking about passing legislation to quiet the nation's schools. With the American educational system falling behind the systems of other nations, especially evidenced in the lower number of people graduating from college, it is indeed egregious to allow our school children's education to be adversely affected by noise both inside and outside the school as well as the home. It would also be egregious to fail to consider the impacts of new sources of noise, for example, industrial wind turbines on their health.

Dr. William H. Stewart, the former Surgeon General of the United States, in a keynote talk to a 1969 Conference on Noise as a Public Health Hazard stated the following: "Must we wait until we prove every link in the chain of causation. In protecting health, absolute proof comes late. To wait for it is to invite disaster or to prolong suffering unnecessarily." I was taught that an ounce of prevention was worth more than a pound of cure. I believe we should explore the potential harmful noise effects of industrial wind turbines before we adopt this energy source; taking corrective action many years down the road, when the proof is overwhelming, would be, as Dr. Stewart says, "prolonging suffering unnecessarily."

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Bio

Arline L. Bronzaft is a Professor Emerita of Lehman College, City University of New York. She serves on the Mayor's GrowNYC, having been named to this organization by three previous Mayors as well. Dr. Bronzaft is the author of landmark research on the effects of elevated train noise on children's classroom learning; has examined the impacts of airport-related noise on quality of life; and has published articles on noise in environmental books, academic journals and the more popular press. In 2007, she assisted in the updating of the New York City Noise Code.

District 225
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William Mulvaney, Superintendent
Darren Loschen, Principal

Dear Chairman Weinard,

My name is Bill Mulvaney and I am the Superintendent of Schools for Armstrong Township High School and Armstrong-Ellis CUD #61. I also served on the wind panel that met to try and give direction to the county board on wind turbine ordinances. Our panel did not come up with any recommended changes, but I would like to share a few thoughts with you.

I have noticed that we have some children in our district that appear to be having some medical issues related to the wind turbines. Headaches, lack of sleep and jaw issues seem to be the most common. The students also complain about not being able to sleep or not getting a full night's sleep due to sound issues.

We have also been advised that we will be losing a couple of families because the wind turbines were placed close to homes and the families can no longer handle the flicker and noise issues.

While these issues were brought up at our panel discussions, I was not fully aware of the impact that the wind turbines would have to my school districts. It is never a good thing when children have health issues or families have to leave their homes to get away from the turbines. The revenue generated by the turbines is a blessing to our schools, but the unintended consequences are real.

I hope this letter sheds some light on real issues that affect districts that house wind farms. I also hope that when ordinances are discussed in the future, that these issues are considered.

Sincerely,

William C. Mulvaney
Superintendent
Armstrong Schools

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CHAMPAIGN COUNTY
PLANNING & ZONING

Enjoying a windfall

BY BRIAN L. HUCHEL bhuchel@dancomnews.com | Posted: Sunday, August 2, 2015 6:50 am

Enjoying a windfall

Brian Huchel|Commercial-NewsTurbines in the Hoopeston Wind Farm stand out against the sunset west of Rossville. Area school districts where two wind farms are located have seen a boost in tax revenue from the turbines.

DANVILLE — The blades of the second wind farm in Vermilion County began turning this year and with it another round of local school districts are preparing for the financial windfall that could come as a result.

The Hoopeston Wind Farm, located just northwest of Rossville, began producing electricity earlier this year. It brings more schools into the mix as recipients see a rise in equalized assessed valuation as a result of the new turbines.

Hoopeston School District Superintendent Hank Hornbeck was “cautiously optimistic” four years ago when looking ahead at the possible additional funding that could come from the wind turbines. Now, with the blades turning, he is working toward trying to take advantage of the 19 turbines that stand in his school district.

“We’re working on the levy and seeing what it means for us,” Hornbeck said last week, adding that not a lot has been completed yet. “We’re trying to learn from Paxton, Milford and Armstrong.”

The wind farm resulted in the construction of almost 50 wind turbines along a stretch reaching from around 3 miles east of Illinois Route 49 to the Hubbard Trail Country Club north of Rossville. The Potomac and Rossville-Alvin school districts are among the other districts that will see improved equalized assessed valuation as a result of the wind turbines.

The equalized assessed valuation includes all computed property values upon which a district's local tax rate is calculated.

A bill passed earlier this summer gave districts around the state a boost by indicating schools would receive 92 percent of state funding they should receive, rather than 89 percent.

Hornbeck said the school relies heavily on state-funding, which came up at less-than-expected levels a year ago. It is a boon to have an extra source to provide funds.

"It's always a question mark of what we're going to get funding wise from the state," he said. "It's good anytime you can have additional revenue coming into your district locally."

Winds of change

County officials were given an idea in March of how schools were benefiting from the presence of the wind turbines. Danville Area Community College President Alice Jacobs and then-Oakwood School District Superintendent Keven Forney stood before members of the Vermilion County Board.

Both cited receiving more than $100,000 this year as a result of the taxation on the California Ridge Wind Farm turbines, a turnaround from the lack of funding both schools suffered in recent years. Forney championed the need for more local fiscal support, such as through the wind farms.

While Hoopeston, Rossville-Alvin and Potomac press forward on what the turbines could mean for their school districts, others in Vermilion County already have seen and put the benefits to good use.

Bill Mulvaney is superintendent of the Armstrong-Ellis Grade School and Armstrong Township High School. Four years ago, he was hopeful of what the money from the California Ridge turbines could mean for the students.

"From a school perspective, it's been a huge success," he said. "Revenues from the turbines have been very beneficial."

The way school district lines fall, the high school received the benefits of 110 of the California Ridge turbines. That results in $500,000 for the high schoolers. Eighty turbines fall within the grade school's district, translating into an additional $400,000 in funding.

The result of an additional $500,000 has been big for the high school, which was able to initiate a 1:1 program for the upcoming school year. The program puts a Chromebook tablet in the hands of each student.

"I don't know if we'd be able to do that without that funding," Mulvaney said. "Small districts rely so much on property taxes. I'm not sure we could have done it."

He added: "Especially with the fact the state's not living up to its obligation of funding districts because of the financial issue it faces."

While the benefits have not been as drastic for the grade school, the opportunities are still there. Mulvaney pointed out the grade school operates on a budget of $1.1 million-$1.2 million, making the extra $400,000 a "pretty substantial" addition.

"We want to use those dollars to be beneficial," he said.

The California Ridge Wind Project, owned by Invenergy LLC, has been producing electricity since the end of the 2012. The project consists of as many as 134 wind turbines, 104 of which are in Vermilion County.

The California Ridge wind farm starts along County Road 2150N just north of Newtown in Pilot Township and stretches north and west to just across the line into Compromise and Ogden townships in Champaign County.

Frugal spending

Gary Lewis is the superintendent of the Oakwood school district. With 11 of the California Ridge wind turbines standing in his district, the school is continuing to receive $100,000 of additional funding.

It's a benefit for the school, he said, following the loss of the Dynegy power plant a few years ago. It lost between $4 and $5 million with that closing.

He noted that the turbines do have a depreciation of rate of about 4 percent, but said that hardly detracts from the schools opportunity to use the additional funding.

"It goes into our general fund and we spend as wisely and as best we can," he said.

Latest Research on Wind Turbine Health Impacts Brings Unsurprising Results

https://www.sciencealert.com/study-after-study-shows-wind-turbine-syndrome-is-a-myth-including-this-latest-one
AFP 23 JUNE 2020

The low-frequency, inaudible sounds made by wind power stations are not damaging to human health despite widespread fears that they cause unpleasant symptoms, research published in Finland on Monday said.

A number of studies have already concluded that the audible noise from the energy-generating windmills does not cause health impacts beyond annoyance and sleep disturbance in people living close by.

However, the two-year Finnish project, commissioned by the government, examined the impact of low-frequency - or infrasound - emissions which cannot be picked up by the human ear.

People in many countries have blamed the infrasound waves for symptoms ranging from headaches and nausea to tinnitus and cardiovascular problems, researchers said.

Scientists used interviews, sound recordings and laboratory tests to explore possible health effects on people living within 20 kilometres (12 miles) of the generators.

Yet the findings "do not support the hypothesis that infrasound is the element in turbine sound that causes annoyance," researchers said, adding: "It is more likely that these symptoms are triggered by other factors such as symptom expectancy."

Tests also found no evidence that wind turbine sounds affected heart rates, the study said.

Wind power can be one of the cheapest forms of renewable energy and has spread widely in recent years, not least in China, the United States and Brazil.

Fifteen percent of the EU's energy comes from wind power, according to 2019 research by industry body WindEurope, with Denmark, Ireland and Portugal the member states most reliant on it.

Opponents of the windmills, which can stand up to 140 metres (460 feet) high, argue they blight the landscape and have an adverse effect on the well-being of people living in the vicinity.

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The link between health complaints and wind turbines: support for the nocebo expectations hypothesis

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The worldwide expansion of wind energy has met with opposition based on concerns that the infrasound generated by wind turbines causes health problems in nearby residents. In this paper, we argue that health complaints are more likely to be explained by the nocebo response, whereby adverse effects are generated by negative expectations. When individuals expect a feature of their environment or medical treatment to produce illness or symptoms, then this may start a process where the individual looks for symptoms or signs of illness to confirm these negative expectations. As physical symptoms are common in healthy people, there is considerable scope for people to match symptoms with their negative expectations. To support this hypothesis, we draw an evidence from experimental studies that show that, during exposure to wind farm sound, expectations about infrasound can influence symptoms and mood in both positive and negative directions, depending on how expectations are framed. We also consider epidemiological work showing that health complaints have primarily been located in areas that have received the most negative publicity about the harmful effects of turbines. The social aspect of symptom complaints in a community is also discussed as an important process in increasing symptom reports. Media stories, publicity, or social discourse about the reported health effects of wind turbines are likely to trigger reports of similar symptoms, regardless of exposure. Finally, we present evidence to show that the same pattern of health complaints following negative information about wind turbines has also been found in other types of environmental concerns and scares.

Keywords: wind farms, infrasound, nocebo effect, psychological expectations, health scares, symptom reporting, environmental risks, media warnings

INTRODUCTION

In recent years, challenges to new wind farm developments have been mounted on the basis that exposure to sound, and particularly infrasound, generated by wind turbines poses a health risk (1). Unfortunately, addressing concerns about health effects has been complicated by a lack of clarity about what might be causing the symptoms reported. Perceived adverse health effects said to be experienced by people living near wind turbines include symptoms such as sleep disturbance, headache, earache, tinnitus, nausea, dizziness, heart palpitations, vibrations within the body, aching joints, blurred vision, upset stomach, and short-term memory problems (2). In this article, we explore factors that might explain symptom reporting attributed to wind farms and put forward the case for the nocebo expectations hypothesis; that symptom reporting can be explained by negative expectations, rather than any pathophysiological link between symptoms and wind farm sound. Research consistently indicates that the expectation of adverse health effects can itself produce negative health outcomes, which is a phenomenon known as the nocebo effect (3). Negative expectations generating nocebo responses have been shown to have a powerful influence on health outcomes in clinical populations (4), and reported symptom experiences in community samples (5).

THE LINK BETWEEN WIND FARM SOUND AND HEALTH COMPLAINTS

When investigating the cause of symptom reporting attributed to any purported environmental hazard, it is axiomatic that the existence of a biological basis for symptomatic experiences is thoroughly explored, so that an organic cause of symptoms is not erroneously discounted (6). Given that symptom reporting has been attributed to wind farm sound (2), it is necessary to consider the evidence for any direct relationship between exposure to such sound and symptom reporting. Given reductions in mechanical noise, as a result of refinements to wind turbine design, aerodynamic sound is now the dominant source of noise from modern wind farms (7). This aerodynamic noise, which is generated as a result of the flow of air past the turbine blades, is present across a range of frequencies, from the audible to sub-audible infrasound (8).

At this time, studies have not found a direct causal link between living in the vicinity of wind farms, audible wind farm sound exposure, and physiological health effects (1). Audible sound levels, assessed at the nearest residence, have been consistently found to fall within accepted health and safety limits for ambient background noise, and evidence does not support a direct link between such sound exposure and symptom reporting (9).

To elaborate further, although a small proportion of people report being annoyed by wind farm sound, particularly by detectable fluctuations of sound in the mid-frequency range (500–1000 Hz), the evidence does not indicate that exposure to such sound is directly causing adverse physiological effects in those living in the vicinity of wind farms (8). In addition, despite concerns that audible low frequency noise (20–200 Hz) produced by wind turbines is triggering symptomatic experiences, this is not supported by the scientific evidence (10).

Further, the evidence does not substantiate conjecture that exposure to sub-audible wind farm generated infrasound (sound below 20 Hz) is responsible for health complaints. It is important to note that exposure to infrasound is an everyday experience. Infrasound is constantly present in the external environment, caused by phenomena such as weather variations, air turbulence, ocean waves, traffic, and other machinery (11). Notably, the body and vestibular systems have evolved to prevent disturbance from infrasound generated from internal processes, such as respiration and heart rate, which is produced at higher levels than infrasound generated by wind farms (12). While sound in the infrasonic range may become audible at sufficiently high pressure levels, infrasound produced by wind turbines is below the threshold of human perception (11, 13), and research does not support the existence of adverse health effects of exposure to infrasound at sub-audible levels (14). Importantly, a recent investigation found the contribution of wind turbines to measured infrasound levels at residential locations near wind farms was insignificant in comparison with the background level of infrasound in the environment (15). Given consistent evidence that infrasound produced by wind turbines does not exceed typical levels of infrasound found in everyday urban or rural environments, health impacts of infrasound produced by wind turbines are not indicated (12, 16).

As the evidence does not support a direct link between audible or sub-audible sound generated by wind turbines and reported symptomatic experiences by people living in the vicinity of wind farms, it is apparent that factors beyond exposure to wind turbine sound are implicated in symptom reporting.

PERCEPTION OF HEALTH RISK AND EXPECTATIONS

There is accruing evidence that some people facing the prospect of a new wind farm near their residence, or currently living within the vicinity of a wind farm, are genuinely fearful of the potential health effects of operating wind turbines (1). This has relevance as evidence shows a relationship between assessment of health risk and symptom reporting, which does not depend upon whether a health risk is genuine (17). This is seen in community examples where there has been an error about exposure to a perceived toxic agent. In one such case, symptom complaints attributed to exposure to electromagnetic radiation from a mobile phone tower occurred when the tower itself was not yet active (18).

In fact, extreme increases in symptom reports, in instances of both genuine and perceived toxic exposure to harmful agents, have been repeatedly shown in community settings (19) with strength of environmental concern being a critical factor in predicting the occurrence of symptom complaints (20). This was highlighted in a study in which participants, from 10 villages in Germany, had their sleep monitored over 12 nights during which they were exposed to sham signals and electromagnetic field signals from an experimental base station (21). There was no evidence for short-term physiological effects of electromagnetic fields emitted by mobile phone base stations on sleep quality, but findings demonstrated a negative influence on objective and subjective sleep quality in subjects who were concerned that proximity to mobile phone base stations might negatively affect health.

Evidence shows that health-related worries about perceived environmental hazards inform negative expectations, which in turn draw attention to body processes and shape how individuals decipher symptoms [e.g., Ref. (22)]. Negative expectations translate into symptomatic experiences, because focused attention to the body has the tendency to draw awareness to common sensations that might otherwise go unnoticed (23). Further, increased anxiety itself causes a rise in physiological activity giving rise to symptoms such as dry mouth and rapid heart-beat (23). Evidence suggests people may misinterpret symptoms of hypervigilance and anxiety as a sign of illness, particularly if symptoms experienced are consistent with concerns about health (24).

Recently, there has been a noticeable rise in the number of people expressing concern about health effects presented by the sound generated by wind farms, and fears about health risk have emerged as a key predictor of opposition to wind farm development (25, 26). Such fears are more prominent in countries where wind farms are relative new comers on the landscape, which aligns with consistent evidence of associations between the introduction of new technologies, community concern about related health risks, and symptom reporting (27, 28).

MATTER OF EXPECTATION

While the operation of modern commercial wind farms commenced more than 20 years ago in several nations, widespread claims that exposure to wind farm sound produces adverse, often acute and immediate, symptomatic experiences, are much more recent (29). This change is reflected in the shifting focus of community opposition to wind farms over time. Historically, community opposition to wind farms has centered on concerns about depreciation of property values, problems with esthetic integration on the landscape, and apprehension about the intrusiveness of noise produced by wind turbines (30, 31). However, in recent years, concern about the adverse health risk of exposure to wind turbine sound has repeatedly emerged as a new focal point of community opposition to wind farms, indicating a change in the way in which wind farms are now perceived (1).

Such concern, as well as a dramatic amplification of symptom reports (29), coincided with the promotion in 2009 of the self-published book *Wind Turbine Syndrome-A Natural Experiment* (2), also available and summarized on the internet. The book portrays infrasound produced by wind turbines as a threat to health, and explicitly sets out the physical symptoms and health effects to be expected by those living in proximity to a wind farm. Given that wind farms simultaneously generate infrasound and audible sound, negative health information about infrasound is likely to influence the perception of wind farm sound in its entirety. Further, although the narrative of the book emphasizes the perniciousness of the sub-audible components of wind farm sound, it also sets out health concerns about audible sound, particularly low frequency audible wind farm sound. Thus, health concerns triggered by the type of information contained in the book are likely to inform negative expectations extending to both the audible and sub-audible components of wind farm sound exposure.

The concurrence of the publication of *Wind Turbine Syndrome-A Natural Experiment* and an increase in symptom reporting attributed to wind farms (29) supports the argument that symptoms are more likely due to negative expectations triggered by health information, rather than being caused by pathogenic exposure to wind farm sound. This is exemplified in a study assessing historical complaints, in relation to 51 Australian wind farms operating from 1993 to 2012 (29). Findings illustrated that, prior to 2009, health and noise complaints were rare, despite small and large wind farms having operated in Australia for many years. The study found that 90% of complainants made their first complaint post 2009, after anti-wind farm campaigners disseminated information about the purported health effects of wind farms. Further, the majority of complaints were confined to the six wind farms targeted by anti-wind farm campaigners, indicating complainants had accessed negative health information (29).

Additional support for the involvement of negative expectations, in relation to the increase in symptom reporting seen since 2009, is also provided by recent field research demonstrating that people higher in negative-oriented personality traits are more likely to report higher levels of perceived noise (unrelated to actual noise levels) and more non-specific physical symptoms around wind farms (32). Experimental research demonstrates that individuals with higher levels of negative affect are more susceptible to the influence of expectations about health effects created by suggestion and more likely to report expectation consistent symptoms (33).

The ascription of a disease label "Wind Turbine Syndrome" is a powerful way to create health concerns and set expectations. Where individuals adopt disease labels to reflect symptomatic experiences attributed to environmental causes they are more likely to be concerned about the environmental health risk posed, and less likely to be reassured by scientific investigation if it indicates there is no link between the perceived environmental hazard and symptoms (34). The use of an illness label "Wind Turbine Syndrome" (2), along with a widely publicized and explicated list of syndrome symptoms, not only creates the impression that there is a risk that those living near wind turbines will develop a recognized medical condition, but also creates a comprehensive idea of expected symptoms. Simply reading about symptoms of an illness can prompt self-detection of disease specific symptoms, a phenomenon seen in medical student disease. Here, medical students, in the course of learning about an illness, start to experience symptoms indicative of the disease studied (35, 36). The process of learning about an illness appears to generate a cognitive representation of the illness, or mental schema, which guides the way in which internal sensory information is attended to, so that symptoms or sensations that align with the schema are noticed and reported. Symptoms that are inconsistent with the schematic representation of the relevant illness are likely to be overlooked or discounted (37).

Thus, negative expectations operate as a blueprint or heuristic for the type of symptoms attended to and reported. In a clinical research setting, a substantial number of patients, randomized to the placebo arms of placebo controlled drug trials, experience and report symptoms reflective of the side effects of active treatment [e.g., Ref. (38)]. In an experimental study, participants inhaling a benign substance, described to them as a "suspected environmental toxin" known to cause headache, nausea, itchy skin, and drowsiness, reported increases in symptoms, particularly in relation to symptoms they had been told they might expect to experience (39).

Therefore, merely being aware of the type of symptoms that have been attributed to wind turbines is likely to trigger an expectancy directed cognitive body search, whereby the body is selectively monitored for sensations and symptoms consistent with ideas about the physiological effects of exposure to wind farms. During this process, individuals will be inclined to notice common symptoms, which align with expectations and to interpret ambiguous sensations in accordance with such beliefs (40). This was demonstrated in a double-blind provocation study, where participants who watched material from the internet suggesting that infrasound produced by wind farms generated symptoms, reported significant increases from pre-exposure assessment, in the number and intensity of symptoms experienced during exposure to both infrasound and sham infrasound (41). Importantly, elevations in symptom reporting, during exposure periods, coincided with information about the precise symptom profile, said to be related to infrasound exposure. During both exposure periods, participants reported more symptoms characterized as typical symptoms of infrasound exposure, than symptoms differentiated as atypical symptoms of exposure to infrasound. Results suggested that expectations formed by accessing negative health information about wind farm sound could be providing a pathway for symptom reporting in community settings.

EXPECTATIONS AND MISATTRIBUTION

It is important to note that many of the symptoms said to arise from exposure to wind farms, such as headache, fatigue, concentration difficulties, insomnia, gastrointestinal problems, and musculoskeletal pain, are commonly experienced by healthy individuals (23). If people are worried about the health effects of an environmental agent and form symptom expectations, they are also more likely to notice and misattribute their current symptomatic experience to that environmental agent. This can occur even when symptoms are more consistent with everyday experiences and may, under different circumstances, be explained as just part and parcel of normal life (22). Given that the symptoms said to be associated with wind turbines, such as tinnitus, sleep problems, and headache, are extremely common in the general community (42–44), many hearing about a putative connection with wind turbine exposure may be persuaded that health problems they experience can be attributed to this exposure. An analysis of symptom reporting by people living in the vicinity of wind turbines in Canada indicated that the prevalence of reported symptoms was consistent with symptom prevalence in the general population, suggesting that people are likely to be misattributing their ordinary experience of common symptoms to wind turbines, rather than becoming more symptomatic (45).

Many of the symptoms associated with wind turbines, such as dizziness and heart palpitations, are also stress-related concomitants of autonomic arousal associated with anxiety and distress (46). Further, evidence indicates a bidirectional relationship between anxiety and insomnia (47), so that people who are anxious about the health effects of wind farms may experience sleep difficulties because of this anxiety, and sleep difficulties may, in turn, exacerbate the experience of physiological symptoms of anxiety. These symptoms may then be misattributed to wind farm sound, if there is an expectation that wind farm sound poses a health risk.

Evidence also indicates that fears associated with beliefs that innocuous stimuli have dangerous health consequences, engenders associations between such stimuli and stress-related symptoms, so that exposure to such stimuli may become a cue for symptom expression (48). Therefore, detecting wind turbine noise may facilitate symptom expression because, for those concerned about the health effects of wind turbines, hearing the noise signifies exposure to a perceived environmental hazard. Such an interpretation would provoke anxiety, resulting in heightened physiological arousal and stress-related symptoms.

Interestingly, evidence suggests that individuals are much less likely to be annoyed by wind turbine noise if they unable to see wind turbines from their dwelling, even if the sound itself is at a relatively high level (49). Where individuals are worried about the health effects of wind turbines, the visibility of wind turbines from a residence is likely to be a particularly concrete reminder of their concern, thus perpetuating anxiety and related physiological arousal. Therefore, both audibility of sound and visibility of a wind turbine may act as situational cues for symptom expression, triggering stress-related symptoms, thereby reinforcing health concerns (48).

Concerns about a perceived environmental hazard and corresponding negative expectations can also lead to misattribution of current illness, so that illnesses are viewed as a reaction to environmental exposure rather than the result of aging or other disease processes. Over the past 50 years, an increasing concern about the environment appears to have led to heightened sensitivities to environmental change, which have also impacted on the way people perceive illness and disease (17). Individuals are more inclined than previous generations to view ill health as a by-product of a toxic environment, and to worry about the enduring health effects of environmental changes. The propensity to look for external environmental causes for ill health is illustrated by research indicating a tendency among cancer survivors of the 10 most common cancers to believe environmental factors play a much more significant role in carcinogenesis than scientific evidence warrants (50). Therefore, an environmental change, particularly involving the use of an emerging technology, is likely to be regarded with suspicion and trigger expectations impacting on the way individuals interpret their own symptomatic experiences. Diseases such as diabetes, skin cancer, and stroke, with much more established etiology, have instead been ascribed to wind farms indicating a process of misattribution (51).

MEDIA HEALTH WARNINGS AND EXPECTATIONS

A recent study has demonstrated that the upsurge in noise and health complaints seen in Australia since 2009 has arisen primarily in localities where there has been targeted publicity about the alleged harmful impacts of wind farms (29). Two entire Australian states with wind farms, but no history of anti-wind farm advocacy, had no reported instances of health or noise complaints. Findings are consistent with research indicating that media warnings about potential harm from environmental factors may create health concerns prompting symptom reporting, even in the absence of objective health risk (48). Merely watching a television report about the supposed adverse effects of Wifi has been shown to elevate concern about the health effects of electromagnetic fields and increase the likelihood of experiencing symptoms following exposure to a sham Wifi signal (52).

In the case of wind farms, recent media stories have been shown to contain fright factors likely to trigger fear, concern, and anxiety about the health risk posed by wind turbines (53). Assertions about the adverse impacts of wind farm sound have been widely disseminated by the media, particularly via anti-wind farm internet websites, and have led to misconceptions about infrasound generated by wind turbines and a conviction in some that wind farms cause a myriad of health complaints (12) Conjecture about the adverse health effects of wind farms is a consistent theme in public discourse about wind turbines found in media reports embodied in headlines such as "*Wind turbines cause heart problems, headaches and nausea...*" (54); "*Coming to a house, farm, or school near you? Wind Turbine Syndrome...*" (55); and television news items such as "*Wind Turbines cause health problems, residents say*" (56). Further, misleading reports about the impact of living in the vicinity of wind farms, such as inaccurate accounts of home abandonment and emotive references to wind farm refugees, is also liable to create disquiet (57).

It has been verified in a recent double-blind provocation study that the kind of information disseminated in the case of wind farms elevates health concerns and creates corresponding negative expectations, which result in symptomatic experiences. Participants viewing a DVD, containing extracts from the internet outlining the alleged health effects of infrasound generated by wind turbines, reported increased concern about the health effects of sound produced by wind farms, which was associated with amplification of symptom reporting during both genuine and sham exposure to infrasound (41). Results showed negative expectations may be created by media portrayal of alleged health risks posed by the sound created by wind turbines, which could explain symptom reporting around wind farms.

The profound effect of the media narrative on the experience of wind farm sound was confirmed in a follow-up study in which subjective health was influenced in either positive or negative directions, depending on how the sound was portrayed. In keeping with previous findings, participants with negative expectations, formed from media warnings about infrasound, reported increased symptoms and deterioration in mood during simultaneous exposure to infrasound and audible wind farm sound (58). In contrast, participants delivered positive expectations derived from information extracted from the internet about the alleged therapeutic effects of infrasound, experienced an improvement in symptomatic experiences and mood. Findings demonstrated the malleability of symptomatic responses and the power of information disseminated through the media to create expectations, which determine how wind farm sound is experienced. It was particularly telling that positive expectations about infrasound triggered a placebo response in participants listening to audible wind farm sound, while being exposed to infrasound. This highlights that exposure to audible wind farm sound can be a pleasurable experience, if the narrative about the sound is depicted positively. The study provides encouraging indications that if information disseminated about wind farm sound is framed in more neutral or benign ways, then reported symptoms or negative health effects can be ameliorated.

EXPECTATIONS CREATED BY SOCIAL INTERACTIONS

It is important to bear in mind that the experience of symptoms attributed to wind turbines occurs in community settings, and in a social context where there are a range of opinions, concerns, and pressure group activity about the construction of wind farms and about possible health risks associated with them (1, 30). Evidence has shown residents' fears about the health effects of wind turbines are increasingly becoming the focal point of community public consultation meetings, formed as part of resource consent and environmental assessment processes that relate to wind farms (1). Expectations can be learned from such social interactions (59), and may also be created and reinforced by observation and modeling (Faasse et al. under review). The potential effect of observation on symptom experience is indicated in an experimental study demonstrating that one-third of healthy controls, when exposed to images of other people in pain, reported pain in the same location as the observed pain (60). Further, in an experimental study in which participants inhaled an inert substance portrayed as a possible environmental toxin, seeing someone exhibiting expected symptoms increased participant reports of those specific symptoms, illustrating the phenomenon of contagion by observation, seen in mass psychogenic illness (61).

There are various avenues for observation and modeling of symptoms within communities where wind farms are established. Neighbors and members of the wider community may be exhibiting and talking about their symptomatic experiences, which they attribute to wind farms. Television reports about the health effects of wind turbines have also incorporated interviews with symptomatic people, describing their experiences in detail, providing another medium by which symptoms may be modeled [e.g., Ref. (56)]. These interviews can usually be accessed on the internet, so people researching the effects of wind farms can observe modeled behavior with ease.

There are also indications that, where symptoms are attributed to wind turbines, health problems are reported by everyone within the affected household, including children [e.g., Ref. (2)]. This suggests that familial modeling may play a role in symptom reporting, particularly in relation to affected children. Parental pain and symptom modeling is implicated in the development of unexplained pain and somatic complaints in pediatric populations (62, 63).

ANNOYANCE AND EXPECTATIONS

It seems apparent that elevated concern about the health effects of living in the vicinity of wind farms, and the related formation of negative expectations, is also exacerbating reported annoyance with wind farm sound. There is much variability between studies in relation to the extent of reported wind farm noise annoyance indicating that contextual matters are influencing annoyance reactions. Related studies undertaken in Sweden and the Netherlands have indicated that approximately 10–20% of residents living in proximity to wind farms find wind turbine noise annoying, and 6% of residents find wind turbine noise very annoying, at 35–40 dB exposure (7, 49, 64). However, another study conducted in New Zealand reported that 59% of respondents living within 2 km of a wind farm experienced noise annoyance (65). The New Zealand study was undertaken at a time when there had been adverse publicity about expected noise and health effects of living in the vicinity of the wind farm in question, including a story that aired on free to air television (66). Understanding the factors that contribute to annoyance is important because, although noise annoyance is not in itself a disease or health state, annoyance is related to distress, which can lead to the experience of stress-related symptoms (9, 67).

Being annoyed by noise is related to a range of personal and situational variables, beyond the acoustic characteristics of noise (68, 69), and psychosocial factors account for more variation in individual annoyance, than objective measures of noise level (70). Experimental work indicates that not being aware of the source of sound is associated with reduced noise annoyance in people exposed to wind farm sound, further confirming that the context of sound exposure has more relevance for annoyance assessment, than the acoustic properties of wind farm sound (71). Importantly, a strong relationship has been found between concern about the negative health effects of noise and noise annoyance (72). The evidence also shows that wind turbine noise annoyance is more strongly related to other negative attitudes about wind turbines, particularly the visual impact of wind turbines on the land scape, than to sound level (7, 49). Thus, rhetoric that creates health concerns about wind turbine sound, and presents a negative view of wind farms, is likely to influence not just symptom reporting and distress, but reported noise annoyance.

There is compelling evidence that creating a positive context for the experience of wind farm sound, has a correspondingly positive impact on reported annoyance. A field study conducted in The Netherlands indicated that respondents who benefited economically from wind turbines, by either full or partial turbine ownership or by receipt of other economic benefits, such as a yearly income, were less annoyed by wind turbine noise than other respondents, despite exposure to higher sound levels (49). Notably, there were no differences in either likelihood to notice sound, or subjective noise sensitivity between those who did or did not derive economic benefit. However, there were attitudinal differences. Respondents who benefited economically were less negative both about wind turbines in general, and about the visual impact of wind turbines on the landscape. Results suggest that experiencing wind farm sound in a positive context decreases the likelihood of forming negative views of wind turbines associated with annoyance. This provides promising indications that changing the narrative around wind farms, so that worried residents become less concerned about their proximity to wind farms and adopt more positive expectations and attitudes, might not only alleviate symptom reporting but also reduce noise annoyance.

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PATTERNS OF HEALTH COMPLAINTS SEEN IN OTHER INSTANCES OF PERCEIVED TOXIC EXPOSURE

It is relevant to note that symptom reporting, in response to perceived exposure to a toxic agent when no plausible health threat is posed, has been seen throughout history (17). Francis Bacon (1561–1626) noted "*infections...if you fear them, you call then upon you*" (73). In one pertinent example, a dramatic elevation in reported symptoms in a community setting in Memphis followed a health scare fueled by media messages that the town was located in close proximity to an old toxic waste dump (74). While a comprehensive examination of soil toxicity revealed no hazard was presented, health fears did not abate until it became apparent authorities were mistaken as to the locality of the dump, which had actually been situated many miles from the town (19). Although symptom reporting then subsided, some residents continued to insist they experienced symptoms from the phantom dump site.

Further, the advent of new technologies has consistently been associated with the development of subjective illness complaints, involving a constellation of symptoms, akin to those attributed to wind farms (28, 75). For instance, in 1889, following the increasing use of the telephone, The British Medical Journal cautioned about the emergence of "*telephone tinnitus*" in respect of which "*the patients suffered from nervous excitability, with buzzing noises in the ear, giddiness, and neuralgic pains*" (76). With striking parallels, almost a century later, the experience of a range of non-specific symptoms such as headache, fatigue, tinnitus, and concentration problems have been attributed by some individuals to exposure to electromagnetic fields via mobile telephones (77). This occurs despite the fact there is no generally accepted causal bio-electromagnetic mechanism, by which such symptoms would be triggered (78). Given that provocation studies have repeatedly shown that sham electromagnetic exposure is sufficient to activate symptoms in individuals who believe they are sensitive to electromagnetic fields, the evidence suggests the involvement of nocebo responses; that it is anxiety about exposure and related negative expectations, which are triggering symptomatic experiences (52).

