Subcontractor Report

October 2002 • NREL/SR-500-29493A

Addendum to WindPACT Turbine Design Scaling Studies Technical Area 3 – Self-Erecting Tower and Nacelle Feasibility

March 2000—March 2001

Global Energy Concepts, LLC
Kirkland, Washington

National Renewable Energy Laboratory

1617 Cole Boulevard
Golden, Colorado 80401-3393

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NREL Technical Monitor: A. Laxson

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Introduction

Global Energy Concepts (GEC) conducted the turbine design scaling study on self-erecting towers[1] for the U.S. Department of Energy's Wind Partnerships for Advanced Component Technologies (WindPACT). This study included an extensive survey and analysis of self-erecting tower techniques, including an analysis of the potential reductions in the cost of energy (COE) resulting from taller towers. The COE calculation methodology used in the study incorporated a simplified approach to the annual energy yield calculation by assuming that a given percentage increase in wind speed would result in twice as large a percentage increase in annual energy. Recently completed work identified this as an oversimplification for modern equipment and higher wind speeds. This report presents a revised analysis using a more accurate modeling of the relationship between wind speed and energy production in order to more accurately define the potential cost of energy reductions available from taller towers.

Method

The spreadsheet model used in the original study estimated the COE from a 1.5-MW wind turbine installed on a 65-m tower with a hub-height wind speed of 8.0 m/s. This estimate was made using a simplified version of the Electric Power Research Institute Technical Advisory Group (EPRI-TAG) COE equation. The weight, cost, and performance characteristics of this turbine were estimated based on industry information. The model was then revised to permit scaling of the relevant parameters for a second tower height. The following key assumptions were applied to the scaling analysis[2]:

1. Tower cost scales are in proportion to tower mass.
2. Tower mass scales with height raised to the 1.67 power.
3. Wind speeds for higher hub heights vary with the power law exponent alpha.
4. Percent increase in energy production is twice the percent increase in wind speed.
5. Foundation costs scale linearly with tower height, assuming foundation scales with overturning moment.
6. Operation and maintenance (O&M) costs are a constant $0.008/kWh.
7. Conventional-crane costs are proportional to the tower height ratio raised to the 1.6 power.
8. Self-erection costs will be proportional to tower height.

Recent work by GEC indicates that Assumption 4 oversimplifies the relationship between wind speed and energy output and results in overestimating the benefits of self-erecting towers. To address this concern, a relationship was derived between annual energy production and wind speed based on a measured power curve and typical wind speed distribution. Assuming that the annual wind speeds roughly form a Rayleigh distribution,

[1] Global Energy Concepts, LLC. (2001) *WindPACT Turbine Design Scaling Studies Technical Area 3 -- Self-Erecting Tower and Nacelle Feasibility: March 2000 - March 2001*. 72 pp.; NICH Report No. SR-500-29493.
[2] Ibid. p 45.

a range of possible distributions with different mean wind speeds was developed. A sea-level power curve for a 1.5-MW, 70.5-m diameter turbine was then used to calculate the annual energy production for each of the different mean wind speeds. Figure 1 shows the results of this analysis, with a trend line and equation for the relationship between energy production and mean wind speed for any mean wind speed in the range.

