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Regional Field Verification — Operational Results from Four Small Wind Turbines in the Pacific Northwest

Preprint

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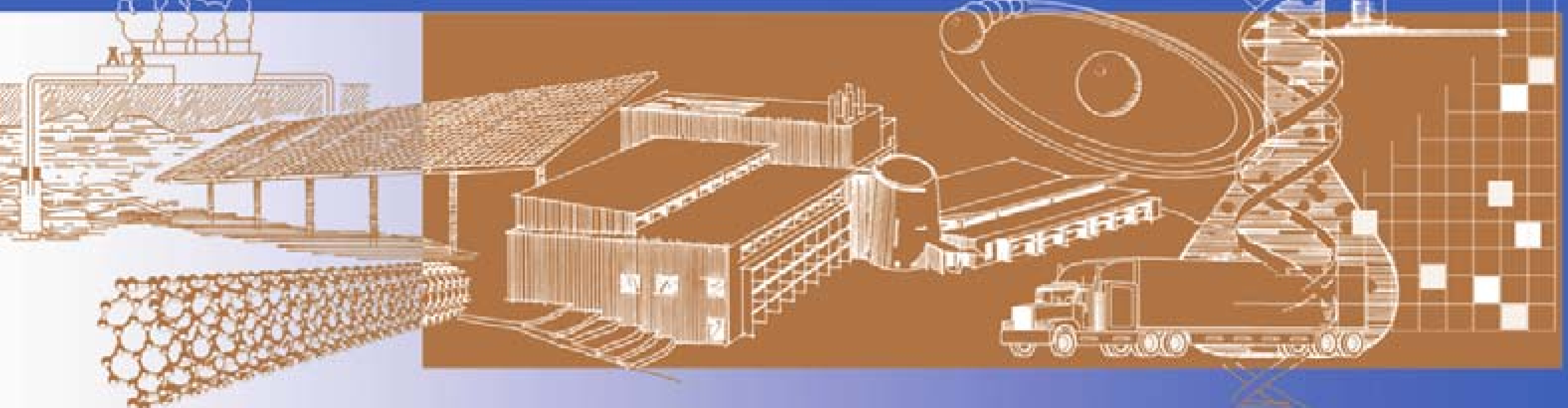
Presented at the American Wind Energy Association WindPower 2006
Pittsburgh, Pennsylvania
June 4–7, 2006

Conference Paper
NREL/CP-500-38110
August 2006

NREL is operated by Midwest Research Institute ● Battelle   Contract No. DE-AC36-99-GO10337



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Regional Field Verification - Operational Results from Four Small Wind Turbines in the Pacific Northwest

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Abstract

The purpose of the Department of Energy/National Renewable Energy Laboratory's (DOE/NREL) Regional Field Verification (RFV) project is to support industry needs for gaining initial field operation experience with small wind turbines and to verify the performance, reliability, maintainability, and cost of small wind turbines in diverse applications. In addition, RFV aims to help expand opportunities for wind energy in new regions of the United States by tailoring projects to meet unique regional requirements, and document and communicate the experience from these projects for the benefit of others in the wind power development community and rural utilities.

Under RFV, Bergey Excel S (10kW) wind turbines were installed at sites in the Pacific Northwest as part of Northwest Sustainable Energy for Economic Development's (NWSEED) Our Wind Cooperative. Each installation was instrumented with data acquisition systems to collect a minimum of two years of operating data.

The four turbines highlighted in this paper were installed between 2003 and 2004. At least two years of operational data have been collected from each of these sites by Northwest SEED. This paper describes DOE/NREL's RFV project and summarizes operational data from these sites.

Purpose

The purpose of this paper is to describe the Department of Energy/National Renewable Energy Laboratory's (DOE/NREL) Regional Field Verification (RFV) project and summarize the first two years of operation and performance data collected from four Bergey Excel S (10kW) turbines installed under this project. Data collection from a 5th turbine will be completed in Fall 2006.

In 2000, DOE/NREL issued a RFV project Request for Proposal (RFP). The purpose of the RFP was to solicit projects that would support industry needs for gaining initial field operation experience with small wind turbines, and verify the performance, reliability, maintainability, and cost of small wind turbines in diverse applications. The RFV project was also intended to help expand opportunities for wind energy in new regions of the United States by tailoring projects to meet unique regional requirements, and document and communicate the experience from these projects for the benefit of others in the wind power development community and rural utilities.

After reviewing proposals submitted in response to the RFP, NREL ultimately executed a subcontract with Northwest Cooperative Development Center (NWCDC). Under this subcontract, Bergey Excel S (10kW) wind turbines would be installed at a number of sites in the Pacific Northwest. Each installation was instrumented with data acquisition systems to collect a minimum of two years of operating data.

Northwest Sustainable Energy for Economic Development (NWSEED), a lower-tiered subcontractor for NWCDC, is responsible for the actual project installations and data collection/analysis. NWSEED has expanded this project, known as Our Wind Cooperative (OWC), partnering with numerous other organizations, including Bonneville Environmental Foundation (BEF), Last Mile Electric Cooperative (LMEC), United States Department of Agriculture (USDA), Bullitt Foundation, Climate Solutions, Renewable Northwest Project, host utilities, and others to assist with lowering the project cost to hosts and supporting outreach activities. For information on OWC, go to http://ourwind.org/windcoop/.