CONCLUSION

An analysis of the evidence concerning symptom reporting attributed to sound produced by wind farms supports the nocebo expectation hypothesis; that health complaints can be explained by the influence of negative expectations. It is apparent that symptom reporting coincided with an increase in health concern about wind farms promoted by a book and internet sites focused on highlighting the purported heath dangers posed by sound, particularly infrasound produced by wind turbines. Such information, which has been further circulated though social discourse and media reporting, is liable to trigger health concerns and related symptoms of anxiety, while also creating a blueprint for what symptoms can be expected – expectations, which, in turn, are likely to guide the type of symptoms noticed and reported. This is supported by epidemiological evidence that increased symptom reporting has occurred in locations where there has been targeted dissemination of negative health information about wind farms, indicating that exposure to such information is shaping symptomatic experiences. Experimental work also suggests that it is expectation rather than wind farm sound exposure that is responsible for symptom complaints.

Symptom reporting is also consistent with patterns of health complaints seen in other environmental health scares involving benign exposure, and which often follow the introduction of new technologies. Importantly, indications that negative expectations are implicated in symptomatic experiences ascribed to wind farms aligns with evidence that instances of symptom reporting attributed to perceived environmental hazards and exposure to modern technologies have been triggered by nocebo responses.

Understanding the underlying cause of health concerns and symptom complaints, which have arisen in communities in which wind farms have been proposed and developed, is critical if such concerns are to be addressed, and symptom reporting alleviated. Given indications of the determinative role of negative expectations in creating and maintaining symptom reporting, successful strategies to address health complaints are likely to involve changing the narrative about wind farms, to create more positive expectations.

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All authors contributed to the conceptualization, writing, and editing of this manuscript.

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Increasing Wind Turbine Tower Heights: Opportunities and Challenges

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List of Abbreviations

1P	rotor rotational frequency
3P	blade passing frequency
BAR	big adaptive rotor
BAU	business as usual
BOS	balance of station
CapEx	capital expenditures
CSM	Cost and Scaling Model
GW	gigawatts
IEC	International Electrotechnical Commission
kN	kilonewton
kNm	kilonewton-meter
kW	kilowatt
LandBOSSE	Land Balance of Station Systems Engineering
LCOE	levelized cost of energy
LDST	large-diameter steel tower
MWh	megawatt-hour
OEM	original equipment manufacturer
O&M	operation and maintenance
R&D	research and development
RNA	rotor nacelle assembly
TowerSE	Tower Systems Engineering
Wind	Wind Integration National Dataset Toolkit
WTT	Wind Tower Technologies

Executive Summary

This report presents the opportunities, challenges, and potential associated with increasing wind turbine tower heights, focusing on land-based wind energy technology. Our principal conclusions are as follows:

- **Wind resource quality improves significantly with height above ground.** Over large portions of the country, our mesoscale resource data indicate an increase in annual average wind speed of 0.5 to 1.0 meters per second (m/s) when moving from 80 to 110 meters (m) and 1.0 to 1.5 m/s when moving from 80 to 160 m.
- **Wind speed differences translate to sizable capacity factor improvements.** Although the observed variance is broad, median capacity factor gains with higher hub heights are estimated at approximately 2 to 4 percentage points when going from 80 to 110 m and an additional 2 to 4 percentage points when going from 110 to 140 m. Between 140 and 160 m, median capacity factor gains are approximately 1 percentage point. Relatively larger gains occur east of the Rocky Mountains, with the greatest gains sprinkled throughout the Heartland, the Midwest, and the Northeast.
- Based on first-order cost estimates informed by current technology, **the most wind-rich regions of the country generally show an economic preference for the lowest considered tower height; higher hub heights (e.g., 110 m and 140 m) are often preferred in more moderate wind speed regions.** This result is consistent with industry experience to date.
- **Higher nameplate and lower specific power turbines (e.g., 150 to 175 watts per square meter) also show a general economic preference for the lowest considered tower height; however, these larger turbines require tower heights of at least 110 m.** Tower heights of 140 m and in some cases 160 m tend to be preferred in more moderate wind speed areas.
- **The highest nameplate capacity turbine we considered (4.5 megawatts) has a relatively greater preference for 140-m hub heights than similar 3-megawatt-class turbines.** This observation is driven by the proportionally lower cost associated with taller towers and tall tower installations in dollars per kilowatt ($/kW) for larger turbines and indicates that turbine scaling (which offers additional cost saving potential) and taller tower deployment is likely to occur in parallel.
- **Future tower innovations could make higher hub heights more attractive.** In a tower cost-bounding scenario, where we apply a fixed $200/kW tower cost for each turbine at all hub heights, we see an economic preference for 160-m tower heights in 70% to 90% of sites, depending on the specific turbine configuration.
- **Reducing the cost of realizing taller towers is critical to capturing the value of higher wind speeds at higher above ground levels** as well as for increasing the viability of wind power in all regions of the country.
- **Additional factors that could impact tower height include blade tip clearance requirements, balance-of-station costs, turbine nameplate capacity, and specific power**. Turbines with higher specific power ratings experience more energy gain for a given change in wind resource. Larger wind turbines tend to have an economic advantage for tall tower applications and offer additional cost saving potential in balance-of-station and turbine-level

economies of scale. Ultimately, wind turbine design reflects an optimization across an array of potential criteria; focusing on tower height alone may result in suboptimal outcomes.

- **When pursuing higher tower heights, a system-level incremental capital cost of less than $500/kW for low specific power turbines and potentially as low as $200/kW, particularly for higher specific power turbine configurations, could support a levelized cost of energy reduction across much of the country, and might also push less-energetic wind resource regions further along the path to economic competitiveness**. Depending on the specific focus regions and turbine configurations under consideration, variance from this general guidance could be merited.
- **To realize taller wind turbine towers, an array of potential concepts remain in play. These concepts rely on various materials spanning rolled tubular steel (currently the most widely used option), concrete, and lattice steel, for space frame designs, as well as hybrid designs that use a combination of concepts**. Although there are clear advantages and disadvantages to each known concept, the future design of tall wind turbine towers remains to be determined. At the same time, our examination suggests that tubular towers can continue to be viable at the higher above-ground heights, particularly with continued advances in control technology that allow for reliable use of soft-soft designs. Tower erection strategies and innovation may also be a determining factor in the viability of future tall tower concepts.

Notable caveats in this analysis include uncertainty in the underlying resource data, which increases at higher above ground levels, coupled with high sensitivity in terms of the analysis results to the assumed wind shear. In addition, our capital expenditure and levelized cost of energy estimates are based on cost characterizations that generally reflect modern state-of-the-art technology and do not consider the potential for future innovations to alter the capital expenditures required to achieve a given tower height. Finally, the tower height economic preference analysis is limited to tower heights of 80 m, 110 m, 140 m, and 160 m; in many cases, real-world economically preferred tower heights will likely fall between these points.

Future research needs elicited from this work include activities that quantify and ultimately reduce the uncertainty of the wind resource data, particularly at higher above ground levels. More robust cost assessments and analysis including more sensitivities as well as evaluation of specific technology opportunities and alternative turbine configurations would also be valuable and further inform the potential for innovative solutions to capture value from taller towers.

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1 Introduction

Wind power is one of the fastest-growing sources of new electricity generation in the United States. Since the early 2000s, annual investments in new wind capacity have exceeded the billion-dollar threshold, with investments in recent years often more than $10 billion annually. Cumulative installed capacity was estimated at more than 96 gigawatts (GW) at year-end 2018 (American Wind Energy Association [AWEA] 2019) and wind power supplied approximately 6.6% of total electricity generation in 2018 (Energy Information Administration 2019). The recent growth of the wind power industry has been spurred, in part, by innovation and subsequent reductions in costs coupled with state and federal policy support.

Looking ahead, further cost reduction is anticipated to be critical to continued economic competitiveness. This is due, in part, to competitive pressure from low-cost natural gas and solar photovoltaics (Mai et al. 2017; Dykes et al. 2017). Notably, however, with continued cost reduction, economic deployment of wind energy through 2050 could be more than 430 GW and possibly as high as 550 GW, with wind power supplying between 38% and 46% of total electricity generation (Mai et al. 2017). Moreover, the quantity of available wind energy resource is such that the opportunity for capturing thousands of terawatt-hours of low-cost, clean wind energy remains of significant interest.

Key technology attributes enabling cost reductions realized to date include advancements that have resulted in the capture of turbine, balance of station (BOS), and operation and maintenance (O&M) economies of scale as well as increased energy production per turbine and per unit of installed capacity. More specifically, increased energy production has been realized with taller towers that place turbines into higher-quality resource regimes as well as larger rotors that enable more of the wind passing by the turbine to be converted into electricity. Basic science research and development (R&D) coupled with industry innovation has allowed tower height and turbine rotors to grow and increase energy capture while simultaneously eliminating excess material, improving production processes, and maintaining reliability, enabling this increased energy to be achieved at little to no capital cost penalty.

To further drive down costs, wind turbine researchers, designers, and engineers continue to pursue strategies that could use even higher hub heights to be economically attractive. Higher hub heights remain of interest due to the more energetic wind resource that exists at higher above ground levels as well as the need to provide additional clearance for increasingly long blades that maximize energy capture per turbine. In this context, the current analysis seeks to understand and explore the potential opportunity space around tall wind turbine tower technologies. We also demonstrate a new approach to analyzing technology opportunity and potential across a broad geographic area, in this case the contiguous United States. This approach is useful when evaluating wind technology given the significant spatial variability in resource quality and the impact that spatial variability has on optimal technology design.

1.1 A Brief History of Wind Power Technology

In the 1980s, a commercial wind turbine was approximately 100 kilowatts (kW) in nameplate capacity and had a hub height and rotor diameter that were both on the order of 20 meters (m). By the early 1990s, a typical commercial turbine was approximately 300 kW in nameplate capacity and had a hub height and rotor diameter that were both on the order of 30 m. By the early 2000s, machines had achieved a nameplate capacity in excess of 1 megawatt (MW) and a rotor diameter and hub height of approximately 70 m. Most recently, wind turbines installed in the United States in 2018 had a nameplate capacity averaging 2.4 MW, rotor diameters averaging 116 m, and hub heights averaging about 88 m (AWEA 2019). In Germany, where the wind resource is often of lower quality and developable land area is more limited, designers are forced to consider energy production per unit of land area as well as cost per unit of energy among other factors, with optimums favoring larger turbines. The average nameplate capacity for projects commissioned in 2017 in Germany was 2.97 MW; average rotor diameter was 113 m, and average hub height was 128 m (Deutsche WindGuard 2018). In the German context, larger machines and more design constraints (e.g., land area) have resulted in higher wind cost of energy relative to the United States (Hand et al. 2019; Vitina et al. 2015). Nonetheless, these larger turbines have proven preferable for German sites. Although design conditions and optimums in Germany differ from those in the United States and other parts of the world, the German data illustrate that under the right conditions a continued push toward higher hub heights provides value.

Driving trends in turbine configuration, scale, and cost of energy are fundamental economic considerations associated with wind turbine technology and design (Zayas et al. 2015). Historically, increased hub heights have resulted from a general trend of improved wind resource at levels higher above the ground that are less affected and slowed by surface roughness (e.g., trees, buildings) and local topography. At the fundamental level, hub height growth has been constrained by impacts on installation and erection cost, and the incremental cost of the taller tower relative to the additional energy that might be extracted from the improved wind resource quality found at higher above ground levels with the state-of-the-art turbine rotor nacelle assembly (RNA). More recently, hub height growth has also been impacted by transportation and logistics barriers that restrict the sectional tower diameter to fit under highway and railway underpasses. These transport constraints result in relatively inefficient tower designs from a material use and cost perspective, as compared to towers designed solely to meet their fundamental functional design requirements.

In the United States, there has been a partial plateau in tower or hub height scaling (Wiser and Bolinger 2018). The leveling off of tower height is in part a function of the excellent wind resource available in the interior region of the United States and a function of the logistics and transport trends noted earlier—which require substantially greater quantities of steel at higher hub heights to maintain sufficient stiffness while adhering to the transport-dictated sectional diameter constraints. With respect to the former, the world-class wind resource present in the interior region of the United States—even at levels of 80 m above ground level—has allowed projects using modern technology to achieve performance levels that support levelized cost of energy (LCOE) values at or below $40/megawatt-hour (MWh) to $45/MWh (excluding the production tax credit). These performance levels have positioned wind to be competitive at 80-m hub heights as a fuel-saving, electricity-generating technology over the past several years, with the federal production tax credit in place.

This is not to suggest that the incentives for continuing to pursue tall wind have diminished, rather that it simply has become more difficult to reap the rewards of turbine scaling as a result of additional constraints that must be addressed as well as the increasingly complex construction requirements of very large turbines. This is particularly true in regions that have very good resources at the heights above ground that are within reach of modern wind industry original equipment manufacturers (OEMs), as well as readily available transport and logistics capabilities. Evidence for the continued pursuit of tall wind in the United States exists in recent turbine offerings from the top-three global wind turbine OEMs: Vestas, GE, and Siemens. Combined, these three OEMs captured more than 90% of the U.S. market (AWEA 2017). In 2016, each of these OEMs began marketing turbines in the 3-MW class, with rotor diameter offerings from approximately 100 m to 140 m, and tower heights from 75 m to 165 m.[1]

1.2 Analysis Objectives and Organization

This report has two primary objectives. First, it seeks to inform the opportunities and potential associated with increasing wind turbine hub heights. It also explores the conditions and locations where taller towers offer the most significant potential to increase wind technology performance and reduce costs. This initial objective is discussed in Section 2. The second objective is to examine the status of tall tower technology as a key subcomponent of wind power advancement. This objective is discussed in Section 3, where we analyze the potential for continued innovation in tubular steel wind turbine towers and explore the status and potential for a select set of alternative tall tower technologies. Key findings and lessons learned are covered in Section 4. A brief summary and final conclusions are found in Section 5. The appendices include more resolved data on estimated LCOE, capacity factor change with height above ground, and breakeven cost.

[1] Recent increases in the turbine scale and hub heights now being offered by OEMs generally are perceived to have been made more feasible by advanced turbine controls that allow the machines to avoid certain portions of the operating envelope that resulted in more conservative design requirements. Looking ahead, the opportunities created by continued evolution of advanced controls deserve continued attention and tracking.

2 Tower Opportunities and Cost Estimation

To begin to understand the potential for higher hub heights as a source of further wind power cost reduction, the authors assessed how taller towers could impact key indicators of wind energy viability across the nation. We begin by examining the change in wind speed that is achieved by increasing hub height from a baseline of 80 m typical of today's commercial installations to 110 m and 160 m across the contiguous United States. Second, we quantify the impact this wind speed change could have on wind power capacity factors by estimating wind energy production for four wind turbine configurations. We conclude this portion of the analysis by estimating LCOE for these four turbine configurations and evaluating which hub height for each configuration tends to have the lowest LCOE, using cost and scaling estimates informed by recent state-of-the-art technology. LCOE and tower height preferences are also estimated for a sensitivity scenario wherein wind turbine tower costs are fixed at levels of $200/kW, even while turbines are able to scale and access hub heights up to 160 m. This additional sensitivity helps to inform the potential LCOE and preferred tower heights that might be achieved if tower R&D and innovations are very successful.

2.1 Wind Speed Change with Height Above Ground Level

As a first step in characterizing the opportunity offered by achieving higher hub heights than the typical 80-m hub height for turbines installed in the United States over the past decade, we utilized wind speed data from the National Renewable Energy Laboratory (NREL) Wind Integration National Dataset (Wind) Toolkit (https://www.nrel.gov/grid/wind-toolkit.html) to compare differences in mean annual wind speeds at each pixel or site within the contiguous United States. The Wind Toolkit is a mesoscale wind-resource data set that was funded by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Wind Energy Technologies Office, and created through the collaborative efforts of NREL and 3TIER.[2] The data set includes meteorological data, including wind speed for more than 1.85 million locations in the contiguous United States for a period of 7 years between 2007 and 2013. Each pixel in the Wind Toolkit represents a 2-km-by-2-km grid cell. The data are generated by meteorological models that have used real-world historical input data to recreate a complete suite of output data to be used in analysis and research. The Wind Toolkit has wind speed data for multiple hub heights. For this analysis, we consider hub heights of 80 m, 110 m, 140 m, and 160 m above ground level, and relied on data from the 2012 calendar year.

A significant caveat to these results that extends throughout the analysis is that the uncertainty in the wind speed data from the Wind Toolkit is not fully understood or characterized, particularly as one moves to higher above ground levels (e.g., 140 m and 160 m). Moreover, the analysis conducted here focuses only on the 2012 weather year. Some variability in the results therefore is likely when considering normal interannual resource variability. Anecdotal evidence from limited site-specific validation suggests that in some locations the uncertainty in the mesoscale data is large (e.g., potentially in excess of 1 meter per second [m/s]). Although the impact of this uncertainty is sizable and important and would undoubtedly impact the precise quantitative outcomes from the analysis, the broad trends and qualitative outcomes from the work are

[2] In the years since the Wind Toolkit was developed, 3TIER has been acquired by Vaisala http://knowledge.vaisala.com/3TIER (accessed March 6, 2019).

generally useful in understanding the opportunity offered by further increases in hub heights for the wind turbines evaluated here.

Figure 1 and Figure 2 illustrate the difference in mean annual wind speed in the Wind Toolkit when comparing 80-m and 110-m hub heights and 80-m and 160-m hub heights, respectively. These data show that nearly all regions of the country observe wind speed increases when moving to 110 m. Minor exceptions in this regard are in small isolated pockets in the Southwest and in California. These “negative” wind-shear locations have relatively rare topographical and meteorological patterns that drive these anomalies. West of the Rocky Mountains, the wind speed increase is largely in the 0- to 0.5-m/s increase category at 110 m. With the exception of the mountainous regions (e.g., along the Appalachian Mountains; the Ouachita Mountains of West Central Arkansas) and Florida, the portion of the country that falls east of the Rocky Mountains primarily sees a wind speed increase of 0.5- to 1.0-m/s when moving from 80 to 110 m.

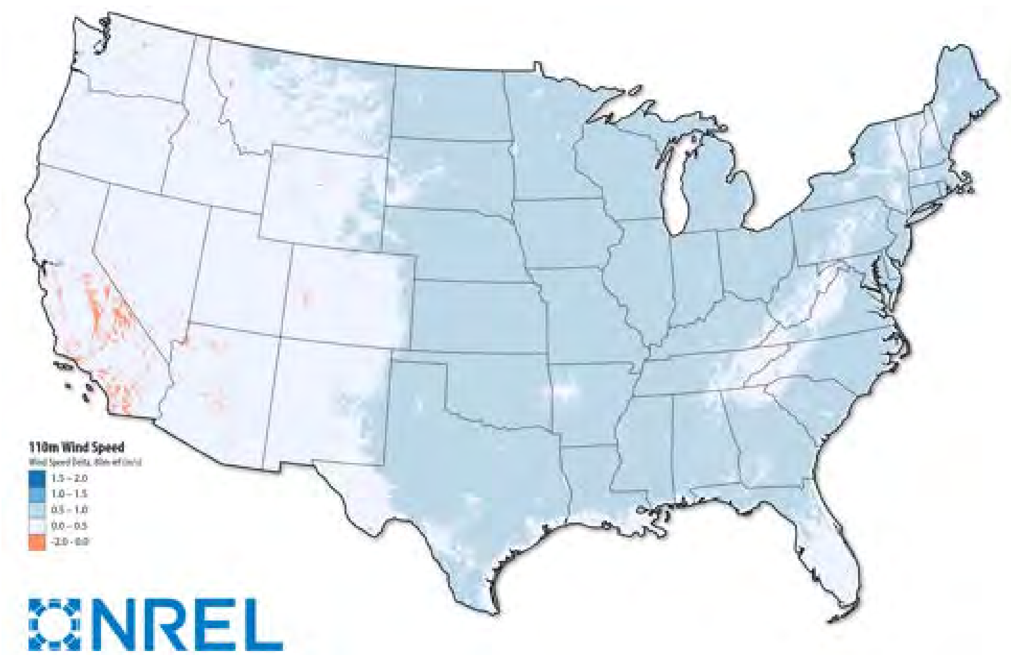

Figure 1. Difference in mean annual wind speed at 110 m above ground level relative to 80 m, based on the Wind Toolkit

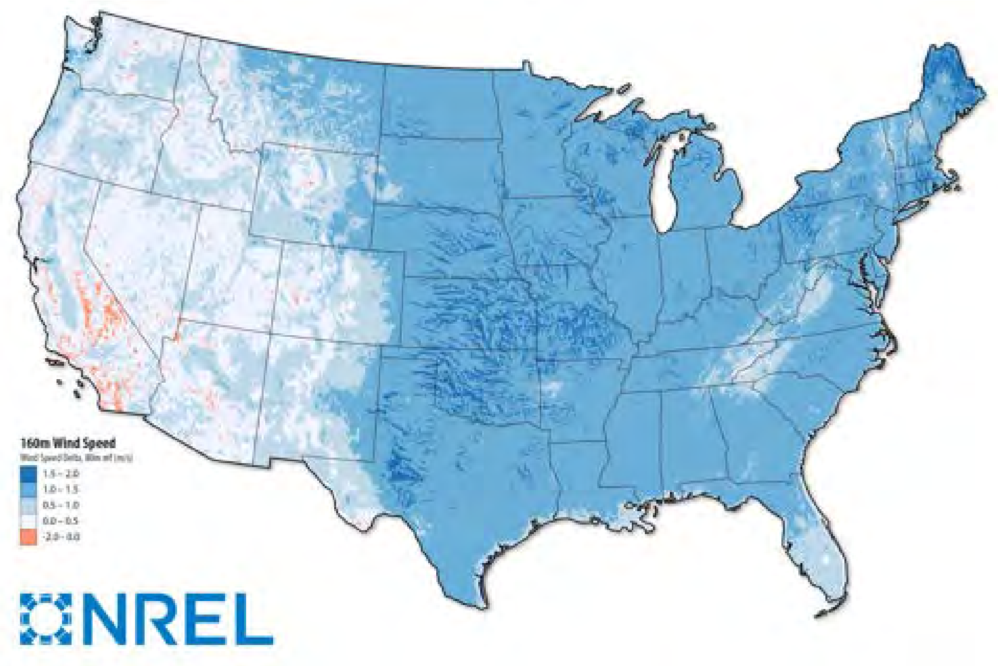

Figure 2. Difference in mean annual wind speed at 160 m above ground level relative to 80 m, based on the Wind Toolkit

When moving from 80 to 160 m, the results are more pronounced and heterogenous. In much of the Interior West between the Rockies and the Sierra Nevada ranges, the improvements are still in the 0- to 0.5-m/s increase category but scattered throughout, and in a loose ring around this region significant portions see increases in wind speed that are in the 0.5- to 1.0-m/s category. Moving east from the Rocky Mountains, when comparing 80 m with 160 m greater increases (1.5–2.0 m/s) can be observed in the lower-lying portions of the central plains, in particular in the river valleys of Oklahoma, Kansas, and Nebraska, as well as along the upper Mississippi River Valley on the borders of Minnesota, Wisconsin, and Iowa. Increases of this magnitude also show up in Southwestern Texas, Missouri, and parts of Arkansas. The remaining portions of the Great Plains generally are in the 1.0- to 1.5-m/s category.

Moving further east, the mountainous regions of Tennessee and surrounding states continue to exhibit a 0–0.5 m/s increase in wind speed. These regions, however, are surrounded by larger areas that observe increases that are more broadly in the 1.0- to 1.5-m/s range. Pennsylvania, New York, and Maine see a broad range of increases, with some areas in the 0.5- to 1.0-m/s category, some in the 1.0- to 1.5-m/s category, and some in the 1.5- to 2.0-m/s category.

In general, these data suggest that the value of achieving higher hub heights—at least according to differences in mean annual wind speed—is widespread but most significant east of the Rocky Mountains. Within that region, the largest increase in wind speeds appear to be in the relatively low-lying areas that fall in otherwise very windy regions (e.g., the river valleys of the Great Plains).

2.2 Capacity Factor Change with Height Above Ground Level

As a second step in understanding the potential value associated with placing wind turbines at higher hub heights, we used hourly wind speed data from the Wind Toolkit coupled with four wind turbine power curves to estimate potential energy generation and capacity factors for these four turbines at multiple hub heights. Net capacity factors were estimated assuming a simple 16.7% losses adjustment, which reflects a combination of array and electrical losses as well as turbine downtime.

The four modeled turbines used to estimate capacity factors were intended to represent state-of-the-art technology available today as well as potential turbines of tomorrow (Table 1). Our "Today," or reference turbine, was calculated from the average nameplate capacity and rotor diameter of turbines installed in the United States in 2017 (Stehly et al. 2018). This composite turbine was 2.3 MW and had a rotor diameter of 113 m, resulting in a specific power of approximately 231 watts (W)/m^2. Our business as usual (BAU) turbine was intended to reflect turbine technology that under BAU or median conditions is expected to be the average turbine installed around the United States by 2030. This turbine was derived from the simple extrapolations of historical trends for turbines installed in the United States and has a nameplate capacity of 3.3 MW and a rotor diameter 156 m, resulting in a specific power of approximately 173 W/m^2.

Two additional turbine concepts reflect potential future turbines in the 3-MW and 4- to 5-MW class, respectively, that are "low specific power," or Low-SP, turbines with specific power of approximately 150 W/m^2. These turbine configurations were selected based on recent trends suggesting continued pursuit by turbine designers and researchers of relatively low specific power wind turbines (Wiser and Bolinger 2018). Given these trends, we sought to understand how turbines with even lower specific power relative to our Today and BAU configurations might compare and contrast, in terms of their ability to extract value from higher hub heights. Including configurations in the 3- to 5-MW range also helps to illuminate potential value from coupled turbine scaling and hub height increase.

Table 1. Turbine Configurations Used To Estimate Capacity Factors at Higher Hub Heights

	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/m^2)	231	173	150	152

To estimate the capacity factor change associated with each increased hub height, a turbine power curve was calculated for each defined turbine configuration. These power curves were then applied to the 2012 hourly wind speed data for each of the 1.85 million Wind Toolkit sites or "pixels." This process was completed at four hub heights for the Today turbine: 80 m, 110 m, 140 m, and 160 m. Only three hub heights were considered for each of the other turbine configurations: 110 m, 140 m, and 160 m to allow for ground clearance when the turbine blades come closest to the ground. Notably, the Low-SP 4.5-MW turbine with an approximately 95-m blade likely does not have sufficient ground clearance to be commercially deployed at a 110-m hub height. Nevertheless, these data were included in the analysis results to help us understand what the opportunity could be at this hub height. The resulting data were then plotted by capacity factor and frequency to understand the potential capacity factors across the continental United States for each turbine configuration and each hub height.

Spatially, capacity factor trends are closely aligned with the wind speed increases displayed in Section 2.1. Figure 3 illustrates the range and distribution of specific capacity factor improvements for the four modeled turbines at each of the respective hub heights where they were analyzed. Figure 4 illustrates the differences in capacity factor in percentage points for each location in the Wind Toolkit data set for each turbine configuration and hub height, relative to the Today turbine at 80 m. In effect, these data illustrate the potential capacity factor difference relative to current state-of-the-art technology and project norms. Figure 5 is similar to Figure 4 except that in Figure 5 the change in capacity factor is calculated relative to the lowest available hub height for a given turbine platform. In general, increases in hub height shift the resulting capacity factors to higher values. In many cases, as hub height changes, the frequency of certain capacity factors is also changed. For the Today turbine, there is a noticeable shift to the right as one moves from 80 m to 110 m and to 140 m. The increase between 140 and 160 m is more subtle. Similar trends are observed when moving between 140 and 160 m for the BAU and Low-SP turbines.

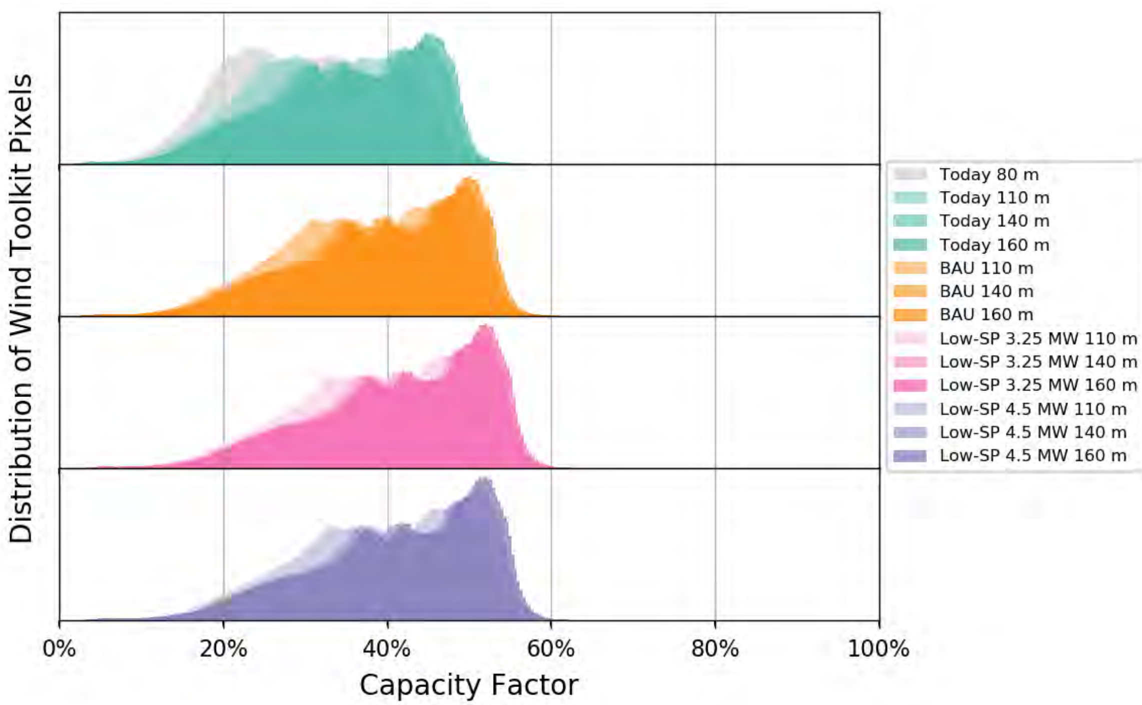

Figure 3. Estimated net capacity factor, all turbines and hub heights

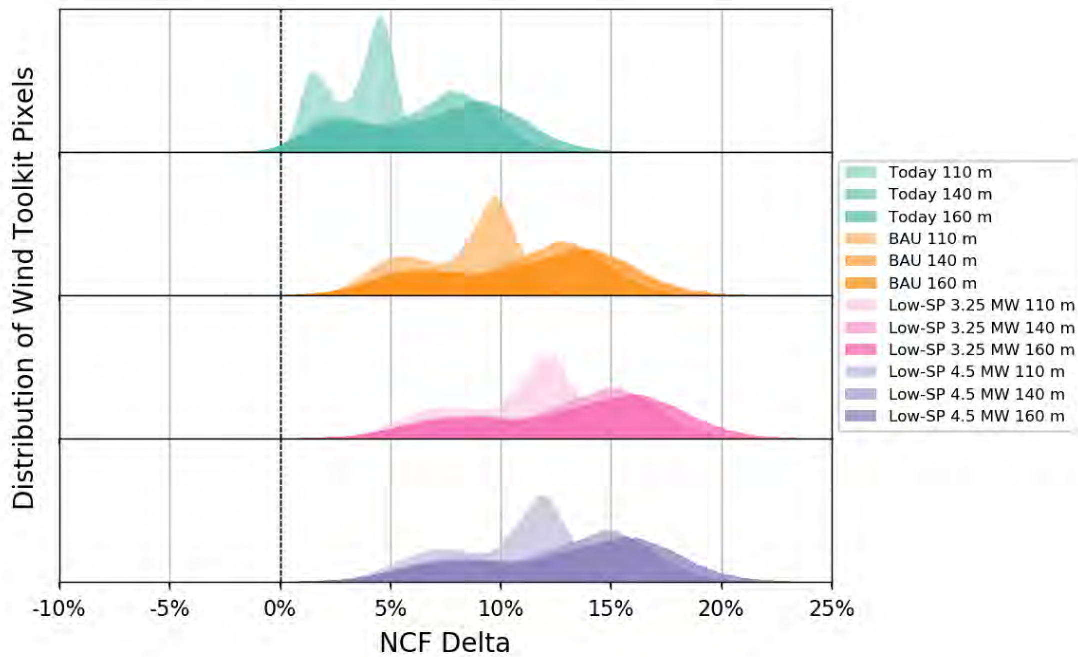

Figure 4. Estimated difference in net capacity factor, all turbines and hub heights, relative to the Today turbine at 80 m (percentage points)

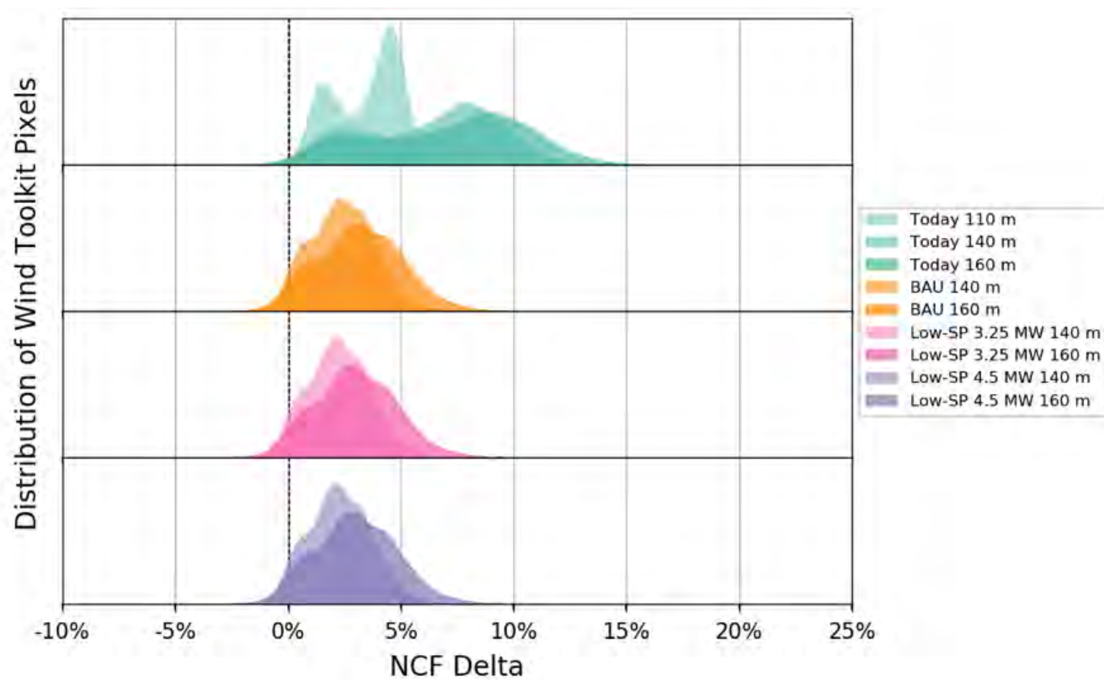

Figure 5. Estimated difference in net capacity factor, all turbines and hub heights, relative to the lowest hub height available per platform (percentage points)

Not surprisingly, the highest capacity factors are observed at 160 m and with the Low-SP turbines. Even at the higher specific power platforms of the Today and BAU turbines, however, the 160-m hub height yields substantial quantities of sites with 40% or greater capacity factors. For the Low-SP turbines, however, a significant number of sites have capacity factors even greater than 50%; approximately 60% of the resource sites for these turbines have a capacity factor greater than 40%.