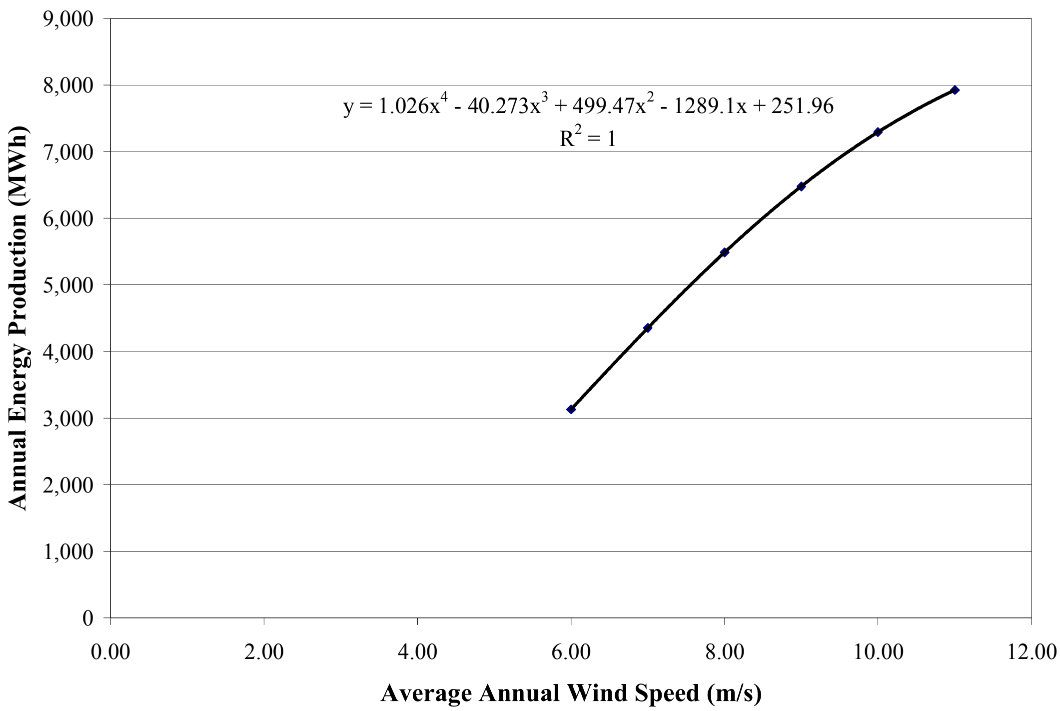

Figure 1. Annual energy production as a function of mean wind speed for a GE 1.5-MW/70.5-m turbine.

This method of calculating annual energy production directly from wind speed distributions and power curves more accurately characterizes the relationship between annual energy production and mean wind speed. For low annual wind speeds of 6.0-7.5 m/s, energy yield does increase at twice the rate that wind speed increases as assumed in the original study. However, this relationship no longer applies above mean wind speeds of 7.5 m/s. Table 1 shows how increases in energy vary for given increases in wind speed at some higher mean wind speeds. Note that this analysis assumes that the rating of the turbine remains the same for all hub heights. Increasing the rating of the turbine would increase energy production but would also increase system costs. The tradeoffs associated with changing the rating were not examined as part of this study.

Table 1. Increases in Annual Energy Production (AEP) with Respect to Increases in Wind Speed, Using a Reference of 5,448 MWh/Year at 8 m/s

Wind Speed (m/s)	8.0	8.25	8.5	8.75	9.0
Wind Speed Increase (%) from 8 m/s Reference	0%	3%	6%	9%	13%
AEP (MWh)	5,488	5,751	6,004	6,247	6,479
AEP Increase (%) from 5,448 MWh Reference	0%	5%	9%	14%	18%
Increase in Energy/ Increase in Wind Speed	0.0	1.534	1.504	1.475	1.445

Figure 2 shows the results of the COE analysis using the new wind-speed-to-energy relationship. This analysis shows a maximum COE reduction of 5% resulting from height increases in a wind shear regime with alpha = 0.30. This occurs around 100 m. This COE reduction is significantly less than the 12% decrease estimated in the original study.

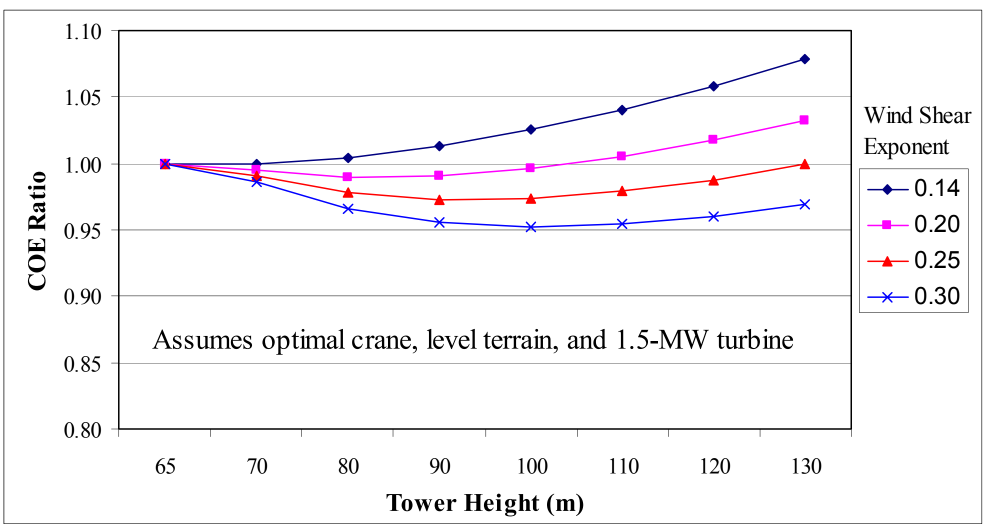

Figure 2. Change in cost of energy as a function of tower height and wind shear, as compared to a baseline turbine at 65 m with 8 m/s wind speed.

