Fort Carson Wind Resource Assessment

R. Robichaud

Produced under direction of the Department of Defense by the National Renewable Energy Laboratory (NREL) under Interagency Agreement IAG-11-1837 and Task No WFL5.1008.

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Technical Report
NREL/TP-7A40-56409
October 2012

Contract No. DE-AC36-08GO28308

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

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NREL staff members involved were Robi Robichaud, principal investigator, and Kate Anderson, NREL's project lead for net zero energy planning at Fort Carson.

List of Acronyms

ASOS	automated surface observing systems
AWEA	American Wind Energy Association
BAU	business as usual
BLCC	building life-cycle cost
COE	cost of energy
DAS	data acquisition system
DOE	U.S. Department of Energy
ECIP	Energy Conservation and Investment Program
EISA	Energy Independence and Security Act of 2007
E.O.	Executive Order
EPAct 2005	Energy Policy Act of 2005
ESPC	energy savings performance contract
FAA	Federal Aviation Administration
ft	feet
FY	fiscal year
GIS	geographic information systems
IEC	International Electrotechnical Commission
ITC	investment tax credit
LCC	life cycle cost
m	meter
MCP	measure-correlate-predict
MW	megawatts
NEXRAD	next-generation weather radar program
NOAA	National Oceanic and Atmospheric Administration
NREL	National Renewable Energy Laboratory
NWS	National Weather Service
O&M	operation and maintenance
PPA	power purchase agreement
PTC	Production Tax Credit
RFP	request for proposal
RLOS	radar line of sight
R&D	research and development
ROI	return on investment
SODAR	sonic detection and ranging
SPB	simple payback
TI	turbulence intensity
TSR	tip speed ratio
UESC	utility energy services contract
VWSF	vertical wind shear factor
Wp	peak Watt

Executive Summary

The U.S. Army has long been interested in reducing its dependence on fossil fuels for energy, increasing its energy security, and reducing its energy intensity. Increasing the use of renewable energy at Army bases serves all of these goals. As part of these efforts, the Army has been collaborating with the U.S. Department of Energy's (DOE's) National Renewable Energy Laboratory (NREL) to evaluate renewable energy options at Fort Carson, Colorado.

This report focuses on the wind resource assessment, the estimated energy production of wind turbines, and economic potential of a wind turbine project on a ridge in the southeastern portion of the Fort Carson Army base.

Wind data was collected from a 50-meter (m) meteorological (met) tower on a small ridge in the southeastern part of the Fort Carson base. A mini sonic detection and ranging (miniSODAR) unit was also deployed at this site to measure wind speeds at elevations 30 to 140 m (98 to 459 ft) above the ground. The data collected provided an effective dataset for comparative analysis of wind speed, turbulence intensity, and energy production of several wind turbines suitable for the wind conditions at the site. Table ES-1 shows the summary results of estimated annual energy production figures, capacity factors, and percent of Fort Carson load the wind can supply.

Table ES-1. Summary Wind Project Energy Performance of Sample Wind Turbines

Turbine Manufacturer & Model	Rated Power	Mean Net Power	Mean Net Annual Energy /Turbine/Yr	Net Capacity Factor	FC#2 Site	Wind Plant Capacity	Wind Plant Annual Output	% of Base Energy
Turbine	MW	kW	kWh/yr	%	# Turb.	MW	MWh/yr	%
GE 1.6 XLE	1.6	415	3,634,101	25.9	7	11.2	25,439	15.7%
Suzlon S97	2.1	475	4,162,921	22.6	7	14.7	29,140	18.0%
Siemens SWT-2.3 108	2.3	572	5,014,293	24.9	7	16.1	35,100	21.6%
Siemens SWT-2.3 113	2.3	691	6,049,308	30.0	7	16.1	42,345	26.1%
Nordex N117	2.4	647	5,665,505	26.9	7	16.8	39,659	24.4%
Vestas V112 - 3.0 MW	3.0	677	5,933,315	22.0	7	21.0	41,533	25.6%

Table ES-2 provides a sensitivity analysis, comparing the impacts of different project financing scenarios assuming third-party ownership with a production tax credit (PTC) of $0.022/kWh in effect, and targeting approximately 11.2 megawatts (MW) of wind capacity. Two sets of assumptions are analyzed, the first assuming a 20-year power purchase agreement (PPA) with 0% debt fraction as the base case. The second set of assumptions being the similar, but increasing the debt fraction from 0% to 30% and 100%. The impacts (items that vary) are shown in the colored boxes.

Table ES-2. Sensitivity Analysis and Comparison of Financing Scenarios

Sensitivity Factors	Mean Net Annual Energy Output	Net Capacity Factor	Total of Annual Energy Savings	Annual O&M	% Ater-Tax ROI to Equity Partner	Estimated Installed Cost	Life Cycle Cost	Estimated Cost of Wind Energy	Savings to Investment Ratio	Simple Payback
	MWh/yr	%	$	$	%	$	$	$/kWh	unitless	yrs
PPA - 20 yr; 0% debt	25,439	25.9%	$2,060,643	$331,130	4.7%	$25,345,600	$1,292,988	$0.056	1.05	14.7
PPA - 20 yr; 30% debt	25,439	25.9%	$2,060,643	$331,130	4.5%	$25,345,600	$777,496	$0.057	1.04	14.7
PPA - 20 yr; 100% debt	25,439	25.9%	$2,060,643	$331,130	-0.03%	$25,345,600	($641,052)	$0.061	N/A	14.7
PPA - 25 yr; 0% debt	25,439	25.9%	$2,060,643	$331,130	4.9%	$25,345,600	$5,735,813	$0.047	1.23	14.7
PPA - 25 yr; 30% debt	25,439	25.9%	$2,060,643	$331,130	5.4%	$25,345,600	$5,150,676	$0.049	1.29	14.7
PPA - 25 yr; 100% debt	25,439	25.9%	$2,060,643	$331,130	pos	$25,345,600	$3,472,020	$0.052	N/A	14.7

Overall, the wind resource at the selected sites at Fort Carson is sufficient for a wind turbine project, though the specific approach needs refinement. There are a number of other factors to consider before turbine selection is undertaken, including cost, availability, constructability, and transportability. There are also a number of other factors still to be explored as the parameters of this project become more clearly defined, including on-site military operations, Federal Aviation Administration (FAA), financing, National Environmental Protection Act (NEPA), constructability, subsoil/foundations, impact on neighbors, and transportation planning and logistics.

There are a number of proposed tasks to continue to move this project forward, including:

- Fort Carson to complete the NEPA evaluation already underway
- Complete an electrical interconnection study
- Determine the most appropriate financing mechanism and secure project funding/finance
- Complete the transportation and logistics study
- Complete the visual and sound impact study
- Develop and implement a public information plan.

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1 Introduction

The U.S. Army has long been interested in reducing its dependence on fossil fuels for energy; increase its energy security and reducing its energy intensity. Increasing the use of renewable energy at Army bases serves all of these goals. As part of these efforts, the Army has been collaborating with the U.S. Department of Energy's (DOE's) National Renewable Energy Laboratory (NREL) to evaluate renewable options at Fort Carson, Colorado.

This report focuses on the wind resource assessment, the estimated energy production of wind turbines, and a survey of potential wind turbine options based upon the site-specific wind resource.

2 Location

Fort Carson, initially named Camp Carson, was established in 1942. It is located several miles south-southwest of Colorado Springs, Colorado. Most of the base is in El Paso County though it extends into Fremont County to the southwest and into Pueblo County to the south and southeast.

Fort Carson encompasses ~137,000 acres extending ~40 kilometers (km) (~25 miles) south from the primary base facilities near Colorado Springs. The base is located south-southeast of Pikes Peak, elevation 4,300 m (14,110 ft), in south-central Colorado. Much of the base elevation ranges between 1,600 to 1,800 m (5,200 to 5,900 ft) though the Front Range of the Rocky Mountains provides rough, mountainous terrain to the west and northwest of the northern two thirds of the base with elevations in the 2,000 to 3,000 m (6,600 to 9,800 ft) range. Figure 1 shows Fort Carson relative to Colorado Springs.

Figure 1. Location of Fort Carson in south-central Colorado

Source: http://www.colorado.gov/apps/maps/neighborhood.map

The areas of interest (rectangles labeled "Wind site") for potential wind resource assessment and development are shown in the map in Figure 2 below. Two potential met tower sites, labeled Met Tower Site #1 and Met Tower Site #2 are marked within the areas of interest. Met Tower Site #1 site was eliminated from consideration early in the project development cycle due to its close proximity to the area labeled "Off Limits

Impact Area." Met Tower Site #2 became the primary site of interest for further investigation. This site is referred to as Fort Carson #2 (FC#2).