Host Sites

Four of the systems installed under the RFV subcontract are described in this paper[1]. They are all equipped with the same turbine system blades and connected to the utility grid. Three are located in Montana and one is located in Washington, as shown in Figure 1. The turbines were commissioned between December 2003 and October 2004 (Table 1). Because of the involvement of the Federal Government in this project, a National Environmental Policy Act (NEPA) determination from DOE was required. Ultimately, DOE determined a categorical exclusion B5.1 applied to each site.

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[1] For a detailed discussion of each site, refer to a paper presented at last year's Windpower conference: *Regional Field Verification - Case Study of Small Wind Turbines in the Pacific Northwest*, NREL/CP-500-38166. Presented at American Wind Energy Association Windpower 2005, Denver, CO, May 15-18, 2005. http://www.nrel.gov/docs/fy05osti/38166.pdf

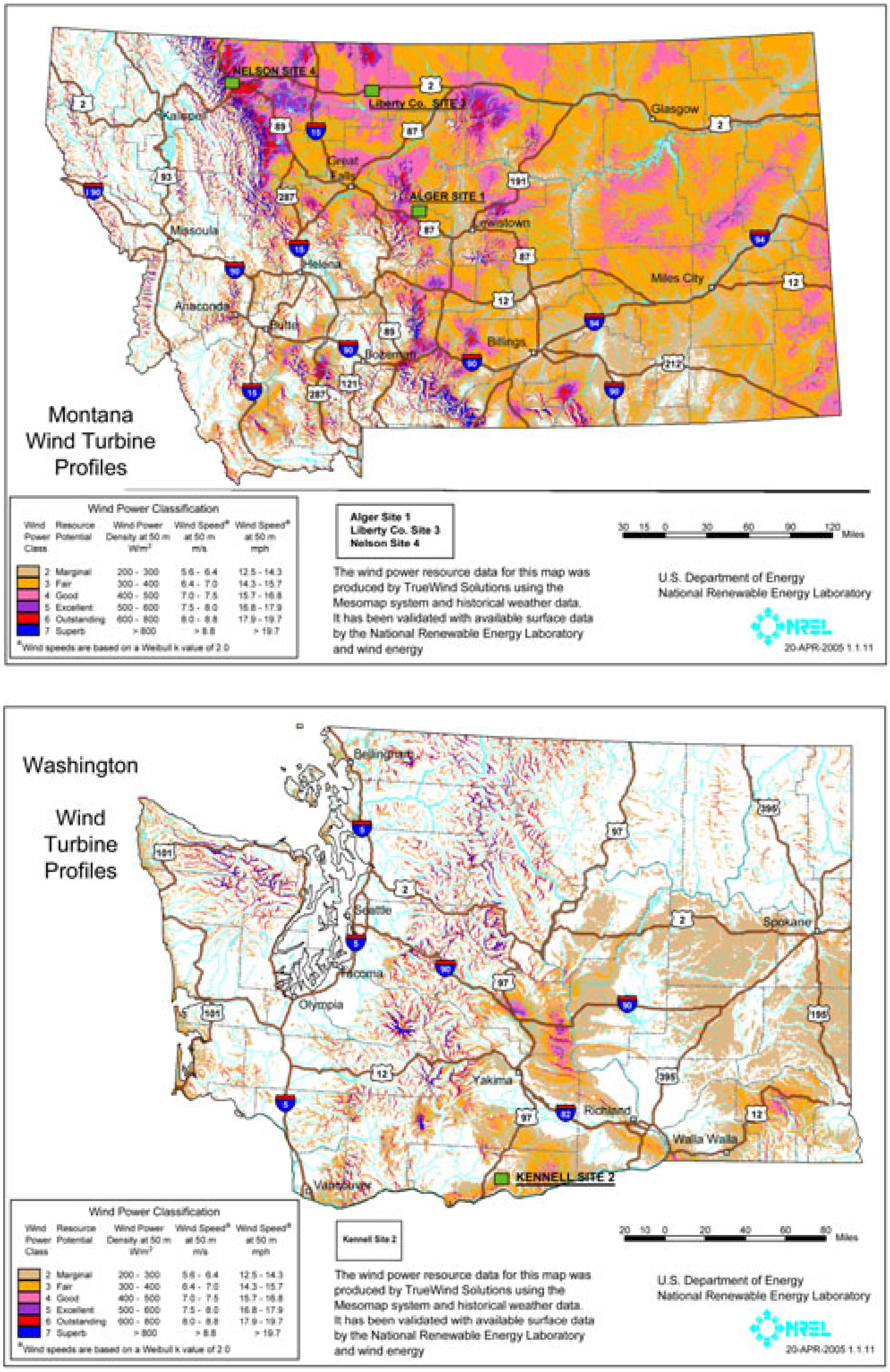

Figure 1. Location of four RFV host sites

Table 1. RFV Host Sites – Location and Commissioning Dates

Photo #	Host	Location	Lat/Long	Elevation	Tower Type	Assumed Wind Class[2]	Commission Date
1	Alger, Jess	Stanford, MT	47.265/ -110.234	1219 m	30 m guyed	3	10/2/2004
2	Kennell, Ed	Goldendale, WA	45.82/ -120.628	670 m	24 m guyed	3	12/29/2003
3	Liberty County	Chester, MT	48.51/ -110.995	969 m	24 m tilt up	3	2/24/2004
4	Nelson, Doug	Browning, MT	48.55/ -113.197	1474 m	18 m guyed	5	2/24/2004

Source: NWSEED

Wind Speed Data

Predicted and measured site-specific wind speeds, shown in Tables 2, 4, 6 & 8, have been normalized. Predicted wind speeds were taken from wind resource maps available for each state, modeled at site-specific hub heights. Each site's wind speed was measured at anemometer height (6 m below hub height) and adjusted to hub height.