In terms of capacity factor differences, the BAU turbine configuration has a large number of sites that are approaching a 10% increase in capacity factor relative to the Today turbine at 80 m—even with a move to only 110 m. The Low-SP configurations see a large quantity of resource sites that exceed the 10% improvement level at 110 m relative to the Today turbine at 80 m, and many sites approach a 15% increase at 140 m. Based on the Wind Toolkit data, the benefit of achieving 160-m above-ground-level hub heights is estimated at approximately 1 percentage point in capacity factor, relative to 140 m.

Focusing on the comparison in Figure 5, to the lowest available hub or tower height by platform, it is evident that the higher specific power Today turbine actually sees the largest magnitude of improvement in capacity factor from moving to higher hub heights. Although the lower specific power BAU and Low-SP turbines have higher absolute capacity factors, they also spend more time at full rated power, which limits their ability to increase annual energy production merely by increasing hub height. Of course, one must be cautious not to focus solely on the magnitude of the change as such characterizations can be overstated when comparing against a low value reference or starting point. Although somewhat more obscure, this effect can also be observed in the following LCOE analysis by noting that for a given platform, preferences for taller towers are somewhat lower with lower specific power.

2.3 Levelized Cost of Energy Estimations

Data and analysis presented thus far have focused on the energy production potential associated with realizing higher wind turbine hub heights. Achieving these higher hub heights, however, would—all else being equal—require additional capital cost expenditure because of additional tower material requirements and increased BOS cost increases associated with lifting the nacelle and rotor to these higher above-ground-level heights.[3] It is this trade-off between incremental capital cost expenditure and incremental energy production,[4] coupled with the overall cost of energy for a given site, that ultimately determines the hub heights for commercial wind farms. Here, our analysis begins to shed light on the potential outcomes of this trade-off, as a function of LCOE, for all resource sites in the Wind Toolkit.

Given significant uncertainty in the potential costs of the turbine technology and plants modeled, we do not anticipate our results to be the final word on LCOE or the relative competitiveness of tall wind towers. Instead, this section seeks to establish a method for examining the potential for higher hub heights from a continental perspective with computed LCOE results based on a first-order set of cost assumptions. The results presented should be thought of more as scenarios with the findings contingent on the assumptions associated with the stated scenario. Additional follow-on work to further refine the cost characterizations and LCOE results is strongly

[3] Notably, this latter cost increase could be partially or fully offset by moving to a larger nameplate capacity (e.g., relative to the Today turbine), which for a fixed plant capacity results in fewer turbine lifts and roads and potentially reduced cabling requirements. Analysis to date suggests that indeed balance-of-station (BOS) cost savings associated with achieving higher nameplate capacity turbines could offset a potential BOS cost increase associated with installing nacelles and rotors on hub heights up to 160 m.
[4] In reality, it is the balance between incremental cost and incremental power sales. Where there may be transmission capacity or energy constraints, the timing of any potential energy production increase is also important.

encouraged. Notwithstanding these caveats, the results do provide an indicator of the potential value of achieving higher hub heights across the continental United States.

In addition to the uncertainty in the potential costs of future tall tower technologies and the evaluated tower heights, it is important to note that our cost estimates are primarily scaled from recent vintage wind turbine technology cost and scaling trends. They do not consider the potential for future innovations to impact cost and scaling functions for any turbine subsystem, including towers.

In effect, the analysis represents an LCOE assessment based on extrapolation from recent scaling trends. To the extent that these trends are not indicative of innovation potential for the tower, the results will be biased toward relatively shorter towers. In other words, these results reflect a technology and cost snapshot based on scaling relationships of recent technology; in this sense, they should be somewhat indicative of the calculations and decisions that the development community has made in the very recent past. However, they may be less indicative of the calculations and decisions made in the future, as innovations that improve upon recent technology could have greater preference for tall towers.

To evaluate potential LCOE impacts associated with increased hub heights, we first estimated the installed capital cost for each turbine configuration at each hub height analyzed in Section 2.2. To characterize turbine capital cost, we used the 2015 NREL Cost and Scaling Model (CSM), which is a part of the larger NREL Wind Plant Integrated Systems Design and Engineering Model (WISDEM®) toolset and informs most costing estimates derived from the modeling toolset. The 2015 NREL CSM uses empirically derived—based on industry data points and semistructured interviews—component-level scaling relationships to ascertain the potential change in component costs associated with both higher hub heights and changes in rotor size. Given the vintage of the model and the related empirical data, these relationships are expected to be generally indicative of state-of-the-art technology from the 2012–2014 period.

One update made to the default scaling relationships was in the blade mass scaling exponent. For this analysis, we apply a mass-scaling exponent of 2.2. This is based on more recent (2018) direct input from turbine designers and blade manufacturers, acquired in the parallel and ongoing U.S. Department of Energy “Big Adaptive Rotor” project. Estimated tower costs calculated in the model are believed to be somewhat optimistic relative to historical turbine installations, but anecdotal evidence suggests they may be conservative relative to emerging tall tower solutions under development today. The estimated nacelle and drivetrain costs are believed to be conservative, particularly for larger turbines, given the applied empirical data in the model indicating that larger nameplate turbines may actually be more competitive than suggested here. An additional caveat in this cost characterization is that the 2015 NREL CSM does not consider potential changes in loads associated with these configurations. Changes in mass, and subsequently cost, are calculated based on the empirical scaling functions, not engineering analysis of specific designs or loads. Overall, this approach represents a relatively basic estimation of potential costs but provides an initial starting point for understanding LCOE impacts of these technological changes.

To characterize plant BOS costs, we used the NREL Land Balance of Station Systems Engineering (LandBOSSE) model. This model was developed in calendar year 2018 and, on

December 20, 2018, initially was released to the public as version 1.0. To date, the model has been used and verified internally, and validated by a limited set of industry contacts during development. The LandBOSSE model is a process-based model that allows us to capture potential cost increases associated with lifting the rotor and nacelle to greater above-ground heights, as well as the potential cost savings associated with fewer lifts overall, as a function of increased turbine nameplate capacity.

The model in its current form is relatively comprehensive but has only simplistic collection-system cost algorithms and does not capture site access or transport and logistics costs. Moreover, the modeling approach applied assumes flat terrain. Moving very large cranes capable of lifting components to 160 m is difficult and risky, and moving cranes in complex terrain could require complete disassembly and reassembly for each turbine installation. These additional costs for complex terrain were not captured here. Additionally, we assumed that the nacelle will be split into 80-ton lifts, as some of the world's largest mobile crawler cranes will be required for these lifts. Correspondingly, investigations into alternative erection technologies is suggested for future research. BOS estimates developed here assume 100 turbines in all cases but normalize costs to $/kW for the purposes of calculating total capital expenditures (CapEx). Depending on actual power plant sizes, this approach might overstate potential economies of scale for larger-capacity facilities. Due diligence conducted since these results were developed suggests that the estimated economies of scale embedded in these results are not likely to impact the qualitative results as the captured economies of scale for larger turbines remain significant even when applied to a fixed-capacity plant. Nevertheless, based on these modeling simplifications and limitations, the BOS benefit from larger turbines can be characterized as somewhat optimistic, and future research on BOS cost impacts is encouraged.

Based on the version 1.0 LandBOSSE model and the simplifying assumptions noted earlier, we estimate that the Today turbine would require an approximate 11% increase in BOS cost to move from 80 m to 160 m. The cost would change similarly for the BAU and Low-SP turbines to move from 110 m to 160 m. For the BAU and Low-SP turbines, however, this cost essentially is offset by the reduced number of turbines required to achieve a fixed plant size (e.g., 100 MW). In fact, the estimated cost savings from increased turbine size drives a calculated net savings in BOS cost, at least on a $/kW basis, for the larger turbines, ranging from 10% for the BAU and Low-SP 3.25-MW turbines to nearly 35% for the Low-SP 4.5-MW turbine—even at 160 m—relative to the Today turbine at 80 m.

Estimated total CapEx values based on the first-order cost characterization described earlier are shown in Figure 6, with a more detailed tabular breakdown provided in Appendix A. Based on CapEx alone, these data show the relative competitiveness of the Today turbine at 80 m as well as the relative BOS savings associated with larger turbine nameplate capacities, particularly in moving toward the higher hub heights. These cost estimates are best utilized to provide a context for how the capacity factor benefits associated with higher hub heights might begin to translate into LCOE impacts assuming basic scaling of costs from recent vintage technology.

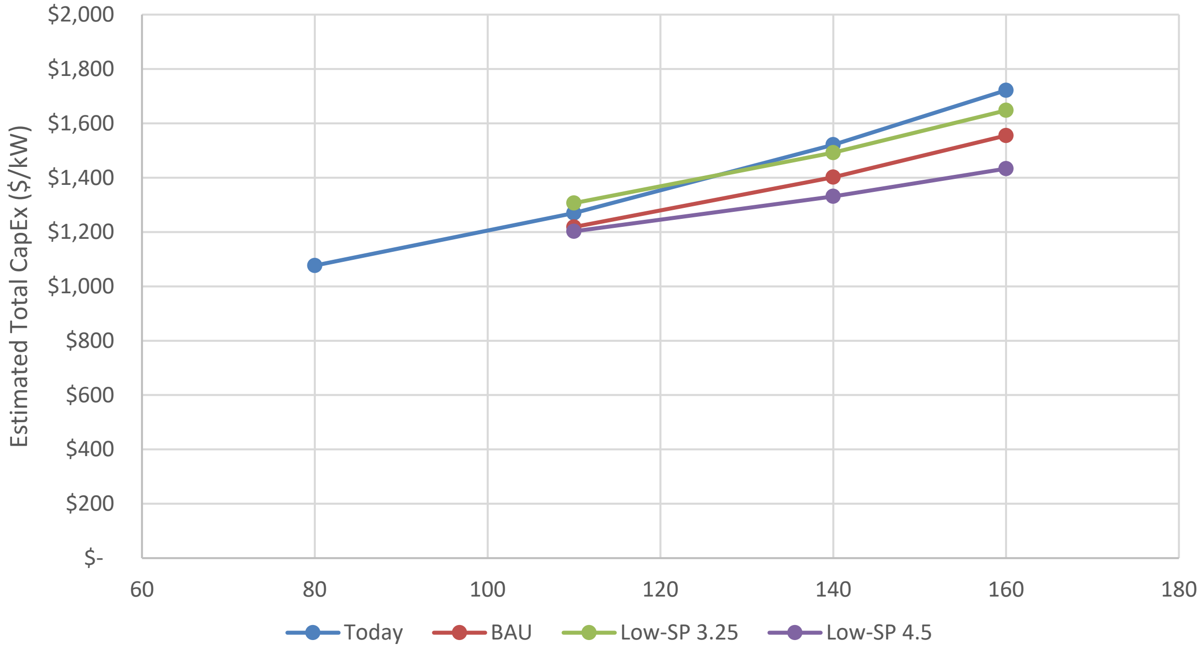

Figure 6. Estimated total installed capital cost by turbine and hub height

The next step in assessing potential LCOE impacts was to estimate the remaining LCOE input variables, specifically operational expenditures (OpEx) and the fixed charged rate, a term that allows us to annualize the total capital cost estimate, considering the cost of capital (i.e., weighted-average cost of capital) as well as the relevant tax treatment, in terms of tax on assumed revenue and allowable depreciation. For these two values, we use an estimated $41/kW for OpEx, as informed by Wiser et al. (forthcoming) and Stehly et al. (2018) and 8% for the real fixed charge rate, commensurate with an implied nominal, after-tax weighted-average cost of capital of approximately 6.4%, and an implied real, after-tax weighted-average cost of capital of approximately 3.9%. Note that OpEx could increase for higher hub heights assuming all else remains equal and no improvements in reliability, as larger component replacements—such as gearboxes, main bearings, and blades—require larger cranes or greater labor costs for up-tower repairs. Additional downtime and lost revenue could also erode the capacity factor benefit estimated here.

The final step in estimating LCOE values was to use these values along with the respective capacity factor data detailed in Section 2.2 to calculate site-specific LCOE for each Wind Toolkit resource pixel or site. The LCOE values were computed for each turbine configuration at each available hub height for all sites. Selected results from the LCOE calculations are illustrated in Figure 7 and Figure 8. Figure 7 shows the calculated LCOE for the Low-SP 4.5-MW turbine at a 110-m hub height. Figure 8 shows the calculated LCOE for the Low-SP 4.5-MW turbine at 160 m. Of course, changes in turbine configuration, estimated energy generation, CapEx, OpEx, and the fixed charge rate all could impact the results.

These results illustrate the potential competitiveness for 110- and 160-m hub heights based on the Low-SP 4.5-MW turbine. Based on the calculations applied here and this specific turbine configuration, much of the interior wind belt plausibly could support unsubsidized LCOE between \$20/MWh and \$35/MWh at 110-m hub heights. Moreover, large swaths of the eastern half of the continental United States could achieve unsubsidized LCOE in the \$35/MWh to \$50/MWh range with nontrivial pockets of potential at lower LCOE values. Results in the Intermountain West and Pacific are more mixed, with large areas falling into virtually all reported cost bins.

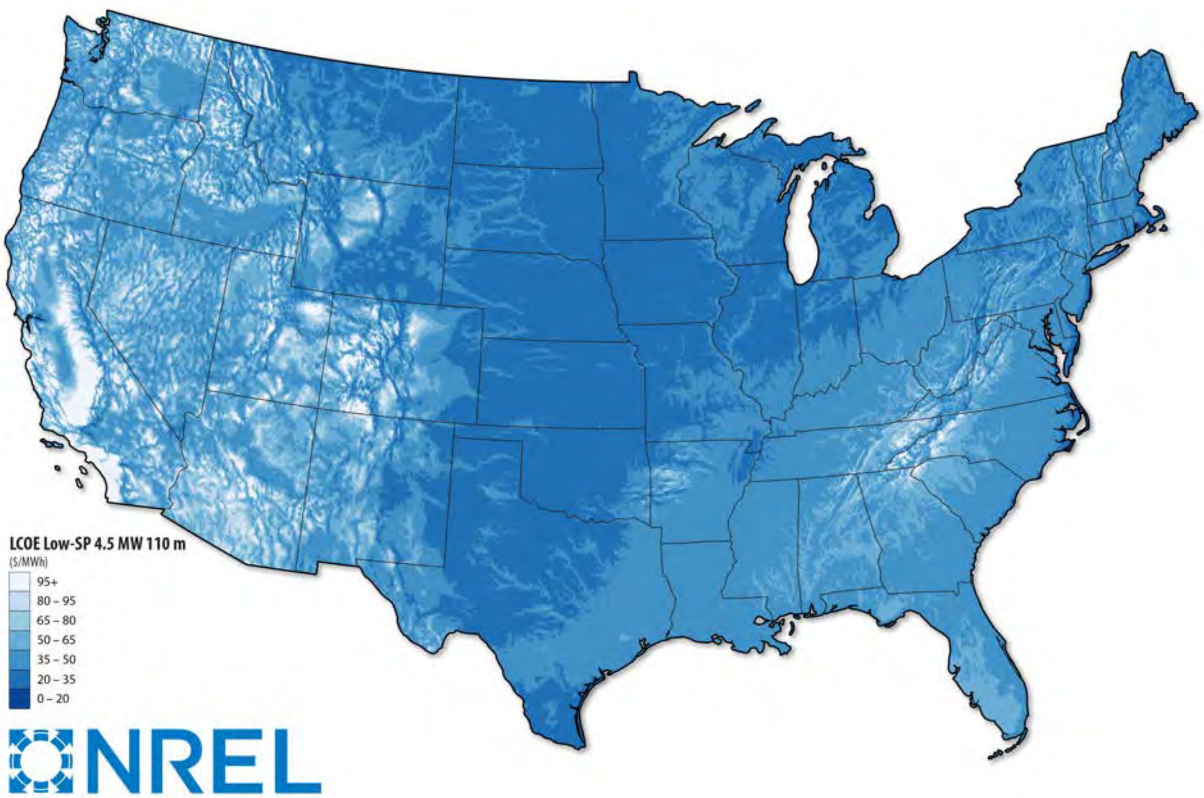

Figure 7. Estimated LCOE for each Wind Toolkit pixel, assuming the Low-SP 4.5-MW turbine at a 110-m hub height

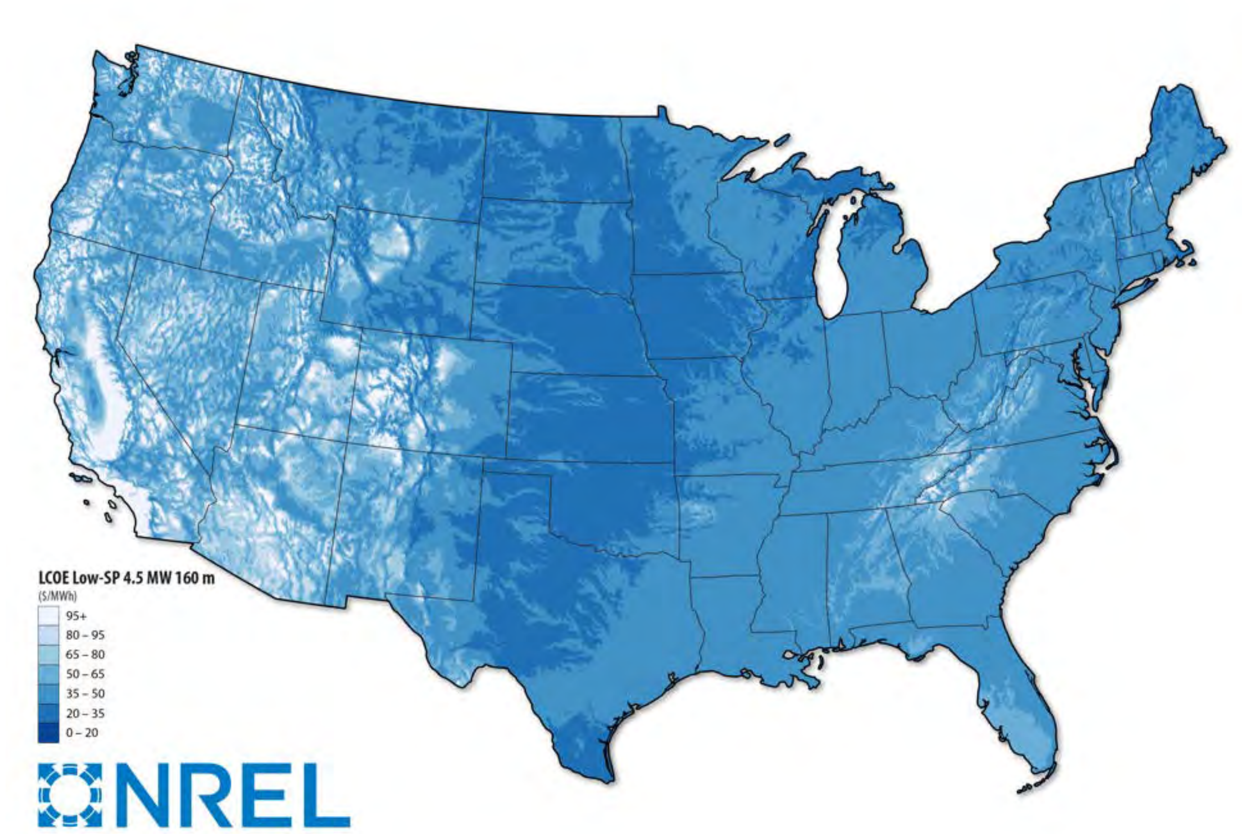

Figure 8. Estimated LCOE for each Wind Toolkit pixel, assuming the Low-SP 4.5-MW turbine at a 160-m hub height

Interestingly, at 160 m, the area of $20/MWh to $35/MWh LCOE is reduced, in the interior region, and the $50/MWh to $65/MWh is also reduced in parts of the east. This outcome is the result of the incremental estimated capital cost to realize 160-m tower heights and indicates somewhat lower competitiveness for the 160-m tower height, under the current estimated costs and performance at 160 m.

To further illustrate the potential impact on LCOE, Figure 9 and Figure 10 detail the distribution of LCOE values by turbine configuration and hub height. Recall that these LCOE values are indicative of recent vintage technology opportunities. Future innovation potential that may increase the relative competitiveness of a given turbine configuration or hub height would alter these results. Additional summary statistics of LCOE results are included in Appendix A.

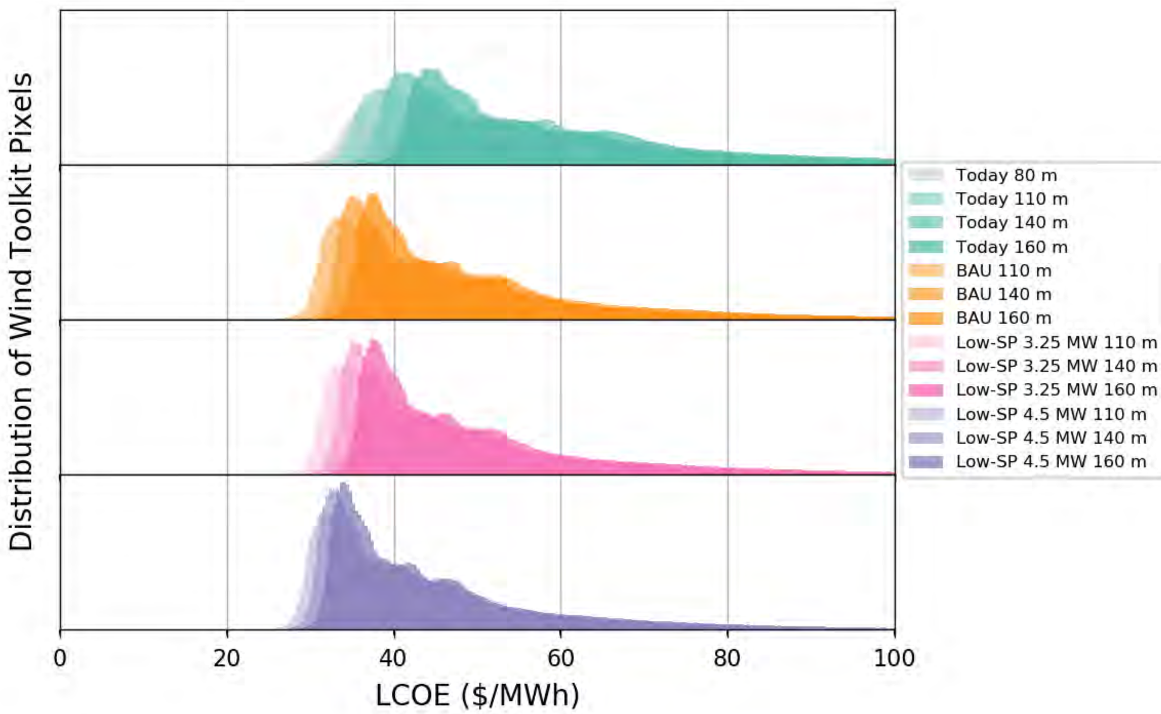

Figure 9. Estimated LCOE for each Wind Toolkit pixel; all turbines and all applicable hub heights

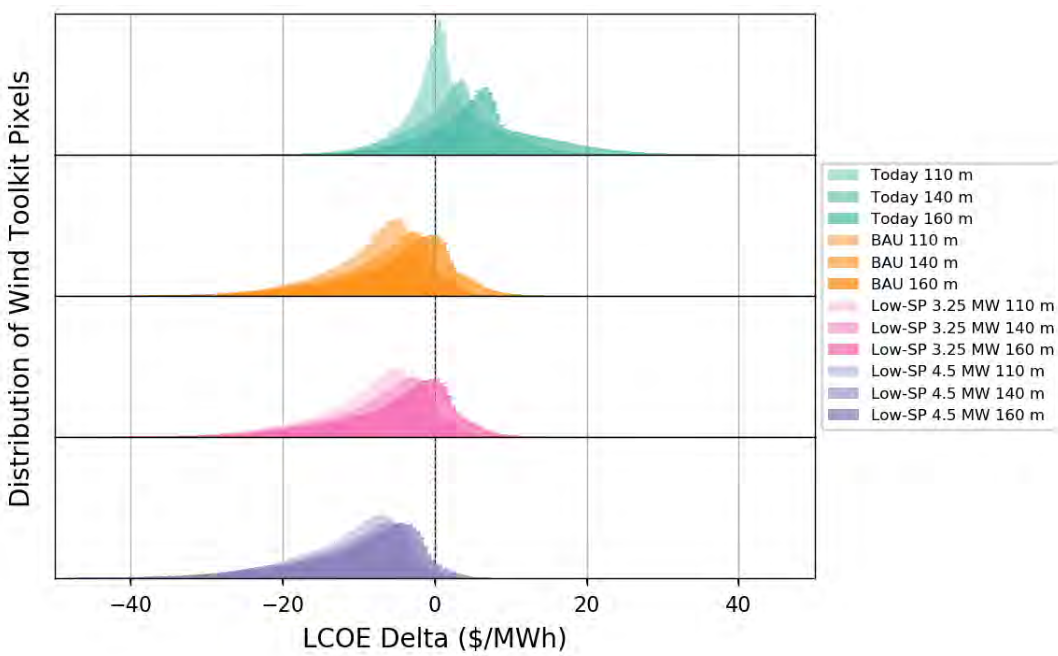

Figure 10. Estimated LCOE differences for each Wind Toolkit pixel, relative to the Today turbine at 80 m

Given cost data that are indicative of recent technology scaling trends, (see also Appendix A), the largest quantity of low LCOE values and the most sizable LCOE reductions appear to be generally associated with the Low-SP 4.5-MW turbine at a 110-m hub height. The 3-MW BAU and Low-SP 3.25-MW turbines, however, also appear to offer nontrivial opportunities to drive down cost at 110 m. The Today turbine LCOE results illustrate why current state-of-the-art commercial technology is most often deployed at a hub height of approximately 80 m.

Real-world results will vary, of course, depending on the actual costs for these turbine platforms, including transport and logistics costs, which may disadvantage larger turbines with larger component sizes, relative to what is shown here. Moreover, these results are indicative of the national trends but may not correspond to subnational or regional economically preferred outcomes. Notwithstanding those caveats, these data suggest that if a single hub height was to be selected for deployments of tall tower technology based on our assumed cost and performance inputs, then 110 m would be preferred. Of course, in real-world commercial applications, developers could select the optimal hub height for a given site based on the available technology.

These conclusions can be further examined by a direct comparison of hub heights for each specific turbine configuration. Figure 11 shows that, for the Today technology, the 80-m hub height is most commonly preferred from an LCOE perspective, applying our current costing assumptions. For the larger turbines, however, the 110-m hub height, which is also the lowest option for these turbines, dominates, with 140 m holding a sizable minority share that varies from approximately 15% to 35% of Wind Toolkit pixels. In these results, preferences for 140 m are typically associated with lower wind speed sites at 80 m that have relatively higher shear. Variability in the share of 140-m sites with the lowest LCOE is a function of the relative benefit that can be gained from a given turbine configuration achieving a higher hub height (i.e., the higher specific power of the BAU turbine means that it is able to extract relatively more benefit from 140 m) and the proportionally lower tower and more limited BOS cost penalty associated with realizing taller towers for larger nameplate capacity machines (i.e., for the Low-SP 4.5 MW).

Notwithstanding the analysis outcomes derived from the current assumptions, the uncertainties in the cost characterization and the magnitude of the differences in the estimated LCOE values suggest that there may not be a clear and dominant winner. More specifically, under our current assumptions, the 110-m height looks attractive but in fact is only economically preferred over the other turbine configurations by a few $/MWh in many cases. Accordingly, if turbine scaling costs vary from recent trends in rotor diameter and specific power or if tower costs come in substantially lower than assumed, then the hub height distribution of future installations could diverge substantially from what is suggested in Figure 11. Moreover, given these differences, investments in tall tower technology that are intended to serve lower wind speed areas could, if successful, easily extend into higher wind speed areas based on the relatively small current advantages of shorter towers on an LCOE basis in those regions.

Finally, the analysis conducted here is somewhat coarse in that it only considers three potential hub heights for the BAU and Low-SP turbines. In reality, commercial developers and OEMs could have the ability to consider additional hub heights that might fall between the three primary focal points of the current analysis with potentially a broader mix of optimal turbine hub heights.

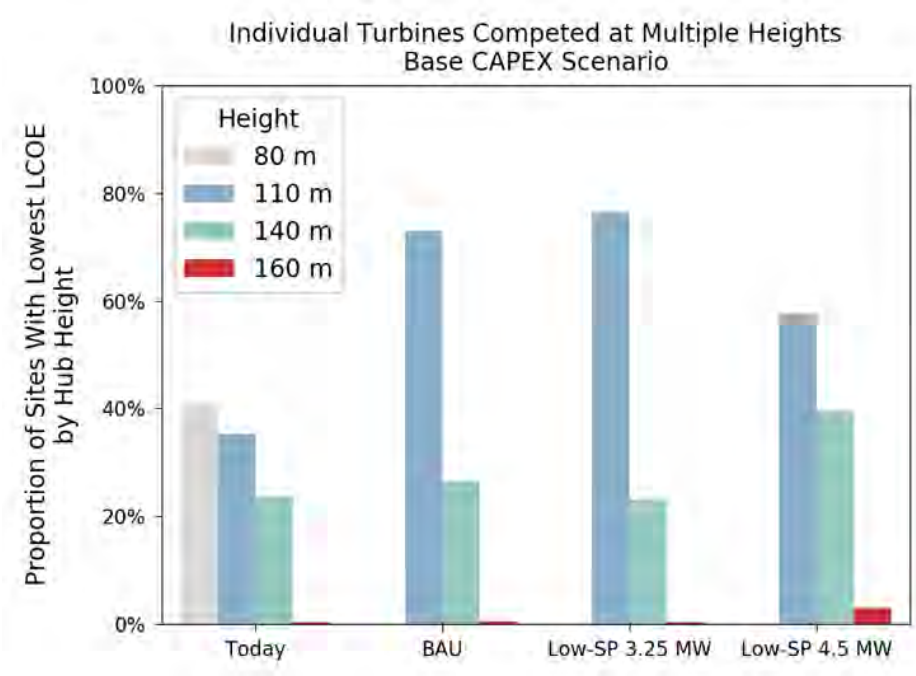

Figure 11. Calculated preferred hub height by turbine configuration, based on estimated performance and costs

Results presented thus far, with their focus on the contiguous United States, do not provide insights into the regions and locations where specific hub heights might prevail. In the same way that the wind speed differences varied geographically, the relative favorability of one hub height (per turbine configuration) or another also varies geographically. Figures 12 through 15 illustrate the economically preferred hub height by location for each of the four turbine configurations evaluated. Although the results presented in the figures are a function of the estimated cost and performance applied here, and therefore are subject to uncertainty, the relative consistency in the trends between turbines is indicative of areas where higher hub height applications will tend to be preferable.

