PO. 060

Larger Turbines and the Future Cost of Wind Energy

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Presented at the European Wind Energy Association Annual Event, March 14-17, 2011, Brussels, Belgium

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Abstract

The move to larger turbines has been observed in the United States and around the world. Turbine scaling increases energy capture while reducing general project infrastructure costs and landscape impacts, each of which can reduce the cost of wind energy. However, scaling in the absence of innovation, can increase turbine costs. The ability of turbine designers and manufacturers to continue to scale turbines, while simultaneously reducing costs, is an important factor in long-term viability of the industry. This research seeks to better understand how technology innovation can allow the continued development of larger turbines on taller towers while also achieving lower cost of energy.

Modeling incremental technology improvements identified over the past decade demonstrates that cost reductions on the order of 10%, and capacity factor improvements on the order of 5% (for sites with annual mean wind speed of 7.25 m/s at 50m), are achievable for turbines up to 3.5 MW. However, to achieve a 10% cost reduction and a 10% capacity factor improvement for turbines up to 5 MW, additional technology innovations must be developed and implemented.

Objectives

Scaling to larger turbines has been an industry trend (Figures 1-3). This research assumes that continued scaling is desirable and advantageous for the industry. It evaluates an array of proposed technical innovations and quantifies their impact on hypothetical future turbines conceptualized to achieve performance targets identified in the literature. It compares the impact of these proposed innovations on turbine costs with the cost projections articulated in the 2008 U.S. DOE report, *20% Wind Energy by 2030.*

Project Goals: (1) Identify and model the impact of technology innovations that are both incremental and widely recognized as viable technological improvements on turbines that scale gradually to 5.0 MW, (2) evaluate whether future cost and capacity factor projections in the DOE (2008) report, *20% Wind Energy by 2030,* are compatible with industry trends towards larger rotors, taller hub heights, larger capacity ratings, (3) identify the turbine systems most likely to support cost reductions as the industry scales

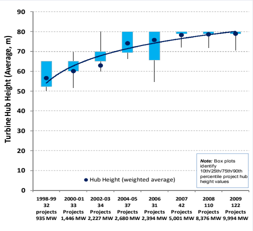

Figure 1. Trends in Hub Height in the U.S.

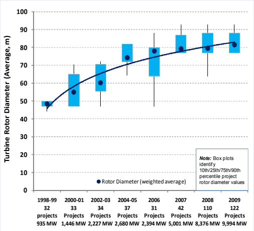

Figure 2. Trends in Rotor Diameter in the U.S.

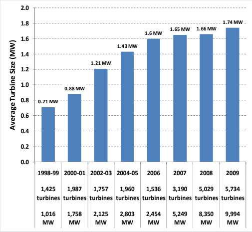

Figure 3. Trends Turbine Capacity in the U.S.

Methods

We first conceptualized future turbines that scale to 2.5 MW, 3.5 MW, and 5.0 MW and increase capacity factors gradually from 39% to 43% (capacity factors estimates assume a Class 4 wind regime, 7.25m/s at 50m). This task was carried out using NREL's Wind Turbine Design Cost and Scaling model (Fingersh et al. 2006). This model allows basic optimization in developing general turbine parameters (e.g., hub height and rotor diameter) and generates turbine cost and performance estimates. Two sets of innovation opportunities, *expected technology* and *best technology* were also developed. Both scenarios rely on the same basic set of technology changes, which originally emerged from the U.S. DOE Wind Partnership for Advanced Technology Components (WindPACT) (e.g., Bywaters et al. 2005, Malcolm and Hansen 2002, Cohen et al. 2008) and are summarized in Table 2. "Expected technology" indicates that a specific technology is likely to be widely adopted in the future. "Best technology" is indicative of the maximum beneficial impact from a given technology change, as determined by Cohen et al. (2008). One additional scenario was included that assumes future turbines could be built with today's blade and drivetrain mass ratios (i.e., kg/m^2 and kg/kW, respectively). Changes in some parameters (e.g., reduced losses) resulted in increased energy capture. As a result, turbines modeled in the expected and best technology scenarios were scaled down so as not to exceed the explicit capacity factor targets. Basic design features of the conceptual turbines used in each scenario are shown in Figure 4 and Table 1. The general scope of technology change captured in this analysis is described in Table 2. Table 3 summarizes other modeling inputs used in this analysis.

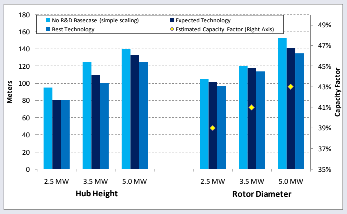

Figure 4. Conceptual Future Turbines Scaled to 5.0 MW and Designed to increase Class 4 Capacity Factors 10%

Table 1. Drivetrain Designs Employed in the Conceptual Turbines Developed for this Study

	2.5 MW	3.5 MW	5.0 MW
No R&D Base Case	3-stage geared		
Expected Technology	multi-generator	single-stage geared	direct drive
Best Technology			

For major turbine components (blades, towers, drivetrain), advanced technology impacts were captured with advanced technology scaling functions (Fingersh et al. 2006). These advanced technology functions were based on empirical data for technology in prototype form today or conceptual designs developed in the WindPACT studies. Because current data do not allow for the ability to calculate multiple advanced technology scaling curves, the impact of technology change in blades, towers, and drivetrains is equivalent for the expected and best technology scenarios (Figure 5).