The average wind speed was calculated by figuring the 10-minute mean data collected over a 2-year period. At all sites, the annual average data recovery was 80% or better. In all cases, actual measured wind speed was lower than the predicted wind speed. However, in three of the four cases, the measured wind speed was reasonably close to the predicted wind speed. Wind speed distributions (Figures 2, 4, 6, & 8) have been developed for each site.

Power Curves

Predicted power curves were developed for each site using the manufacturer provided spreadsheet. Each site was adjusted for elevation. Measured power curves, reflecting two years of data, were developed for each site (Figures 3, 5, 7, & 9).

Annual Energy Output

Annual Energy Output (AEO), also known as annual energy production, is presented based on three different scenarios (Tables 3, 5, 7, & 9). In each of the first two scenarios, the predicted production was calculated utilizing the manufacturer's power curve adjusted for the elevation at each site. The difference between these estimates is that the first one is calculated based on the predicted wind speed and the second one is calculated based on the measured wind speed. The third production figure reflects the actual measured annual energy production.

Site-Specific Summaries

For each host site, wind distribution graphs, power curves, average predicted and measured wind speeds, and performance data summaries are provided. The measured AEO is consistently lower than the estimated output, based on either the predicted or measured wind speed. Lower energy output attributable to differences between predicted and measured wind speeds have been identified. An analysis to identify the other factors contributing to the performance shortfall will be conducted at the completion of this project. These factors may include equipment, operator, or the environment.

[2] Based on available wind resource maps for Montana and Washington.

1. Alger (Stanford, MT)

Photo 1: Turbine installed at Alger ranch
Source: NWSEED

Data from the Alger site (see Photo 1) are summarized in Tables 2 and 3 below for the period January 2004 – December 2005. With 80% data recovery, the actual measured AEO is 37% lower than originally anticipated. Roughly 11% of this shortfall is attributable to the difference between the measured wind speed and the predicted wind speed. The remaining 26% of this underperformance is due to other factors, yet to be identified.

As shown in Figure 3, the turbine underperformed but also exceeded the peak power production. Wind speeds found at this site were predominately 3 – 6m/s but rarely 15 – 20m/s (Figure 2).

Table 2. Wind Speed

Wind	m/s
Predicted wind speed	6.1
Measured wind speed	5.8

Table 3. Performance Data

Wind	kWh/y
Based on predicted wind speed	18,034
Based on measured wind speed	15,969
Actual measured annual energy production	11,389
Data recovery	80%