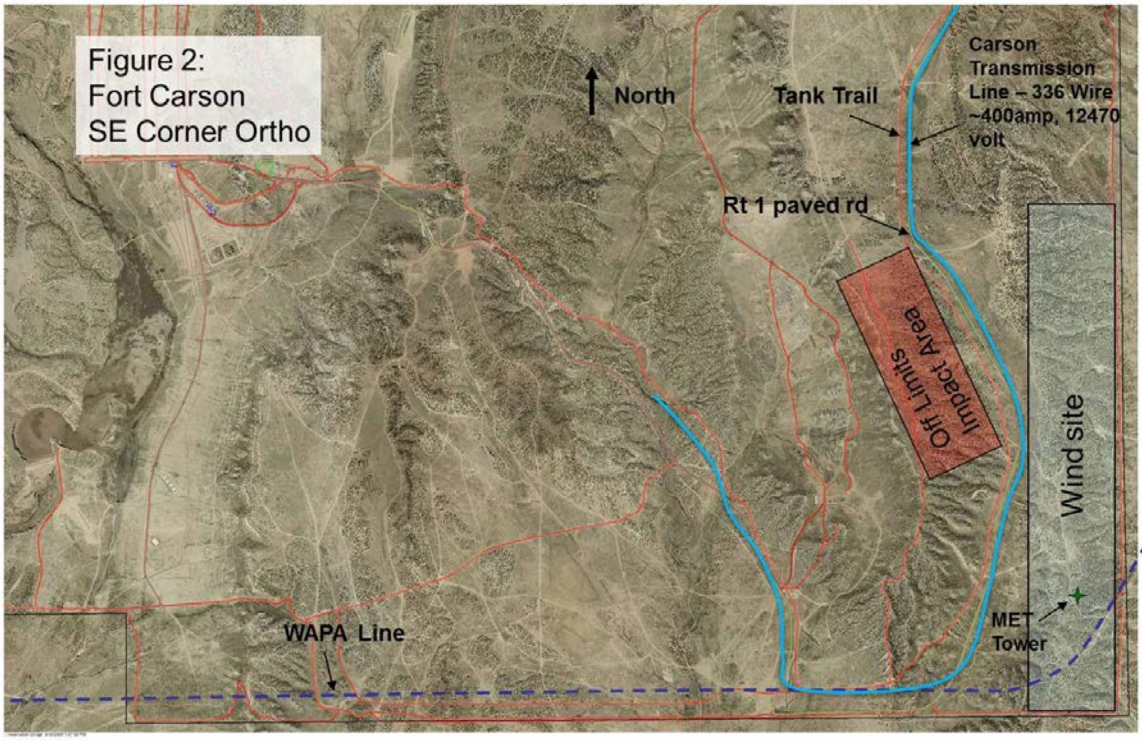

Figure 2. Southeastern Fort Carson with potential met tower sites

Source: Vince Guthrie, Energy Manager, Fort Carson

3 Site Characterization

The entire base of Fort Carson (excluding the Pinon Canyon training area) is relatively flat, semi-arid terrain that bridges high plains and foothills land formations.[1] The Fort Carson land has broad, gently sloping valleys and generally rounded ridges markedly smoother than the more mountainous regions to the north and northwest. The ridges provide improved exposure to wind; though their orientation to prevailing wind direction and proximity to more abrupt terrain will impact the degree of turbulence intensity experienced at particular sites.

Overall vegetation is relatively sparse compared to the higher terrain of the foothills region south of Pikes Peak. There are more vegetated pockets scattered around the base that tend to be in areas where the terrain provides greater shade or water than the more exposed areas do.

The topography of the southern portion of the Fort Carson base is displayed within the green boundary on the map below in Figure 3. The green rectangle in the southeast corner represents the primary area of interest for wind development.

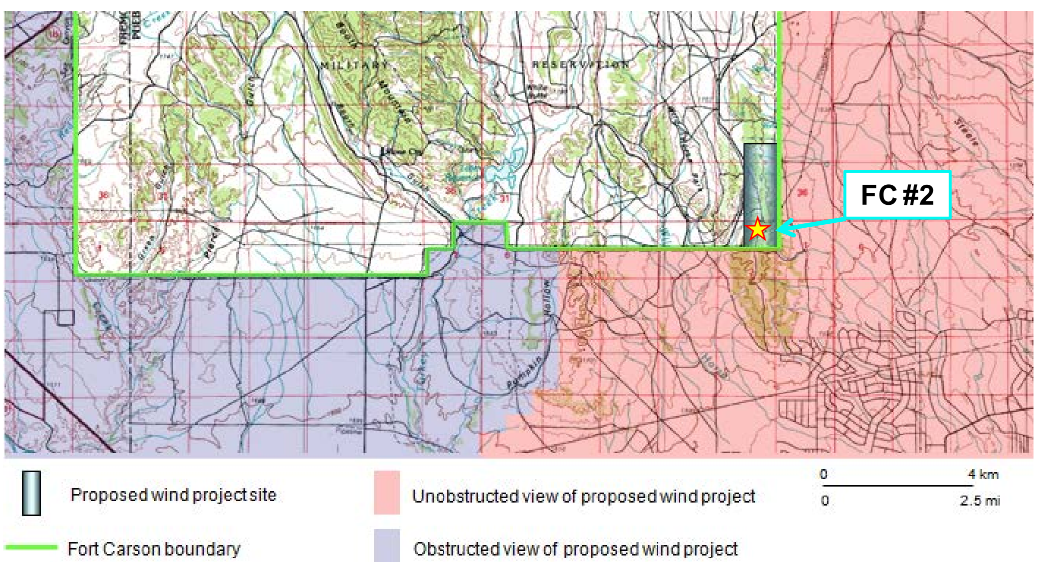

Figure 3 Topographical map of Fort Carson area with FC#2 shown

Source: Tibor Hedegus, General Manager, Revolution Energy LLC

Within a 2 km (1.2 mi) radius from FC#2, the landscape is dotted with pinion trees ranging in size from ~3 to 8 m (~10 to 25 ft). The terrain near FC#2 is generally undulating with small hills, ridges, and canyons. FC#2 is near the top of a small north-south ridge with elevations varying between 1,700 to 1,730 m (5,580 to 5,675 ft). The ridge elevation is generally consistent extending 2 km (1.2 mi) both north and south from

[1] Fort Carson Installation Design Guide, Standards, Section 7 – Site Planning Design Standards, Natural Conditions, Topography http://www.carson.army.mil/DPW/FtCarsonDesignGuide/06_Standards/Section07_SitePlanningDesignStandards/7.4.1_body.htm, accessed Jan 25, 2012.

FC#2. The land slopes consistently downward from the northeast through southeast. To the west is a gently sloping drainage or canyon that slopes south with elevation changes from 1,730 to 1,670 m (5,675 to 5,480 ft) from north to south. West of the canyon is a slightly higher, more rugged ridge with elevations ranges of 1,710 to 1,760 m (5,610 to 5,775 ft). Winds coming over this ridge from the west moving towards FC#2 will likely experience turbulence at lower elevations above the ground due to the undulations of the canyon/drainage.

4 Wind Resource Assessment Campaign

The intent of the wind resource assessment was to characterize the wind resource for the southeastern portion of the base in proximity to FC#2. The primary wind characteristics of interest include:

- Wind speed at or close to proposed wind turbine sites
- Vertical wind shear factor (VWSF) to determine wind speeds at hub height of potential wind turbines
- Wind speed frequency distribution, or probability distribution function
- Turbulence intensity (TI) to determine turbine site suitability based upon standard International Electrotechnical Commission (IEC) classifications.

4.1 Wind Resource Assessment Activities at Fort Carson

Wind measurement equipment and assessment activities were installed and performed in the southeastern corner of the base. Due to variation in terrain and large topographical features, this wind resource assessment is not suitable for determining the wind resource at the cantonment area of Fort Carson.

Training and operations at Fort Carson make it challenging to find any sites for wind development completely out of the way of military activities. FC#2 was deemed potentially viable for wind development due to its proximity to the southeastern border of Fort Carson. Further investigation with all aspects of Fort Carson's training and operations units will be necessary before any decisions to move forward with a wind turbine project.

The wind assessment campaign actively engaged in assessing the wind resource through different approaches with a variety of wind sensor equipment, as follows:

- FC#2: 50-m (164-ft) met tower installed and commissioned 12/27/2007 and operational for 22 months until 10/15/2009.
- MiniSODAR: trailer unit installed and operational at Fort Carson from 3/19/2008 through 9/25/2008.

The wind data collected by these devices during the timeframes listed was used for the subsequent analyses in this report.

5 Wind in Colorado

Wind maps provide a graphical estimation of the wind resource in an area but do not incorporate sufficient information to reliably estimate annual electricity generation at any specific point. Areas of varying vegetation (e.g., tall trees versus grassland or cropland), complex topographical features (e.g., ridges versus valleys or canyons versus mountains), and varying surface roughness (e.g., city skyscrapers versus flat or rolling farmland) are characterized by highly variable wind resources that are very site specific.

Sites in close proximity to each other, but with the above variations, can represent different wind power densities. Wind maps are valuable for understanding, where strong winds merit further investigation with on-site wind monitoring stations. Wind maps are not, however, typically used to site large wind farms, because maps lack the micro-siting detail required to minimize the energy estimation uncertainty to the level required by financiers. On-site wind data collected for a period of 1 to 3 years is the industry norm to estimate wind turbine performance accurately. This study used recently collected on-site wind data for its analysis and energy production estimates.

The wind map for Colorado, shown in Figure 4, provides a context for the data analysis that follows. The wind map indicates that the Fort Carson region has an expected mean annual wind speed between 6.0 to 7.0 meters per second (m/s) (13.4 to 15.7 miles per hour (mph)) at 80 m (262 ft). Depending upon access to wind as it moves across the mountains, rolling hills, canyons and mesas, some variation in wind speeds is expected.