The relative benefits of taller towers will increase at low wind sites. As shown in Figure 3, reducing the 65-m annual average wind speed from 8.0 m/s to 7.5 m/s increases the estimated reduction in COE from 5% to 6.5% and the optimal tower height to 110 m.

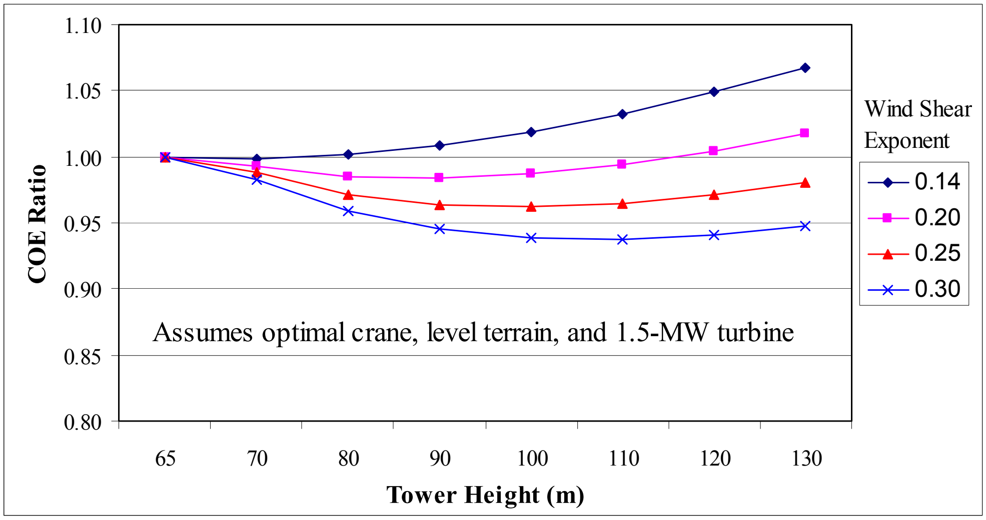

Figure 3. Change in cost of energy (COE) as a function of tower height and wind shear, as compared to a baseline turbine at 65 m with 7.5 m/s wind speed.

As discussed in the original study, additional benefits are realized for self-erecting towers in complex terrain. Large cranes can require substantial disassembly before moving from site to site in complex terrain. Figure 4 presents the COE ratio as a function of the tower height and terrain complexity, assuming a wind shear exponent of 0.2. The figure shows how COE varies with the number of turbines that can be erected before crane disassembly is required. It shows that for complex terrain sites, self-erecting towers are needed to attain the same cost of energy achieved in benign terrain.

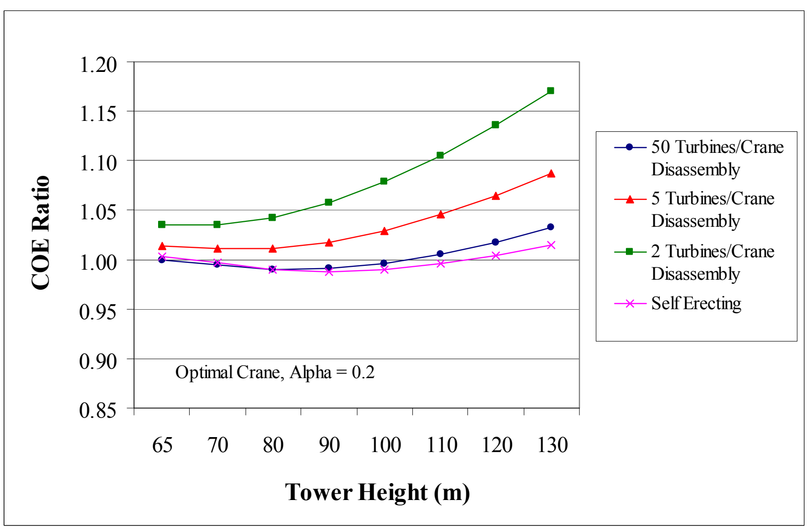

Figure 4. Cost of energy as a function of tower height and terrain roughness.

The benefits of tall towers would be more significant for higher shear values, but this condition is generally less representative of typical complex terrain sites.

Conclusion

The original study overstates the COE reduction possible from self-erecting towers, assuming constant operations and maintenance costs. However, the work presented in this report shows that self-erecting towers do offer a COE advantage, particularly in complex terrain. In addition, self-erecting towers will reduce the cost and risk associated with failure of major components in large turbines. Although this analysis assumed constant operations and maintence costs, the operations and maintenance cost benefits from self-erecting towers could be significant and should be more fully understood.

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