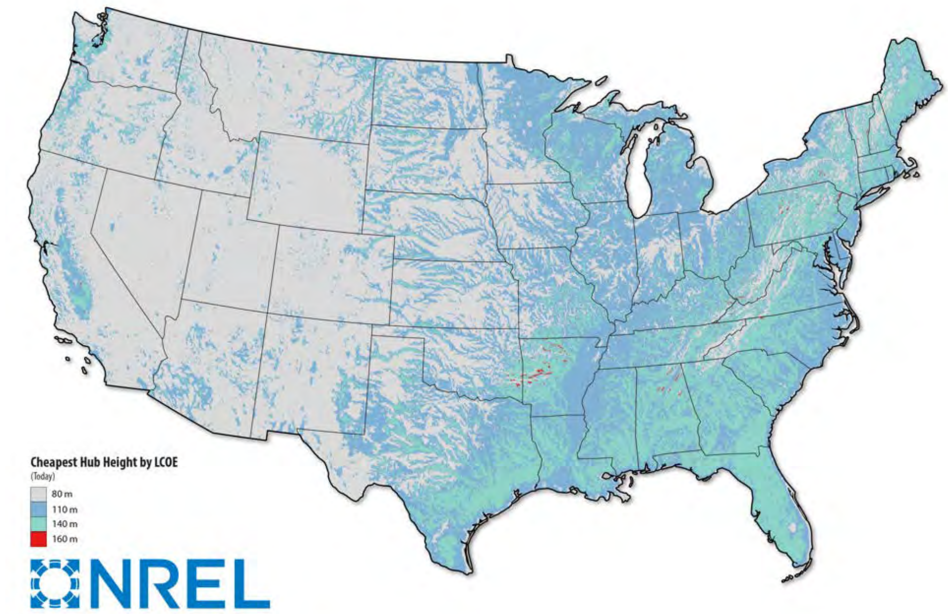

Figure 12. Calculated economically preferred hub heights for the Today turbine, based on estimated costs and performance

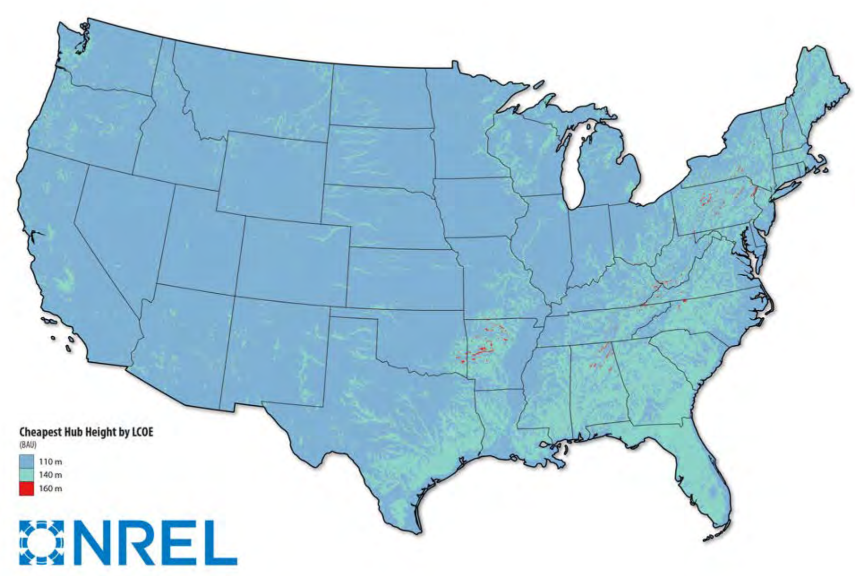

Figure 13. Calculated economically preferred hub heights for the BAU turbine, based on estimated costs and performance

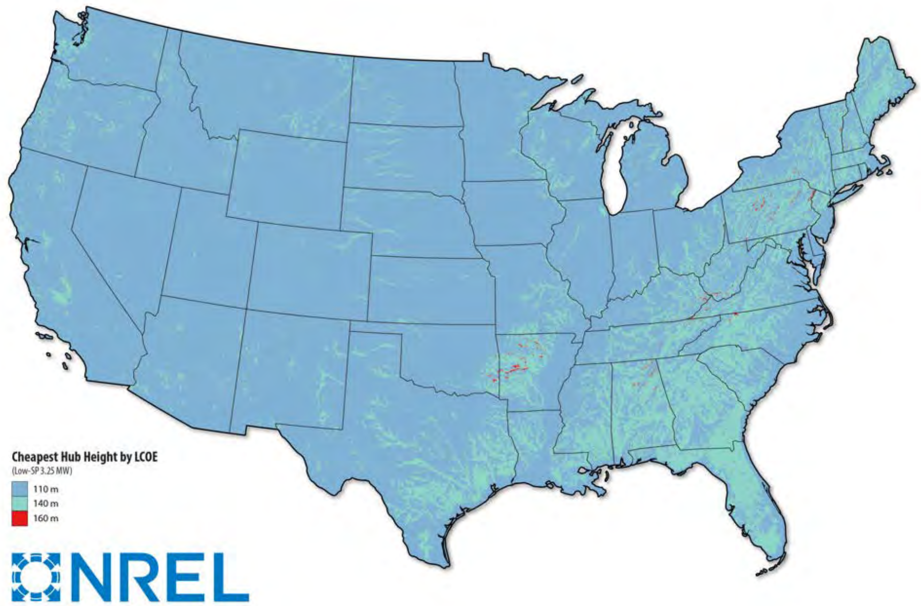

Figure 14. Calculated economically preferred hub height for the Low-SP 3.25-MW turbine, based on estimated costs and performance

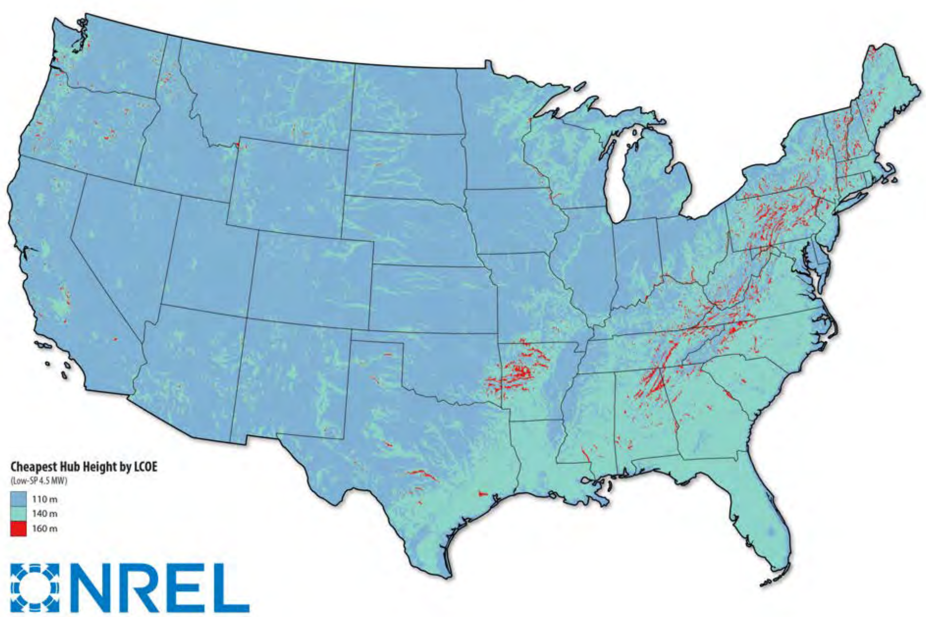

Figure 15. Calculated economically preferred hub height for the Low-SP 4.5-MW turbine, based on estimated costs and performance

The data mapped illustrate that higher hub heights are generally preferred in the east, but the extent of this preference depends on the turbine configuration considered and the estimated costs associated with that turbine. Based on the first-order cost characterization developed for this analysis and the Today turbine, regions experiencing commercial interest today largely fall into those categories where the 80-m and 110-m towers are preferred. This is consistent with the empirical market preferences observed to date. Locations further east suggest more favorable conditions for 140-m towers. Focusing on the BAU turbine and the costs assumed here, the 110-m hub height dominates. Notably, this is the lowest hub height we analyzed for this turbine with an approximately 75-m blade. This suggests that, in many regions of the country, hub heights might be determined simply by requirements for sufficient ground clearance for a given rotor nacelle assembly. Focusing on the Low-SP 3.25-MW turbine, there are only very minor differences from the BAU turbine. Shifting to the Low-SP 4.5-MW turbine, at the assumed costs applied here, results in a modest increase in an area where 140- and 160-m turbines are determined to be economically preferred. Overall, however, the 110-m turbine continues to dominate, especially in the windiest regions of the country.

These results are a direct reflection of the inputs applied and do not account for the potential impact of future tower innovations that might make higher hub heights more attractive. To begin to ascertain the potential impact of tower technology R&D and innovation, we conducted an additional tower cost sensitivity analysis. This sensitivity assumes that tower cost is fixed or static at $200/kW for all turbine configurations and tower heights. This cost is the approximate cost per kilowatt of the Today tower at 80 m. Notably, although this approach fixes cost per kilowatt, it does allow for total tower cost to increase as nameplate capacity increases. This sensitivity scenario enables us to at least partially capture the potential change in competitiveness of the different tower heights, if innovation is able to limit tower cost changes as a function of tower height. The calculated LCOE differences associated with this sensitivity scenario are shown in Figure 16. This plot is an analog to Figure 9, albeit with tower costs fixed at $200/kW for all tower heights. Figure 17 illustrates the economically preferred tower height under these cost assumptions.

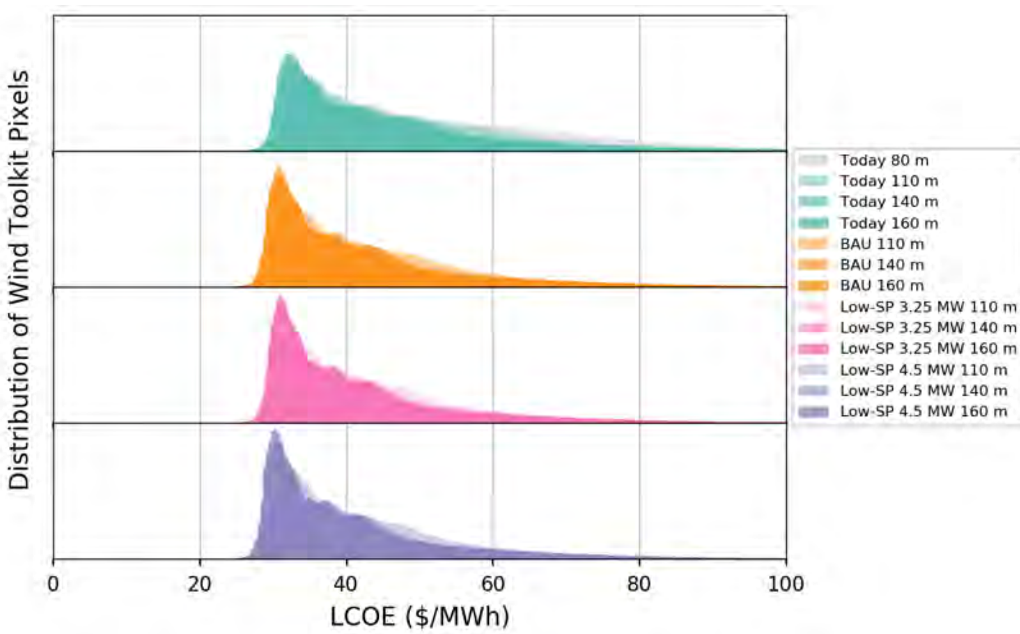

Figure 16. Estimated LCOE differences for each Wind Toolkit pixel, assuming $200/kW tower costs, relative to the Today turbine at 80 m

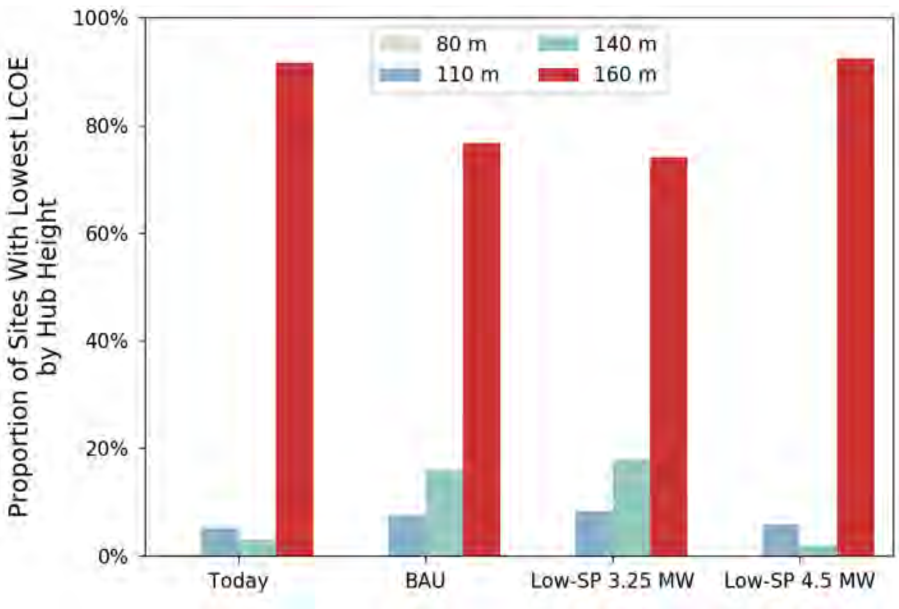

Figure 17. Calculated preferred hub height by turbine configuration, based on estimated performance and costs, assuming $200/kW tower cost

These results illustrate increased competitiveness for tall towers, especially the 160-m tower height and highlight how differences in analysis assumptions and innovation potential could significantly alter preferences and demand for relatively shorter or taller towers. Future analysis would benefit from examination of additional sensitivities and could further parse these results.

2.4 Breakeven Cost Analysis for Turbines with Taller Towers

In addition to the analysis presented thus far, we sought to identify the potential cost targets that must be achieved to justify the application of these technologies at their respective hub heights. To identify these targets, we calculate the incremental price premium or breakeven cost ($/kW) that can be incurred with the improved capacity factors afforded by these technologies and result in an equivalent LCOE as the Today technology at an 80-m hub height. If innovators are able to achieve a total installed capital cost that is at or below the sum of the Today technology capital cost and the breakeven cost, they will be competitive with technology that has recently been installed in the U.S market. In practice, the calculated breakeven cost reflects a potential $/kW cost adder on top of the estimated total CapEx for the Today technology. In regions where the LCOE of the Today technology at 80 m presently is insufficient for wind power to be competitive with other power-generation resources, additional cost reduction beyond the levels associated with the breakeven costs likely would be necessary to drive future wind power deployment.

The concept of the breakeven cost is premised on the idea that a taller turbine might involve more raw material or otherwise be more expensive to install but that the additional energy produced could offset these incremental costs, depending on the magnitude of the energy improvement and the cost premium incurred. It is also possible that innovation could create the conditions under which energy production increases while overall CapEx decreases. In fact, as suggested earlier, this might be necessary for wind power to become viable as an energy-generation resource in some regions. Although anecdotal evidence suggests we may be moving toward this point, we would not necessarily expect increased energy production and lower CapEx to be achieved initially. Increases in energy production per turbine, and reductions in project-level CapEx, however, generally have occurred in concert for much of the last three decades of wind power innovation. Moreover, as a principal benefit of taller turbine innovation is access to turbine- and plant-level economies of scale, it is reasonable to anticipate that these innovations could allow access to better wind resources at higher above ground hub heights while also achieving lower CapEx over time. Numerically, higher values for breakeven costs are generally more advantageous and indicate that there is a relatively greater benefit from moving to taller turbine concepts. As indicated, however, we also must consider that—for sites with relatively low energy production under baseline Today turbine conditions—a high breakeven cost on its own might not justify technology or project investment.

Notwithstanding its limitations, the breakeven cost metric helps to illustrate the costs that innovators must beat to be competitive with state-of-the-art technology available today. In this sense, it is indicative of an innovation cost target that must be achieved simply to be better than the next-best alternative—in this case, the Today technology at an 80-m hub height. The capacity factor change and breakeven cost analysis also begin to inform the potential value of continued tall-turbine technology development in regions that are currently being targeted by wind energy developers, as well as regions that are of less focus to the commercial development community today. The calculated breakeven costs for each of the turbine configurations and hub heights analyzed here are summarized in Figure 18.

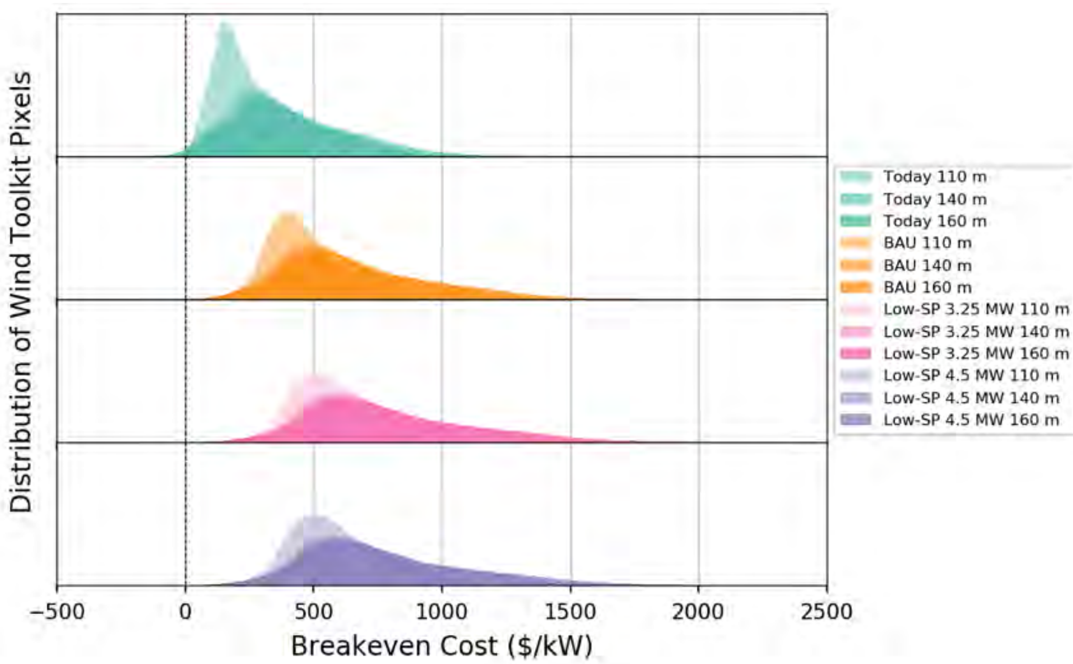

Figure 18. Breakeven costs for all turbines and all hub heights

In addition to the broad distributions in Figure 18, the following maps illustrate the LCOE achieved by the Today turbine (Figure 19)—which constitutes the LCOE from which the breakeven cost is calculated—and show how the estimated breakeven costs (an incremental price premium that would be on top of the estimated capital cost for the Today turbine at 80 m) vary geospatially across the continental United States (Figures 20–23). For these maps, we focus on the BAU and Low-SP 4.5-MW turbine at 110 m and 140 m. A complete summary of average breakeven costs by state is provided in Appendix A.

Collectively, these images illustrate that the distribution of breakeven costs across the country is both broad and sizable. In many locations, the breakeven costs are considerable, suggesting that there is significant opportunity to go to higher hub heights. At the same time, these locations also tend to be where the Today turbine estimated LCOE is quite high and therefore simply achieving the breakeven cost will likely be insufficient to drive economic deployment of new wind power.

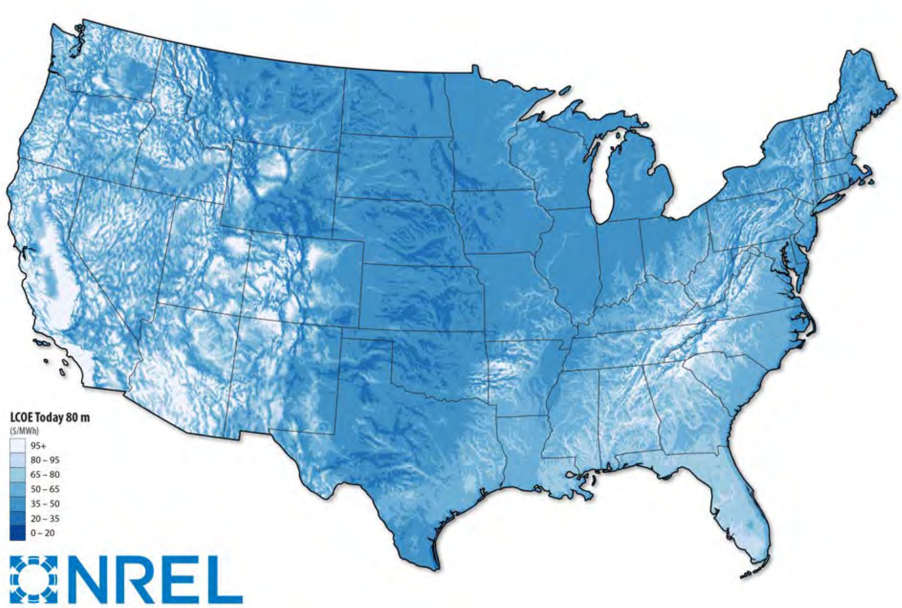

Figure 19. Estimated LCOE for the Today turbine at the 80-m hub height

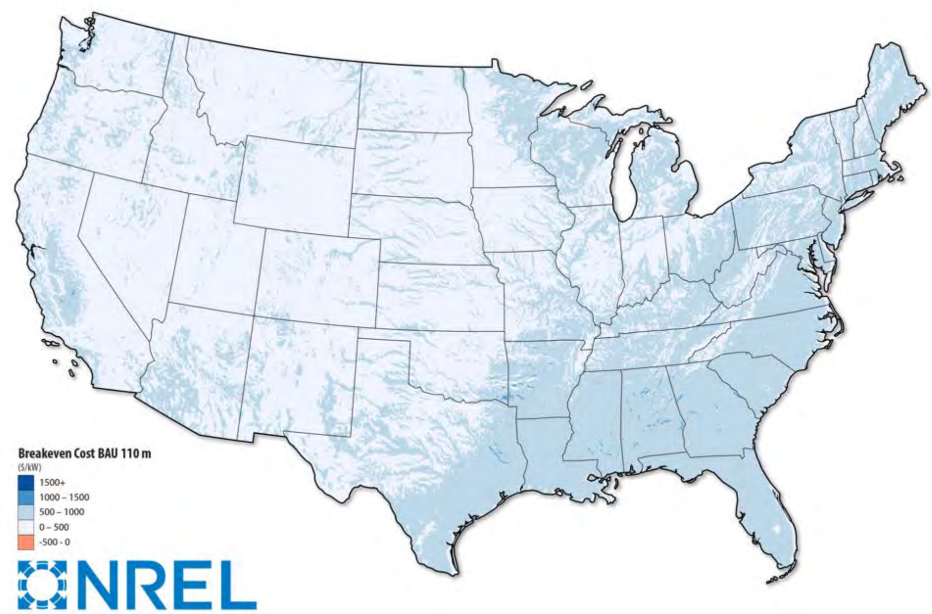

Figure 20. Breakeven costs for the BAU turbine at the 110-m hub height

Note: Breakeven values reported here are the incremental cost premiums that would be added to the CapEx of the Today turbine at 80 m to achieve the same LCOE as the Today turbine at 80 m.

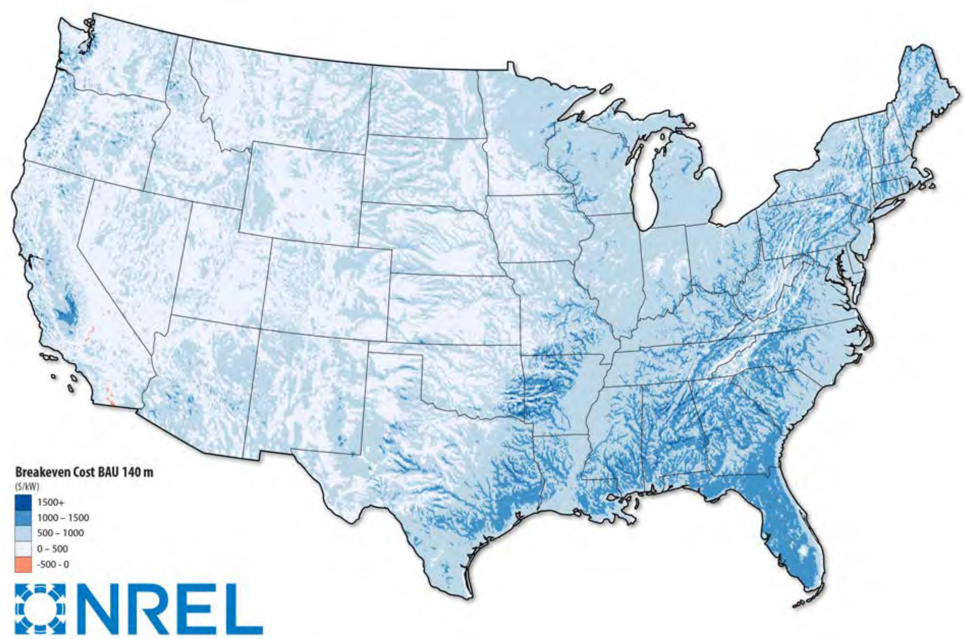

Figure 21. Breakeven costs for the BAU turbine at the 140-m hub height

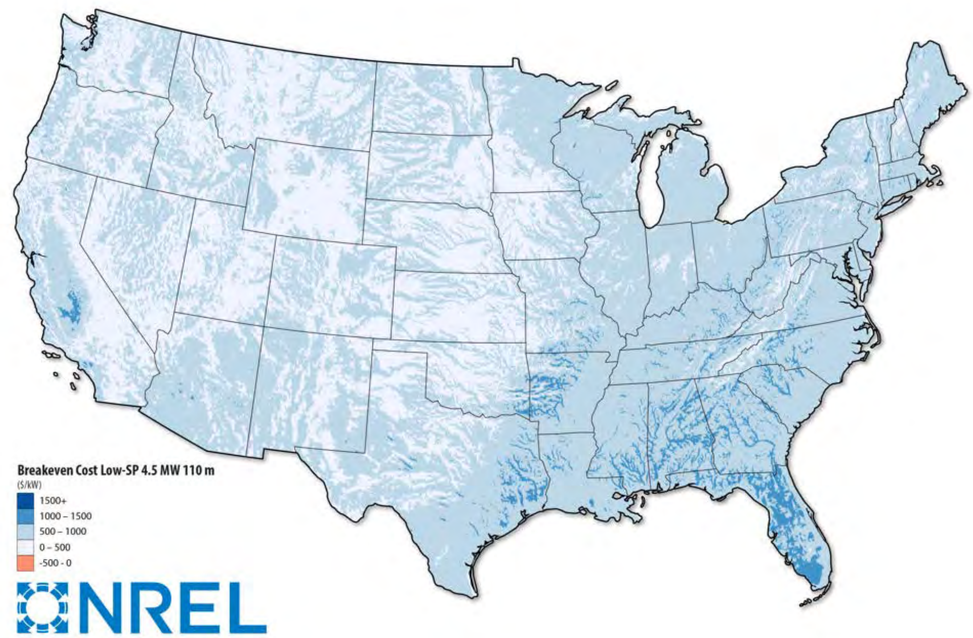

Figure 22. Breakeven costs for the Low-SP 4.5-MW turbine at the 110-m hub height

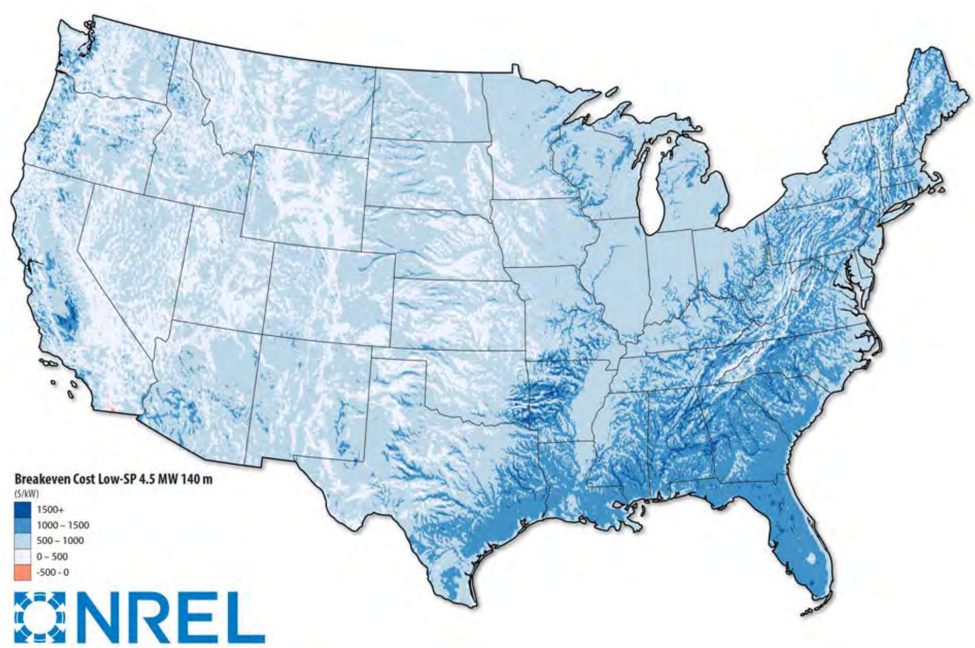

Figure 23. Breakeven costs for the Low-SP 4.5-MW turbine at the 140-m hub height

3 Tower Design Options and Related Analysis

For much of the past two decades, the modern wind industry has been dominated by tubular steel towers also called "cans." Since the mid- to late-2000s, the tubular steel tower has been the industry standard, and tower height trends in the United States largely have plateaued at about 80 m. The dominance of the 80-m tower is, in part, a function of logistics and transport constraints that limit tower-base diameter, and require rapidly increasing quantities of material to get to higher hub heights; and, in part, is a function of the relative cost of energy benefit achieved from realizing higher hub heights. Here, we utilize a systems engineering modeling approach to understand how technology and innovation might impact the future potential of tubular steel tower technology to achieve higher hub heights into the future.

Note: Section 3.1 through Section 3.1.3 is heavily based upon Dykes et al. (2018).

3.1 Systems Engineering Steel Tower Simulations

The designs for land-based wind turbine towers must satisfy a number of criteria, or constraints, to be viable for deployment. The goal for tower design always is to minimize mass, and to reduce material costs, and typically labor costs as well. The tower, however, must be able to support the wind turbine for a large variety of operating conditions and extreme events through the turbine's life. Additionally, the tower needs to be manufacturable and transportable. This last design criterion around transportability has become a challenge as turbine designers push toward higher and higher hub heights. For reasons discussed elsewhere herein, as towers grow larger, the ideal design approach is to increase the diameter at the tower base and keep the wall thickness minimal. For transportation on land, however, tower diameters are limited to approximately 4.3 m dictated by highway and railway overpass heights, which leads to substantial and costly tower designs using conventional technology solutions.

To better understand the potential for steel towers to meet the requisite price points to be viable in the United States, an ideal tall tower modeling analysis was conducted. This effort compares conventional "transportable" tower designs at different hub heights alongside idealized tower designs, with relaxed constraints around transportation and the maximum tower base diameter. In particular, a conventional technology transportable case is compared to a large-diameter steel tower (LDST) design concept with a 6.2-m base diameter as well as an unconstrained base diameter concept potentially accessible through an on-site spiral-welded tower approach. The results compare for each design how tower mass and expected material costs change with increasing hub height, and thus provide insight into the potential of different technical solutions to enable future low-cost tall towers for the wind industry.

3.1.1 Tower Optimization Method

Tower design looks at minimizing mass and cost through manipulation of the diameter and thickness of the tower along its length. The main constraints on the design are associated with the tower strength and stiffness, which are driven by the loads that the tower experiences over its operating lifetime. The loads on the tower stem from aerodynamic, gravitational, and inertial loading from the RNA at the tower top as well as drag loads from the wind impinging directly on the tower, blades, and nacelle. Detailed discussion of the tower design process is provided in "Design of Offshore Wind Turbine Towers" (Damiani 2016).

For this analysis, we use a software tool for Tower Systems Engineering (TowerSE) to optimize the wind turbine tower design to minimize mass by adjusting tower diameter and thicknesses (Ning et al. 2014). TowerSE is a wind turbine tower conceptual design tool that is part of a larger WISDEM toolset (Dykes et al. 2015). The tower-top diameter is fixed so there are two design variables for the diameter—at the base of the tower and at a set point somewhere between the base and top of the tower (which is also a design variable itself). The wall thickness at each of the base, top, and set point are design variables as well (Table 2).

Table 2. Tower Design Variables

Description	Number of Variables
Tower Outer Diameter	2
Tower Wall Thickness	3
Tower Set Point for Tapering	1

The design variables are optimized for minimum tower mass and satisfy constraints caused by key turbine loads (Table 3). We also consider resonance avoidance through a constraint on the tower natural frequencies relative to the RNA frequencies. Depending on the specific case, constraints for manufacturing and transport are applied as well.

Table 3. Tower Design Constraints

Description	Number of Constraints
Utilization against shell and global buckling	68
Utilization against strength	34
Natural frequency lower limit	1
Fatigue damage	1
Diameter-to-thickness ratio (manufacturability)	3
Base diameter (transportability)	1

The methods to calculate the shell buckling, global buckling, fatigue damage, and stresses along the tower for each load case are addressed in prior studies (Ning et al. 2013). The diameter-to-thickness ratio constraint ensures weldability of the tower. The base diameter upper-bound constraint is adjusted depending on the tower design case—4.3 m for conventional technology, 6.2 m for LDST technology, and unconstrained as would be the case for on-site spiral-welded technology.

Finally, the frequency constraint lower bound is adjusted based on the type of tower, present for soft-stiff and absent for soft-soft. The frequency constraint is particularly important to the design because it can often be the binding constraint on a soft-stiff design and push the mass up exponentially as towers grow taller and the natural frequencies move lower (for a fixed diameter and thickness profile). A tower designer must be sure that the tower natural frequencies do not overlap with the rotor rotational frequency (1P) and blade passing frequency (3P for a three-bladed turbine), where excitations can lead to resonance, large amplitude loads, and increased fatigue damage (see Damiani 2016 for detailed discussion). Conventional tower designs historically were soft-stiff and were designed to completely avoid the potential for resonance-induced loading. For modern wind turbine controls, however, it is possible to control loading through resonance conditions and enable the use of soft-soft wind turbine tower designs with very low natural frequencies that are less stiff and require less thickness in towers with smaller diameters. As shown herein, this has significant implications for the small-diameter towers in tall tower applications.

3.1.2 Tower Optimization Case Study

This study examines six different combinations of tower designs for each of six different turbine hub heights for a total of 36 optimization cases (Table 4).

Table 4. Tower Optimization Cases

Tower Configuration	Tower Type	Hub Height
• Conventional (4.3-m base diameter)	• Soft-stiff (constrained to above rated rotor 1P)	• 80 m • 100 m
• LDST (6.2-m base diameter)	• Soft-soft (no frequency constraint)	• 120 m • 140 m
• Spiral-welded (no base diameter constraint)		• 160 m • 180 m

The RNA properties and loads for the study are based on a reference turbine developed by the International Energy Agency (IEA) Wind Task 37 on Wind Energy Systems Engineering (Table 5). The 3.3-MW reference turbine has a rotor diameter of 130 m and a specific power of roughly 240 W/m^2 (IEA 2017). Although not as low in specific power as some machines that are being produced or are expected to be in production soon, it is an International Electrotechnical Commission (IEC) Class 3A turbine design for low wind speed applications and closer to current U.S. land-based wind turbine technology than other available reference turbine designs.

Table 5. IEA Wind Task 37 Land-Based Low Wind Speed Turbine Configuration Data

Wind Turbine Configuration Data	
Lead Developer	Technical University of Munich
Class and Category	IEC Class 3A
Rotor Orientation	Upwind
Number of Blades	3
Control	Variable-speed collective pitch
Drivetrain	Geared machine
Rated Power	~3.3 MW
Rotor Diameter	130 m
Hub Height	110 m

The loads for the turbine were provided by the Technical University of Munich through a comprehensive analysis of the turbine response to various design load cases as defined by IEC design standards for wind turbines (IEC 61400e1 2014). The largest loads for different force and moment components at the tower top were used as input loads to the optimization (including a thrust load of 1,000 kilonewtons (kN) and torsion around the vertical axis of 12,500 kNm). Fatigue loads were applied based on scaling fatigue loads from the NREL 5-MW reference turbine (Jonkman 2009).

3.1.3 Results

Figure 24 shows the results for more traditional soft-stiff tower masses for each of the turbine tower configurations investigated.