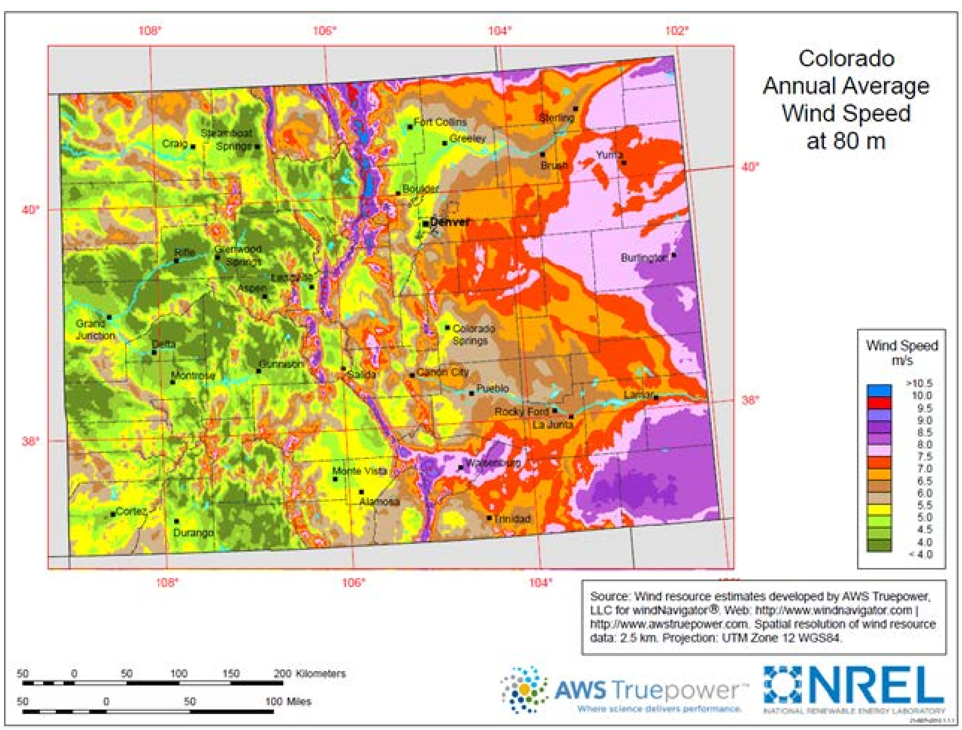

Figure 4. Colorado wind speed map at 80 m

Source: http://www.windpoweringamerica.gov/images/windmaps/co_80m.jpg.

Figure 5 shows an enlarged version of the Colorado wind map. The estimated wind speed near the FC#2 (blue oval) appears to be between 6.5 to 7.0 m/s (14.5 to 15.7 mph).

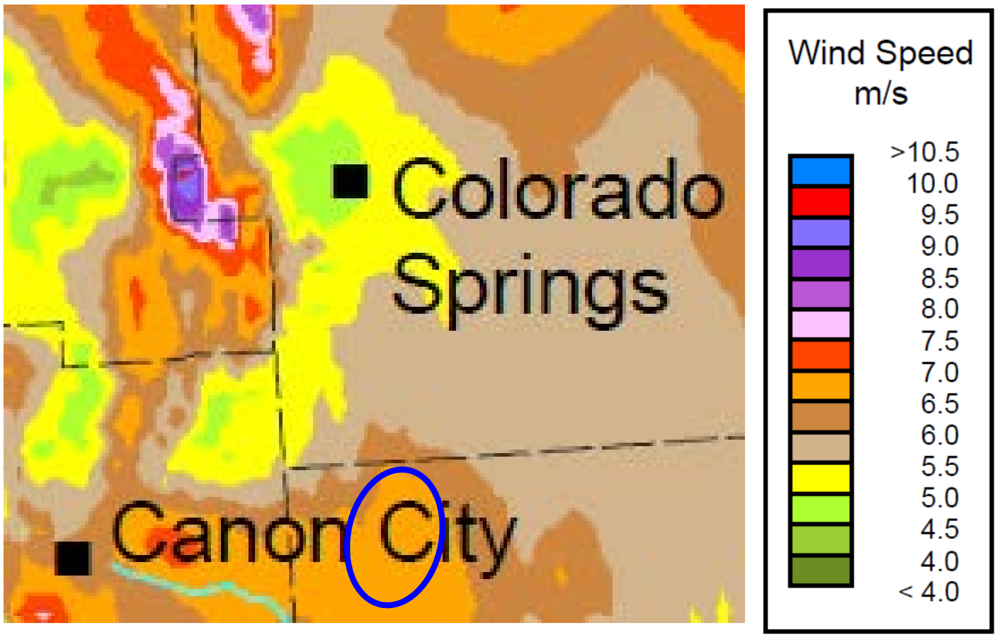

Figure 5. Enlarged Colorado 80-m wind map with Fort Carson met tower site circled in blue

6 Instrumentation and Equipment

6.1 Meteorological (Met) Towers

Met towers are temporary structures installed at, or as close as possible to, potential wind turbine sites to reduce the uncertainty of wind turbine energy production estimates. Towers may be 40 to 100 m (130 to 330 ft) tall, though 60 to 80 m (200 to 260 ft) is the most common for utility-scale wind turbine investigations. Met towers are configured with multiple anemometers to measure the wind speed near the top of the tower and at 10 to 15-m (33 to 50-ft) intervals above the ground to a minimum height of 20 to 30 m (65 to 100 ft). Met towers will also typically have two to three wind vanes to measure the wind direction at several heights.

6.2 50-m Met Tower at Fort Carson

The Army National Guard at Fort Carson contracted for the purchase and installation of a 50-m (164-ft) met tower. The tower was installed in December 2007 and commissioned on 12/29/2007. The instrumentation consisted of an NRG 50-m Tall Tower, four anemometers, two wind vanes, a temperature sensor, and a data logger. The met tower was erected at the FC#2. Table 1 summarizes details of the sensor configuration on the met tower at FC#2. The information was taken from the Fort Carson commissioning report.[2] Sensor and tower details are in Appendix A.

Table 3. Sensors, Heights, and Orientations at FC#2 for 1/1/2008-10/15/2009

Chan-nel	Sensor	Sensor Height	Orient-ation	Boom Length	Scale	Offset	Calibration Date
#	#	m (ft)	deg	m (ft)			mm/dd/yyyy
1	NRG MAX #40 C	48.5 (159)	315	1.2 (3.9)	0.765	0.35	11/20/2007
2	NRG MAX #40 C	48.5 (159)	225	1.2 (3.9)	0.765	0.35	11/20/2007
3	NRG MAX #40 C	40.7 (133.5)	270	1.2 (3.9)	0.765	0.35	11/20/2007
4	NRG MAX #40 C	30 (98.4)	270	1.2 (3.9)	0.765	3.5	11/20/2007
7	NRG #200 - P	48.0 (157)	0	1.2 (3.9)	0.351	0	0
8	NRG #200 - P	29.4 (96.4)	0	1.2 (3.9)	0.351	0	0
9	110S	3 (10)	N/A	N/A	0.136	-86.383	-86.383

6.3 Site Summary – Met Tower

Table 4 summarizes the dataset properties, environmental conditions, and wind power and wind shear coefficients for FC#2.

[2]B. Jackson emailed the report to NREL in January 2008.

Table 4. Site Summary of FC#2 for 1/1/2008-8/31/2009

Variable	Value
Latitude	N 38° 26' 0.1"
Longitude	W 104° 44' 22.3"
Elevation	1731 m
Start date	1/1/2008
End date	9/30/2009 23:50
Duration	21 months
Length of time step	10 minutes
Calm threshold	3 m/s
Mean temperature	13.1 °C
Mean pressure	82.24 mbar
Mean air density	1.002 kg/m³
Power density at 50m	241 W/m²
Power law exponent	0.159
Surface roughness	0.0693 m
Roughness class	1.7

6.4 SODAR Systems

Mini sonic detection and ranging (miniSODAR) systems are a relatively new, remote sensing technology utilized to conduct or augment wind resource measurement and characterization. MiniSODAR systems measure the vertical turbulence structure and the wind profile of the lower layer of the atmosphere at elevations up to several hundreds of meters. SODAR systems operate by emitting an acoustic pulse that travels up into the air and is reflected by moisture or particulates moving in the air. The Doppler (frequency) shift of the return signal is then analyzed to calculate the speed, direction, and turbulent character of the air mass above the SODAR. A profile of the lower atmosphere as a function of height is obtained by analyzing the return signal at different intervals that follow the transmission of each pulse. A miniSODAR system can effectively characterize the wind up to 100 to 150 m (330 to 500 ft) above ground level, which is appropriate for wind turbine applications.

6.5 MiniSODAR at Fort Carson

The miniSODAR system deployed at Fort Carson was a series 4000 Wind Explorer unit manufactured by Atmospheric Systems Corporation (ASC) and designed to record wind speed and direction from 40 to 120 m (130 to 390 ft) above the ground. The Army National Guard contracted for the deployment and data analysis of the miniSODAR that NREL loaned to Fort Carson. The system was commissioned on 3/19/2008 and was operational through 9/25/2008. The period 4/1/2008-9/25/2008 was used for analysis purposes.

The SODAR data was analyzed by ACS to discern wind trends at various heights above the ground. Their summary data tables and analyses were used in conjunction with the collected met tower data to characterize the wind resource at FC#2.

