Wind Energy Technology Trends: Comparing and Contrasting Recent Cost and Performance Forecasts

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Introduction

Forecasts of wind energy costs generally assume that technology development and learning will result in reduced costs over time. Such assumptions are critical to the policy and planning process. However, forecasting potential cost reductions often relies on theoretical concepts or learning curve trends rather than the potential of specific technological advancements.

This work considers the impact of simply scaling to larger and taller turbines and compares this cost trajectory with prior cost projections. It briefly considers the impacts that potential R&D improvements might have on simple scaling of today's technology. It also demonstrates the value in terms of cost of energy (COE) from recent scaling trends and compares this with the implications of continued scaling without technology advances.

Figure 1. The Siemens SWT-2.3-101 prototype shown here at NREL's National Wind Technology Center illustrates current trends towards larger machines with larger rotors. These designs increase energy capture but questions remain regarding the cost effectiveness of continuing to scale turbines. PIX #17118.

Objectives

The purpose of this work is to begin to understand the capacity of the industry to meet cost and performance projections like those established in the report *20% Wind Energy by 2030* (U.S. DOE 2008) and to consider the implications that current trajectories have for R&D efforts. This work is conducted with four primary goals in mind.

Project Goals:

1. Determine the cost impact (focusing on installed cost), and energy capture impacts of simply scaling current wind turbine technology.
2. Compare cost and performance impacts from scaling modern technology with the cost and performance targets established in the DOE report *20% Wind Energy by 2030* (U.S. DOE 2008).
3. Consider the impact that potential technology improvements might have on basic scaling trends.
4. Demonstrate the value of recent turbine scaling trends observed in the market relative to continued scaling in the absence of technological advancements.

Methods

NREL's Wind Turbine Design Cost and Scaling model (Fingersh et al. 2006) was used to evaluate the cost and performance impacts of scaling existing wind turbine technology. Turbines were scaled to meet the capacity factor performance values established in the 20% Wind Report (U.S. DOE 2008). Turbine size was assumed to grow over time up to a maximum 5 MW rated capacity, 153 meter rotor diameter, and a 140 meter tower height (Table 1). Specific future designs are not prescriptive but are intended as possible future technology examples. Table 2 summarizes the relevant model inputs and operating conditions. In order to strictly evaluate the impacts of scaling modern technology, all performance parameters were held constant (Table 2).

By calculating the change in turbine capital cost (TCC), balance of station (BOS) cost, and annual energy production (AEP) from the 20% Wind Report's year 2010 cost and performance values (U.S. DOE 2008), modeled cost and performance outputs were compared with the forecasts in the 20% Wind Report (Figures 2-4).

Modeling outputs were also compared with technology improvement opportunities outlined in Cohen et al. (2008)(Figure 5). Potential changes to AEP, TCC, and BOS are calculated from the Cohen et al. (2008) 2002 reference turbine (Table 1) after adjusting the reference to account for the time value of money and for minor deviations between the reference turbine's performance assumptions and the performance assumptions used to carry out the evaluation of scaling impacts. For example, adjustments to the Cohen et al. (2008) reference were made to overall drivetrain efficiency and array losses based on improved understanding of the performance of modern turbines and projects. By calculating the percent change from the Cohen et al. (2008) reference turbine, it was possible to compare the modeled results with the estimated value of specific potential technology improvements outlined in the same report (Figure 5).

Table 1. Turbine Design Parameters

	2002	2010	2015	2020	2030
Machine Rating (kW)	1500	1500	2500	3500	5000
Rotor Diameter (m)	70	77	105	125	153
Hub Height (m)	65	80	100	120	140

To evaluate the impact of current scaling trends on COE, the Turbine Design Cost and Scaling model's basic COE calculation was used (Fingersh et al. 2006)(Figure 6). Changes in COE were calculated from the adjusted 2002 reference noted above. Changes in net revenue were also relative to the 2002 reference. Net revenue is approximated by multiplying AEP, adjusted for project size, (10 MW in this analysis), by an assumed gross revenue of $85/MWh. Next, project AEP is multiplied by the COE estimated from the model results. The difference between the two products is calculated to determine net revenue.

Table 2. Operating Conditions and Performance 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
Losses (array and soiling)	15%
Availability	98%

Background photo PIX #16805.

Results

Cost and Performance Data

Figures 2-4 show the change in AEP, TCC, and BOS from the year 2010 value as outlined in the 20% Wind Report (U.S. DOE 2008). These figures also illustrate cost impacts of simply scaling turbines to meet the energy capture goals established in the 20% Wind Report.

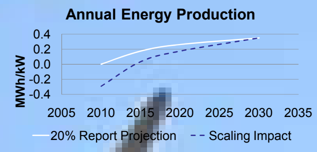


Figure 2. Changes in AEP relative to the 20% Wind Report's 2010 value of 3.4 MWh/kW (39% capacity factor in a class 4 wind regime).