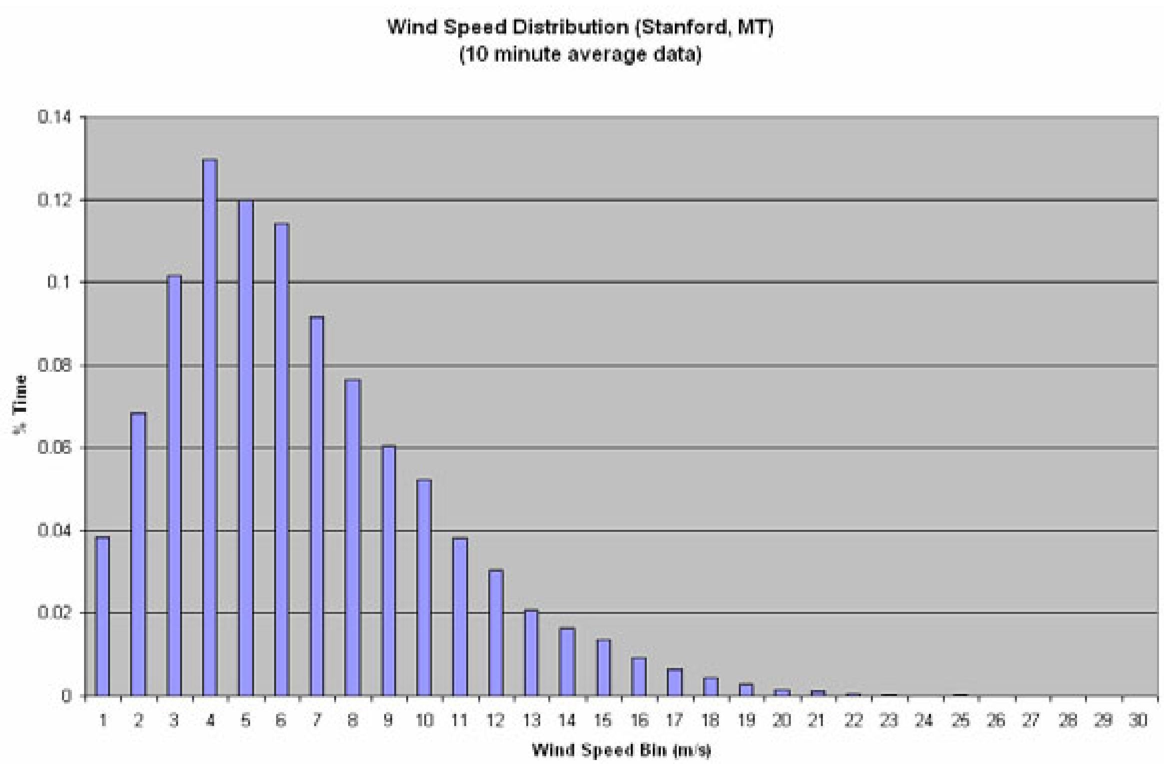

Figure 2. Wind speed distribution

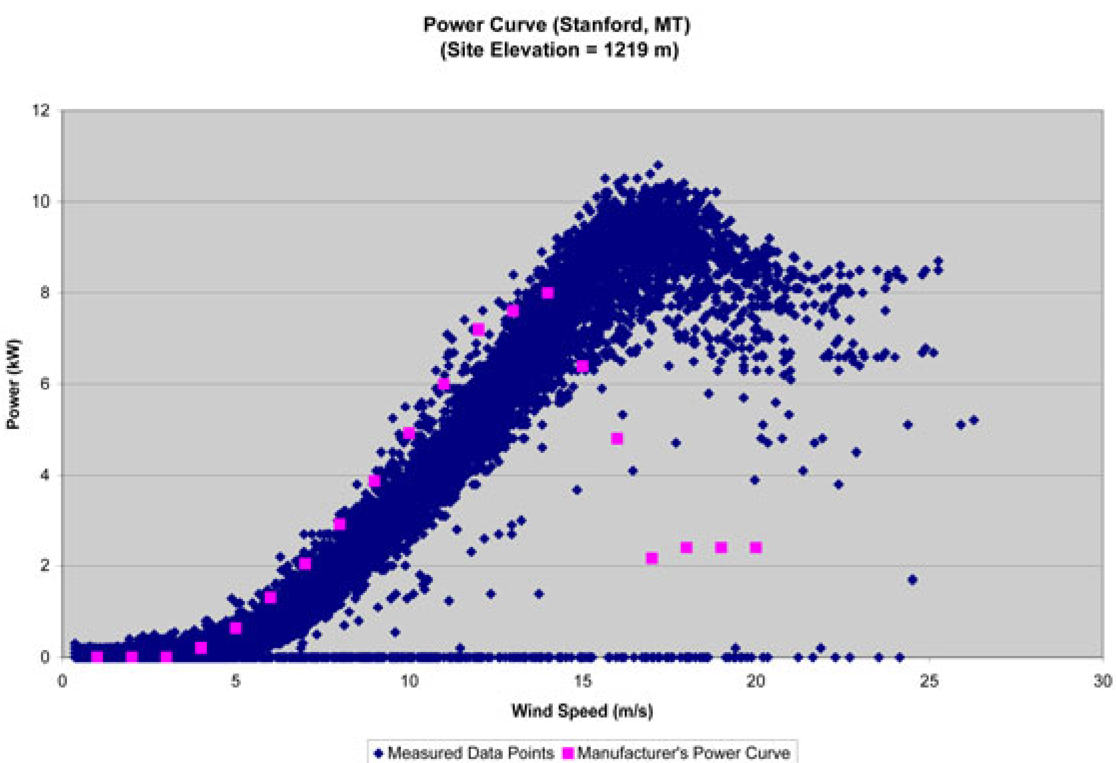

Figure 3. Estimated and actual power curves

2. Kennell (Goldendale, WA)

Photo 2: Turbine installed on Kennell property
Source: NWSEED

Wind speed and performance data from the Kennell site (Photo 2) for the period January 2004 – December 2005 are summarized in Tables 4 and 5 below. The wind distribution curve (Figure 4) does not follow a typical Rayleigh distribution, suggesting the anemometer may not have been working properly (perhaps due to icing or some other factors).

The power curve (Figure 5) data have not been filtered, however the uncharacteristic scatter plots suggest a problem with the anemometer and/or manual furling. The actual measured production is 32% lower than originally estimated, based on 87% data recovery. While approximately 6% of the lower production is a result of the difference between the predicted and measured wind speed, the majority is due to other factors. The specific causes have yet to be determined.

Table 4. Wind Speed

Wind	m/s
Predicted wind speed	5.9
Measured wind speed	5.8

Table 5. Performance Data

Wind	kWh/y
Based on predicted wind speed	18, 485
Based on measured wind speed	17,473
Actual measured annual energy production	12,577
Data recovery	87%