Figure 6. The Wind Explorer^{TM} miniSODAR unit from Atmospheric Systems Corporation
Photo credit: Robi Robichaud, NREL

The miniSODAR was used to enhance the wind resource assessment campaign by providing wind speed measurement data at elevations significantly above the measurements of the met tower.

6.6 Site Summary – MiniSODAR

Table 5 summarizes the dataset properties, environmental conditions, and wind power and wind shear coefficients for the met tower site.

Table 5. Site Summary of the MiniSODAR Site at Fort Carson for 4/1/2008-9/25/2008

Variable	Value
Latitude	N 38° 25' 59.12"
Longitude	W 104° 44' 26.12"
Elevation	1727 m
Start date	4/1/2008
End date	9/25/2008
Duration	5.8 months
Length of time step	10 minutes
Calm threshold	3 m/s
Mean temperature	3.78 °C
Mean pressure	82.28 kPa
Mean air density	1.035 kg/m³
Power density at 50m	243 W/m²
Power law exponent	0.269
Surface roughness	1.53 m
Roughness class	4.26

7 Data Recovery and Validation

The data logger sampled the sensors every 2 seconds and recorded the 10-minute average value for each sensor. The collected data was downloaded manually by Vince Guthrie on a periodic basis and emailed to NREL. Table 6 shows the dataset recovery rates and other major data collection categories for the met tower sensors.

Table 6. Dataset Recovery Rates for FC#2 for 1/1/2008-9/30/2009

Label	Units	Height	Possible Records	Valid Records	Recovery Rate (%)	Mean	Min	Max	Std. Dev
Speed 50 m A 315°	m/s	48.6 m	94,175	82,518	87.62	5.9	0.4	23.5	3.5
Speed 50 m B 225°	m/s	48.6 m	94,175	84,107	89.31	5.9	0.4	24.2	3.6
Speed 40 m 270°	m/s	40.8 m	94,175	93,163	98.93	5.7	0.4	23.7	3.4
Speed 30 m 270°	m/s	30.1 m	94,175	93,564	99.35	5.3	0.4	23.2	3.2
Direction 48 m	°	48 m	94,175	93,969	99.78	261.3	0.9	359.9	103.8
Direction 30 m	°	29.5 m	94,175	93,969	99.78	275.5	0.9	359.9	103.3
Temperature	°C	N/A	94,175	93,470	99.25	13.1	-21	38.9	10.3

Note: Max = maximum wind recorded; Min = minimum wind recorded; Std. Dev = standard deviation

Table 7 displays the data recovery rates for the miniSODAR unit during a shorter, but overlapping timeframe. The raw data recovery rate for the miniSODAR, at 41.79%, was considerably lower than the data recovery rates for the met tower.

Table 7. Wind Speed Recovery Rates for the MiniSODAR for 3/1/2008-9/25/2008

Label	Units	Height	Possible Records	Valid Records	Recovery Rate (%)	Mean	Min	Max	Std. Dev
Wind speed 34m	m/s	34 m	25,488	10,651	41.79	5.9	3.0	21.9	2.4
Wind speed 44m	m/s	44 m	25,488	10,651	41.79	6.6	3.0	22.2	2.6
Wind speed 54m	m/s	54 m	25,488	10,651	41.79	7.0	3.0	22.0	2.7
Wind speed 64m	m/s	64 m	25,488	10,651	41.79	7.3	3.0	22.5	2.9
Wind speed 74m	m/s	74 m	25,488	10,651	41.79	7.6	3.0	23.3	3.0
Wind speed 84m	m/s	84 m	25,488	10,651	41.79	7.8	3.0	23.4	3.1
Wind speed 94m	m/s	94 m	25,488	10,651	41.79	8.0	3.0	23.5	3.2
Wind speed 104m	m/s	104 m	25,488	10,651	41.79	8.2	3.0	23.5	3.3
Wind speed 114m	m/s	114 m	25,488	10,651	41.79	8.3	3.0	24.0	3.4
Wind speed 124m	m/s	124 m	25,488	10,651	41.79	8.5	3.0	24.7	3.4

Note: Max = maximum wind recorded; Min = minimum wind recorded; Std. Dev = standard deviation

7.1 Data Analysis

The wind data from FC#2 was validated by NREL and used for all of the met tower analyses. The wind data from the miniSODAR was validated by ASC and used for the SODAR data analysis. For the purposes of comparing the wind resources from these two assessment tools at Fort Carson, the analysis in this section will examine the time period where the met tower has concurrent data with the miniSODAR, March 1, 2008, to September 25, 2008.

Wind speed data were collected at 50, 40, and 30 m (164, 131, and 98 ft) with a redundant wind speed sensor at 50 m (196 ft). The wind speed sensors were mounted on 1.2 m (3.9 ft) boom arms facing southwest (315°) or west by northwest (225°) to minimize met tower shading effects.

Two anemometers at FC#2, 50-m A 315° wind speed and 50-m B 225° wind speed, were periodically affected by met tower shading and by turbulence caused by wind coming over the top of the met tower. These data points have been flagged and removed from the datasets.

At times, the miniSODAR wind speed data show significant discrepancies with the met tower data as seen in Figure 7. Based on the wind speed variations and the low data recovery rate with the miniSODAR, the miniSODAR data was used to establish the vertical wind shear factor for FC#2 that was applied in creating a long-term data set. The wind speed data from the anemometers on FC#2 were used to determine wind speed, direction, turbulence, and other key statistics.

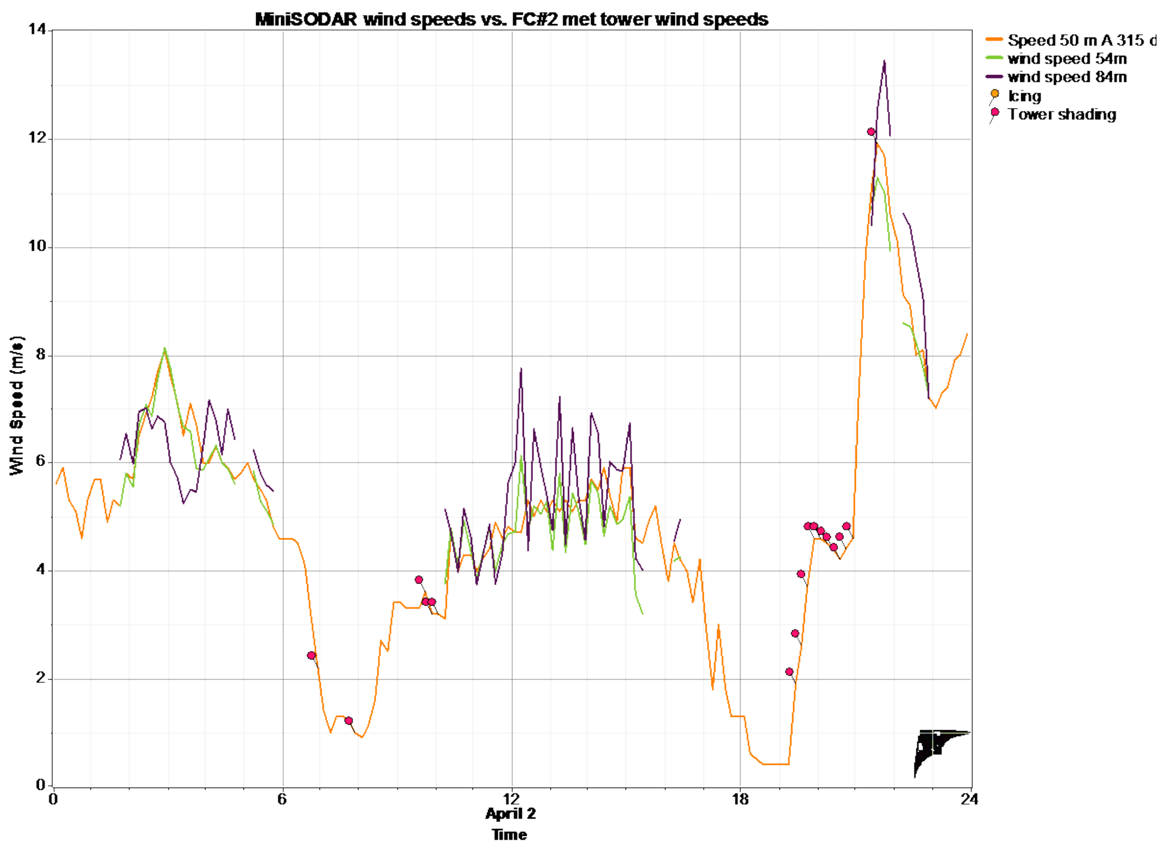

Figure 7. Wind speed variations between miniSODAR and FC#2 met tower

The analyses organized, averaged and sorted the data utilizing a variety of methods to help illustrate important trends and other statistical data relevant to the characterization of the wind resource.

8 Wind Resource Assessment Summary

8.1 Wind Resource Characterization

Uneven heating of the earth's surface creates wind energy. Variation in heating and factors such as surface orientation or slope (azimuth), absorptivity (albedo), and atmospheric transmissivity also affect wind energy. In addition, wind energy can be accelerated, decelerated, or made turbulent by factors such as terrain, bodies of water, buildings, and vegetative cover.

Wind is air with kinetic energy that can be converted into usable energy by means of a wind turbine. Wind is a distributed resource that can generate electricity cost effectively and competitively in many regions.

8.2 Measuring Power in the Wind

Wind speeds vary by season, time of day, and according to weather events.