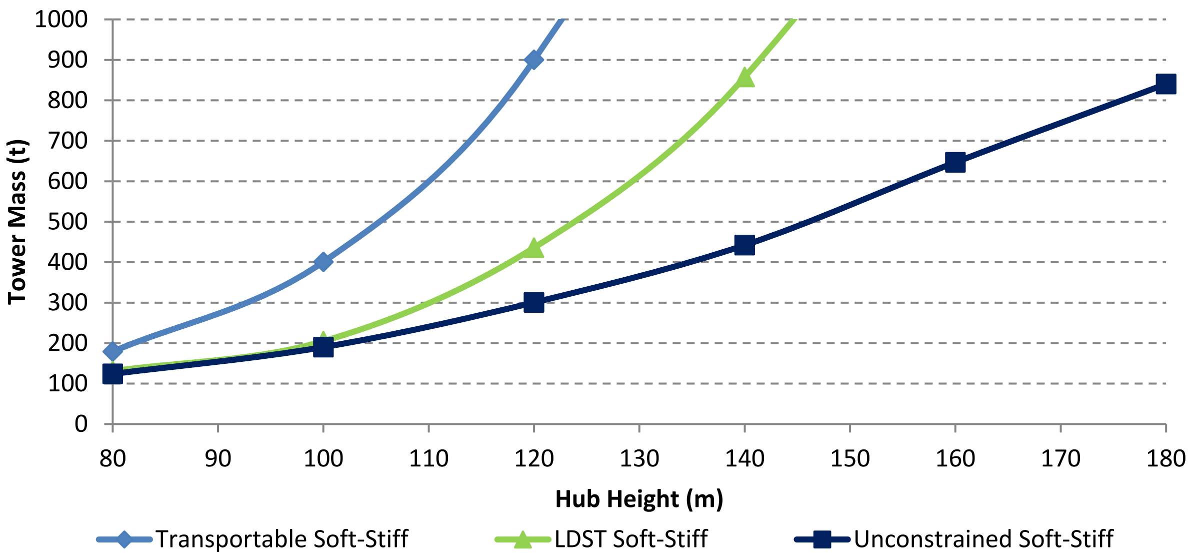

Figure 24. Optimization results for soft-stiff tower design cases

For the transportable towers with a maximum diameter of 4.3 m, the optimizer failed to find a feasible solution for hub heights of 140 m or more. For the heights that were possible to optimize, the weight grows relatively rapidly with tower height. When the constraint on tower base diameter is relaxed, there are benefits in decreasing mass at all heights. Generally, the need to meet the frequency constraint for soft-stiff towers pushes the wall thickness of smaller-based-diameter towers to large values so that the overall mass increases. Notwithstanding these results, it is important to note that tower cost is strongly correlated with mass but is not directly proportional to it, due to the specifics of manufacturing processes.

Figure 25 illustrates the shift in the results when looking not just at traditional soft-stiff towers but also examining soft-soft towers where controls are used to avoid 1P resonance with the rotor.

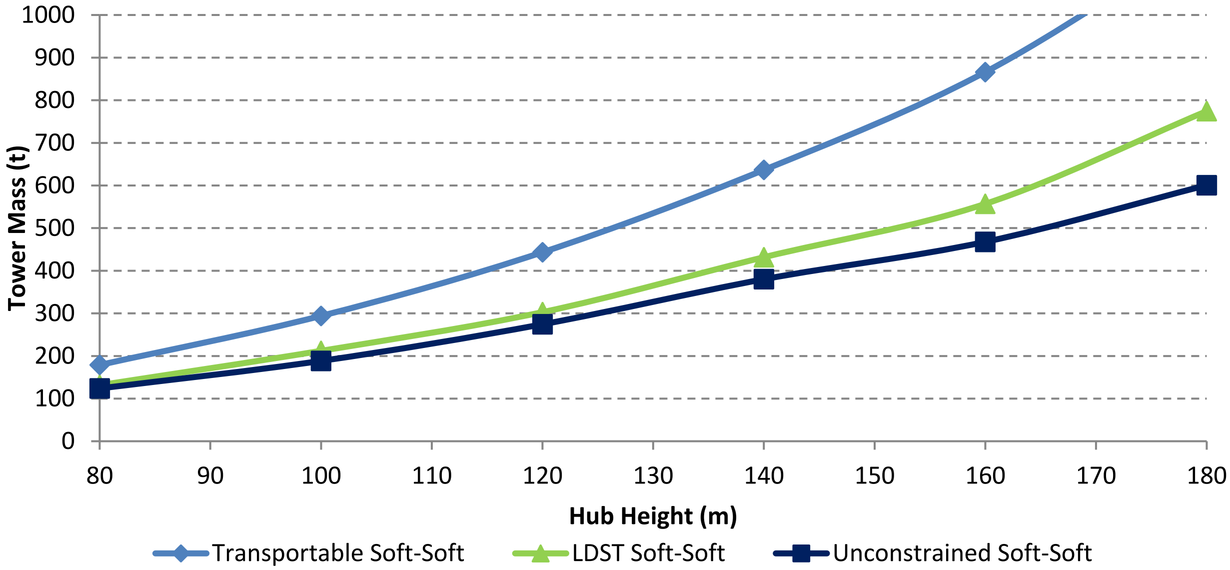

Figure 25. Optimization results for soft-soft tower design cases

Relative to the soft-stiff towers, the mass is reduced in all cases in the soft-soft tower results. The difference is most pronounced in the transportable case with a maximum base diameter of 4.3 m. The optimizer was able to find feasible solutions for all transportable cases, though the 180-m case yielded an optimized mass of 1,200 tons to meet constraints for global buckling. Similarly, the solutions for the LDST and spiral-welded cases all are much lower than before—reduced by as much as 200 tons in the unconstrained case at a 180-m hub height.

Based on data points from actual masses for two transportable towers with hub heights of 120 m and 140 m, we know that these masses can be higher than the transportable tower masses presently available. This likely is due to the fact that the reference turbine design differs from actual technology and the fact that industry has developed more sophisticated control systems to enable not just soft-soft tower designs but also an overall decrease in loads experienced by the tower. The major impact of these advancements will be in reducing fatigue loads, but controls algorithms and load sets for specific turbines are highly valuable intellectual property in the industry. An example of this is Vestas OptiStop and Active Damping technologies that reduce the overall loads experienced by the towers and allow for a more efficient, lower-weight, and reduced-cost tower design (Montanez 2017). These data demonstrate that, although pursuing novel tower technologies holds promise for growing hub heights, innovation around conventional tubular steel tower designs also holds promise and could extend their competitiveness to higher hub heights. At the same time, when the full suite of controls technologies is applied to LDST and unconstrained or spiral-welded technologies, their masses might be decreased even further with further potential to reduce the cost of wind energy for tall tower applications.

3.2 Innovation Opportunities for Additional Alternative Tall Tower Technologies

In spite of the general dominance of tubular steel towers, manufacturers have continued to explore additional alternative tower technologies. The pursuit of alternative tower concepts is justified on various grounds and can result from a desire to hedge against steel-price volatility or from perceived potential for cost reduction. Alternative tower technologies might use lower-cost materials, such as concrete, or could entail more efficient use of steel, such as lattice or space frame designs. Depending on the specifics of a given concept, they also could offer efficiencies in balance of plant and erection. Notably, many alternative tower concepts offer potential solutions to transport challenges and barriers, and in many cases offer opportunities for larger base diameters than the conventional transport limit of 4.3 m. This is of particular interest to OEMs and wind power plant developers operating in the United States, where long transport distances result in nontrivial cost impacts associated with transportation generally. Of course, alternative tower concepts also have challenges that have precluded their broad-based adoption to date, such as much larger labor fraction and on-site labor rates.

One alternative tower design option is on-site manufacturing, which, in principle, should reduce transportation costs and enable taller towers with the trade-off of potentially more labor in the field at the project site. Fundamentally, on-site manufacturing enables the use of commoditized transport and allows the primary production or assembly processes to occur at or near the wind power plant construction site (e.g., avoiding public roads). Currently, a few tower-technology firms—including Wind Tower Technologies (WTT) and Keystone Tower Systems—have conceived and are actively developing on-site manufacturing strategies. Max Bögl is another firm that has commercial offerings of site-cast concrete in mobile factories.

Here, we explore the current status of various alternative tower designs and discuss the design considerations and attributes associated with each of these technologies. Three specific alternative tower concepts are considered: (1) a full-concrete field-cast tower, (2) a hybrid concrete and tubular steel tower, and (3) a lattice or space frame tower. These three alternative tower concepts considered here have all been explored in some depth by wind turbine manufacturers in the past, and all cases have some operational experience in the wind industry. As they were more quantitatively analyzed and discussed, in terms of mass attributes in Section 3.1, we do not reconsider LDST or spiral-welded towers in this section; however, they are also relevant tower options going forward.[5] Notably, this short list of alternatives is not intended to be comprehensive. In particular, it does not consider lower technology readiness level potential solutions such as three-dimensional-printed concrete, which, if successful, could resolve at least some of the challenges with the concrete tower concepts detailed in the following sections.

3.2.1 Full-Concrete Field-Cast Towers

The full-concrete field-cast tower concept has gained interest from the wind industry as a means to circumvent transportation barriers associated with other tall tower technologies. By pouring the tower on-site in the field, overpass clearance barriers are avoided as are other transport hurdles (e.g., weight) associated with moving large concrete sections often utilized in hybrid

[5] Potential challenges associated with these tubular rolled steel variants include significant bolts and on-site assembly costs for the base section of the LDST and the potential needs to set up regional or on-site facilities to manufacturing spiral-welded towers.

concrete and tubular steel concepts. Reliance on concrete as the primary material also offers an opportunity for less sensitivity to steel costs and replaces steel with a lower-cost primary material.

Challenges for full-concrete field-cast concepts include relatively large material quantities, which could erode some of the potential material cost savings associated with lower-cost materials, and a persistent dependence on steel for reinforcing rebar and post-tensioning cables. Additionally, the field-casting and erection process tends to be labor- and time-intensive, increasing labor costs overall and potentially introducing logistics challenges. Moreover, without a self-erecting crane—which has not yet been demonstrated in the field—incremental crane costs could be incurred as the individual sections are cast and ultimately placed on the tower.

In terms of its present status, in the United States, WTT has installed a prototype 115-m hub height (100-m concrete tower, 15-m steel section) tower that utilized concrete annuli that were cast on-site. The WTT tower utilizes a process called "match casting" that provides reduced cycle times during tower installation and less finishing work on the interface of the concrete tower sections. The process involves casting tower sections against one another as they cure; this allows for a precision joint and removes the need for a "wet joint," further decreasing installation cycle time. This process is more widely known as "short line match casting" in civil engineering and the bridge industry and eliminates the need for precision machining of the concrete tower section interface as is typical with factory-cast and highway-transported concrete sections common on hybrid concrete and steel towers.

The WTT technology utilizes concrete that can be produced in the field in most locations in the United States. This approach benefits from having a quarry on or near the wind power plant site. This differs from some hybrid concrete and steel factory-cast sections with compressive strengths of approximately 11,000–13,000 psi. Controlling the quality and strength of these higher-strength mixes can be a challenge in the field. Because the tower segments are assumed to be cast on-site, the moving of the tower segments might only face challenges due to weight and the relatively large diameter. For on-site transport, the additional cost of a specialized trailer, if necessary, and tractor or prime mover are assumed to be limited.

3.2.2 Hybrid Concrete and Tubular Steel Towers

Historically, the hybrid concrete and tubular steel tower is the most common type of tower for hub heights above 120 m. Max Bögl and the turbine OEM Enercon are perhaps the most prominent users of these tower designs, which most frequently have been installed in Germany. Hybrid designs typically use ~90 m of concrete annuli or segmented sections and a 50- to 80-m steel tubular transportable steel tower. Again, an advantage of the concrete construction is that the tower diameter can be optimized (but still considering the transport limits of the concrete sections), which can minimize the material required to construct the concrete portion of the tower.

The cost estimates provided below assume a 90-m concrete tower and a 50-m steel tower. These towers typically use concrete sections that are cast in a factory and utilize high-strength concrete (11,000–13,000 psi). The tower-section mating surfaces are machined parallel and the tower section typically is transported to the site by truck. A transition piece is placed on top of the concrete sections and is used to attach the tubular steel tower section to the concrete base. The transition piece is connected to the base of the steel tubular tower and to steel cables that serve to compress the concrete structure. These cables are post-tensioned after installation of the concrete sections and transition piece, and before the installation of the tubular steel tower segments.

The hybrid concrete-tubular steel tower concept has been pursued explicitly because of its lower sensitivity to fluctuations in steel prices and to avoid transport challenges historically associated with tall steel towers. Hybrid concepts also might provide a viable solution to the geometric constraints within the area covered by the rotor disc. At the same time, transport costs still might be significant because of the need to transport large concrete sections as well as steel sections. Relative to the full-concrete field-cast concept, some labor and material savings could be captured by fabricating the various sections in a centralized manufacturing facility, but this savings potential must be weighed against impacts on transportation costs.

Max Bögl announced the capability of a mobile concrete tower-section manufacturing facility (Max Bögl 2016), which could increase the potential utilization of hybrid concrete towers by reducing the transportation cost and increasing local labor fraction. Relative to a full tubular steel tower, labor and material intensities remain comparatively high. The assembly of the large concrete sections coupled with the joining of the concrete and steel portions of the tower also introduce additional erection-cycle time relative to a tubular steel tower. Notably, as advanced turbine controls have evolved and allowed for alternative steel-tower geometries, LDST-style towers have eroded some of the hybrid concepts market share for tall tower installations in Europe.

3.2.3 Lattice/Space Frame

Lattice towers were used for many years in the wind industry, specifically in the 50- to 400-kW turbine size range from the 1980s to1990s. Lattice towers offer very low material quantities and a complete tower can be moved by a conventional highway legal truck, helping to control transport costs. In the 1990s, these towers fell out of favor for various reasons; however, visual aesthetics and bird interactions are the most commonly cited explanations. The lattice tower concept is sensitive to labor cost because of the large number of individual structural members and fasteners as well as a relatively challenging skin (something often desirable for its favorable aesthetics). Installation time, particularly for the skin, is also sensitive to weather delays. Increased erection-cycle time, due to the increase in number of tower sections and the time needed to install the skin of the tower, compounds the risk of costly weather delays. Despite the move away from lattice towers over the past two decades, designer interest has never been fully eliminated.

This analysis relies on a limited number of data points derived from publicly available sources specific to a GE lattice tower prototype. These data were used as a starting point to define material, labor, and installation estimates. GE acquired the rights to a patented lattice tower design originally from Wind Tower Systems LLC. This design uses a pentagonal base with a varying cross section until roughly the bottom of the rotor plane. The acquired patents included multiple self-erecting designs, including a climbing jib crane to erect the tower, and a lifting apparatus that could be used to install the nacelle and rotor without the need for a large crane. GE installed a 97-m prototype in Tehachapi, California, in 2014 and later installed a 139-m tower. Based on its experience, GE cited issues with the skin installation and torsional stiffness as nontrivial challenges.

Turbine OEM Suzlon is currently offering a 120-m hybrid space frame/tubular steel tower for the Indian market with a total installed capacity of more than 1 GW (Suzlon 2018). This approach might address some of the torsional stiffness issues due to the use of the tubular steel section across the rotor plane, as compared to a full space frame where the lattice structure extends from the yaw ring to the ground. This approach also uses a much smaller rotor diameter (97 m and 111 m versus ~130 m) and a much shorter tubular steel tower section than the typical concrete hybrid towers. After clearing the rotor plane, the Suzlon lattice square cross section grows to ~4.9 m per side or ~6.9 m diagonally (Suzlon 2018).

Nabrawind has demonstrated a 160-m prototype using its Nabralift system, which is a hybrid tubular steel tower within the rotor plane and has a three-leg lattice structure below the rotor. This system uses much larger and fewer members in the lattice structure than used in the GE concept, which reduces labor. This concept also uses much taller segments than many site-cast concrete segments, which reduces cycle times and labor associated with the turbine installation process.

Lattice or other tower approaches with wide footprints also offer the potential use of alternative foundation designs and potentially significant cost reductions in the foundation than a conventional spread foot foundation—which is nearly universally used in the United States. The wider footprint of the lattice towers and potentially spiral-welded towers could allow for large reductions in foundation material, labor, and cost by using individual foundations under each member, or in the case of the spiral-welded tower, use an annular foundation. This could be combined with other foundation approaches, such as rock or soil anchors or small piers, which could result in further reductions in foundation costs. Further cost reductions in BOS could be realized with towers that enable alternative foundation designs. For example, foundation cost fraction is estimated at approximately 15% of total BOS cost for the 4.5-MW Low-SP turbine at 110-, 140-, and 160-m hub heights.

3.2.4 Comparing and Contrasting Competing Tower Alternatives

To begin to understand potential cost differences among tower technologies, we conducted a basic comparison of the relative attributes of the three identified alternatives. Based on this first-order assessment, the lattice tower seems attractive. In particular, its material and transport costs are expected to be quite low. As noted earlier, however, there are significant challenges that need to be overcome for this technology to be achieve widespread commercial utilization. Key weaknesses include substantial and relatively high-risk installation costs—with risks being compounded by potential wind delays during construction and skin installation. Moreover, resolving the torsional structural issues could erode at least some, if not all, of the potential opportunity associated with lattice towers. In this vein, jacket-type offshore wind substructures are a comparable structural strategy to the lattice tower but have yet to substantially displace the use of steel monopole substructures in offshore environments of shallow to moderate depth (Smith et al. 2015; Musial et al. 2017). Although not altogether comparable, this suggests that adequately resolving the potential weaknesses of the lattice tower could result in a significantly reduced opportunity for them relative to what is suggested in this initial first-order assessment.

Focusing on the full-concrete field-cast cost characterization, it appears that there are also nontrivial challenges to achieving cost levels consistent with broad-based deployment. First-order estimates of potential cost are on par with, but not below, what might be achieved with a transportable tubular steel tower of comparable height using current design concepts and manufacturing strategies. Perhaps most challenging from the perspective of fundamentals is that a significant portion of costs is either materials-driven or labor. There certainly is potential to eliminate a large amount of the tower labor cost by having the rebar tied off-site and transported in segments and by improved processes and experience. Self-erecting cranes also could reduce installation and erection costs. It might be more difficult to reduce materials costs.

In the United States, with its relatively large (e.g., 300 mile) transport distances, the factory-cast hybrid concrete and tubular steel tower faces a significant disadvantage. Under these conditions, transport costs are estimated to be significant and potentially prohibitive. Absent these substantial transport costs, it is apparent why the hybrid concept historically has been the tall tower technology of choice. Of course, the magnitude of the transport costs also demonstrate why this approach has lost market share in the tall tower space to the LDST concepts employing advanced controls and “soft-soft” design strategies in recent years. Moreover, material and labor costs for the hybrid concept remain significant even when allowing for substantially shorter transport distances.

4 Insights for Tower Design and Innovation

The previous sections of this report have examined and explored the potential opportunity offered by increased tower height through the lens of wind speed, capacity factor, and LCOE. Additionally, they have explored the potential opportunities afforded by advancements in tubular steel towers, as well as the potential strengths and weaknesses of full-concrete, hybrid, and lattice tower concepts. In this section, we attempt to synthesize the insights generated and posit potential metrics that might be used to characterize the viability of novel tower solutions going forward. Key insights are structured by category and follow the general structure of the report.

4.1 Analysis Results and Insights

4.1.1 Wind Resources

Based on current data in the Wind Toolkit for calendar year 2012, an increase in hub height from 80 to 110 m generally results in wind speed increases of 0 to 0.5 m/s west of the Rockies, and 0.5 to 1.0 m/s east of the Rockies. Additionally, some areas see decreased wind speeds with higher above ground levels, likely owing to unusual topographic features, such as mountainous terrain in California and the Appalachian region. If hub height is increased from 80 to 160 m, portions of the central plains would see wind speed increases of 1.5 to 2.0 m/s. Additionally, some locations in Pennsylvania, New York, and Maine would see increases of 1.0 to 1.5 m/s. These results lead to a general finding that increased hub height is accompanied by increased wind resources. However, there are regional and topographical differences that must be recognized. Moreover, as discussed in Section 2, the quantitative results presented depend in no small part on the accuracy and validity of the Wind Toolkit data. Mesoscale wind resource data, particularly at higher above ground levels, could benefit from further validation and study, in addition to the efforts completed to date.

4.1.2 Capacity Factors

For the Today turbine, capacity factor generally increased when hub height was increased from 80 to 110 m, with the increases clustered at 5 percentage points or less. At 140 m relative to 80 m, capacity factor increases exhibited a range from approximately 0 to 10 percentage points with a relatively flat distribution. For the other three turbines examined and focusing on the comparisons within each turbine platform, median capacity factor increases were approximately 2 to 3 percentage points when moving from 110 to 140 m and approximately 1 percentage point when moving from 140 to 160 m. Generalizing these results indicates that increasing hub heights to 110 and 140 m drives sizable gains across turbine platforms with seemingly diminishing returns above 140 m. These findings exhibit the same regional and topographical variations observed with the wind resource data. These results are highly dependent on the accuracy of the wind resource data, particularly at the higher above ground levels, and also vary depending on the specific turbine configuration applied. While diminishing returns with higher above ground heights is at least partially intuitive, the uncertainty in the underlying resource data makes it difficult to ascertain the robustness of the observed trends.

4.1.3 Energy Costs

Of the four turbines examined, the Low-SP 4.5-MW turbine exhibited the lowest LCOE values. At a 110-m hub height, unsubsidized LCOE for this machine ranged from $25/MWh to $35/MWh throughout much of the nation's interior wind belt. In the eastern half of the nation, LCOE ranged from $35/MWh to $50/MWh. Throughout the Pacific and Intermountain West regions, results were mixed. With hub height increased to 160 m, there was less support for $25/MWh to $35/MWh LCOE in the interior wind belt, whereas in some eastern regions LCOE was reduced relative to the 110-m case. This correlates with experience within the wind industry: commercial wind developers' interest in taller towers is emerging in the eastern states, but as yet there is no corresponding drive in the interior wind belt.

Changes in LCOE relative to the estimated LCOE for the Today turbine at 80 m were also estimated for all four turbines at each Wind Toolkit site (more than 1.85 million nationwide), yielding broad distributions reflecting the wide range of wind resources throughout the nation. For the Low-SP 4.5-MW turbine, the changes in LCOE range from slightly positive to reductions of as much as $30/MWh, with a broad peak clustered around $5/MWh to $10/MWh. In contrast, LCOE values for the Today turbine at the higher hub heights tend to be greater as hub height is increased. Results for the other two machines are similar to those for the 4.5-MW machine but are less pronounced.

Economically preferred tower heights were determined for each of the four turbines at each Wind Toolkit site. The preferred height—selected from the options of 80 m, 110 m, 140 m, and 160 m—yielded the lowest LCOE at that site. Of course, not all of these sites would offer an LCOE low enough to be commercially viable. Many would, however, so the results of this exercise provide an indication of preferred tower heights based on recent technology cost and scaling trends. For today's turbine, 80 m is preferred for more than half of the sites—again consistent with commercial experience in the interior region—but substantial opportunities exist at 110 m and 140 m as well. For the three larger turbines, 110 m is preferred for more than 60% of all sites, with significant opportunities at 140 m as well. The 160-m height was preferred only by the Low-SP 4.5-MW turbine, and at only about 2% of sites.

4.1.4 Breakeven Costs

For a 110-m hub height, the analysis found breakeven costs for today's turbine of well under $500/kW for many locations. For the Low-SP 4.5-MW turbine, breakeven costs were clustered around $500/kW, tailing off to about $1,500/kW. At the 140-m hub height, breakeven costs exhibited a wide distribution with a broad peak. For the Today turbine, breakeven costs were clustered around approximately $250/kW, tailing off to about $1,000/kW.

These results provide turbine designers with a rough indication of the cost budget allowable in pursuing economical taller turbines. Of course, beating the breakeven cost could be accomplished with whatever means are available to designers, manufacturers, and installers. These could include changes in design or other machine features, reduced blade costs or a reduced blade mass scaling exponent, advances in tower design or manufacturing, advanced turbine controls, erection economies or other BOS advances, other unforeseen improvements, or combinations of several of these methods.

4.1.5 Tall Tower Options

In pursuing higher hub heights at affordable costs, tower cost is a major factor. We examined prospects for tubular steel towers and several other options under consideration. Three tubular steel options were analyzed: transportable tower, with a 4.3-m base diameter; LDST, with a 6.2-m base diameter; and an unconstrained base diameter tower, which might be fabricated on-site with spiral-welding techniques. We considered hub heights from 80 to 180 m and examined both soft-stiff and soft-soft designs.

In the soft-stiff case, the transportable tower becomes uneconomical rapidly as its height is increased. At 80 m, its weight is estimated at 180 tons. At 120 m, its weight has increased to 900 tons. Beyond 120 m, it was determined to be economically impractical. For the LDST case, the 80-m weight is estimated at 130 tons, reflecting the reduced steel thickness allowed by the larger base diameter. At 140 m, its weight has increased to 850 tons. For the unconstrained case, the 140-m tower weight is 440 tons (or about half of the 140-m LDST weight). Clearly, the unconstrained option offers a huge advantage with respect to weight; however, on-site production presents its own nontrivial challenges.

For the soft-soft cases examined, significant weight reductions are estimated relative to soft-stiff options. The transportable tower weight at 140 m is 440 tons, less than half the weight of the soft-stiff tower at 120 m. Even at 160 m, its weight of 860 tons is less than that of the 120-m soft-stiff tower. The other two tower options also show comparable reductions. In the unconstrained case, the 160-m tower, at 470 tons, is only slightly heavier than the 140-m soft-stiff tower (440 tons).

It is clear from these results that soft-soft tower designs offer a substantial weight—and thus likely cost—advantage. Even the transportable option that is able to clear today's highway transport constraints becomes feasible at 140 m. The major challenge for soft-soft designs is management of 1P resonances through advanced controls, damping, or some other means. Wind turbine OEMs appear to be making significant progress along these lines, as evidenced by commercial tower weights that are somewhat less than the weights estimated in our analysis.

In addition to steel towers, we also examined prospects and costs for several other tower options, including full-concrete field-cast, hybrid concrete and tubular steel tower, and lattice or space frame. These could offer advantages in transport, erection, and BOS costs, and might allow for larger base diameters, but all are accompanied by much greater labor costs than those of transportable towers. Potential advantages and risks were assessed for each of these options. For installations in the United States, none of these options shows a clear advantage over tubular steel towers. Of the three, the lattice-based approaches seem to offer the greatest potential, based on low material and transport costs. However, there are sizable risks associated with on-site labor requirements, wind conditions during installation, and torsional loads. With the full-concrete field-cast approach, reducing costs below tubular steel presents a major challenge. With the hybrid-concrete approach, large concrete sections are cast in a factory and then transported over long distances. With transportation costs approaching nearly half of total installed tower cost, the prospects for this option appear limited, unless there are logistics or other innovations that can greatly reduce transportation requirements and costs.

4.2 Analysis Results Discussion

Overall, this analysis leads to three primary conclusions. First, 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. Second, tall tower technologies with the greatest potential appear to be tubular steel based on soft-soft design criteria; these towers have gained relative prominence in the industry over the past several years. Third, hub heights of 110 m to 140 m have the potential to offer some LCOE advantages relative to today's typical turbines, with optimal hub heights potentially varying from these discrete points were a more continuous set of solutions available. Based on the initial first-order cost estimates applied here, LCOE reductions between $5/MWh and $10/MWh, and in some cases even larger, are plausible. Tall tower technologies and solutions could be even more attractive if they are able to incorporate innovation potential not captured here that enhances their economics relative to recent scaling trends.

Given the substantial uncertainties embedded in our cost assumptions and the relative optimism toward higher hub heights and larger machines, however, these findings need to be verified and validated with more resolved and comprehensive cost estimates before they can be deemed robust. More specifically, changes in turbine or BOS CapEx could alter the observed outcomes.

Additionally, our analysis indicates somewhat diminishing returns from hub height increases to 140 m and subsequently to 160 m. Moreover, potential returns from achieving 140 m or 160 m are in locations where estimated LCOEs are relatively high, suggesting that simply making an economic case for a higher hub height in these locations might not be sufficient to support wind deployment in these regions. These results suggest that potential future drivers of higher wind turbine hub heights could be governed by factors beyond the observed improvement in wind resource alone. Alternative drivers could include increased land constraints (as has been observed in Germany), with more limited locations to install wind turbines and therefore a need to maximize the energy generation per turbine. Another alternative driver could be a desire to further increase rotor size and therefore increase hub height to provide sufficient ground clearance.

4.3 Lessons Learned for Evaluating Tall Tower Opportunities

This analysis shows that wind resource quality improves in most locations with higher above ground levels, up to at least 160 m. The analysis, however, also shows that the relative value of achieving higher hub heights is not absolute and varies significantly by location. Moreover, the locations where the value is potentially greatest from achieving higher hub heights tend to be places where the wind energy resource is less robust; therefore, economically achieving a higher hub height alone might not be sufficient to make wind power economic in those locations.

Given this context, evaluating the viability of a given tall tower opportunity is both complex and difficult to generalize. Based on our insights from this work, we suggest focusing on LCOE, total CapEx, and breakeven cost as the means of evaluating relative usefulness of a proposed tall tower approach. Consideration of a particular set of site conditions is also important given the variability in value as a function of geospatial variables. Further, tower cost itself is important but can be misleading. Some tower solutions could actually increase tower cost and still result in a lower CapEx if they enable an elegant installation solution that further minimizes BOS cost. Moreover, if computed on a dollars-per-kilowatt ($/kW) basis, a solution requires holding the turbine's nameplate capacity constant to avoid manipulating one particular component cost (e.g., tower) simply by increasing or decreasing nameplate capacity; tower scaling and generator scaling are not directly proportional.

The LCOE and total CapEx (or breakeven costs) are of particular importance given the interplay between turbine and plant subsystems, as well as the potential for hub height to impact BOS and operational expenditures. Notably, the most critical innovation enabling soft-soft towers is the turbine controls, which now enable the machine to avoid operating conditions that were key design constraints in prior eras. Similarly, going forward, alternative erection techniques that reduce BOS costs could be as critical to realizing the value of higher hub heights as is developing novel tower solutions.

If focusing on a singular metric for evaluating the potential afforded by any given tall tower solution, we propose a focus on breakeven cost—computed at the system or total CapEx level. The value of the metric should also consider the LCOE that might be required to support economic deployment of wind energy in a given region. Based on the analysis conducted here, a system-level breakeven cost of less than $500/kW for relatively lower specific power turbines and potentially as low as $200/kW, particularly for higher specific power turbines, could be sufficient to support an LCOE reduction across much of the country, and also would push less-energetic wind resource regions further along the path to competitiveness. Stated from a developer's perspective, if a prospective taller-tower solution (110 m or higher) can be realized at an additional cost of about $200/kW (relative to the same turbine on an 80-m tower), that solution is likely to offer wide applicability across the nation. The same would be true at $500/kW, but to a lesser extent. Depending on the specific focus areas, turbine configuration, and relevant site conditions, and especially if pushing toward higher hub heights (e.g., 140 m, 160 m), divergence of higher breakeven costs from this general guidance could be merited.

5 Conclusions

We find the question of optimal wind turbine tower height to be a rich and complex area of research, particularly when considering the problem at the continental scale. The system nature of wind technology and the variability in key input variables across time and space—not least of which is the wind resource—add dimensions to the analysis that require consideration of a great number of potential trade-offs as well as the possibility for multiple equally optimal solutions. Moreover, we have observed that our results are sensitive to changes in key assumptions (e.g., total CapEx and wind shear) that are highly uncertain but, at the same time, the magnitude of the difference in outcomes is not always significant.

Notwithstanding the complexity of the tasks and the array of potential outcomes, our analysis suggests that there are sizable gains to be had by realizing tall tower technologies. At the same time, there may also be diminishing returns to higher hub heights, and locations where the value of higher hub heights is greatest tend to be the areas where wind energy presently is relatively high cost. Based on our current cost assumptions derived from recent vintage technology scaling functions, it is the case across much of the continental United States that the lowest available hub height (e.g., 80 m, 110 m) often provides the lowest-cost solution. At the same time, taller towers may be critical to increasing the opportunity for wind power across the nation and could become increasingly attractive as innovations drive down the costs required to achieve higher hub heights. Continued tower growth could also be a result of a combination of factors, including land constraints that result in stronger consideration for maximizing energy production per turbine and the need to provide sufficient ground clearance as a function of continued rotor growth.

Future work efforts in this domain are anticipated to benefit from research that quantifies and ultimately reduces the uncertainty of the wind resource data, particularly at higher above ground levels. In addition, more focus on cost estimates including sensitivities, analyzing specific technology opportunities, and analyzing alternative turbine configurations could provide more robust perspectives and insights into the potential for innovative solutions to capture additional value from taller towers.