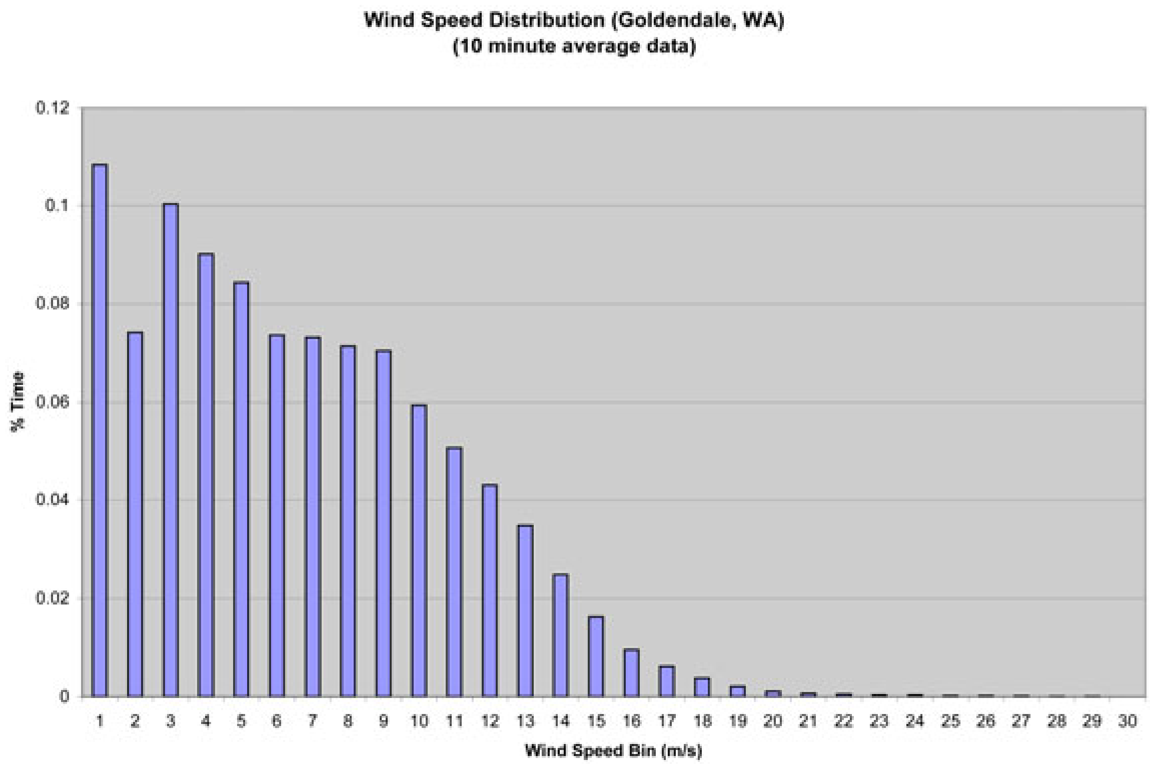

Figure 4. Wind speed distribution

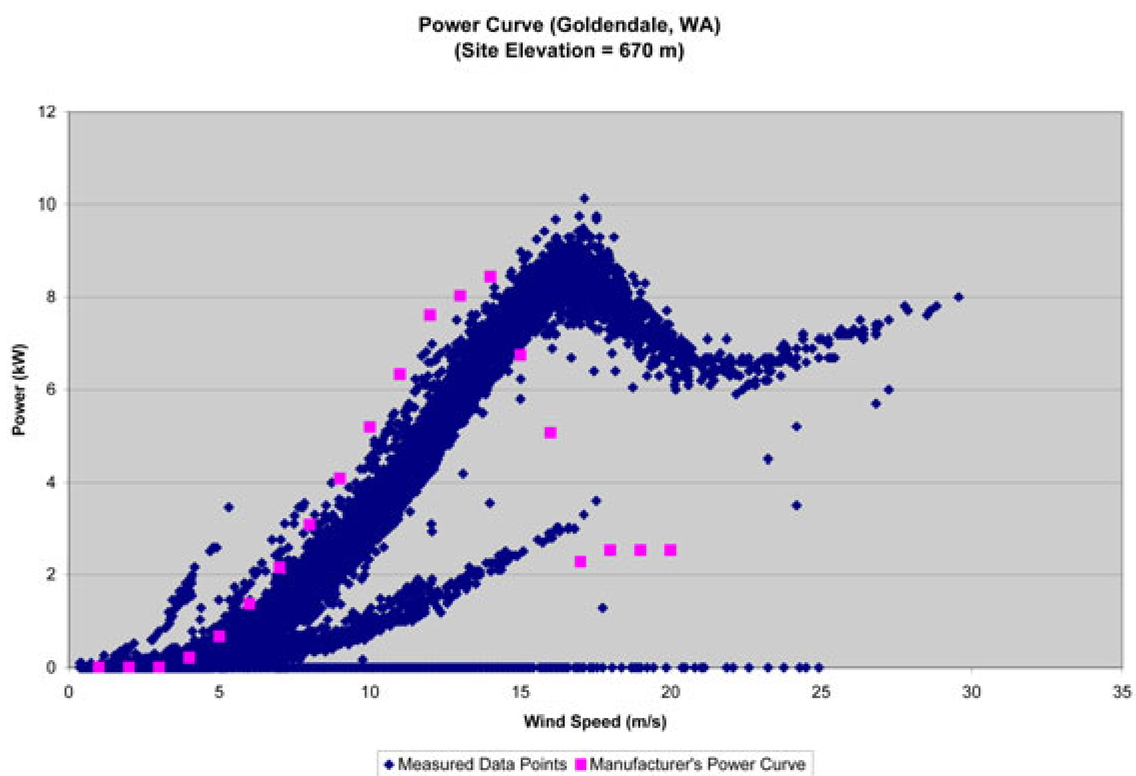

Figure 5. Estimated and actual power curves

3. Liberty County (Chester, MT)

Photo 3: Turbine installed at Liberty County Maintenance Facility
Source: NWSEED

Tables 6 and 7 summarize wind speed and performance data from the Liberty County site (Photo 3) for the period February 2004 – February 2006. With almost 100% data recovery, AEO was 51% lower than the initial production estimate. Of the four sites covered in this paper, this is the only one where the wind map did not accurately predict the site-specific wind speeds. Almost 40% of the production shortfall was due to the difference between predicted and actual wind speeds. The remaining reduction in production is due to other factors. Figure 6 represents a reasonable Rayleigh distribution and there is no indication of manual furling in the power curve (Figure 7).