The wind speed determines the amount of power it contains. The power available is given by:

$$P = \frac{1}{2} * A * \rho * V^3$$

P = power of the wind [W]

A = windswept area of the rotor (blades) [m^2] = $\pi D^2/4 = \pi r^2$

ρ = density of the air [kg/m^3] (at sea level at 15°C)

V = velocity of the wind [m/s]

As shown, wind power is proportional to velocity cubed (V^3). This is important to understand because as wind velocity is doubled, the available power is increased by a factor of eight ($2^3 = 8$). Consequently, what may appear to be a small increase in average speed yields a significant increase in available energy. Typically, developers looking to capture energy from higher velocity winds select taller wind turbine towers. Accordingly, the wind industry has been steadily moving toward taller towers, and the industry norm has increased from 30 m to 80 m over the last 15 to 20 years.

8.3 Fort Carson Wind Speed Variability

The wind varies widely throughout the day and night and by season as illustrated in the graph of two months of data collected at 50 m (164 ft) at FC#2. As shown Figure 8, there are a number of 10-minute periods that have wind speeds less than 3 m/s (~7 mph). There are also many periods that have wind speeds in excess of 10 m/s (~22 mph). This sort of variability is typical, but further statistical analysis will illuminate important trends and patterns.

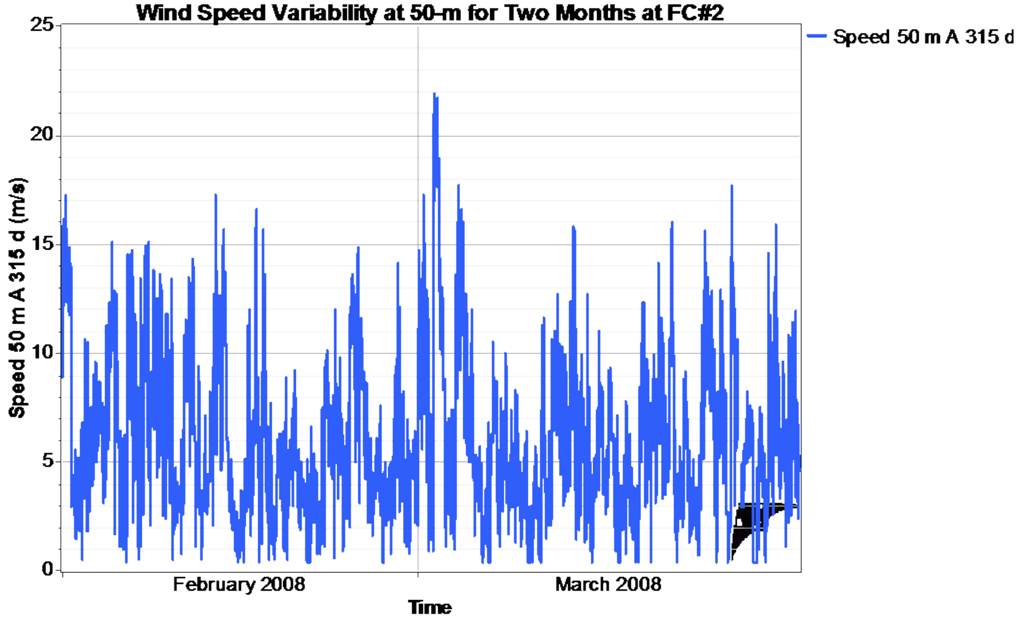

Figure 8. Wind data at 50-m at FC#2

8.4 Fort Carson Monthly Box Plot Statistics

A box plot indicating the monthly maximum wind speed, the daily high, the monthly mean, the daily low, and monthly minimum wind speed measured at FC#2 are shown in Figure 9. This graphic illustrates the seasonal trends of the local wind resource as well as the monthly variability. Every month, FC#2 experiences periods of very high wind speeds. FC#2 experiences wind speeds over 20 m/s (~45 mph) in 9 out of 12 month.

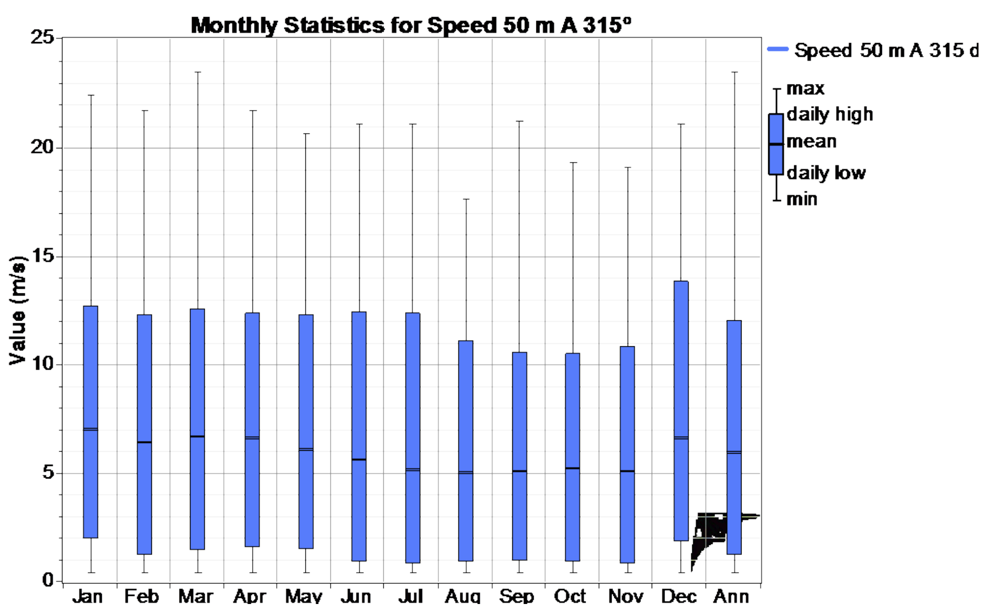

Figure 9. Boxplot of FC#2 for1/1/2008-8/30/2009

8.5 Fort Carson Seasonal Wind Profile

Figure 10 shows the wind speeds at each anemometer height as they are plotted against time to depict the seasonal trends. As can be seen in the graph, the late fall through early spring seasons were the windiest periods. Wind speeds typically increase with increased height above the ground. The collected data follows that pattern. The anemometers at 180° at both 40 m and 58 m showed significant effects of tower shading and were not included in the subsequent analyses.

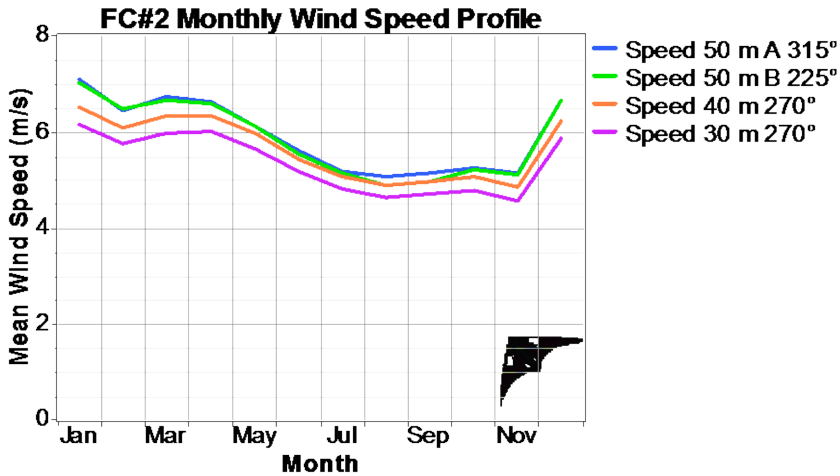

Figure 10. Seasonal wind speed profile at FC#2 for 1/1/2008-8/30/3009

8.6 Fort Carson Diurnal Wind Profile

Figure 11 illustrates how the wind speed varies during the course of the day. The wind speeds increase during late morning and continue increasing until mid-afternoon. Early morning hours are generally the period of lower wind speeds.

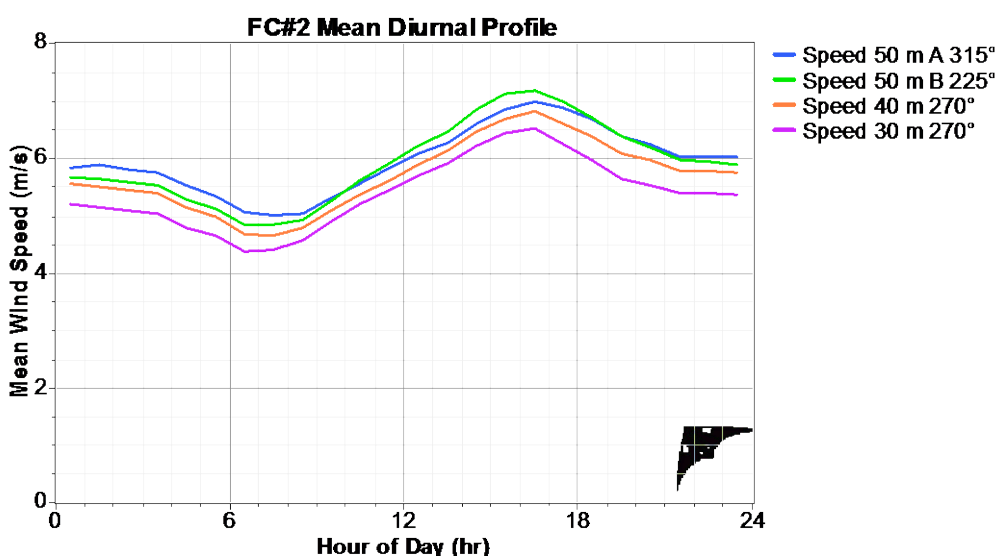

Figure 11. Diurnal profile of the wind speed at FC#2 for 1/1/2008-8/30/3009

Figure 12 shows the diurnal trends for each month of the year. As seen at FC#2, May through August has wind typically peaking in mid-afternoon with very calm conditions in the early morning hours. During the day, the wind speeds at 30, 40, and 50 m (98, 131, and 164 ft) are fairly similar, indicating low vertical wind shear during these periods. January and December are windy, relative to the other months, both day and night.