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Appendix A. Supplemental Input and Results Data

Table A1. Detailed Levelized Cost of Energy Cost Inputs

	Today	Low Specific Power (SP) 4.5	Business as Usual (BAU)	Low-SP 3.25 MW
Nameplate Capacity (megawatts [MW])	2.32	4.50	3.30	3.25
Rotor Diameter (meters [m])	113	194	156	166
Specific Power (watts (W)/m^2)	231	152	173	150
Hub Height 80 m, Tower Cost ($/kilowatt [kW])	$198	—	—	—
Hub Height 110 m, Tower Cost ($/kW)	$378	$195	$266	$270
Hub Height 140 m, Tower Cost ($/kW)	$616	$318	$433	$440
Hub Height 160 m, Tower Cost ($/kW)	$808	$416	$568	$577
Turbine Rotor Nacelle Assembly ($/kW), Blade Exp = 2.2	$562	$802	$695	$779
Balance of Station (BOS) ($/kW), Hub Height 80 m	$317	—	—	—
BOS ($/kW), Hub Height 110 m	$330	$206	$258	$258
BOS ($/kW), Hub Height 140 m	$343	$212	$274	$274
BOS ($/kW), Hub Height 160 m	$352	$215	$292	$292
Capital Expenditures (CapEx) ($/kW), blade Exp = 2.2, 80 m	$1,077	—	—	—
CapEx ($/kW), blade Exp = 2.2, 110 m	$1,270	$1,203	$1,218	$1,306
CapEx ($/kW), blade Exp = 2.2, 140 m	$1,521	$1,331	$1,402	$1,492
CapEx ($/kW), blade Exp = 2.2, 160 m	$1,722	$1,433	$1,555	$1,648
CapEx ($/kW), blade Exp = 2.2, 80 m, $200/kW tower	$1,077	—	—	—
CapEx ($/kW), blade Exp = 2.2, 110 m, $200/kW tower	$1,092	$1,208	$1,153	$1,237
CapEx ($/kW), blade Exp = 2.2, 140 m, $200/kW tower	$1,105	$1,213	$1,168	$1,252
CapEx ($/kW), blade Exp = 2.2, 160 m, $200/kW tower	$1,114	$1,217	$1,187	$1,271

Table A2. Net Capacity Factor Change Statistics, Relative to the Today Turbine at 80 m

(Percentage Points)

Turbine Configuration	Median	25th Percentile	75th Percentile
Today 110 m	3.8	2.1	4.7
Today 140 m	6.67	3.6	8.5
Today 160 m	7.5	4.1	9.7
Business as usual (BAU) 110 m	8.8	6.2	10.0
BAU 140 m	11.3	7.6	13.4
BAU 160 m	12.1	8.1	14.4
Low-SP 3.25 MW, 110 m	11.1	8.2	12.5
Low-SP 3.25 MW, 140 m	13.4	9.5	15.6
Low-SP 3.25 MW, 160 m	14.2	10.0	16.7
Low-SP 4.5 MW, 110 m	10.9	8.0	12.2
Low-SP 4.5 MW, 140 m	13.2	9.3	15.4
Low-SP 4.5 MW, 160 m	13.9	9.8	16.4

Table A3. Net Capacity Factor Breakpoints

(Percentage of pixels with an increase greater than 5, 10, and 15 percentage points as listed in the column head of the table, relative to the Today turbine at 80 m)

Turbine Configuration	5	10	15
Today 110 m	15.3%	0.0%	0.0%
Today 140 m	65.0%	8.4%	0.0%
Today 160 m	69.6%	21.6%	0.3%
BAU 110 m	86.5%	25.0%	0.0%
BAU 140 m	90.9%	61.1%	8.8%
BAU 160 m	91.7%	65.3%	19.4%
Low-SP 3.25 MW, 110 m	95.8%	62.4%	0.9%
Low-SP 3.25 MW, 140 m	96.6%	72.6%	32.7%
Low-SP 3.25 MW, 160 m	96.6%	75.0%	42.3%
Low-SP 4.5 MW, 110 m	95.3%	60.5%	0.6%
Low-SP 4.5 MW, 140 m	96.2%	71.6%	29.8%
Low-SP 4.5 MW, 160 m	96.3%	74.0%	40.1%

Table A4. Levelized Cost of Energy Summary Statistics ($/megawatt-hour [MWh])

Turbine Configuration	Median	25th Percentile	75th Percentile
Today 80 m	$51	$41	$66
Today 110 m	$51	$41	$64
Today 140 m	$52	$44	$66
Today 160 m	$56	$47	$71
BAU 110 m	$42	$35	$53
BAU 140 m	$43	$37	$54
BAU 160 m	$46	$39	$57
Low-SP 3.25 MW, 110 m	$42	$35	$52
Low-SP 3.25 MW, 140 m	$43	$37	$53
Low-SP 3.25 MW, 160 m	$45	$39	$56
Low-SP 4.5 MW, 110 m	$40	$34	$49
Low-SP 4.5 MW, 140 m	$40	$34	$49
Low-SP 4.5 MW, 160 m	$41	$35	$51

Table A5. Levelized Cost of Energy Breakpoints

(Percentage of pixels with an LCOE less than the dollar values listed in the column head of the table)

Turbine Configuration	$30/MWh	$40/MWh	$50/MWh
Today 80 m	0.4%	20.9%	47.8%
Today 110 m	0.1%	20.0%	48.8%
Today 140 m	0.0%	9.3%	44.5%
Today 160 m	0.0%	0.8%	36.4%
BAU 110 m	1.3%	43.0%	69.0%
BAU 140 m	0.1%	39.4%	66.9%
BAU 160 m	0.0%	30.0%	61.2%
Low-SP 3.25 MW, 110 m	1.0%	44.3%	71.1%
Low-SP 3.25 MW, 140 m	0.1%	40.0%	68.6%
Low-SP 3.25 MW, 160 m	0.0%	30.2%	62.5%
Low-SP 4.5 MW, 110 m	5.4%	50.9%	76.2%
Low-SP 4.5 MW, 140 m	1.2%	50.6%	76.3%
Low-SP 4.5 MW, 160 m	0.2%	46.3%	73.6%

Table A6. Average State Levelized Cost of Energy ($/MWh)

State	Today 80 m	Today 110 m	Today 140 m	Today 160 m	BAU 110 m	BAU 140 m	BAU 160 m	Low-SP 3.25 MW 110 m	Low-SP 3.25 MW 140 m	Low-SP 3.25 MW 160 m	Low-SP 4.5 MW 110 m	Low-SP 4.5 MW 140 m	Low-SP 4.5 MW 160 m
AL	$72	$66	$64	$67	$54	$52	$54	$52	$51	$53	$50	$47	$48
AR	$57	$53	$53	$55	$44	$43	$45	$43	$43	$45	$41	$40	$41
AZ	$81	$83	$90	$97	$68	$72	$77	$66	$70	$75	$63	$65	$68
CA	$105	$108	$118	$129	$88	$95	$102	$86	$93	$99	$82	$86	$90
CO	$63	$65	$71	$77	$55	$58	$62	$54	$58	$61	$51	$53	$56
CT	$55	$52	$51	$54	$43	$42	$44	$42	$42	$43	$40	$39	$39
DC	$68	$63	$61	$64	$52	$50	$52	$51	$49	$51	$48	$46	$46
DE	$49	$47	$49	$52	$39	$41	$43	$39	$40	$42	$37	$37	$38
FL	$74	$68	$67	$71	$54	$53	$55	$52	$52	$54	$49	$48	$49
GA	$70	$65	$63	$67	$52	$51	$53	$51	$50	$52	$48	$47	$48
IA	$39	$39	$41	$44	$33	$35	$37	$34	$35	$37	$32	$32	$34
ID	$66	$68	$74	$80	$57	$60	$64	$56	$59	$63	$53	$55	$57
IL	$44	$43	$45	$48	$37	$38	$40	$36	$38	$40	$35	$35	$36
IN	$46	$45	$48	$51	$38	$40	$42	$38	$40	$42	$36	$37	$38
KS	$38	$38	$40	$44	$33	$35	$37	$33	$35	$37	$31	$32	$34
KY	$59	$56	$56	$60	$47	$47	$49	$46	$46	$49	$43	$43	$44
LA	$61	$57	$57	$61	$46	$47	$49	$45	$46	$48	$43	$42	$44
MA	$52	$50	$50	$52	$41	$41	$43	$41	$41	$43	$39	$38	$39
MD	$55	$53	$54	$57	$44	$44	$47	$43	$44	$46	$41	$41	$42
ME	$51	$49	$49	$51	$41	$40	$42	$40	$40	$42	$38	$37	$38
MI	$45	$43	$45	$48	$37	$38	$40	$36	$37	$40	$34	$35	$36

State	Today 80 m	Today 110 m	Today 140 m	Today 160 m	BAU 110 m	BAU 140 m	BAU 160 m	Low-SP 3.25 MW 110 m	Low-SP 3.25 MW 140 m	Low-SP 3.25 MW 160 m	Low-SP 4.5 MW 110 m	Low-SP 4.5 MW 140 m	Low-SP 4.5 MW 160 m
MN	$42	$41	$43	$46	$35	$37	$39	$35	$37	$39	$33	$34	$35
MO	$45	$43	$45	$48	$37	$38	$40	$37	$38	$40	$35	$35	$36
MS	$62	$57	$57	$60	$47	$47	$49	$46	$46	$48	$44	$43	$44
MT	$48	$49	$52	$56	$42	$44	$47	$42	$44	$47	$40	$41	$42
NC	$66	$62	$63	$66	$51	$51	$53	$50	$50	$53	$48	$47	$48
ND	$39	$40	$42	$45	$34	$35	$38	$34	$36	$38	$32	$33	$34
NE	$38	$39	$41	$44	$33	$35	$37	$33	$35	$37	$32	$32	$34
NH	$57	$55	$56	$58	$46	$46	$48	$45	$45	$47	$43	$42	$43
NJ	$55	$52	$52	$55	$43	$43	$45	$42	$42	$44	$40	$39	$40
NM	$59	$60	$65	$69	$50	$53	$56	$50	$52	$55	$47	$48	$50
NV	$66	$69	$77	$83	$58	$63	$67	$58	$62	$66	$55	$57	$60
NY	$52	$51	$51	$54	$42	$42	$44	$42	$42	$44	$40	$39	$40
OH	$52	$50	$51	$54	$42	$42	$45	$41	$42	$44	$39	$39	$40
OK	$40	$40	$42	$45	$34	$35	$38	$34	$36	$38	$32	$33	$34
OR	$65	$67	$72	$77	$56	$59	$63	$56	$58	$62	$53	$54	$56
PA	$57	$55	$54	$57	$45	$45	$46	$44	$44	$46	$42	$41	$42
RI	$47	$45	$46	$49	$38	$38	$40	$37	$38	$40	$35	$35	$36
SC	$69	$64	$64	$67	$52	$52	$54	$51	$51	$53	$49	$47	$48
SD	$40	$41	$43	$46	$35	$37	$39	$35	$37	$39	$33	$34	$35
TN	$65	$62	$62	$65	$51	$51	$53	$50	$50	$52	$48	$46	$48
TX	$47	$46	$47	$50	$38	$39	$41	$38	$39	$41	$36	$36	$37
UT	$69	$72	$79	$86	$61	$66	$70	$60	$65	$69	$57	$60	$63

State	Today 80 m	Today 110 m	Today 140 m	Today 160 m	BAU 110 m	BAU 140 m	BAU 160 m	Low-SP 3.25 MW 110 m	Low-SP 3.25 MW 140 m	Low-SP 3.25 MW 160 m	Low-SP 4.5 MW 110 m	Low-SP 4.5 MW 140 m	Low-SP 4.5 MW 160 m
VA	$66	$63	$63	$66	$52	$51	$54	$51	$51	$53	$48	$47	$48
VT	$55	$54	$55	$58	$45	$45	$47	$44	$44	$46	$42	$41	$42
WA	$64	$66	$71	$77	$56	$59	$63	$55	$58	$62	$53	$54	$56
WI	$46	$45	$46	$49	$38	$38	$40	$37	$38	$40	$35	$35	$36
WV	$66	$63	$63	$67	$52	$52	$54	$51	$52	$54	$49	$48	$49
WY	$50	$52	$56	$60	$44	$47	$50	$44	$46	$49	$42	$43	$45

Table A7. Average State Breakeven Cost ($/kW)

State	Today 110 m	Today 140 m	Today 160 m	BAU 110 m	BAU 140 m	BAU 160 m	Low-SP 3.25 MW 110 m	Low-SP 3.25 MW 140 m	Low-SP 3.25 MW 160 m	Low-SP 4.5 MW 110 m	Low-SP 4.5 MW 140 m	Low-SP 4.5 MW 160 m
AL	$412	$793	$917	$849	$1,208	$1,325	$1,059	$1,406	$1,520	$1,037	$1,385	$1,499
AR	$352	$667	$772	$726	$1,017	$1,116	$902	$1,182	$1,277	$883	$1,165	$1,260
AZ	$166	$266	$302	$532	$628	$662	$713	$806	$838	$694	$787	$819
CA	$146	$221	$245	$470	$537	$558	$631	$694	$713	$614	$677	$697
CO	$151	$254	$290	$446	$540	$573	$587	$677	$708	$572	$662	$694
CT	$332	$669	$790	$715	$1,038	$1,149	$898	$1,210	$1,316	$879	$1,192	$1,299
DC	$373	$771	$919	$773	$1,165	$1,309	$967	$1,353	$1,494	$946	$1,333	$1,475
DE	$285	$504	$571	$628	$818	$878	$788	$965	$1,021	$771	$949	$1,006
FL	$394	$736	$848	$893	$1,220	$1,327	$1,138	$1,455	$1,558	$1,112	$1,430	$1,534
GA	$399	$758	$876	$839	$1,184	$1,297	$1,054	$1,388	$1,499	$1,031	$1,367	$1,477
IA	$228	$393	$440	$481	$617	$657	$594	$718	$756	$583	$707	$746
ID	$150	$253	$291	$462	$560	$596	$612	$708	$743	$596	$692	$727
IL	$262	$455	$512	$560	$723	$774	$695	$847	$895	$681	$834	$882
IN	$254	$442	$497	$561	$725	$774	$704	$857	$903	$689	$843	$890
KS	$208	$352	$392	$450	$567	$601	$559	$665	$697	$548	$655	$687
KY	$315	$587	$672	$665	$917	$997	$833	$1,075	$1,151	$815	$1,058	$1,135
LA	$366	$662	$755	$789	$1,059	$1,144	$991	$1,246	$1,329	$969	$1,227	$1,309
MA	$307	$603	$708	$662	$938	$1,033	$829	$1,092	$1,183	$811	$1,076	$1,167
MD	$294	$549	$634	$645	$880	$959	$811	$1,036	$1,112	$794	$1,020	$1,096
ME	$306	$616	$726	$658	$948	$1,048	$822	$1,100	$1,195	$805	$1,084	$1,180
MI	$274	$502	$573	$588	$784	$845	$731	$913	$969	$716	$899	$956
MN	$245	$434	$491	$531	$690	$739	$660	$806	$852	$646	$794	$840

State	Today 110 m	Today 140 m	Today 160 m	BAU 110 m	BAU 140 m	BAU 160 m	Low-SP 3.25 MW 110 m	Low-SP 3.25 MW 140 m	Low-SP 3.25 MW 160 m	Low-SP 4.5 MW 110 m	Low-SP 4.5 MW 140 m	Low-SP 4.5 MW 160 m
MO	$285	$509	$575	$583	$775	$833	$719	$897	$953	$705	$885	$940
MS	$378	$694	$793	$779	$1,070	$1,162	$969	$1,247	$1,336	$949	$1,228	$1,317
MT	$158	$286	$330	$415	$531	$572	$534	$645	$684	$522	$633	$672
NC	$331	$625	$725	$716	$994	$1,089	$901	$1,170	$1,263	$881	$1,152	$1,244
ND	$216	$381	$430	$485	$623	$665	$606	$733	$772	$593	$721	$761
NE	$207	$360	$406	$460	$588	$626	$574	$690	$726	$562	$680	$716
NH	$262	$534	$638	$599	$865	$964	$759	$1,019	$1,115	$742	$1,003	$1,099
NJ	$326	$629	$732	$702	$984	$1,078	$882	$1,151	$1,241	$863	$1,133	$1,224
NM	$174	$304	$351	$491	$615	$659	$644	$764	$806	$628	$748	$791
NV	$116	$178	$201	$414	$472	$494	$558	$614	$635	$542	$599	$620
NY	$268	$526	$619	$603	$847	$933	$761	$996	$1,078	$745	$980	$1,063
OH	$293	$534	$607	$631	$849	$914	$790	$996	$1,058	$773	$980	$1,043
OK	$239	$423	$478	$500	$654	$701	$618	$758	$802	$605	$747	$791
OR	$158	$281	$326	$458	$577	$620	$604	$719	$761	$588	$704	$746
PA	$304	$617	$733	$667	$969	$1,078	$840	$1,134	$1,239	$821	$1,117	$1,222
RI	$299	$568	$658	$649	$894	$976	$814	$1,046	$1,123	$797	$1,030	$1,108
SC	$381	$718	$829	$806	$1,125	$1,231	$1,012	$1,322	$1,424	$990	$1,301	$1,404
SD	$204	$363	$413	$464	$601	$643	$582	$708	$748	$569	$697	$737
TN	$319	$606	$702	$689	$961	$1,052	$867	$1,130	$1,218	$849	$1,112	$1,201
TX	$273	$499	$572	$611	$807	$869	$766	$947	$1,004	$750	$932	$990
UT	$122	$194	$220	$405	$471	$496	$540	$604	$627	$526	$590	$613
VA	$310	$595	$697	$684	$960	$1,057	$865	$1,134	$1,229	$846	$1,116	$1,211
VT	$246	$494	$592	$586	$831	$925	$749	$990	$1,080	$731	$973	$1,064

State	Today 110 m	Today 140 m	Today 160 m	BAU 110 m	BAU 140 m	BAU 160 m	Low-SP 3.25 MW 110 m	Low-SP 3.25 MW 140 m	Low-SP 3.25 MW 160 m	Low-SP 4.5 MW 110 m	Low-SP 4.5 MW 140 m	Low-SP 4.5 MW 160 m
WA	$159	$278	$320	$447	$558	$597	$585	$692	$728	$571	$678	$714
WI	$296	$543	$619	$618	$833	$899	$766	$965	$1,027	$751	$951	$1,014
WV	$295	$575	$673	$652	$920	$1,012	$824	$1,085	$1,173	$806	$1,067	$1,156
WY	$140	$248	$287	$395	$496	$532	$515	$612	$646	$502	$600	$634

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FINDING OF FACT AND FINAL DETERMINATION of Champaign County Zoning Board of Appeals

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Final Determination: ***{RECOMMEND ENACTMENT/RECOMMEND DENIAL}***

Date: ***{~~March 17, 2022~~May 26, 2022}***

Petitioner: **Zoning Administrator**

Request: **Amend the Champaign County Zoning Ordinance as follows:**

1. Regarding Right to Farm Resolution 3425, add new paragraph 6.1.4 A.3. as follows:

3. The owners of the subject property and the Applicant, its successors in interest, and all parties to the decommissioning plan and site reclamation plan hereby recognize and provide for the right of agricultural activities to continue on adjacent land consistent with the Right to Farm Resolution 3425.

2. Regarding WIND FARM TOWER height, amend Sections 6.1.4 C and D as follows:

A. Amend 6.1.4C. 1. and 2. as follows:

1. ~~At least 1,000 feet~~ The minimum required separation from the exterior above-ground base of a WIND FARM TOWER to any PARTICIPATING DWELLING OR PRINCIPAL BUILDING shall be no less than 2.00 times the maximum allowed total WIND FARM TOWER HEIGHT but not less than 1,000 feet provided that the noise level caused by the WIND FARM at the particular building complies with the applicable Illinois Pollution Control Board regulations.

2. ~~At least 1,200 feet~~ The minimum required separation from the exterior above-ground base of a WIND FARM TOWER to any existing NON-PARTICIPATING DWELLING OR PRINCIPAL BUILDING shall be no less than 2.40 times the maximum allowed total WIND FARM TOWER HEIGHT but not less than 1,200 feet provided that the noise level caused by the WIND FARM at the particular building complies with the applicable Illinois Pollution Control Board regulations and provided that the separation distance meets or exceeds any separation recommendations of the manufacturer of the wind turbine used on the WIND FARM TOWER.

B. Amend 6.1.4 D.5. as follows:

5. The total WIND FARM TOWER HEIGHT (measured to the tip of the highest rotor blade) ~~must be less than 500 feet~~ shall be the specified in the application. A total WIND FARM TOWER HEIGHT of 500 feet or greater shall conform to all Federal Aviation Administration (FAA) requirements including an FAA Determination of No Hazard with or without Conditions.

3. Regarding Aircraft Detection Lighting Systems (ADLS), revise paragraph 6.1.4 D.7. as follows:

The WIND FARM shall comply with all applicable Federal Aviation Administration (FAA) requirements which shall be explained in the application. The minimum lighting requirement of the FAA shall not be exceeded except that all WIND FARM TOWERS are required to use ADLS (aircraft detection lighting system) or equivalent system to reduce the impact of nighttime lighting on nearby residents, communities and migratory birds in accordance with the FAA Advisory circular: 70/7460-IL section 14.1. ~~shall be lighted and unless otherwise required by the FAA only red flashing lights shall be used at night and only the minimum number of such lights with the minimum intensity and the minimum number of flashes per minute (longest duration between flashes) allowed by FAA."~~

4. Regarding the Agricultural Impact Mitigation Agreement, revise Section 6.1.4 as follows:

A. Add new Section 6.1.4 R: Agricultural Impact Mitigation Agreement with the Illinois Department of Agriculture as follows, and re-letter subsequent sections:

(1) If provided by state law, the Applicant shall enter into an Agricultural Impact Mitigation Agreement with the Illinois Department of Agriculture.

(2) The Applicant shall bear full responsibility for coordinating any special conditions required in the SPECIAL USE Permit in order to ensure compliance with the signed Agricultural Impact Mitigation Agreement with the Illinois Department of Agriculture.

(3) All requirements of the signed Agricultural Impact Mitigation Agreement with the Illinois Department of Agriculture shall become requirements of the COUNTY Board SPECIAL USE Permit.

(4) Champaign County shall have the right to enforce all requirements of the signed Agricultural Impact

Mitigation Agreement with the Illinois Department of Agriculture.

B. **Add new paragraph 6.1.4 A.4. as follows:**
All aboveground STRUCTURES and facilities shall be of a type and shall be located in a manner that is consistent with the Agricultural Impact Mitigation Agreement with the Illinois Department of Agriculture as required by paragraph 6.1.4R.

C. **Revise Section 6.1.4E. to require conformance with the approved Agricultural Impact Mitigation Agreement with the Illinois Department of Agriculture.**

D. **Add new paragraph 6.1.4 P.4.g. as follows:**
Any financial assurance required per the Agricultural Impact Mitigation Agreement with the Illinois Department of Agriculture as required by paragraph 6.1.4R. shall count towards the total financial assurance required for compliance with paragraph 6.1.1A.5.

E. **Add new paragraph 6.1.4 S.1.d. as follows and re-letter subsequent paragraphs:**
The Applicant shall include a copy of the signed Agricultural Impact Mitigation Agreement with the Illinois Department of Agriculture with the Zoning Use Permit Application to authorize construction.

5. **Regarding WIND FARM fees, revise Section 9 as follows:**

A. **Revise paragraph 9.3.1 H. as follows:**
WIND FARM TOWER or BIG WIND TURBINE TOWER $~~4,500~~10,000

B. **Revise paragraph 9.3.3 B.6. as follows:**
County Board WIND FARM SPECIAL USE Permit $~~20,000~~34,000 or $~~440~~760 per WIND FARM TURBINE TOWER, whichever is greater

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CONTENTS

FINDING OF FACT

Revisions as of March 31, 2022
Revisions as of May 17, 2022

From the documents of record and the testimony and exhibits received at the public hearing conducted on **March 17 2022, March 31, 2022, April 14, 2022, and May 26, 2022** the Zoning Board of Appeals of Champaign County finds that:

1. The petitioner is the Zoning Administrator.

2. The proposed amendment is intended to revise requirements for wind farms in the Zoning Ordinance.

3. Municipalities with zoning and townships with planning commissions have protest rights on all text amendments and they are notified of such cases.

SUMMARY OF THE PROPOSED AMENDMENT

4. The proposed amendment is attached to this Finding of Fact as it will appear in the Zoning Ordinance.

GENERALLY REGARDING THE LRMP GOALS, OBJECTIVES, AND POLICIES

5. The *Champaign County Land Resource Management Plan* (LRMP) was adopted by the County Board on April 22, 2010. The LRMP Goals, Objectives, and Policies were drafted through an inclusive and public process that produced a set of ten goals, 42 objectives, and 100 policies, which are currently the only guidance for amendments to the *Champaign County Zoning Ordinance*, as follows:
   A. The Purpose Statement of the LRMP Goals, Objectives, and Policies is as follows:

      "It is the purpose of this plan to encourage municipalities and the County to protect the land, air, water, natural resources and environment of the County and to encourage the use of such resources in a manner which is socially and economically desirable. The Goals, Objectives and Policies necessary to achieve this purpose are as follows:…"

   B. The LRMP defines Goals, Objectives, and Policies as follows:
      (1) Goal: an ideal future condition to which the community aspires
      (2) Objective: a tangible, measurable outcome leading to the achievement of a goal
      (3) Policy: a statement of actions or requirements judged to be necessary to achieve goals and objectives

   C. The Background given with the LRMP Goals, Objectives, and Policies further states, "Three documents, the *County Land Use Goals and Policies* adopted in 1977, and two sets of *Land Use Regulatory Policies*, dated 2001 and 2005, were built upon, updated, and consolidated into the LRMP Goals, Objectives and Policies.

REGARDING LRMP GOALS

6. LRMP Goal 1 is entitled "Planning and Public Involvement" and states that as follows:

Champaign County will attain a system of land resource management planning built on broad public involvement that supports effective decision making by the County.

Goal 1 has 4 objectives and 4 policies. The proposed amendment ***WILL NOT IMPEDE*** the achievement of Goal 1.

7. LRMP Goal 2 is entitled "Governmental Coordination" and states as follows:

Champaign County will collaboratively formulate land resource and development policy with other units of government in areas of overlapping land use planning jurisdiction.

Goal 2 has two objectives and three policies. The proposed amendment ***WILL NOT IMPEDE*** the achievement of Goal 2.

8. LRMP Goal 3 is entitled "Prosperity" and states as follows:

Champaign County will encourage economic growth and development to ensure prosperity for its residents and the region.

Goal 3 has three objectives and no policies. Objective 3.1 is most relevant to the proposed text amendment. The proposed amendment will ***HELP ACHIEVE*** Goal 3 as follows:

A. Objective 3.1 states, "Champaign County will seek to ensure that it maintains comparable tax rates and fees, and a favorable business climate relative to similar counties."

The proposed amendment will ***HELP ACHIEVE*** Objective 3.1 as follows:

(1) The proposed text amendment will allow further development of WIND FARMS and WIND TOWERS, which will allow newer technologies to improve Champaign County's business climate.

9. LRMP Goal 4 is entitled "Agriculture" and states as follows:

Champaign County will protect the long-term viability of agriculture in Champaign County and its land resource base.

Goal 4 has 9 objectives and 22 policies. Objectives 4.4, 4.5, 4.7, 4.8 and their policies do not appear to be relevant to the proposed text amendment. The proposed amendment will ***HELP ACHIEVE*** Goal 4 for the following reasons:

A. Objective 4.1 states as follows: **"Champaign County will strive to minimize the fragmentation of the County's agricultural land base and conserve farmland, generally applying more stringent development standards on *best prime farmland*."**

The proposed amendment will ***HELP ACHIEVE*** Objective 4.1 for the following reasons:

(1) The proposed amendment ***WILL NOT IMPEDE*** the achievement of Policies 4.1.2, 4.1.3, 4.1.4, 4.1.5, 4.1.7, 4.1.8, and 4.1.9.

(2) Policy 4.1.1 states: "**Commercial agriculture is the highest and best use of land in the areas of Champaign County that are by virtue of topography, soil and drainage, suited to its pursuit. The County will not accommodate other land**

uses except under very restricted conditions or in areas of less productive soils.”

The proposed amendment will ***HELP ACHIEVE*** Policy 4.1.1 for the following reasons:

a. The standard conditions for a WIND FARM TOWER are very restrictive and will ensure the following:

(a) Section 6.1.4 C. requires minimum separations between any WIND FARM TOWER and existing adjacent use to minimize issues of land use compatibility.

(b) No WIND FARM TOWER shall interfere with agricultural operations (see Objective 4.2).

(c) No WIND FARM TOWER shall be located at any location that is not well-suited for that WIND FARM TOWER (see Objective 4.3).

(d) Section 6.1.4 D. requires minimum standard conditions for any WIND FARM TOWER related to building codes, electrical components, maximum height, and warning signs.

(e) Section 6.1.4 I. establishes standard conditions to ensure that the allowable noise level created by a WIND FARM TOWER is consistent with the Illinois Pollution Control Board regulations that are the same for all rural land uses.

(f) Section 6.1.4 N. requires a WIND FARM to carry minimum liability insurance to protect landowners.

(g) Section 6.1.4 O. requires operational standard conditions intended to ensure that nuisance conditions are not allowed to exist at a WIND FARM.

(h) Section 6.1.4 P. requires any WIND FARM to have an approved Decommissioning and Site Reclamation Plan to ensure that funds will be available to remove a WIND FARM if the WIND FARM ever becomes non-functional.

(3) Policy 4.1.6 states: **“Provided that the use, design, site and location are consistent with County policies regarding:**

i. Suitability of the site for the proposed use;
ii. Adequacy of infrastructure and public services for the proposed use;
iii. Minimizing conflict with agriculture;
iv. Minimizing the conversion of farmland; and
v. Minimizing the disturbance of natural areas; then

a) On best prime farmland, the County may authorize discretionary residential development subject to a limit on total acres converted which is generally proportionate to tract size and is based on the

January 1, 1998 configuration of tracts, with the total amount of acreage converted to residential use (inclusive of by-right development) not to exceed three acres plus three acres per each 40 acres (including any existing right-of-way), but not to exceed 12 acres in total; or

b) On best prime farmland, the County may authorize non-residential discretionary development; or

c) The County may authorize discretionary review development on tracts consisting of other than best prime farmland."

The proposed amendment will ***HELP ACHIEVE*** Policy 4.1.6 for the following reasons:

a. The ZBA has recommended that the proposed amendment will ***HELP ACHIEVE*** Objective 4.3 regarding location at a suitable site and adequacy of infrastructure and public services.

b. The ZBA has recommended that the proposed amendment will ***HELP ACHIEVE*** Objective 4.2 regarding no interference with agricultural operations.

c. The proposed amendment will ***HELP ACHIEVE*** the County's policies regarding minimizing the conversion of best prime farmland as follows:
   (a) The only policy regarding conversion of best prime farmland by non-residential discretionary development is Policy 4.1.6b., which states, "On best prime farmland the County may authorize non-residential development." Policy 4.1.6.b. has no limit on the conversion of best prime farmland for non-residential discretionary development and is merely a statement of fact and therefore, the proposed amendment does help achieve Policy 4.1.6b.

B. Objective 4.2 is entitled "Development Conflicts with Agricultural Operations" and states, "Champaign County will require that each *discretionary review* development will not interfere with agricultural operations."

The proposed amendment will ***HELP ACHIEVE*** Objective 4.2 because of the following:

(1) **Policy 4.2.1 states, "The County may authorize a proposed business or other non-residential *discretionary review* development in a rural area if the proposed development supports agriculture or involves a product or service that is better provided in a *rural* area than in an urban area."**

The proposed amendment will ***HELP ACHIEVE*** Policy 4.2.1 for the following reasons:

a. The Land Resource Management Plan (LRMP) provides no guidance regarding what products or services are better provided in a rural area and therefore that determination must be made in each zoning case.

b. A WIND FARM TOWER ***IS*** a service better provided in a rural area as evidenced by the following:
   (a) WIND FARM TOWERS do not require access to most utilities.

(b) WIND FARM TOWERS are not compatible with principal structures within the minimum separation distance established by the Zoning Ordinance, which is currently at least 1,000 feet.

c. Even though a WIND FARM TOWER does not serve the surrounding agricultural uses directly, the land owner receives payment from the WIND FARM TOWER operator in excess of the value of a crop from that land.

(2) **Policy 4.2.2 states, "The County may authorize *discretionary review* development in a rural area if the proposed development:**
a) is a type that does not negatively affect agricultural activities; or
b) is located and designed to minimize exposure to any negative affect caused by agricultural activities; and
c) will not interfere with agricultural activities or damage or negatively affect the operation of agricultural drainage systems, *rural* roads, or other agriculture-related infrastructure."

The proposed amendment will ***HELP ACHIEVE*** Policy 4.2.2 for the following reasons:

a. Section 6.1.4 E. details standard conditions to mitigate damage to farmland, including agricultural drainage tile and soil disturbance.

b. Proposed Section 6.1.4 R. requires that an applicant shall enter into an Agricultural Impact Mitigation Agreement with the Illinois Department of Agriculture, including the following:

(a) The Applicant shall bear full responsibility for coordinating any special conditions required in the SPECIAL USE Permit in order to ensure compliance with the signed Agricultural Impact Mitigation Agreement with the Illinois Department of Agriculture.

(b) All requirements of the signed Agricultural Impact Mitigation Agreement with the Illinois Department of Agriculture shall become requirements of the County Board SPECIAL USE Permit.

(c) Champaign County shall have the right to enforce all requirements of the signed Agricultural Impact Mitigation Agreement with the Illinois Department of Agriculture.

(3) Policy 4.2.3 states, **"The County will require that each proposed discretionary development explicitly recognize and provide for the right of agricultural activities to continue on adjacent land."**

The proposed amendment will ***HELP ACHIEVE*** Policy 4.2.3 for the following reason:

a. Proposed paragraph 6.1.4 A.3. creates a standard condition requiring compliance with the Right to Farm Resolution 3425.

(4) Policy 4.2.4 states, "**To reduce the occurrence of agricultural land use and non-agricultural land use nuisance conflicts, the County will require that all**

discretionary review consider whether a buffer between existing agricultural operations and the proposed development is necessary."

The proposed amendment will ***HELP ACHIEVE*** Policy 4.2.4 for the following reason:

a. Section 6.1.4 C. requires minimum separations from adjacent uses and structures as a standard condition.

C. Objective 4.3 is entitled "Site Suitability for Discretionary Review Development" and states: "Champaign County will require that each discretionary review development is located on a suitable site."

The proposed amendment will ***HELP ACHIEVE*** Objective 4.3 because of the following:

(1) **Policy 4.3.1 states "On other than best prime farmland, the County may authorize a discretionary review development provided that the site with proposed improvements is suited overall for the proposed land use."**

The proposed amendment will ***HELP ACHIEVE*** Policy 4.3.1 for the following reasons:

a. See the discussion under Policy 4.3.2 regarding achievement of Policy 4.3.2. If the proposed amendment achieves Policy 4.3.2, it will also achieve Policy 4.3.1.

(2) **Policy 4.3.2 states, "On best prime farmland, the County may authorize a discretionary review development provided the site with proposed improvements is well-suited overall for the proposed land use.**

The proposed amendment will ***HELP ACHIEVE*** Policy 4.3.2 for the following reasons:

a. Because so much of Champaign County consists of best prime farmland soils, any development of a WIND FARM is likely to be on best prime farmland.

b. Standard conditions for a WIND FARM will ensure that a WIND FARM shall not be approved on any location that is not well-suited as follows:

(a) Section 6.1.4 A.(2) identifies areas where a WIND FARM should not be located.

(b) Section 6.1.4 E. details standard conditions to mitigate damage to farmland including underground agricultural drainage tile.