Table 6. Wind Speed

Wind	m/s
Predicted wind speed	5.7
Measured wind speed	4.6

Table 7. Performance data

Wind	kWh/y
Based on predicted wind speed	16,242
Based on measured wind speed	9,786
Actual measured annual energy production	7,926
Data recovery	98.5%

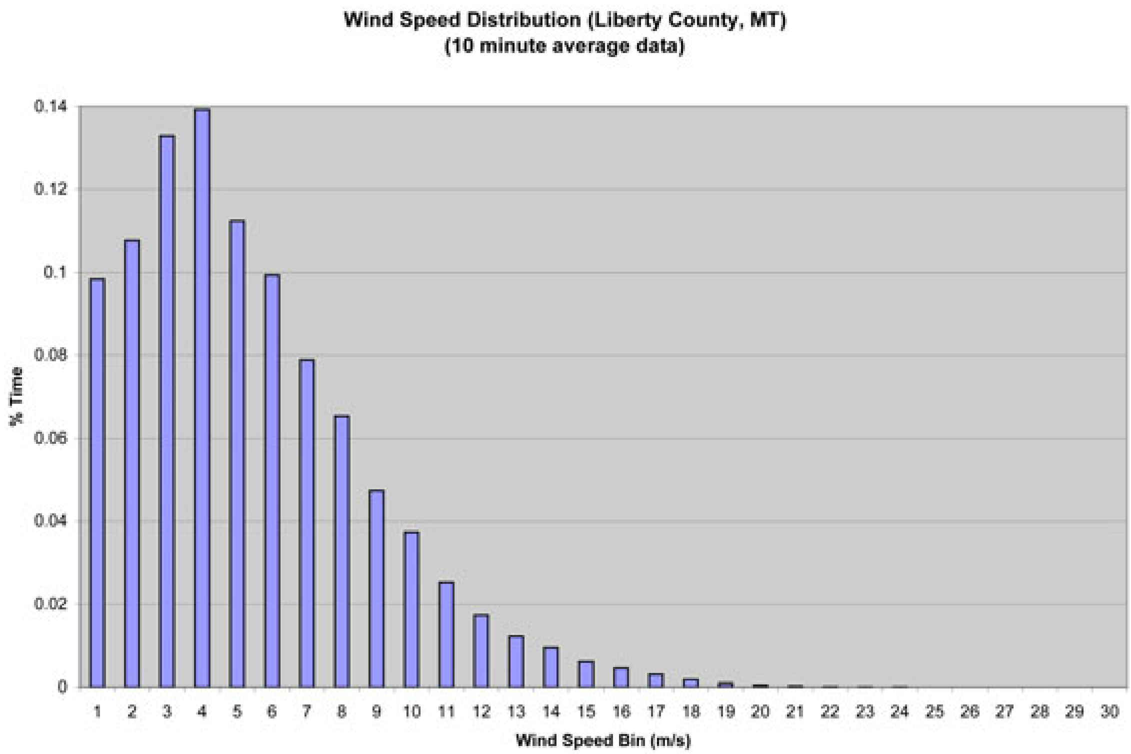

Figure 6. Wind speed distribution

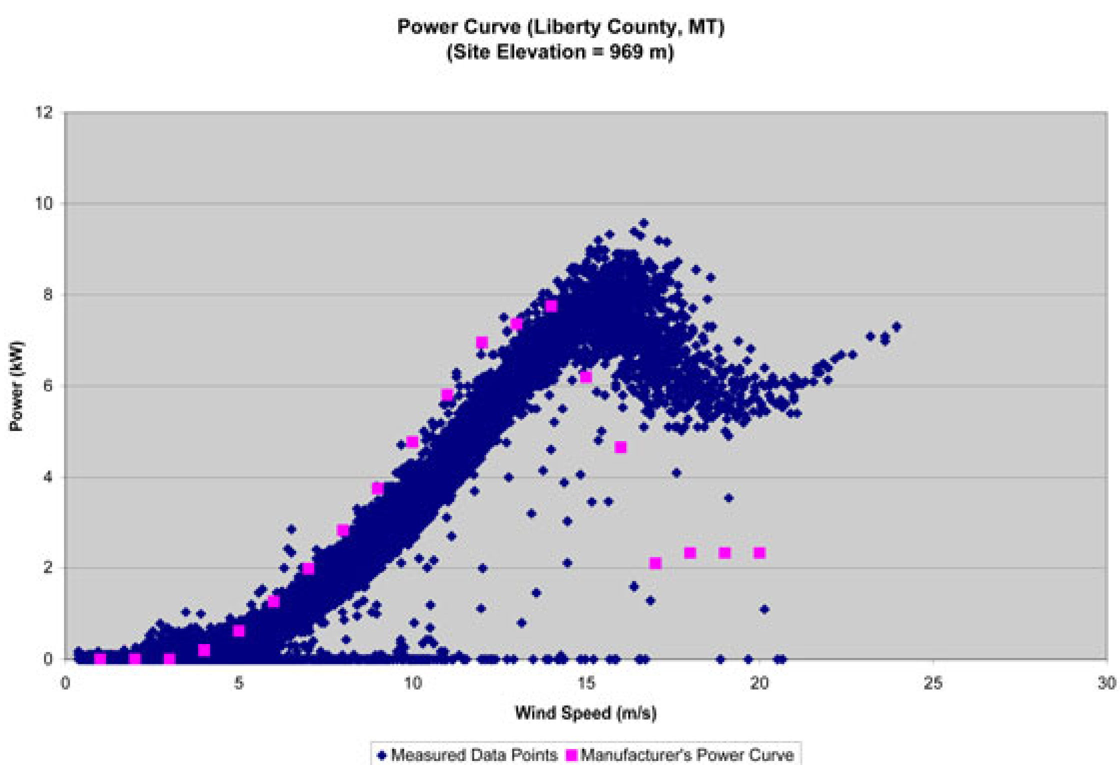

Figure 7. Estimated and actual power curves

4. Nelson (Browning, MT)

Photo 4: Turbine installed at Nelson farm
Source: NWSEED

For the period February 2004 – February 2006, wind speed and performance data was collected from the Nelson site (Photo 4). Tables 8 and 9 summarize these data. Figure 8 depicts a reasonable Rayleigh wind speed distribution. The data points on the power curve graph (Figure 9) reflect many points at zero, suggesting the inverter may have been off or the grid was down. The scatter plot also suggests the turbine may have been manually furled.

Overall, measured AEO was 47% lower than originally estimated. Less than 2% of the production shortfall was due to the difference between the predicted and actual wind speed.

Table 8. Wind Speed

Wind	m/s
Predicted wind speed	5.7
Measured wind speed	5.6

Table 9. Performance Data

Wind	kWh/y
Based on predicted wind speed	15,959
Based on measured wind speed	15,679
Actual measured annual energy production	8,424
Data recovery	90%