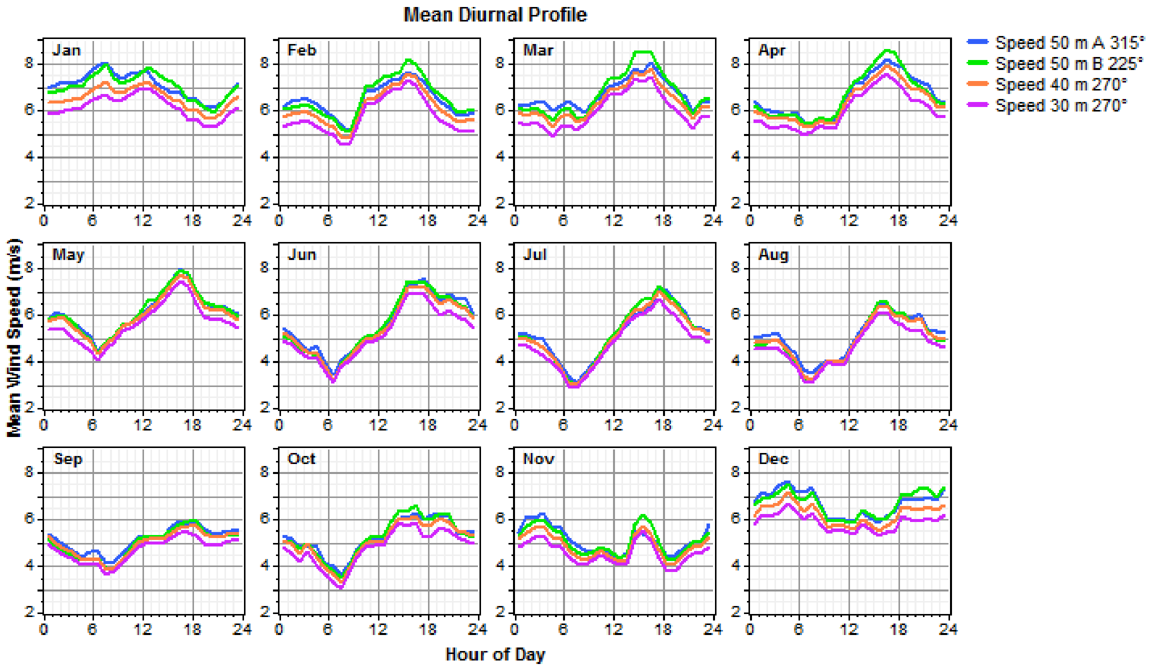

Figure 12. Monthly diurnal profile of the wind speed at FC#2 for 1/1/2008-8/30/3009

8.7 Fort Carson Wind Direction Data

Wind direction informs decisions about turbine siting to maximize exposure to the best winds and minimize exposure to turbulent winds. In this analysis of direction, the compass was divided into 12 sectors, each 30° in size.

8.7.1 Fort Carson Wind Frequency

The graphic on the left in Figure 13 shows the frequency the wind blows from each direction at FC#2. As shown, the wind most frequently comes from the southwest-by-west with secondary wind directions coming from the southeast and the north. It is calm (i.e., wind speed less than 3 m/s (6.7 mph)) about 20% of the time.

The graphic on the right in Figure 13 provides the mean wind speed from each direction that the wind blows, regardless of how often it comes from that direction. When the wind blows, the winds from the north are of nearly as strong as those from southwest-west, whereas the winds from the southeast are considerably milder.

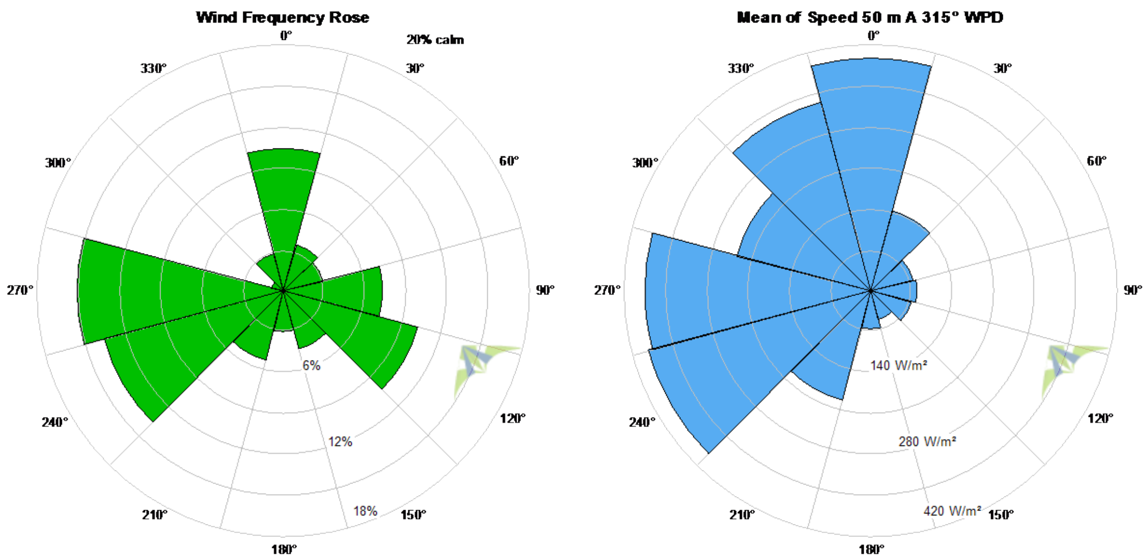

Figure 13. Wind Frequency Rose on left and Mean of Speed Rose on right at FC#2 for 1/1/2008-8/30/3009

The Total Wind Energy Rose in Figure 14 summarizes the direction the most energetic winds come from. The most energetic winds are those from the southwest through west arc. The secondary wind direction is from the north. The winds from the west-southwest (225° to 284°) account for 57% of the wind energy, while those from the north (345° to 14°) account for 16% of the wind energy.

In siting wind turbines at FC#2, there is relatively clear fetch to the west of each potential wind turbine, though there is the higher ridge to the west and the small canyon between the two. This canyon may be a source of turbulence. To the north, the fetch is generally clear with pinion and other relatively short trees and bushes and with the ground relatively flat.

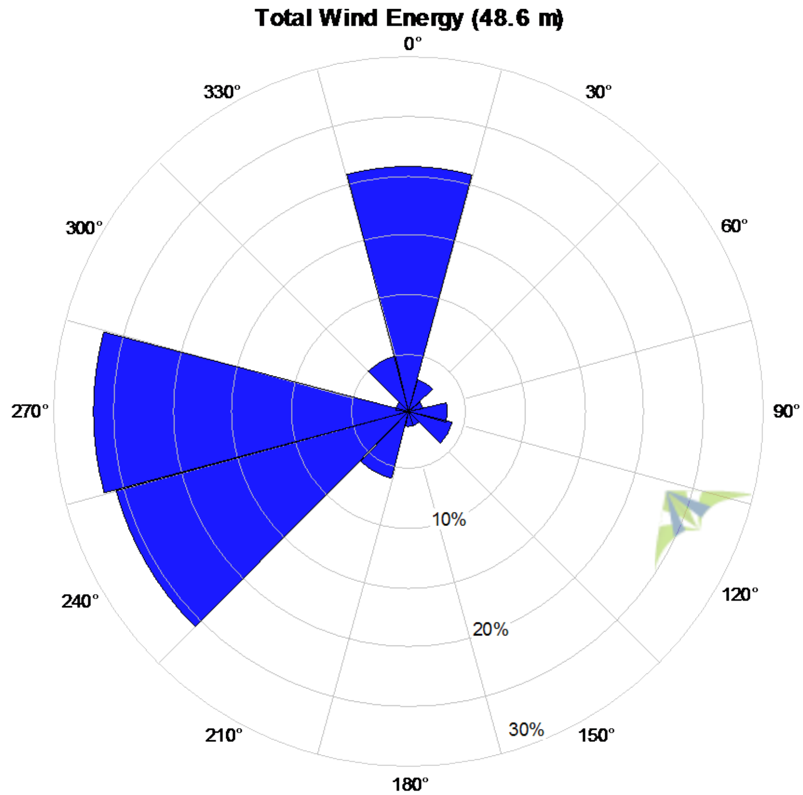

Figure 14. Total wind energy rose at FC#2 for 1/1/2008-8/30/3009

The monthly total wind energy roses at FC#2 in Figure 15 point to both the southwest-through-west arc as predominant in the fall/winter (November through March) as a source of wind energy. The north sector has its most energetic winds, though with lower power, during the spring/summer/early fall (April through October).