(c) Section 6.1.4 J. requires and Endangered Species Consultation with the IDNR and IDNR recommendations will be included in the Agency Action Report submitted with the Special Use Permit Application.

(d) Section 6.1.4 K. requires consultation with the State Historic Preservation Officer of IDNR and IDNR recommendations will be included in the Agency Action Report submitted with the Special Use Permit Application.

(e) Section 6.1.4 L. requires that the WIND FARM shall be located, designed, constructed, and operated so as to avoid and, if necessary, mitigate impacts to wildlife.

(f) Section 6.1.4 M. requires that landscaping, awnings, or fencing shall be provided for any part of a WIND FARM where shadow flicker exceeds the standards established in the Zoning Ordinance.

(g) Proposed revision to paragraph 6.1.4 D.7. requires all WIND FARM TOWERS to use ADLS (aircraft detection lighting system) or equivalent system to reduce the impact of nighttime lighting on nearby residents, communities and migratory birds in accordance with the FAA Advisory circular: 70/7460-IL section 14.1.

(3) **Policy 4.3.3 states, "The County may authorize a discretionary review development provided that existing public services are adequate to support to the proposed development effectively and safely without undue public expense."**

The proposed amendment will ***HELP ACHIEVE*** Policy 4.3.3 for the following reasons:

a. Section 6.1.4 H. requires the applicant for any WIND FARM to submit a copy of the site plan to the relevant Fire Protection District and to cooperate with the Fire Protection District to develop the Fire Protection District's emergency response plan for the proposed WIND FARM.

(4) **Policy 4.3.4 states, "The County may authorize a discretionary review development provided that existing public infrastructure, together with proposed improvements, is adequate to support the proposed development effectively and safely without undue public expense."**

The proposed amendment will ***HELP ACHIEVE*** Policy 4.3.4 for the following reasons:

a. Section 6.1.4 F. requires a Roadway Upgrade and Maintenance agreement with the relevant highway authority.

(5) **Policy 4.3.5 states, "On best prime farmland, the County will authorize a business or other non-residential use only if:**

a. It also serves surrounding agricultural uses or an important public need; and cannot be located in an urban area or on a less productive site; or

b. the use is otherwise appropriate in a rural area and the site is very well suited to it."

The proposed amendment will ***HELP ACHIEVE*** Policy 4.3.5 for the following reasons:

a. As reviewed for Policy 4.2.1 in this Finding of Fact:

(a) A WIND FARM ***IS*** a service better provided and therefore ***IS*** appropriate in a rural area.

b. Regarding location of a WIND FARM on a less productive site, the following is reviewed under Policy 4.3.2 in this Finding of Fact:
(a) It is unlikely that a WIND FARM in Champaign County will be located on less than best prime farmland.

10. LRMP Goal 5 is entitled “Urban Land Use” and states as follows:

Champaign County will encourage urban development that is compact and contiguous to existing cities, villages, and existing unincorporated settlements.

Goal 5 has 3 objectives and 15 policies. The proposed amendment is ***NOT RELEVANT*** to Goal 5 in general.

11. LRMP Goal 6 is entitled “Public Health and Safety” and states as follows:

Champaign County will ensure protection of the public health and public safety in land resource management decisions.

Goal 6 has 4 objectives and 7 policies. Objectives 6.2, 6.3, and 6.4 are not relevant to the proposed amendment. The proposed amendment will ***HELP ACHIEVE*** Goal 6 for the following reasons:

A. Objective 6.1 states, “**Champaign County will seek to ensure that development in unincorporated areas of the County does not endanger public health or safety**.” Objective 6.1 has four subsidiary policies; policy 6.1.3 is the only relevant policy, and it states the following:
(1) Policy 6.1.3 states, “**The County will seek to prevent nuisances created by light and glare and will endeavor to limit excessive night lighting, and to preserve clear views of the night sky throughout as much of the County as possible**.” The proposed amendment will ***HELP ACHIEVE*** Objective 6.1.3 as follows:
a. Section 6.1.2 A. of the Zoning Ordinance requires that any SPECIAL USE Permit with exterior lighting shall be required to minimize glare onto adjacent properties by the use of full-cutoff type lighting fixtures with maximum lamp wattages.

b. Proposed revision to paragraph 6.1.4 D.7. requires all WIND FARM TOWERS to use ADLS (aircraft detection lighting system) or equivalent system to reduce the impact of nighttime lighting on nearby residents, communities and migratory birds in accordance with the FAA Advisory circular: 70/7460-IL section 14.1.

c. Section 6.1.4 M. requires that landscaping, awnings, or fencing shall be provided for any part of a WIND FARM where shadow flicker exceeds the standards established in the Zoning Ordinance.

12. LRMP Goal 7 is entitled "Transportation" and states as follows:

    Champaign County will coordinate land use decisions in the unincorporated area with the existing and planned transportation infrastructure and services.

    Goal 7 has 2 objectives and 7 policies. The proposed amendment is ***NOT RELEVANT*** to Goal 7 in general.

13. LRMP Goal 8 is entitled "Natural Resources" and states as follows:

    Champaign County will strive to conserve and enhance the County's landscape and natural resources and ensure their sustainable use.

    Goal 8 has 9 objectives and 36 policies. The proposed amendment is ***NOT RELEVANT*** to Goal 8 in general.

14. LRMP Goal 9 is entitled "Energy Conservation" and states as follows:

    Champaign County will encourage energy conservation, efficiency, and the use of renewable energy sources.

    Goal 9 has 5 objectives and 5 policies. The proposed amendment will ***NOT IMPEDE*** the achievement of Goal 9.

15. LRMP Goal 10 is entitled "Cultural Amenities" and states as follows:

    Champaign County will promote the development and preservation of cultural amenities that contribute to a high quality of life for its citizens.

    Goal 10 has 1 objective and 1 policy. The proposed amendment is ***NOT RELEVANT*** to Goal 10 in general.

REGARDING THE PURPOSE OF THE ZONING ORDINANCE

16. The proposed amendment will ***HELP ACHIEVE*** the purpose of the Zoning Ordinance as established in Section 2 of the Ordinance for the following reasons:
    A. Paragraph 2.0 (a) of the Ordinance states that one purpose of the zoning regulations and standards that have been adopted and established is to secure adequate light, pure air, and safety from fire and other dangers.

       The proposed amendment is consistent with this purpose.

    B. Paragraph 2.0 (b) of the Ordinance states that one purpose of the zoning regulations and standards that have been adopted and established is to conserve the value of land, BUILDINGS, and STRUCTURES throughout the COUNTY.

       The proposed amendment is consistent with this purpose.

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C. Paragraph 2.0 (c) of the Ordinance states that one purpose of the zoning regulations and standards that have been adopted and established is to lessen and avoid congestion in the public STREETS.

The proposed amendment is not directly related to this purpose.

D. Paragraph 2.0 (d) of the Ordinance states that one purpose of the zoning regulations and standards that have been adopted and established is to lessen and avoid hazards to persons and damage to property resulting from the accumulation of runoff of storm or flood waters.

The proposed amendment is not directly related to this purpose.

E. Paragraph 2.0 (e) of the Ordinance states that one purpose of the zoning regulations and standards that have been adopted and established is to promote the public health, safety, comfort, morals, and general welfare.

~~The proposed amendment is consistent with this purpose.~~

(1) The following is a summary of communications received prior to the March 17, 2022 ZBA public hearing for this case:

a. In an email received March 16, 2022, Shannon Reel asked for clarification on several questions related to the proposed wind farm ordinance revisions. She expressed concerns about ensuring her entire property, not just her residence, would not be infringed upon by insufficient setback from turbines. She also mentioned noise, lights, vibrations, and ice shed. She would like a setback that is 6 times the total height for non-participatory property lines. She would like a moratorium of 18 months on special use wind farm applications in Champaign County.

b. In an email received March 16, 2022, Jennifer Eisenmenger said that she is opposed to industrial wind farms. She said wind Farms are invasive to wild places, damaging to animals and humans, and require so much fossil fuel in the manufacturing, transportation, maintenance, and disposal that they actually do little to offset it's usage. She is against unlimited heights on wind turbines, and in favor of significantly increased setbacks from households. She asked that consideration be given to what happens (as illustrated in Douglas County) when wind farms go out of business, leaving counties and land owners with the health and safety issues that come with deteriorating turbines.

c. In an email received March 17, 2022, Benjamin Rice said he is opposed to having no height restrictions and also to the setback being measured from his home and not his property line. He said his yard would be unenjoyable due to noise and it could be dangerous for his family.

d. In an email received March 17, 2022, Heidi Leerkamp said she is opposed to all changes which increase the height allowed for wind turbines or lessen setbacks from non-participating property or dwellings. She said a wind farm project might be considered a win for economic development but would be a long term drain on the health and welfare of our county. She said these projects greatly impact their daily quality of life and enjoyment of their home property. They negatively affect their ability to operate their family farm as well as the values of their home and farm properties. She mentioned negative impacts on area infrastructure and little benefit for local jobs related to the wind farms. She said that both physical and mental health are negatively impacted by living under and around moving structures of an unprecedented size. She expressed concern about decommissioning of the wind turbines. She asked that no more wind projects be approved in our area and no increases be made to the current wind turbine height limits, and no decreases to the turbine setback limits be made.

e. In an email received March 17, 2022, Justin Leerkamp said that he is against any increase above the current height restriction on wind turbines. He said that further and larger setbacks from property lines, not just occupied dwellings would be welcome, but increases in height will only add to further problems for rural residences, and property values for rural homes. He expressed concern about the decommissioning of wind turbines. He said his biggest objections to increasing height is both noise and shadows from the blades, both during the day and from the lighting systems at night bouncing off the blades. He said he supports the use of new lighting systems that are activated when aircraft are near, but questions how effective this will be when areas south east of Willard airport are in the ILS path of its runways.

f. In an email received March 17, 2022, David Happ said he supports adding the ADLS lighting requirements to the ordinance. He said he does not support increases to maximum height of the turbines. He said that Champaign County should change their ordinance to specify a separation distance of 3,250 feet from any residence, and one-half mile from any property line, and he does not think a property owner should be allowed to waive these requirements. He said that increasing the maximum tower height and supporting lower separation distances, is exactly the opposite of what people who have lived near windfarms in the past have asked for.

g. In an email received March 17, 2022, Todd Horton said that there is insufficient concern to remedy shadow flicker in the Zoning Ordinance.

h. In an email received March 17, 2022, Darrel and Regina Rice said it makes no sense to them to take ground in this part of the country out of production for a wind farm. They don't want to see it, hear it, farm around it, and they don't want it near their homes or on their land. They asked for reasonable height limits on the turbines, and to increase the setbacks beyond what is currently being considered.

i. In an email received March 17, 2022, Donald Carter expressed concern about health impacts due to insufficient setbacks and noise from the turbines. He is concerned about decreased property values due to wind farms, infrastructure damage and harm to productivity of farm ground where turbines are located, and with ongoing maintenance of turbines as deterioration had been experienced in other nearby windfarms.

j. In an email received March 17, 2022, Cary and Pam Leerkamp said they have concerns about decreasing property values and asked that the ZBA consider the welfare of county residents.

k. In an email received March 17, 2022, Traci Bosch had concerns about Carle hospital helicopter safety as they maneuver around turbines. She is concerned about her water supply, noise, rural infrastructure during and after construction of the turbines, and permanent scarring of the soil and roads due to turbine construction. She asked for consideration of rural taxpayers and decreasing property values.

l. In an email received March 17, 2022, Brandon and Sarah Hastings said they are opposed to having no height restriction on wind turbines. They expressed concern about debris being thrown from turbines, health issues caused by turbines, potential impacts on internet service, reduced property values, damage to fields and drainage tile, and how fee revenues from turbine projects would be used by the County.

m. In an email received March 17, 2022, Michelle and Scott Wiesbrook said they had concerns about traffic during wind farm construction, having an unlimited height for wind turbines, noise, flicker, vibration, constructing wind farms on productive farmland, and decommissioning the turbines.

n. In an email received March 17, 2022, Lynn Rice said the proposed unlimited height and short setback restrictions being proposed at tonight's meeting should be denied. She mentioned adverse health and sleep effects due to proximity to wind turbines, and said they should have a maximum height of 500 feet and minimum setback of 1.25 miles from homes.

o. In an email received March 17, 2022, Josh Kamerer asked what would be done to alleviate any broadband/internet service interruptions as many have school age children who depend on internet access.

p. In an email received March 17, 2022, Steven Herriott said that wind turbines are a blight on our beautiful countryside. He said turbine companies should be held to standards of fixing the roads they destroy.

q. In an email received March 17, 2022, Tiffany Byrne said she had concerns about health impacts due to proximity to wind turbines. She also mentioned impacts on wildlife and livestock. She asked that the height limit not exceed the current 500 feet and that homes should be at least 1.25 miles away from wind turbines.

r. In an email received March 17, 2022, Adam Watson said that he is in complete opposition of changing the wind tower height limit to unlimited and changing the setbacks.

s. In an email received March 17, 2022, Natalie Thomas said she had concerns about noise from the turbines, having sufficient setbacks from the turbines, impacts on area communities, sleep deprivation and other health issues, travel safety and making sure roads are in good repair, decommissioning of wind turbines, impacts on wildlife, and public welfare.

t. In an email received March 17, 2022, Jan Niccum said that she had concerns about decommissioning, road conditions, financial benefits to local communities from the wind farms, and reducing flicker and hum from the turbines.

u. In an email received March 17, 2022, Aaron Fenter said he had concerns about unlimited height and insufficient setbacks from wind turbines. He said the zoning department has a responsibility to the many rural residents to not allow anything that would detract from their quality of life, their comfort in their homes or the value of their properties.

v. In an email received March 17, 2022, Kate Boyer said she opposes wind farms, especially due to concerns with her health and that of her children. She said noise and flickering are major triggers for her seizures and for her children's autistic episodes, and living in the peaceful country has improved their health.

w. In an email received March 17, 2022, Stephen Smith said he opposes putting a wind farm in the area. He expressed concerns about road conditions, damaged field tiles, the hazard of wind turbines to agricultural air applications of seeds and chemicals, noise, strobe effect/lighting, blade breakage, and traffic increases from turbine construction.

x. In an email received March 17, 2022, Jennifer Miller, DVM, said she had concerns about the impacts of wind farms on livestock. She said that chronic stress may impact egg laying, rate of gain, milk production, fertility and stereotypies (cribbing and weaving). She said this can impact families raising the livestock. She asked for consideration of setback to property lines and not just to homes, and for noise levels below 39 decibels. She would like the height capped at 500 feet.

(2) The following is a summary of testimony received at the March 17, 2022 ZBA public hearing for this case:

a. Stephen Smith stated that he is against putting wind farms in and has several concerns: roads being destroyed during wind farm construction and not being repaired after, broken drainage tiles that are not always repaired, the hazard of wind turbines to agricultural air applications of seeds and chemicals, noise, turbine blade breakage, shadow flicker, and ice/snow shed. He said the turbines should be set back farther and setback should be measured from the property line.

b. William Boyer spoke on behalf of his mother, Kate Boyer. He said they have health concerns related to the wind turbines. She suffers from temporal lobe epilepsy, and several of her children are on the autism spectrum. One of the main reasons they purchased an isolated country house was to bring relief to their health. Noise and flickering lights are major triggers for both her epileptic seizures and her children's autistic episodes. She said moving to the peaceful country was such an amazing transformation of mental and physical health. She asked that the County not allow wind turbines in the area.

c. Dirk Rice said that the setback for non-participating residences should be at least twice that of participating residences. He spoke in favor of the Aircraft Detection Lighting System. He recommended against the proposed setbacks and said the turbines need to be much farther away from residences.

d. Sarah Hastings said she opposed the unlimited height restriction. She provided articles, one of which said that a 300-foot wind turbine could throw debris 1,200 feet. She said that another article stated that wind turbines can cause health issues and interfere with radio, TV, satellite and radar signals. She also expressed concern about decreased property values.

e. Kirk Allen said he was with Edgar County Watchdogs, expressed concern about property rights, and how the Zoning Act in the Illinois County Code stipulates the "authority to regulate and restrict location and use of structures for the purpose of promoting the public health, safety, morals, comfort, general welfare, conserving the value of property throughout the County." He suggested that the Board review Zoning Ordinances from Christian County and Edgar County.

f. Brian Armstrong, Attorney with the firm of Luetkehans, Brady, Garner & Armstrong, said he was speaking on behalf of numerous people in the audience and some who could not attend the meeting. He expressed concerns about noise, the insufficient setbacks proposed, and how turbine height should have a limit. He provided eight exhibits for the Board. He provided data from noise analyses done by Dr. Paul Schomer, acoustician. He encouraged the Board to adopt a setback of no less than 3,250 feet from a wind turbine. The following is a synopsis of those exhibits:

(a) Exhibit 1 was a publication by Health Canada (the department of the Government of Canada responsible for health policy) titled *Wind Turbine Noise and Health Study: Summary of Results* published 11/6/2014. The study was undertaken in two Canadian provinces, Ontario and Prince Edward Island, and included responses from 1,283 households in the vicinity of 18 wind turbine developments with a total of 399 wind turbines. The study consisted of three primary components which were as follows and with the following results:

i. An in-person questionnaire to randomly selected participants living at varying distances from wind turbine installations regarding self-reported sleep; self-reported illnesses and chronic diseases; self-reported stress; quality of life indicators; and annoyance. Wind turbine noise exposure was not found to be associated with self-reported sleep quality or with self-reported illnesses or self-reported stress or with any significant change in quality of life. Annoyance towards several wind turbine features (i.e. noise, shadow flicker, blinking lights, vibrations, and visual impacts) were statistically associated with increasing levels of wind turbine noise

ii. Collection of objectively measured outcomes that assessed hair cortisol, blood pressure, and sleep quality. Exposure to wind turbine noise was not observed to be related to hair cortisol concentrations, blood pressure, resting heart rate, or measured sleep. Note that

iii. More than 4,000 hours of wind turbine noise measurement that supported the calculation of wind turbine noise at the residences in the study. The 1,283 residences were grouped into different categories of calculated outdoor A-weighted wind turbine noise levels of less than 25 dBA; 25 to <30DBA; 30 to <35dBA; 35 to < 40 dBA; and greater than 40dBA (but an inadequate sample size above 46dBA).

(b) Exhibit 2 was a January 2017 paper in the journal Sound & Vibration titled *Health Effects from Wind Turbine Low Frequency Noise & Infrasound* by authors George Hessler (George Hessler Associates, Inc., Haymarket VA), Geoff Leventhall (consultant, Ashtead, Surrey, UK), Paul Schomer (Schomer and Associates, Inc., Champaign IL), and Bruce Walker (Channel Islands Acoustics, Camarillo, CA). This study by four experts concluded that infrasound (0 to 20 Hz) can almost be ruled as a potential mechanism for stimulating motion sickness symptoms but some additional research was recommended. Pending those results, the four authors recommended that an acceptable A-weighted noise level is all that should be required. In the paper the four authors also share their recommended noise limits for wind farms which are 35 to 39 dBA (Schomer) and 40 dBA (Leventhall and Hessler with Hessler having a 45 dBA maximum) and 45dBA (Walker).

(c) Exhibit 3 was a paper titled *The Results of an Acoustic Testing Program, Cape Bridgewater Wind Farm Prepared for Energy Pacific by Steve Cooper, The Acoustic Group, A Review of this Study and Where it is Leading* by Paul D. Schomer, PhD., P.E.; Schomer and Associates, Inc.; Standards Director, Acoustical Society of America, and George Hessler, Hessler Associates, Inc. The paper is dated 10 February 2015. This paper reviewed a very limited study regarding the perceived effects of noise on three couples who lived between 650 meters and 1600 meters from the Cape Bridgewater wind farm in Australia. The Cape Bridgewater study found that the three couples could sense the operation of wind turbines in the wind farm even when there was no acoustical or visual stimulus from wind turbine operation and their reactions were correlated with the power output of the wind turbines. One of the couples was so affected by the wind farm emissions that they abandoned their home. The Cape Bridgewater study was too limited for the results to be generalized to the population, but the study did demonstrate a cause and effect relation at these locations.

(d) Exhibit 4 was an excerpt of McLean County Zoning Board of Appeals minutes from 1/24/2018. The excerpt is the questioning of Dr. Schomer by Attorney Luetkehans and members of the Zoning Board of Appeals. The questioning focused on the various wind farm noise limits and the Cape Bridgewater study. Dr. Schomer stated his recommended noise limit for wind farm noise to be 38 to 40 dB.

(e) Exhibit 5 is a report titled *A Cooperative Measurement Survey and Analysis of Low Frequency and Infrasound at the Shirley Wind Farm in Brown County, Wisconsin* that was partially funded by the Wisconsin Public Service Commission and by Clean Wisconsin, a nonprofit environmental advocacy organization. Although the study was about the Shirley Wind Farm the results of the study were to be used in a pending wind farm proposed for St. Croix County, WI. The report was issued on 12/24/2012. Four acoustical consulting firms jointly conducted the study. The firms were Channel Islands Acoustics (principal Dr. Bruce Walker); Hessler Associates, Inc. (principals George and David Hessler); Rand Acoustics (principal Robert Rand); and Schomer and Associates, Inc, (principal Dr. Paul Schomer). Each consultant presented their individual findings in a separate Appendix but all agreed that in regards to the Shirley Wind Farm there was "…enough evidence and hypotheses given to classify low frequency noise and infrasound as a serious issue…it should be addressed beyond the present practice of showing that wind turbine levels are magnitudes below the threshold of hearing at low frequencies." Hessler Associates, Inc. recommended a noise limit of 39.5 dBA or less for the proposed St. Croix wind farm. Schomer and Associates recommended additional testing and if that was not possible they recommended a noise limit of 33.5 dBA or less for the proposed St. Croix wind farm, based on a 6 dB decrease in noise that the Navy used when dealing with severe noise induced nausea. Neither Channel Islands Acoustic nor Rand Acoustics made recommendations for the proposed St. Croix wind farm.

(f) Exhibit 6 is an undated report titled *Proposed minimum siting distances for Livingston County Wind Farms* prepared by Schomer and Associates, Inc. The paper is an analysis of separation distances and calculated noise levels from existing wind turbines for the 1,283 dwellings in the Health Canada publication titled *Wind Turbine Noise and Health Study: Summary of Results* published 11/6/2014. The report divides the separations for 745 dwellings in the Health Canada study into nine separation categories from 1,500 feet to

3,750 feet. 493 dwellings in the Health Canada study were located further than 3,750 feet from a turbine and those dwellings are not included in this analysis. The 745 dwellings in this analysis were divided into 6 noise levels from 35 dB(A) to 40 dB(A). The report also included the results of a study by Minnesota Department of Commerce regarding international wind turbine noise limits for residences and the requirements of the American National Standards Institute (ANSI). The report concludes with a recommendation for a noise limit of 38dB(A) and a minimum separation of 3,250 feet.

(g) Exhibit 7 is a report titled *Alta Farm Wind Project II, LLC, Dewitt County, Illinois, Property Value Impact Analysis: Residential improved and vacant agricultural land properties* by Kurt C. Kielisch of Forensic Appraisal Group of Neenah, Wisconsin, dated February 18, 2019. The report is a summary of a study contracted by DeWitt County Residents Against Wind Turbines group, represented by Atty. Phillip A. Luetkehans, Schirott, Luetkehans & Garner, LLC, Itasca, Illinois, to study the impacts that the proposed Alta Farms Wind Project II, LLC, would have on improved residential and vacant agricultural land values. The report has four parts: a literature study regarding wind farms and land use; a summary of wind farm value impact studies; an analysis of how residential property values are being impacted by a wind farm using paired sales analysis in the Twin Groves II wind farm in McLean, Illinois; and a multiple regression analysis on the impact of agricultural land values being impacted by the Twin Groves II wind farm. The impact studies found little to no evidence of an impact in wind industry and government supported studies, but found a "significant impact" from independent studies using a variety of valuation methods from paired sales analysis to multi-regression analysis. Losses amongst the nine independent studies that were completed between 2007 and 2015 ranged from 7.7% to 50% in value, with distances ranging from adjacent to a wind farm to within 3 miles of a wind farm. The report also indicated that "Agricultural land also is impacted by the presence of a wind farm losing -6.3% to -8.5% of its overall value if located within a wind farm." For the proposed wind farm, the report concluded that "the presence of wind turbines in close proximity to residential properties and agricultural land will have a negative impact on property value and this impact is permanent. The magnitude of that impact will be dependent on the proximity of the wind turbines to the property, the disruption of the viewshed and disruption of the land use."

(h) Exhibit 8 is a PowerPoint presentation authored by Jerry Punch, Ph.D., titled "Wind Turbine Noise: Effects on Human Health" that was given to the Christian County, Illinois Zoning Board of Appeals on June 23, 2020. The presentation covered the following topics:

- Physical nature of wind turbine noise
- Common health effects of wind turbine noise exposure

- Research evidence that wind turbine noise causes adverse health effects
- Methods of limiting wind turbine noise
- Standards and guidelines relevant to wind turbine noise

Recommendations included maximizing setback distance and minimizing noise levels. Dr. Punch provided numerous citations for recommended setback and noise levels, but did not make recommendations himself.

g. Ted Hartke communicated his personal experience with how turbine noise caused him and his family to move from a perfectly good home in Vermilion County. He recommended that Champaign County adopt a setback of no less than 3,250 feet from a wind turbine based on Dr. Schomer's noise analyses. He said he supports a 500 foot limit on the turbine height.

h. Darrell Rice said that it makes no sense to them to take ground in this part of the country out of production for a wind farm; they don't want to see it, hear it, farm around it, have it near their homes or on their land. He asked the Board to place reasonable height limits on turbines and increase the setbacks beyond what is being considered.

i. Benjamin Rice said that he wants his family to be able to enjoy their entire seven acres of land. He expressed concerns about noise, safety from turbines breaking apart and throwing ice, and the height of the turbines. He asked for consideration of their rights and getting to enjoy peace and quiet in the country.

j. Brad Shotton asked the Board to give them a voice in order to preserve the properties they have. He would like increased setbacks, a limit on the wind turbine height, and asked the Board not to accept the proposal before them. He expressed concern about noise, vibrations, and shadow flicker.

k. Ed Decker said it would be totally irresponsible to give the wind turbine an unlimited height, and he would like the Board to keep it at the 500 feet height limit. He said he thinks the 3,250 feet has come up several times tonight for the setback, and he thinks that would be a reasonable setback, and he thinks that needs to be from each property line as well as each dwelling. He expressed concern about noise and property values.

l. Kelly Vetter said that she thinks there is a conflict of interest that the wind company's engineer oversees the decommissioning estimates for the existing wind farm. She asked that Champaign County do what other counties have done, which is to make ordinances that prevent a wind farm from even coming in.

m. Todd Horton said that he is really concerned that an incompatible land use would be something, that creates flickering lights coming through the windows of their homes. He said when it comes to shadow flicker, there is no standard for what an acceptable reduction of shadow flicker is, but they don't have anything in the current Zoning Ordinance that says anything is enforceable, other than the wind farm project developer provides a shadow flicker study, but it doesn't say the wind farm project developer has to follow the study. He said that he hopes the wind turbines are not allowed to be taller.

n. Don Carter said that there is a company, NextEra Energy, that is planning a wind farm on 50,000 acres south of Philo, Sidney and Homer. He said the Board members are the residents' champions; the Board is the one that stands between the residents and people that many of the residents feel would ill-use that land out there. He asked the Board to take up their case, take up their cause by passing responsible aspects of this ordinance that is before them.

o. Charlie Mitsdarfer said he is really worried about the height, and even more concerned about the setbacks. He said these are an eyesore, and he is worried about property values and mitigating existing land problems caused by wind farm construction. He said roads are in poor shape and there are broken field tiles, and the land will never be what it was before that construction. He said he has heard of issues with well water. He questioned the unlimited height proposed, and asked for a one-mile setback from turbines.

p. Justin Leerkamp said he farms in the Douglas County area adjacent to many of these windmills, and he feels that the setback multiplier is not large enough having worked under these 600 foot towers. He said if we do use a multiplier, to increase the height, it should not be linear, it should be exponential as the height increases. He said the purpose of that would be to reduce the shadow flicker. He said he really doesn't feel that the height increase is warranted at this time; he feels that the 500 foot limit has worked for this county. He said he is in favor of lighting mitigation.

q. William Mitsdarfer said he hears people complain about the railroad a lot, or living next to a grain elevator. He said he understands that it's probably noisy and dirty or whatever, but that elevator or railroad were there before the house was or the town, so people knew that when they moved there. He said their homes are there now and there's no windmills. He saw no good in having windmills.

r. Traci Bosch said she is just 3-3/4 miles from the Douglas County windmills. She said they sound like a constant blowtorch, and urged the Board to drive out to a windmill and listen before making any decisions. She said that the Board should talk to residents of northern Champaign County about what it is like when a turbine blows apart. She expressed concerns about road conditions, property values, and impacts on school and fire station revenues.

s. Daniel Herriott asked the Board to consider Dekalb County's wind farm ordinance, which has a setback that is six times the turbine height and allows zero flicker on non-participating neighbors. He said the height limit should be kept at 500 feet.

(3) The following is a summary of communications received between March 18 and April 1, 2022 for this case:

a. In an email received March 18, 2022, Mick & Mary Schumacher said they had concerns about the height of the towers, designed setbacks, and setbacks from neighboring property owners.

b. In an email received March 29, 2022, Ted Hartke provided citations supporting a 39 dBA maximum noise limit because 40 dBA begins adverse health impacts.

c. In an email received March 29, 2022, Don Carter stated he is opposed to the proposed changes in turbine heights and setbacks. He would like to maintain the current 500 foot height limitation in the ordinance, and increase the setback to the property line of non-participating land owners to 3,250 feet. He agrees with the adoption of county-level AIMA standards and adding aircraft detection lighting systems for wind turbines. He agrees with the proposed increase in turbine fees, and thinks the fee should be even higher.

d. In an email received March 29, 2022, Michael Mooney is opposed to having more wind farms in the county. He expressed concerns about damage to field tiles and ruined roads due to wind farm construction.

e. In an email received March 29, 2022, Gary Place expressed concerns about wind farms effects on safety and quality of life. He would like to keep the current 500 foot height limit, would like to have a 3,250 foot setback to non-participating landowners' property lines, and have a noise limit of 38 dBA.

f. In an email received March 30, 2022, Shannon Reel expressed concerns about noise, sleep deprivation, loss of home value, and flicker from the wind turbines. She is against removing the 500 foot height restriction and in favor of setback to a non-participating property line of 6 times the height of a turbine.

g. In a second email received March 30, 2022, Shannon Reel expressed concerns about roads not getting repaired and the County not having enough money to repair the roads once wind farm construction has occurred. She urged the County to deny the proposed changes.

h. In an email received March 30, 2022, Drs. Andrew & Jennifer Miller stated they are opposed to changing the setbacks and the height of wind turbines. They feel the setback from property lines should be 3,250 feet and the height of turbines limited to 500 feet.

i. In an email received March 30, 2022, Darrel Rice expressed concern about water quality related to bedrock damage caused by wind turbine installation and underground vibrations from turbines. He also mentioned concerns about shadow flicker, effects on bats and honeybees, adverse health impacts of wind turbines. He asked that the 500 foot height limit be maintained and that the setback requirements be extended to the property lines and be extended in distance.

j. In an email received March 31, 2022, Justin Leerkamp said he does not support an unlimited height for turbines. He thinks setbacks should increase in distance and also be measured from property lines, not residences. He supports the adoption of the Agricultural Impact Mitigation Agreement, and suggested that the proposed fee increases be increased even more. He said he supports the adoption of the ADLS lighting system.

k. In an email received March 31, 2022, Todd and Sharon Herbert said they would like the 500 foot wind turbine height maintained, and the setback to be increased to 3,250 feet from the neighboring property lines. They are also in favor of the aircraft detection system. They expressed concerns about broken drainage tiles and roads caused by wind farm construction.

l. In an email received March 31, 2022, Michelle and Scott Wiesbrook asked to maintain the current wind turbine height limit at 500 feet. She supports the adoption of the county-level Agricultural Impact Mitigation Agreement and aircraft lighting detection systems. She thinks the fees should be increased even higher than what is currently proposed. She expressed concern about groundwater quality.

m. In an email received March 31, 2022, David Happ said he supports the Right to Farm Resolution. He does not support changing the maximum allowable wind turbine height of 500 feet. He does not think that the minimum required separation should be a factor of tower height; it should be 3,250 feet. He said he supports aircraft lighting detection systems and Agricultural Impact Mitigation Agreements. He supports the proposed fee increase.

n. In an email received March 31, 2022, Tiffany Byrne said that she supports a setback of 6,600 feet from non-participating dwellings. She said that the height limit should remain unchanged.

o. In an email received March 31, 2022, Brandon and Sarah Hastings asked that the height limit for wind turbines be kept at 500 feet. They expressed concern about groundwater quality, ice throw, noise, and flicker. They support aircraft lighting detection systems and Agricultural Impact

Mitigation Agreements. They support the proposed increase in fees and think they could be even higher.

p. In an email received March 31, 2022, Traci Bosch expressed concern about safety of pilots who spray crops and fly emergency helicopters in wind turbine areas.

q. In an email received March 31, 2022, Stephen Smith asked that height of turbines be limited to 200 feet. He supports an increase in the setback to the non-participating landowners' property lines. He expressed concern about shadow flicker.

r. In an email received March 31, 2022, Doug Downs said he opposes changing the height limitation. He would like to see the setback increased to 3,250 feet.

s. In an email received March 31, 2022, Kris Petersen described flying conditions and the dangers wind turbines impose on their aerial application service. He said allowing the turbines to be taller will make their jobs more dangerous and less efficient. He said he had concerns about the aircraft lighting detection systems and how they might impact pilot safety.

t. In an email received March 31, 2022, Mike Lockwood expressed concern about possibly being surrounded by wind turbines, light pollution, and impacts on his quality of life. He favors longer setbacks than those proposed, and favors keeping the current 500 foot height limitation.

u. In an email received April 1, 2022, Heidi Leerkamp asked that the ZBA abandon the proposed changes to special use permits for industrial wind energy complexes. She asked that wildlife and best prime farmland be more thoroughly studied before allowing any more wind turbines in the County.