Table 2. Technology Concepts Captured by This Analysis

Cost Reducing Innovations	Technology Concepts	Input Data Source
Blade Technology	•Enhanced structural design, targeted reinforcement •High tech composites possibly including carbon fiber	Cost and Scaling Model Advanced Technology Scaling Curves
Tower Technology	•Tower feedback to blade pitch controls •Flap-twist coupling in blade design •Reduced blade chord with tip speed increase	
Drivetrain Technology	•Multi-generator drive path •Single-stage, medium speed gearbox •Direct drive	
Manufacturing efficiency	•Increased automation •Improved resins with greater ease of use •Reduced design margins resulting from more consistent fabrication •Reduced profit margins as a result of increased volume	Cohen et al. 2008 (WindPACT)
Power electronics	•High voltage circuitry •Multi-switch capacity •Semi-conductor devices	
AEP Innovations		
Reduced losses	•Improved micro-siting to reduce array losses •Real-time monitoring and operational modifications •Low soil blades	Industry estimates
Power electronics (higher efficiency)	•High voltage circuit topologies •Multi-switch capacity	Cohen et al. 2008

Table 3. Operating Conditions and Parameters

Operating Wind Class 4 (m/s @50 m)	7.25
Weibull K Factor	2
Base Wind Shear	0.143
Air Density	1225 kg/m^3
Max Rotor Cp	0.47
Max Combined Drivetrain Efficiency	90.2%
Max tip speed	70 m/s
Max tip speed ratio	7.25
Availability	98%

For other indirect cost drivers including manufacturing improvements, reduced siting and array losses, and power electronics efficiency, estimates emerged from WindPACT study data, as summarized in Cohen et al. (2008), and from industry estimates to develop both expected and best technology modeling inputs.

Results

The effect of the advanced technology inputs on specific parameters is represented in Figure 5. Actual impacts varied depending on the turbine size (i.e., 2.5 MW or 5.0 MW). Where direct comparisons can be made, these results are shown along with the estimates from Cohen et al. (2008). Error bars represent the range of impact, or in the case of the Cohen et al. (2008) data, estimates of the expected range of potential impact.

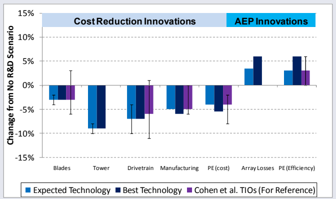

Figure 5. Resulting Impact from Advanced Technology Inputs

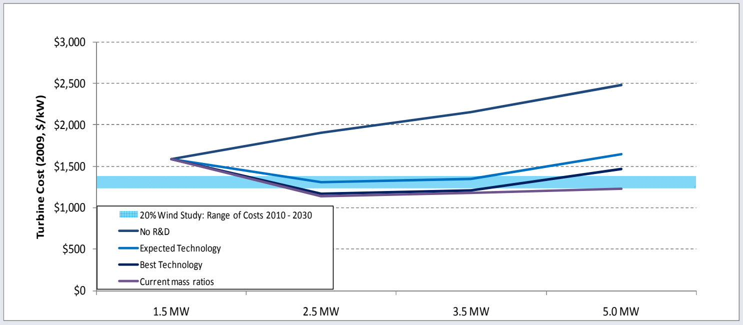

Figure 6. Results Summary Across All Scenarios.

Results (Figure 6) show that without technology advancement, continued scaling will be halted by excessive costs. However, with incremental changes in technology, turbines up to 3.5 MW are expected to achieve both performance increases and lower costs. For 5.0 MW turbines, incremental technology improvements will reduce costs. However, to see continued turbine cost reductions and capacity factors on the order of 43% (for a mean annual wind speed of 7.25 m/s at 50m), additional innovations will be required.

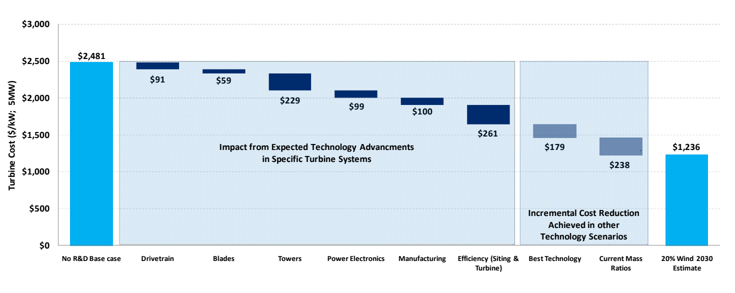

Figure 7. Sources of Cost Reduction for a Conceptual 5 MW Wind Turbine

The impact of technological advancements in various turbine component areas along with the incremental value of the best technology scenario and additional innovations that allow for today's nacelle (kg/kW) and rotor (kg/m^2)mass ratios to be achieved with larger future turbines are shown in Figure 7. Examining the results by impacts from specific turbine component areas shows that implementation of advanced technology across turbine systems is important for continued scaling. Improvements in drivetrains, advanced tower designs, and reductions in array and other turbine losses are especially critical.

Conclusions

Although this research emphasizes incremental technology change, and focuses on a relatively conservative set of proposed technology advancements, it demonstrates that lower turbine costs ($/kW) and increased performance are possible as the industry moves to larger turbines. In addition, when focusing on technology impacts to cost, projections of modest cost declines are realizable. Should more significant technology developments or emerging technology innovations gain traction, additional cost reductions and performance increases are possible. Moreover, balance of plant cost reductions and reduced industry impacts to landscape may be achieved through a move to larger capacity turbines, which may offer additional cost of energy savings.

These cost reductions should not be interpreted as automatic. Innovation across turbine systems is required to realize the level of cost reduction discussed here. Significant research and field testing is necessary to move even the most basic new concepts from the design phase towards widespread acceptance by manufacturers and investors. In addition, if manufacturers have already begun to adopt a subset of the innovations captured here, or if any single innovation is ultimately not realizable, additional technology advancements are likely to be necessary to achieve future cost, performance, and scaling objectives.

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