There were two anemometers at 48.6 m (159 ft), one at 225° and one at 315°. Given the predominant wind direction depicted in Figure 14, there is potential for the tower to influence the anemometer readings at 225° (often referred to as tower shading). The relatively consistent lower wind speed measurements with the anemometer at 225° vs. the anemometer at 315° may be the result of turbulence caused by the tower itself. Consequently, for the duration of the report, the anemometer at 315° will be used. In the event that the anemometer measurements at 315° are deemed unreliable due to occasional tower shading because of the wind direction, the readings from the anemometer at 225° will be used.

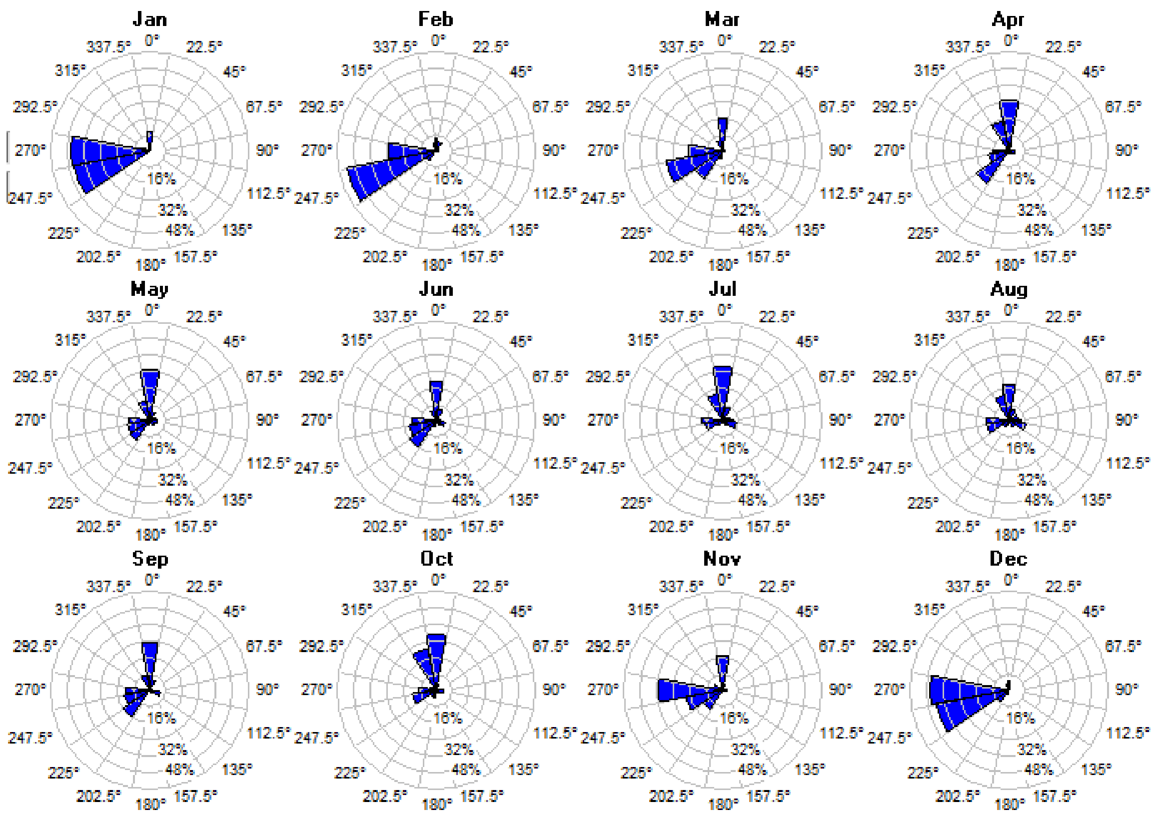

Figure 15. Total wind energy rose by month at FC#2 for 1/1/2008-8/30/3009

8.8 Fort Carson Wind Frequency (Probability) Distribution

Figure 16 illustrates a Weibull distribution of the frequency (percent of time) that the wind at 58 m is at a given speed. There are two commonly used factors to describe the distribution function, the Weibull *c* and Weibull *k* factors. The Weibull *c* is the scale factor for the distribution related to the annual mean wind speed. The Weibull *k* value is a unitless measure indicating the shape of the distribution of the wind speeds about the mean with values ranging from 1.0 to 3.0.

In Figure 16, the best-fit Weibull distribution parameters for the measured data at FC#2 are k = 1.78 and c = 6.71 m/s. The distribution shows that the most frequent winds, or mode of the dataset, are between 4 to 5-m/s as measured by the wind sensor at 58 m.

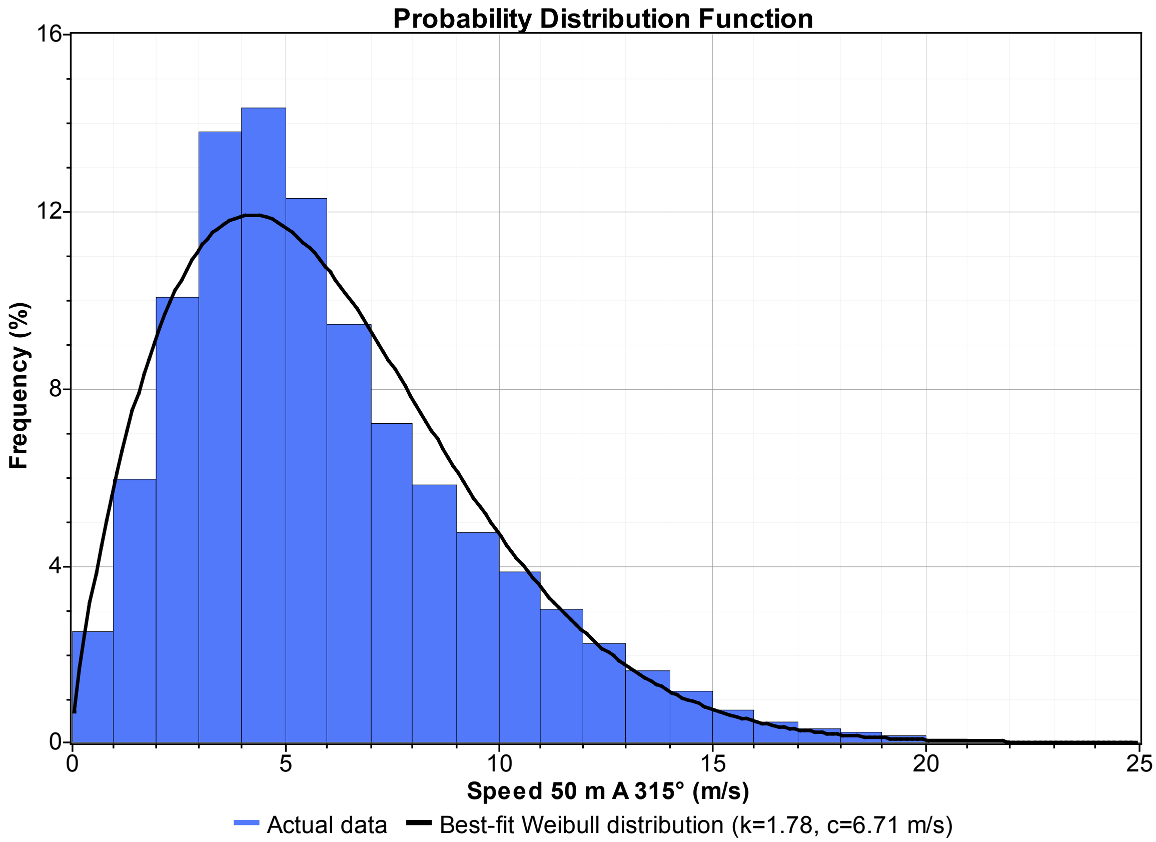

Figure 16. Wind frequency distribution at FC#2 for 1/1/2008-8/30/3009

8.9 Vertical Wind Shear Factor (VWSF)

VWSF is the change in wind speed with increasing height above ground. Typically, wind speeds increase with height. This variation of wind speed with elevation is called the vertical profile of the wind speed, or VWSF. In wind turbine engineering, the determination of VWSF is an important design parameter since: (1) it directly determines the productivity of a wind turbine on a tower of certain height, and (2) it can represent the level of cyclic mechanical loading on the wind turbine system.

Analysts typically use one of two mathematical relations to characterize the measured wind shear profile:

- Power Law profile
- Logarithmic Law profile.

8.9.1 Power Law

The Power Law equation is:

$$V = V_{ref}\left[\frac{Z}{Z_{ref}}\right]^{u}$$

V = wind speed at height of interest (e.g., hub height)

V_{ref} = wind speed measured at height Z_{ref}

Z = height of interest (e.g., hub height)

Z_{ref} = height of measured data

α = wind shear exponent

The wind shear exponent, α, or VWSF, defines how the wind speed changes with height. When the actual wind shear value is not known, a typical value used for estimation is 0.14 (1/7 Power Law). When wind speed data are available at multiple heights, the wind shear factor can be calculated using the Power Law equation.

The VWSFs from several heights with known wind speeds are used to estimate both the VWSF and wind speed at other heights of interest (e.g., turbine hub height). Depending on the type of terrain and surface roughness features, the VWSF may vary from 0.0 to 0.4.

8.9.2 Logarithmic Law

The Logarithmic Law uses a parameter known as the *surface roughness length* (measured in meters) in predicting the wind shear profile. Surface roughness length describes the conditions of the ground and its expected impact on wind flows and ranges, as shown in Table 8.