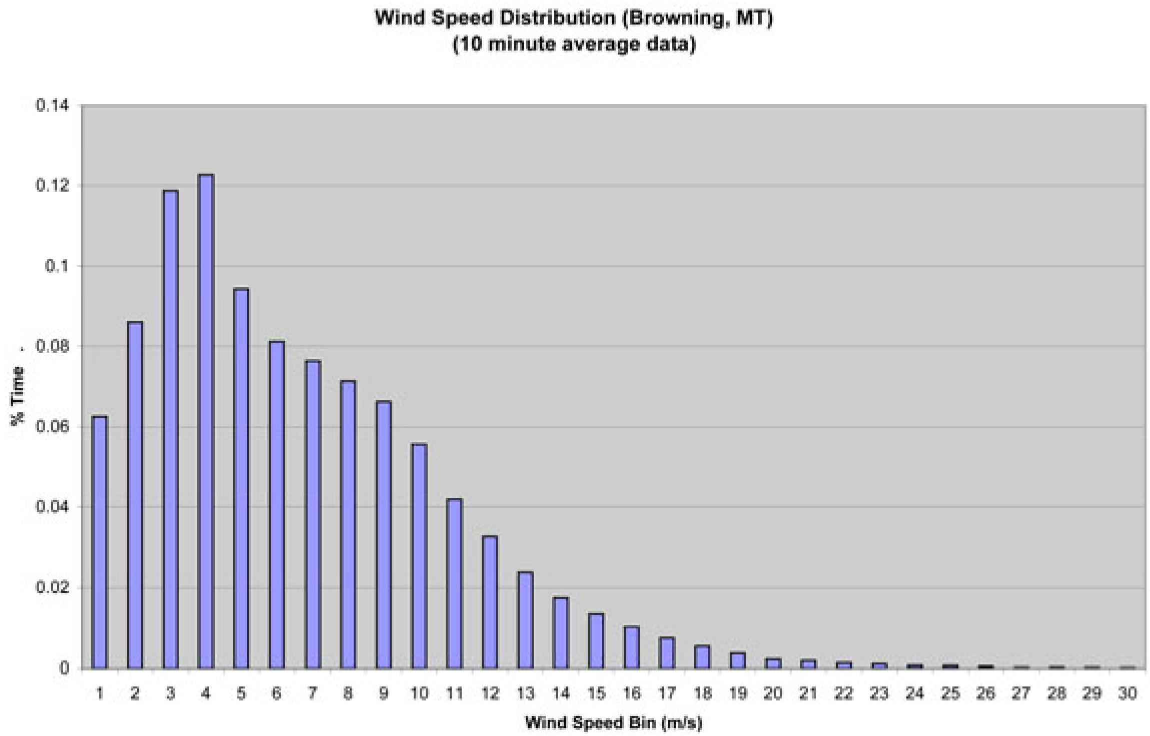

Figure 8. Wind speed distribution

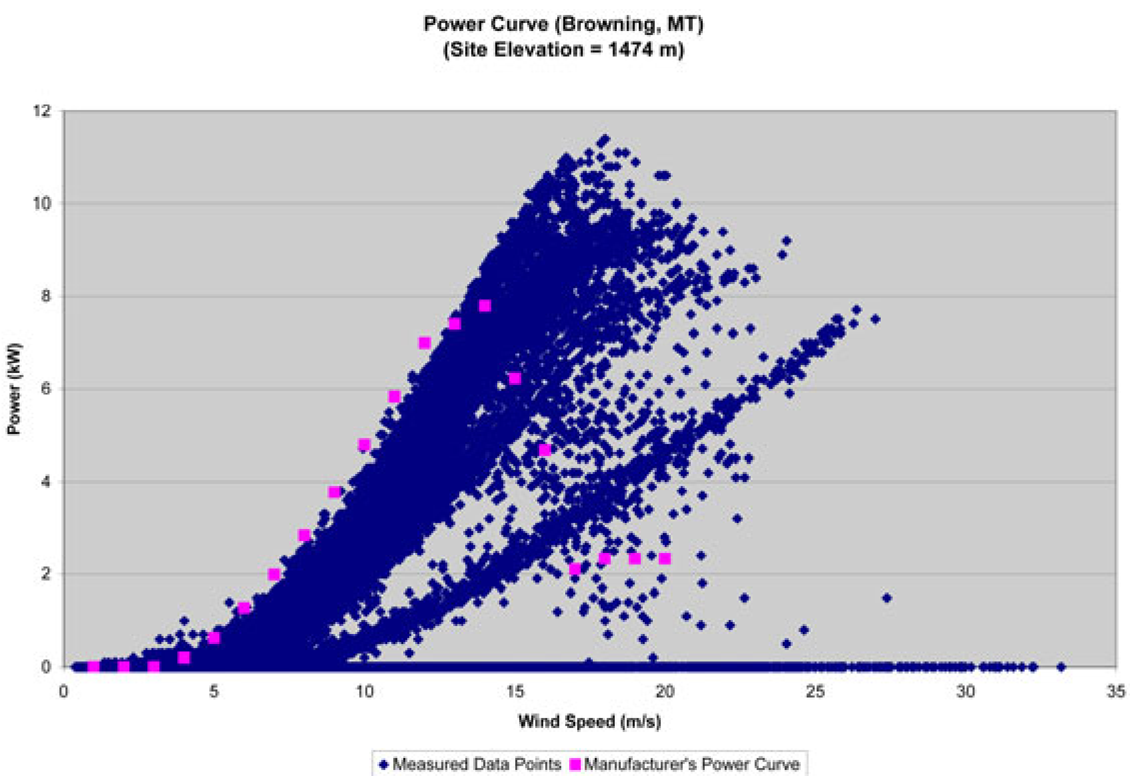

Figure 9. Estimated and actual power curves

Conclusion

Under its RFV project, NREL has been monitoring 5 Bergey 10-kW turbines installed in the PNW. This paper summarized 2 years of data collected at 4 of the sites. Data collection for the 5th site will be completed in Fall 2006. At that time, a full analysis of the performance data for all 5 sites will be conducted.

For the data presented in this paper, several observations can be made. Data recovery ranged from 80% to 98.5%. In all cases, the annual energy output was lower than originally estimated. Actual performance was 32% to 51% lower than expected. A portion of this underestimation can be attributable to lower actual wind speeds than predicted. In three of the four cases, the difference between the estimated wind speeds (which were based on the state-specific wind resource maps) and the measured wind speeds accounted for a small portion of the shortfall. In one case (Liberty County), the lower measured wind speeds accounted for 40% of the 51% reduction in output. Thus, in 75% of the cases, the wind resource maps did a reasonable job of predicting the site-specific wind speeds.

Numerous other factors contributed to performance shortfalls. These likely include operator decisions (such as manual furling), environmental factors (such as grid outages) or the equipment (including inverter outages). A detailed analysis of the performance will be conducted later this year.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
August 2006	Conference paper	June 4 - 7, 2006

4. TITLE AND SUBTITLE
Regional Field Verification — Operational Results from Four Small Wind Turbines in the Pacifc Northwest: Preprint

5a. CONTRACT NUMBER
DE-AC36-99-GO10337

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
K. Sinclair and J. Raker

5d. PROJECT NUMBER
NREL/CP-500-38110

5e. TASK NUMBER
WER6.7502

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

8. PERFORMING ORGANIZATION REPORT NUMBER
NREL/CP-500-38110

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)
NREL

11. SPONSORING/MONITORING AGENCY REPORT NUMBER

12. DISTRIBUTION AVAILABILITY STATEMENT
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

13. SUPPLEMENTARY NOTES

14. ABSTRACT *(Maximum 200 Words)*
This paper describes four Bergey Excel S (10 kW) wind turbines installed on sites in the Pacific Northwest under DOE/NREL's Regional Field Verification Program between 2003 and 2004 and summarizes operational data from each site.

15. SUBJECT TERMS
small wind turbine; field tests; field verification program; Northwest Sustainable Energy for Economic Development

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
Unclassified	Unclassified	Unclassified	UL		19b. TELEPHONE NUMBER *(Include area code)*

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

F1147-E(12/2004)