(4) The following is a summary of testimony received at the March 31, 2022 ZBA public hearing for this case:

a. Jed Gerdes stated he is opposed to having wind farms in Champaign County, and that our area's prime farmland should be protected from that kind of development. He said he supports a 1.25 to 1.5 mile setback. He expressed concern about broken drainage tiles, noise, and decreased property values.

b. Michael Mooney said that he does not think it prudent to put wind farms on prime farmland. He expressed concern about broken drainage tiles and bad roads caused by wind farm construction.

c. Kelly Vetter offered to put together a citizen's taskforce to assist the County Board with their decision making regarding wind turbines.

d. Dennis Riggs said that the 500 foot height limit should be maintained, and a setback of at least 3,250 feet from property lines should be established to protect against the problem of unsightliness, noise, air pressure fluctuations, and light flicker. He expressed concerns for broken drainage tiles and bad roads, and supports strong Agricultural Impact Mitigation Agreements and decommissioning agreements.

e. David Reel asked for a moratorium on any new wind turbines for at least 18 months in order to ensure that any revisions to the wind ordinance are not hastily done without due diligence as to what is in the best interest of the county. He said he does not feel the current setback requirements are sufficient.

f. Kris Petersen said he is a pilot and expressed concerns for pilot safety in wind farms and more so if taller turbines are allowed.

g. Roger Negangard expressed concerns about decommissioning and letting the wind companies keep anything in the ground below 46 inches; he thinks they should remove all they put into the ground. He said there needs to be a longer setback and that the height of the turbines needs to be limited.

h. Jennifer Eisenmenger said she is very concerned about the environment. She asked what would happen to mitigation plans when wind farms go out of business.

i. Heidi Leerkamp asked that the ZBA abandon the proposed changes to special use permits for industrial wind energy complexes. She asked that wildlife and best prime farmland be more thoroughly studied before allowing any more wind turbines in the County.

j. Brian Schluter said he is the Compromise Township Road Commissioner. He expressed concern about sufficient setbacks and height, and he does not favor a blanket ordinance.

k. Aaron Fenter said that height limitations should be reviewed periodically rather than allowing an unlimited height. He believes that property values will decrease for residences in a wind farm area. He believes that Champaign County should look at Livingston County's ordinance as an example if they are going to change the current requirements.

l. Adam Watson said he believes changing to an unlimited height would be irresponsible. He said that he feels their county should be the most concerned about the health and safety of its residents. He said he is in agreement with needing to use aircraft detection lighting systems.

m. Stephen Smith said he would like to recommend would be keeping these windmills under 200 feet if they do put them in the area, which would reduce harmful, environmental, and aesthetic impact, and it would also keep from the shadow flicker occurring.

n. Dirk Rice said that as he looks at the proposal for these changes in the regulation and there is no science behind it. He expressed concern for property values, setback and height requirements.

o. Charlie Mitsdarfer said that he has a couple concerns with the Agriculture Impact Mitigation Agreement, and he agrees that it is important, but he has a lot of reservations about how it is going to get enforced. He expressed concerns about returning the soil to its prior condition once wind turbines are removed. He also was concerned about drainage and about crop productivity if the wind turbines affect his ability to spray, and about declining property values due to wind turbines.

p. Justin Leerkamp said he generally supports the Agricultural Impact Mitigation Agreement, but was concerned about its ability to be enforced. He suggested increasing the fees even more and to use part of those fees to enforce the AIMA. He expressed concern for having enough money in the escrow for decommissioning wind turbines. He said that he doesn't support an increase in height, and he doesn't feel their current setbacks are large enough. He said he would like to see more studies on property values.

q. Darrell Rice asked the Board to give them the best possible restrictions to ensure their lives are the most pleasant they could have living within a wind farm footprint, including lower height limits and larger setbacks. He expressed concern for shadow flicker, road conditions and drainage related to construction of wind turbines.

r. Ted Hartke began a presentation, but due to time limits, he agreed to do his presentation at the next meeting on April 14th.

(5) The following is a summary of communications received between April 2, 2022 and April 14, 2022 for this case:

a. In an email received April 12, 2022, Kim Decker provided a list of some locations, sources, or reports that have or are recommending more than one mile setbacks from wind turbines.

b. In an email received April 14, 2022, Matthew Herriott said he was opposed to wind turbine height limits above 500 feet. He said the proposed setback is insufficient to protect the safety and wellbeing of residents. He suggested using Livingston County's ordinance as an example. He said he supported the aircraft lighting detection system, but wondered how well it would work due to the airport. He suggested that the proposed fee increase could be higher and could be used to ensure complaints are addressed. He said he supports the Agricultural Impact Mitigation Agreement if the guidelines are enforced.

(6) The following is a summary of testimony received at the April 14, 2022 ZBA public hearing for this case:

a. Ted Hartke said the ICPB noise limits don't address health issues, only annoyance. He said Dr. Schomer, who helped make these standards, said the ICPB noise levels do not protect health and he said the maximum noise limit from wind turbines should be 39 dB or less. Mr. Hartke gave a presentation citing various sources and testified about his family's negative experience with noise from wind turbines that forced them out of their home. He said that if the Board put the setback at 3,250 feet away and the wind company would want to make the setback at 2,500 or 3,000 feet away, this would put the citizens who live in the wind farm in control, and they would get to decide if they would want to sign off on noise, shadow flicker, and property value loss – the citizens could negotiate that themselves.

Regarding turbine height limits, Mr. Hartke said the taller wind turbines have a longer blade and the blade would flex more causing the low frequency increase along with the thumping and pulsation noise, which is going to be more disturbing.

b. Margie Kolter recommended that people go out to a wind farm area and listen to the noise and feel the vibration that turbines cause. She expressed concern about decommissioning costs and the possibility that the wind companies will go bankrupt and leave the equipment behind. She said that the wind farms are taking prime farm ground and putting concrete in, affecting the drainage, and then they are affecting these peoples' lives.

c. Phil Luetkehans stressed the importance of having sufficient setbacks to protect the health, safety, and welfare of residents and their property values. He said that he thinks anywhere in that setback range of 3,000 feet to 3,250 feet they would probably give a significant protection to residents. He spoke of the probable decrease in property values attributable to proximity to wind turbines. He made a few recommendations for changing the County wind farm ordinance to better protect the County and its residents.

d. Steve Littlefield, a real estate agent, provided five examples of property values for lots that had sold between 2012 and the present in the California Ridge wind farm area. His overall takeaway was that property values are negatively impacted by proximity to wind turbines.

e. Kim Decker said that she would like to have a longer setback, and that the setback should be measured between the turbine and the property line, not to the residence. She provided a list of several dozen setbacks that have been adopted in the US and abroad. She said she is asking the Board to do the responsible thing and in her opinion that is to vote down the proposition they have before them and hopefully revamp this whole process of setbacks and wind height.

f. Matthew Herriott said he is opposed to a tower height taller than 500 feet and suggested that Champaign County take a closer look at Livingston County's ordinance for height and setback. He expressed support for the ALDS lighting, but questioned how often the lights would actually be off given airport traffic. He suggested that the fee increase should be even higher, and that the higher amount be used in part to have an enforcement officer dealing with complaints about wind and solar farms. He said he supports the Agricultural Impact Mitigation Agreement if it is correctly enforced. He recommended that the Champaign County Zoning Board deny the current proposed changes to the ordinance regarding turbine height and setback distance.

g. Brandon Hastings said the height restriction should stay at 500 feet, setbacks should be 3,250 feet or six times the height, whichever is greater to match Livingston County regulations, but it should measure setback from the property line rather than from the residence. He said he thinks the zoning should eliminate the chance of shadow flicker for non-participating parcels. He expressed concern about how big an issue drainage is, and that the Agricultural Impact Mitigation Agreement should include that. He said that fees should be huge, and escrow accounts should be established not only for decommissioning, but for drainage issues and road repair.

h. Kelly Vetter urged the Board to consider the possibilities of the unintended consequence as related to protecting water resources from wind farm development.

i. Steven Herriott said he thinks the height needs to be maintained at 500 feet. He said he feels that sometimes we are doing things to encourage or bend over backwards to help these wind companies, and he doesn't think it is our responsibility to encourage them to come but to let them conform to what we need out there in the country. He said if by chance the turbines get higher, we need to go with six times the height in setback, and measure from the property line and not the residence.

(7) The following is a summary of communications received between April 15, 2022 and May 16, 2022 for this case:

a. In an email received May 2, 2022, Ted Hartke provided four documents that he asked to be distributed to the ZBA and ELUC members. The documents were distributed and added to the Documents of Record.

b. At the May 5, 2022 ELUC meeting, Mary King distributed three handouts, which have been distributed to the ZBA and added to the Documents of Record.

F. Paragraph 2.0 (f) of the Ordinance states that one purpose of the zoning regulations and standards that have been adopted and established is to regulate and limit the height and bulk of BUILDINGS and STRUCTURES hereafter to be erected.

The proposed amendment is consistent with this purpose.

G. Paragraph 2.0 (g) of the Ordinance states that one purpose of the zoning regulations and standards that have been adopted and established is to establish, regulate, and limit the building or setback lines on or along any street, trafficway, drive or parkway.

The proposed amendment is not directly related to this purpose.

H. Paragraph 2.0 (h) of the Ordinance states that one purpose of the zoning regulations and standards that have been adopted and established is to regulate and limit the intensity of the use of LOT areas, and regulating and determining the area of open spaces within and surrounding BUILDINGS and STRUCTURES.

The proposed amendment is not directly related to this purpose.

I. Paragraph 2.0 (i) of the Ordinance states that one purpose of the zoning regulations and standards that have been adopted and established is to classify, regulate, and restrict the location of trades and industries and the location of BUILDINGS, STRUCTURES, and land designed for specified industrial, residential, and other land USES.

The proposed amendment is consistent with this purpose.

J. Paragraph 2.0 (j) of the Ordinance states that one purpose of the zoning regulations and standards that have been adopted and established is to divide the entire County into DISTRICTS of such number, shape, area, and such different classes according to the USE of land, BUILDINGS, and STRUCTURES, intensity of the USE of LOT area, area of open spaces, and other classification as may be deemed best suited to carry out the purpose of the ordinance.

The proposed amendment is not directly related to this purpose.

K. Paragraph 2.0 (k) of the Ordinance states that one purpose of the zoning regulations and standards that have been adopted and established is to fix regulations and standards to which BUILDINGS, STRUCTURES, or USES therein shall conform.

The proposed amendment is consistent with this purpose.

L. Paragraph 2.0 (l) of the Ordinance states that one purpose of the zoning regulations and standards that have been adopted and established is to prohibit USES, BUILDINGS, or STRUCTURES incompatible with the character of such DISTRICTS.

The proposed amendment is consistent with this purpose.

M. Paragraph 2.0 (m) of the Ordinance states that one purpose of the zoning regulations and standards that have been adopted and established is to prevent additions to and alteration or remodeling of existing BUILDINGS, STRUCTURES, or USES in such a way as to avoid the restrictions and limitations lawfully imposed under this ordinance.

The proposed amendment is not directly related to this purpose.

N. Paragraph 2.0 (n) of the Ordinance states that one purpose of the zoning regulations and standards that have been adopted and established is to protect the most productive agricultural lands from haphazard and unplanned intrusions of urban USES.

The proposed amendment is consistent with this purpose.

O. Paragraph 2.0 (o) of the Ordinance states that one purpose of the zoning regulations and standards that have been adopted and established is to protect natural features such as forested areas and watercourses.

The proposed amendment is not directly related to this purpose.

P. Paragraph 2.0 (p) of the Ordinance states that one purpose of the zoning regulations and standards that have been adopted and established is to encourage the compact development of urban areas to minimize the cost of development of public utilities and public transportation facilities.

The proposed amendment is not directly related to this purpose.

Q. Paragraph 2.0 (q) of the Ordinance states that one purpose of the zoning regulations and standards that have been adopted and established is to encourage the preservation of agricultural belts surrounding urban areas, to retain the agricultural nature of the County, and the individual character of existing communities.

The proposed amendment is consistent with this purpose.

R. Paragraph 2.0 (r) of the Ordinance states that one purpose of the zoning regulations and standards that have been adopted and established is to provide for the safe and efficient development of renewable energy sources in those parts of the COUNTY that are most suited to their development.

The proposed amendment is consistent with this purpose.

17. The proposed text amendment ***WILL*** improve the text of the Zoning Ordinance because it ***WILL*** provide:

A. A classification which allows WIND FARMS and WIND TOWERS to be developed while establishing minimum requirements that ensure the purposes of the Zoning Ordinance will be met.

B. A means to regulate an activity for which there is demonstrated demand.

18. ZBA member Tom Anderson appreciated the handout titled *Wind Turbine Noise: Effects on Human Health* by Jerry Punch that was LBGA Exhibit 8. In particular, Mr. Anderson appreciated the following:

A. Slide 10 regarding noise and stated that wind turbine noise is an annoyance (and therefore a nuisance) to a substantial percentage of the population.

B. Slide 30 which stated as follows:

(1) To protect human health, recommendations in the literature for industrial wind turbine setback distances range from 0.5 to 2.5 miles and the distance most often recommended by researchers is 1.25 miles.

(2) Recommendations in the literature typically limit noise levels to 30 – 40dBA Leq and some local ordinance support limiting noise levels to 5 – 10 dB above prevailing background noise levels.

C. Slide 31 which recommended the following to limit wind turbine noise:

(1) Maximizing setback distance and that typical setbacks of a half-mile or less are not adequate to protect general health and well-being.

(2) Minimizing the noise level but regulations based on noise level are difficult to implement and because noise modeling is imprecise and often underestimates noise level, noise levels of industrial wind turbines should always be verified post-construction.

D. Slide 32 which had the following additional considerations:

(1) Low-frequency noise levels are typically not masked by wind or other noises and cannot be controlled effectively by barriers so that distance is the only practical means of achieving acceptable noise levels.

(2) Wind turbine noise easily crosses property lines so setback distances should be based on the acceptable noise levels at property lines and not just at the residence.

19. Regarding Part 2.B. of the text amendment regarding the proposed change to maximum WIND FARM TOWER HEIGHT:

A. Regarding the existing Zoning Ordinance maximum WIND FARM TOWER HEIGHT:

(1) Existing Zoning Ordinance Section 6.1.4D.5. limits maximum WIND FARM TOWER HEIGHT to less than 500 feet and was adopted in Ordinance No. 848 (Zoning Case 634-AT-08 Part A) on 5/21/09.

(2) Existing Zoning Ordinance Section 6.1.4D.1.b. requires each Zoning Use Permit Application for a WIND FARM TOWER to include a certification by an Illinois Professional Engineer or Illinois Licensed Structural Engineer that the foundation and tower design of the WIND FARM TOWER is within accepted professional standards given local soil and climate conditions.

B. The California Ridge Wind Farm was approved by the Champaign County Board on 11/17/2011 with a hub height of 100 meters (328 feet) and a rotor diameter of 100 feet meters (328 feet) for an overall WIND FARM TOWER HEIGHT of 492 feet.

C. The Sapphire Sky Wind Farm was approved by the McLean County Board on 7/14/2021 with a with a hub height of 105 meters (344.4 feet) and a rotor diameter of 150 meters (492 feet) for an overall WIND FARM TOWER HEIGHT of 591 feet. The Harvest Ridge Wind Farm recently approved in Douglas County has a similar height.

D. The National Renewable Energy Laboratory (NREL) Technical Report NREL/TP-5000-73629 titled Increasing Wind Turbine Tower Heights: Opportunities and Challenges dated May 2019 reviewed opportunities, challenges, and potential associated with increasing wind turbine tower heights focused on land-based wind energy and concluded the following:

(1) Wind resource quality (wind speed) improves significantly with height above ground. Over large portions of the country, annual average wind speed doubles and sometimes triples when moving from 80-meter hub heights to 160-meter hub heights. Hub height is the mid-point of the rotor (blades).

(2) Wind speed differences translate to sizable capacity factor (actual power output divided by optimal power output) improvements.

(3) Higher hub heights (110 meter to 140 meter) are often preferred in more moderate wind speed regions. Champaign County is generally considered a moderate wind speed region.

(4) The highest nameplate capacity turbine considered in the study (4.5 megawatts) has a greater preference for 140-meter hub heights than similar 3-megawatt class turbines.

(5) The "business-as-usual" (BAU) turbine considered in the study is expected to be the average turbine installed around the United States by 2030. The BAU turbine has a nameplate capacity of 3.3 megawatts and a rotor diameter of 156 meters and was considered at the hub heights of 110 meters with an overall WIND FARM TOWER HEIGHT of 617 feet; a hub height of 140 meters with an overall WIND FARM TOWER HEIGHT of 715 feet; and a hub height of 160 meters with an overall WIND FARM TOWER HEIGHT of 781 feet.

(6) The analysis found diminishing returns from hub height increases to140 meter and subsequently to 160 meters.

(7) The report notes that the analysis was limited to hub heights of 80 meters, 110 meters, 140 meters, and 160 meters but in many cases the real-world preferred tower heights will likely fall between those points.

(8) To realize taller wind turbine towers, an array of potential concepts remain in play relying on various materials spanning from rolled tubular steel, concrete, lattice steel, and hybrid designs.

E. Based on current practice in nearby counties and on the National Renewable Energy Laboratory (NREL) Technical Report NREL/TP-5000-73629 titled Increasing Wind Turbine Tower Heights: Opportunities and Challenges, the following seems clear:

(1) Any new wind farm proposed in Champaign County in the next decade will likely have an overall WIND FARM TOWER HEIGHT between 591 feet (the same as the Sapphire Sky and Harvest Ridge wind farms) and 715 feet (assuming a rotor diameter of 156 meters and a hub height of not more than 140 meters).

(2) A height of 715 feet is achievable based on the typical limit of 4.3 meters width for tower base diameter (based on transportation requirements) and using conventional tubular steel tower technology.

(3) Adopting a maximum WIND FARM TOWER HEIGHT of less than 715 feet at this time would result in an artificial limit on WIND FARM development in Champaign County.

F. If the proposed no maximum WIND FARM TOWER HEIGHT is adopted, Champaign County would not be the only Illinois county to not have a maximum WIND FARM TOWER HEIGHT. At least six other Illinois counties (Boone, Fulton, LaSalle, Peoria, Woodford, and Vermilion) have no specific height limit for wind farm towers and Logan County limits wind farm tower height to 750 feet.

G. Adopting a no maximum WIND FARM TOWER HEIGHT is the same as the current Zoning Ordinance approach to tower height in general, in which there is no maximum tower height but any tower height over 100 feet must be approved by the Zoning Board of Appeals in a special use permit, the same kind of approval required for a WIND FARM.

H. Existing Zoning Ordinance Section 6.1.4D.1.b. requires each Zoning Use Permit Application for a WIND FARM TOWER to include a certification by an Illinois Professional Engineer or Illinois Licensed Structural Engineer that the foundation and tower design of the WIND FARM TOWER is within accepted professional standards given local soil and climate conditions. Safety of wind farm towers will always be an issue and will always be certified regardless of WIND FARM TOWER HEIGHT.

I. WIND FARM TOWER HEIGHT is not related directly to noise and Zoning Ordinance Section 6.1.4I. has limits for the allowable noise level from a WIND FARM. Adopting a no maximum WIND FARM TOWER HEIGHT will have no impact on the allowable WIND FARM noise level.

J. WIND FARM TOWER HEIGHT is directly related to shadow flicker and Zoning Ordinance Section 6.1.4M. has limits for the allowable shadow flicker. Adopting a no maximum WIND FARM TOWER HEIGHT will result in shadow flicker being controlled the same as it is today.

SUMMARY FINDING OF FACT

From the documents of record and the testimony and exhibits received at the public hearing conducted on **March 17, 2022, March 31, 2022, April 14, 2022, and May 26, 2022,** the Zoning Board of Appeals of Champaign County finds that:

1. The proposed Zoning Ordinance text amendment ***IS NECESSARY TO ACHIEVE*** the Land Resource Management Plan because:
   A. The proposed Zoning Ordinance text amendment will ***HELP ACHIEVE*** LRMP Goals 3, 4 and 6.

   B. The proposed Zoning Ordinance text amendment ***WILL NOT IMPEDE*** the achievement of LRMP Goals 1, 2 and 9.

   C. The proposed Zoning Ordinance text amendment is ***NOT RELEVANT*** to LRMP Goals 5, 7, 8 and 10.

2. The proposed text amendment ***WILL*** improve the Zoning Ordinance because it will:
   A. ***HELP ACHIEVE*** the purpose of the Zoning Ordinance (see Item 16).

   B. ***IMPROVE*** the text of the Zoning Ordinance (see Item 17).

DOCUMENTS OF RECORD

1. Legal advertisement for Case 037-AT-22

2. Preliminary Memorandum for Case 037-AT-22, with attachments:
   A Legal advertisement

   B ELUC Memorandum dated December 27, 2021
   - Exhibit A: Proposed Amendment dated December 27, 2021

   C Land Resource Management Plan (LRMP) Goals & Objectives
   (available on ZBA meetings website)

   D Preliminary Finding of Fact, Summary Finding of Fact, and Final Determination for Case 037-AT-22 dated March 17, 2022, with attachment:
   - Exhibit A: Proposed Amendment dated March 17, 2022

3. Emails received prior to March 17, 2022 ZBA meeting:
   A Received from Shannon Reel on March 16, 2022
   B Received from Jennifer Eisenmenger on March 16, 2022
   C Received from Benjamin Rice on March 17, 2022
   D Received from Heidi Leerkamp on March 17, 2022
   E Received from Justin Leerkamp on March 17, 2022
   F Received from David Happ on March 17, 2022
   G Received from Todd Horton on March 17, 2022
   H Received from Darrel & Regina Rice on March 17, 2022
   I Received from Donald Carter on March 17, 2022
   J Received from Cary and Pam Leerkamp on March 17, 2022
   K Received from Traci Bosch on March 17, 2022
   L Received from Brandon and Sarah Hastings on March 17, 2022
   M Received from Michelle & Scott Wiesbrook on March 17, 2022
   N Received from Lynn Rice on March 17, 2022
   O Received from Kim Decker on March 17, 2022
   P Received from Steven Herriott on March 17, 2022
   Q Received from Tiffany Byrne on March 17, 2022
   R Received from Adam Watson on March 17, 2022
   S Received from Natalie Thomas on March 17, 2022
   T Received from Jan Niccum on March 17, 2022
   U Received from Aaron Fenter on March 17, 2022
   V Received from Kate Boyer on March 17, 2022
   W Received from Stephen Smith on March 17, 2022
   X Received from Jennifer Miller on March 17, 2022

4. Exhibits received at ZBA meeting from Brian Armstrong, Attorney with Luetkehans, Brady, Garner & Armstrong LLC:
   1 Wind Turbine Noise & Health Study: Summary of Results
   2 Health Effects from Wind Turbine Low Frequency Noise & Infrasound
   3 A Review of an Acoustic Testing Program of Cape Bridgewater Wind Farm
   4 McLean County ZBA meeting transcript from January 24, 2018

5 A Cooperative Measurement Survey and Analysis of Low Frequency and Infrasound at the Shirley Wind Farm in Brown County, Wisconsin
6 Proposed Minimum Siting Distances for Livingston County Wind Farms
7 Alta Farm Wind Project II, LLC, DeWitt County, Illinois, Property Value Impact Analysis
8 Wind Turbine Noise: Effects on Human Health presentation at Christian County ZBA, June 23, 2020

5. Email received from Mick & Mary Schumacher on March 18, 2022

6. Supplemental Memorandum #1 dated March 23, 2022, with attachments:
A Legal advertisement for Case 037-AT-22 dated March 2, 2022
B Email from Mick & Mary Schumacher received March 18, 2022
C Revised Finding of Fact, Summary Finding of Fact, and Final Determination for Case 037-AT-22 dated March 31, 2022, with attachment:
- Exhibit A: Proposed Amendment dated March 17, 2022

7. Emails received prior to March 31, 2022 ZBA meeting:
A Received from Ted Hartke on March 29, 2022, with attachment: presentation
B Received from Donald Carter on March 29, 2022
C Received from Michael Mooney on March 29, 2022
D Received from Gary Place on March 29, 2022
E Received from Shannon Reel on March 30, 2022
F Received from Shannon Reel on March 30, 2022, with attachment: Douglas County Highway Department press release on road repairs/construction
G Received from Drs. Andrew and Shannon Miller on March 30, 2022
H Received from Darrel Rice on March 30, 2022
I Received from Justin Leerkamp on March 31, 2022
J Received from Todd and Sharon Herbert on March 31, 2022
K Received from Michelle and Scott Wiesbrook on March 31, 2022
L Received from David Happ on March 31, 2022
M Received from Tiffany Byrne on March 31, 2022
N Received from Brandon and Sarah Hastings on March 31, 2022
O Received from Dave and Traci Bosch on March 31, 2022
P Received from Stephen Smith on March 31, 2022
Q Received from Doug Downs on March 31, 2022
R Received from Kris Petersen on March 31, 2022
S Received from Mike Lockwood on March 31, 2022

8. Email received from Heidi Leerkamp on April 1, 2022

9. Email received from Kim Decker on April 12, 2022 with attachment: list of setbacks

10. Email received from Matthew Herriott on April 14, 2022

11. Handouts regarding property appraisals received from Steve Littlefield at April 14, 2022 ZBA meeting

12. The National Renewable Energy Laboratory (NREL) Technical Report NREL/TP-5000-73629 titled *Increasing Wind Turbine Tower Heights: Opportunities and Challenges* dated May 2019

13. Email from Ted Hartke received May 2, 2022, with attachments:
    - A Schomer testimony regarding Highland Wind Farm LLC application
    - B Article: *Big Wind Needs to Address Wind Turbine Syndrome*
    - C Article: *The Noise from Wind Turbines: Potential Adverse Impacts on Children's Well-being*
    - D Letter from Bill Mulvaney, Armstrong School Superintendent

14 Supplemental Memorandum #2 dated May 17, 2022, with attachments:
    - A Legal advertisement for Case 037-AT-22 dated March 2, 2022
    - B Submittals from Ted Hartke received May 2, 2022:
        - Schomer testimony regarding Highland Wind Farm LLC application
        - Article: *Big Wind Needs to Address Wind Turbine Syndrome*
        - Article: *The Noise from Wind Turbines: Potential Adverse Impacts on Children's Well-being*
        - Letter from Bill Mulvaney, Armstrong School Superintendent
    - C Handouts from Mary King at the May 5, 2022 ELUC meeting:
        - Article: *Enjoying a Windfall*
        - Article: *Latest Research on Wind Turbine Health Impacts Brings Unsurprising Results*
        - Article: *The link between health complaints and wind turbines: support for the nocebo expectations hypothesis*
    - D The National Renewable Energy Laboratory (NREL) Technical Report NREL/TP-5000-73629 titled *Increasing Wind Turbine Tower Heights: Opportunities and Challenges* dated May 2019
    - E Revised Finding of Fact, Summary Finding of Fact, and Final Determination for Case 037-AT-22 dated May 26, 2022, with attachment:
        - Exhibit A: Proposed Amendment dated March 17, 2022

FINAL DETERMINATION

Pursuant to the authority granted by Section 9.2 of the Champaign County Zoning Ordinance, the Zoning Board of Appeals of Champaign County recommends that:

The Zoning Ordinance Amendment requested in **Case 037-AT-22** should ***{BE ENACTED / NOT BE ENACTED}*** by the County Board in the form attached hereto.

The foregoing is an accurate and complete record of the Findings and Determination of the Zoning Board of Appeals of Champaign County.

SIGNED:

Ryan Elwell, Chair
Champaign County Zoning Board of Appeals

ATTEST:

Secretary to the Zoning Board of Appeals

Date

PROPOSED AMENDMENT DATED MARCH 17, 2022

Original proposed amendment
Revisions as of May 17, 2022

1. Regarding Right to Farm Resolution 3425, add new paragraph 6.1.4 A.3. as follows:

3. The owners of the subject property and the Applicant, its successors in interest, and all parties to the decommissioning plan and site reclamation plan hereby recognize and provide for the right of agricultural activities to continue on adjacent land consistent with the Right to Farm Resolution 3425.

2. Regarding WIND FARM TOWER height, amend Sections 6.1.4 C and D as follows:

A. Amend 6.1.4C. 1. and 2. as follows:

1. ~~At least 1,000 feet~~ The minimum required separation from the exterior above-ground base of a WIND FARM TOWER to any PARTICIPATING DWELLING OR PRINCIPAL BUILDING shall be no less than 2.00 times the maximum allowed total WIND FARM TOWER HEIGHT but not less than 1,000 feet provided that the noise level caused by the WIND FARM at the particular building complies with the applicable Illinois Pollution Control Board regulations.

2. ~~At least 1,200 feet~~ The minimum required separation from the exterior above-ground base of a WIND FARM TOWER to any existing NON-PARTICIPATING DWELLING OR PRINCIPAL BUILDING shall be no less than 2.40 times the maximum allowed total WIND FARM TOWER HEIGHT but not less than 1,200 feet provided that the noise level caused by the WIND FARM at the particular building complies with the applicable Illinois Pollution Control Board regulations and provided that the separation distance meets or exceeds any separation recommendations of the manufacturer of the wind turbine used on the WIND FARM TOWER.

B. Amend 6.1.4 D.5. as follows:

5. The total WIND FARM TOWER HEIGHT (measured to the tip of the highest rotor blade) ~~must be less than 500 feet~~ shall be the specified in the application. A total WIND FARM TOWER HEIGHT of 500 feet or greater shall conform to all Federal Aviation Administration (FAA) requirements including an FAA Determination of No Hazard with or without Conditions.

3. Regarding Aircraft Detection Lighting Systems (ADLS), revise paragraph 6.1.4D.7. as follows:

The WIND FARM shall comply with all applicable Federal Aviation Administration (FAA) requirements which shall be explained in the application. The minimum lighting requirement of the FAA shall not be exceeded except that all WIND FARM TOWERS are required to use ADLS (aircraft detection lighting system) or equivalent system to reduce the impact of nighttime lighting on nearby residents, communities and migratory birds in accordance with the FAA Advisory circular: 70/7460-IL section 14.1. ~~shall be lighted and unless otherwise required by the FAA only red flashing lights shall be used at night and only the minimum number of such lights with the minimum intensity and the minimum number of flashes per minute (longest duration between flashes) allowed by FAA."~~

4. Regarding the Agricultural Impact Mitigation Agreement, revise Section 6.1.4 as follows:

A. Add new Section 6.1.4R: Agricultural Impact Mitigation Agreement with the Illinois Department of Agriculture as follows, and re-letter subsequent sections:

(1) If provided by state law, the Applicant shall enter into an Agricultural Impact Mitigation Agreement with the Illinois Department of Agriculture.

(2) The Applicant shall bear full responsibility for coordinating any special conditions required in the SPECIAL USE Permit in order to ensure compliance with the signed Agricultural Impact Mitigation Agreement with the Illinois Department of Agriculture.

(3) All requirements of the signed Agricultural Impact Mitigation Agreement with the Illinois Department of Agriculture shall become requirements of the COUNTY Board SPECIAL USE Permit.

(4) Champaign County shall have the right to enforce all requirements of the signed Agricultural Impact Mitigation Agreement with the Illinois Department of Agriculture.

B. Add new paragraph 6.1.4A.4. as follows:
All aboveground STRUCTURES and facilities shall be of a type and shall be located in a manner that is consistent with the Agricultural Impact Mitigation Agreement with the Illinois Department of Agriculture as required by paragraph 6.1.4R.

C. Revise 6.1.4E.1. as follows:
All underground wiring or cabling for the WIND FARM shall be at a minimum depth of 4 feet below grade or deeper if required to maintain a minimum one foot of clearance between the wire or cable and any agricultural drainage tile or a lesser depth if so authorized by the Agricultural Impact Mitigation Agreement with the Illinois Department of Agriculture as required by paragraph 6.1.4R.

D. Revise paragraph 6.1.4E.2.h. as follows:
Permanent tile repairs shall be made within 14 days of the tile damage provided that weather and soil conditions are suitable or a temporary tile repair shall be made. Immediate temporary repair shall also be required if water is flowing through any damaged tile line. Temporary repairs are not needed if the tile lines are dry and water is not flowing in the tile provided the permanent repairs can be made within 14 days of the damage. All permanent and temporary tile repairs shall be made as detailed in the Agricultural Impact Mitigation Agreement with the Illinois Department of Agriculture as required by paragraph 6.1.4R. and shall not be waived or modified except as authorized in the SPECIAL USE Permit.

E. Revise paragraph 6.1.4E.3. as follows:
All soil conservation practices (such as terraces, grassed waterways, etc.) that are damaged by WIND FARM construction and/or decommissioning shall be restored by the applicant to the pre-WIND FARM construction condition in a manner consistent with the

Agricultural Impact Mitigation Agreement with the Illinois Department of Agriculture as required by paragraph 6.1.4R.

F. Add new paragraph 6.1.4E.4.e. as follows:
All topsoil shall be placed in a manner consistent with the Agricultural Impact Mitigation Agreement with the Illinois Department of Agriculture as required by paragraph 6.1.4R.

G. Add new paragraph 6.1.4E.5.c. as follows:
All mitigation of soil compaction and rutting shall be consistent with the Agricultural Impact Mitigation Agreement with the Illinois Department of Agriculture as required by paragraph 6.1.4R.

H. Add new paragraph 6.1.4E.6.c. as follows:
All land leveling shall be consistent with the Agricultural Impact Mitigation Agreement with the Illinois Department of Agriculture as required by paragraph 6.1.4R.

I. Add new paragraph 6.1.4P.4.g. as follows:
Any financial assurance required per the Agricultural Impact Mitigation Agreement with the Illinois Department of Agriculture as required by paragraph 6.1.4R. shall count towards the total financial assurance required for compliance with paragraph 6.1.1A.5.

J. Add new paragraph 6.1.4S.1.d. as follows and re-letter subsequent paragraphs:
The Applicant shall include a copy of the signed Agricultural Impact Mitigation Agreement with the Illinois Department of Agriculture with the Zoning Use Permit Application to authorize construction.

5. Regarding WIND FARM fees, revise Section 9 as follows:

A. Revise paragraph 9.3.1H. as follows:
WIND FARM TOWER or BIG WIND TURBINE TOWER…………$~~4,500~~10,000

B. Revise paragraph 9.3.3B.6. as follows:
County Board WIND FARM SPECIAL USE Permit ………………………$~~20,000~~34,000 or $~~440~~760 per WIND FARM TURBINE TOWER, whichever is greater