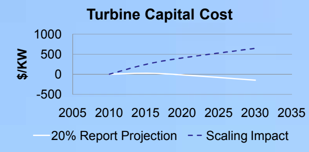


Figure 3. Changes in TCC relative to the 20% Wind Report's 2010 value of $1230/kW (2008$ assumes TCC is 73% of installed cost).

With today's turbine scaling relationships, increased rotor size and hub height can achieve energy capture targets but at much greater costs than predicted in the 20% Wind Report.

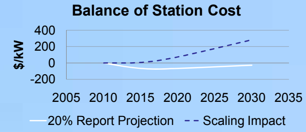
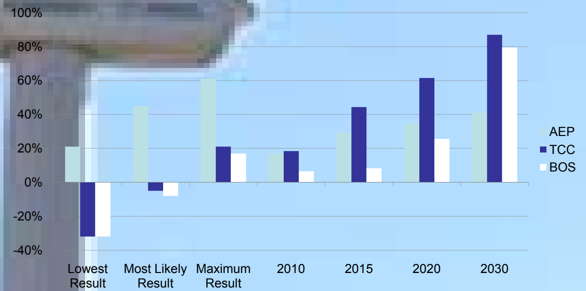


Figure 4. Changes in BOS cost relative to the 20% Wind Report's 2010 value, of $460/kW (2008$, assumes BOS is 27% installed cost).

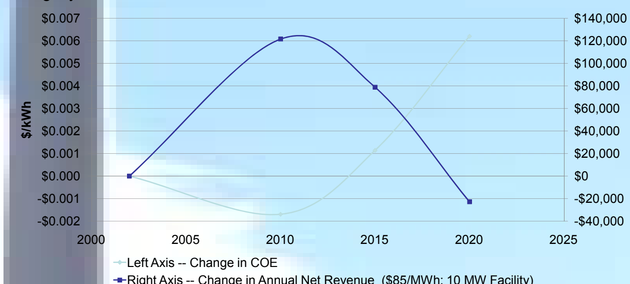
Figure 5 illustrates the magnitude of the challenge faced by wind energy R&D to meet both energy capture and cost goals. Cohen et al. (2008) estimated that future technology advancements could reduce installed costs by as much as 30%, but modeling based purely on scaling today's technology suggests installed cost could grow by as much as 80%.



While Cohen et al. (2008) suggest that improvements in AEP are achievable, doing so at a reduced cost appears to be a clear challenge.

Figure 5. Relative impacts from anticipated technology improvement opportunities (adapted from Cohen et al. 2008) compared with the impacts of simply scaling today's wind turbine technology.

However, Figure 6 suggests that through 2010 installed cost increases have been offset by increased energy capture such that the actual cost of energy production has remained flat or even declined slightly.



From a COE perspective, moderate capital cost increases associated with the current scaling trends are offset by increased energy capture.

Figure 6. Changes in cost of energy and net revenue as turbines scale; values are based on modeling of the turbines outlined in Table 1.

Conclusions

Historically, modest increases in installed cost have been offset by increased energy capture. Cohen et al. (2008) indicate that there may be room for a 50% increase in AEP above and beyond that forecast by the 20% Wind Report. In addition, various studies point to an array of technology improvement opportunities (Cohen et al. 2008, Bywaters et al. 2005, Malcolm and Hansen 2002) to reduce capital investment while increasing energy capture. Ultimately, however, engineering design and innovation will be required to continue scaling wind turbines cost-effectively. Future work will attempt to gain better insights into specific technological improvements that can be implemented to meet the ambitious cost reduction goals presented in the 20% Wind Report.

References:

Bywaters, G.; Salata, M; Labath, O; et al . (2005). Northern Power Systems WindPACT Drive Train Alternative Design Study Report. NREL/SR-500-35524. Golden, CO: National Renewable Energy Laboratory. http://www.nrel.gov/docs/fy05osti/35524.pdf Cohen et al. 2008

Cohen, J.; Schweizer, T.; Laxson, A.; Butterfield, S.; Schreck, S.; Fingersh, L.; Veers, P.; Ashwill, T. (2008). *Tehnology Improvement Opportunities for Low Wind Speed Turbines and Implications for Cost of Energy Reduction.* NREL/TP-500-41036. Golden, CO: National Renewable Energy Laboratory

Fingersh, L.; Hand, M.; Laxon, A. (2006). *Wind Turbine Design Cost and Scaling Model.* NREL/TP-500-40566. Golden, CO: National Renewable Energy Laboratory. http://www.nrel.gov/docs/fy07osti/40566.pdf

Malcom, D. and A. Hansen. (2002). WindPACT Turbine Rotor Design Study. NREL/SR-500-32495. Golden, CO: National Renewable Energy Laboratory. http://eduhosting.org/windpics/wgstudy.pdf

U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy. (2008). *20% Wind Energy by 2030: Increasing Wind Energy Contribution to the U.S. Electricity Supply.* DOE/GO-102008-2567

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