Table 8. Surface Roughness Lengths and Descriptions[3]

Terrain Description	Surface Roughness Length, z_0 (m)
Very smooth, ice and mud	0.00001
Calm open sea	0.0002
Blown sea	0.0005
Snow surface	0.003
Lawn grass	0.008
Rough pasture	0.01
Fallow field	0.03
Crops	0.05
Few trees	0.1
Many trees, hedges, few buildings	0.25
Forest and woodlands	0.5
Suburbs	1.5
Centers of cities with tall buildings	3.0

[3] Ray, M.L.; Rogers, A.L.; McGowan, J.G.; (2002). *Analysis of Wind Shear Models and Trends in Different Terrains.* http://www.ceere.org/rerl/publications/published/2006/AWEA%202006%20Wind%20Shear.pdf. Accessed July 2011.

The Best Fit Power Law Exponent was calculated with the data collected at FC#2. Table 8 shows the calculated wind shear values in the "Best-Fit Power Law Exponent" column. The wind shear exponent is high in the two sectors from 75° to 134° and from 255° to 315°. Combined, these two sectors represent 46.2% of the data, so the impact is considerable.

Table 9 shows the application of surface roughness lengths. The surface roughness parameter is "solved for" from the existing wind speed data at various heights. The resultant characterization may not always match the actual surface conditions, but it serves as a descriptor of the vertical wind shear profile. The surface roughness lengths have been calculated for FC#2 and are shown in the "Surface Roughness" column at the far right in Table 9. There are two primary directions where surface roughness appears to have an impact (high values): from 75° to 134° and from 255° to 315°. There is rough, rugged terrain both east and west of FC#2, so this characterization appears accurate.

Table 9. Power Law Exponent and Surface Roughness Length at FC#2 for 1/1/2008-8/30/3009

Direction Sector	Time Steps	Mean Wind Speed			Best-Fit Power Law Exponent	Surface Roughness
		Speed 50 m A 315°	Speed 40 m 270°	Speed 30 m 270°		
°	#	m/s	m/s	m/s	unitless	m
15° - 45°	3,867	5.1	5.3	5.1	0.019	0
45° - 75°	3,686	4.3	4.3	4.1	0.101	0.001716
75° - 105°	7,967	4.5	4.0	3.9	0.295	1.366647
105° - 135°	10396	4.6	4.4	4.1	0.220	0.412073
135° - 165°	5187	4.0	4.0	3.8	0.149	0.044264
165° - 195°	4013	4.0	4.0	3.8	0.126	0.012998
195° - 225°	5,992	5.2	5.2	4.9	0.125	0.012433
225° - 255°	12,579	7.4	7.3	6.9	0.145	0.037992
255° - 285°	13,360	7.8	7.5	7.0	0.240	0.588244
285° - 315°	1,020	5.9	5.7	5.4	0.200	0.257560
315° - 345°	2,833	7.0	6.9	6.6	0.149	0.044522
Overall Annual Figure		**6.605**	**6.383**	**6.245**	**0.121**	**0.009460**

Figure 17 is a graph comparing the measured data to the Power Law approach to vertical wind shear versus the Logarithmic Law approach. Both methods track closely with the measured data at FC#2 and each other. The difference between these approaches, even extrapolated to 80 m (262 ft) is negligible. The Power Law was used for subsequent energy calculations as it is tied more closely to statistical calculations rather than surface roughness approximations.

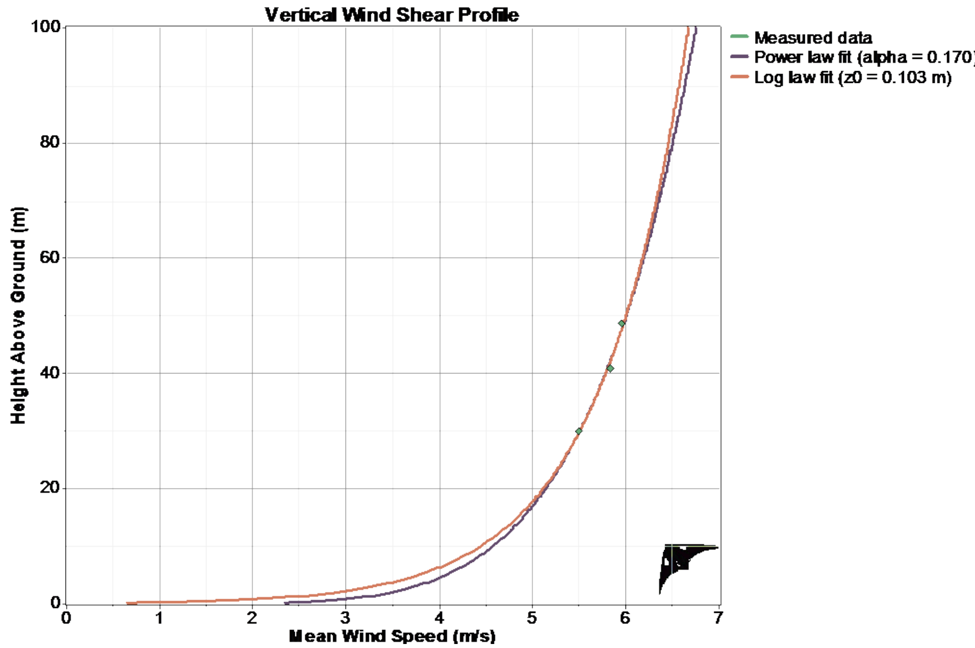

Figure 17. Vertical wind shear profile at FC#2 for 1/1/2008-8/30/3009

The daily wind shear at Fort Carson as it varies by month is shown in Figure 18 below. The months with the higher wind shears generally have higher wind speeds, especially during nighttime hours.

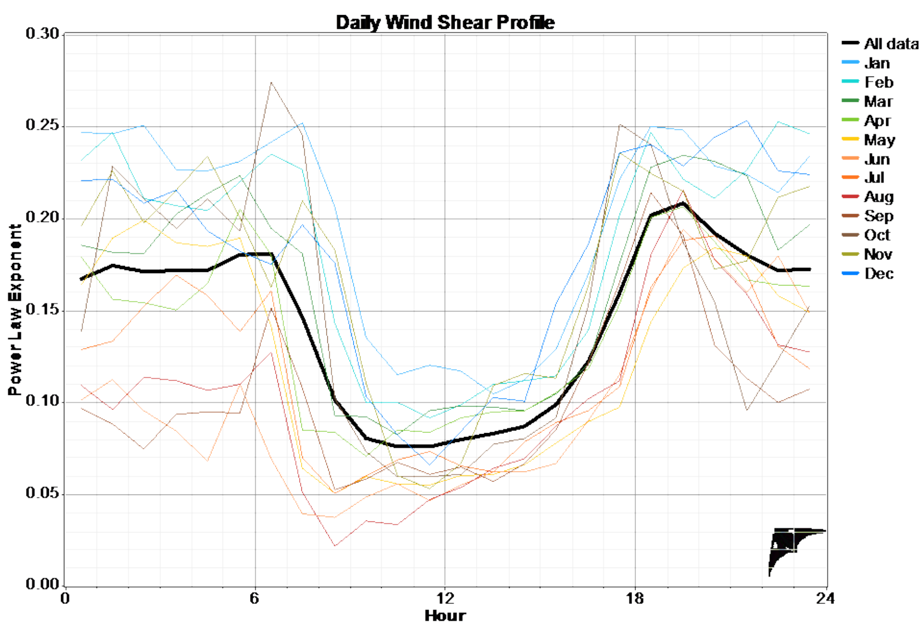

Figure 18. Daily wind shear profile by month at FC#2 for 1/1/2008-8/30/3009

8.10 Turbulence Intensity (TI)

TI is the standard deviation of the wind speed within a time-step, divided by the mean wind speed over that same time-step. TI is a measure of the gustiness of the wind. High turbulence is associated with increased wind turbine system wear and increased operation and maintenance (O&M) costs. At lower wind speeds, the calculated turbulence intensity is higher, as seen in Figure 19. However, the higher turbulence at low wind speeds is not a concern because of the low power available at those low wind speeds. Turbulence at higher winds speeds is of greater interest and concern to wind turbine manufacturers.

Turbulence analysis determines the suitable types of turbine designs for a wind energy project. Because wind turbines must withstand a variety of wind conditions, design standards have been developed by the International Electrotechnical Commission (IEC). The IEC 61400-1:2005[4] has components for wind speed and for turbulence, and can be seen in Table 10. The standard designates four different classes of wind turbines, I through IV, which are designed for varying degrees of wind resource, with Class I being very high mean wind speed and Class IV being low mean wind speed.

The standard also designates a wind turbulence classification, A through C, that describes the amount of turbulence a turbine must be designed to withstand, with A being the highest turbulence and C being the lowest. In recent years, wind turbine manufacturers have introduced designs for sites with lower wind speeds and low turbulence known as low wind speed turbines. These turbines have larger rotors, for a given generator size, and are thus capable of producing significantly more annual energy at a low wind speed site than the Class I or II or Class A or B turbines of similar generator size.

There are several types of TI of interest. The representative TI, for a set of 10-minute time-steps, is equal to the 90th percentile of the TI values. Assuming a normal distribution of these values, it represents the mean value plus 1.28 standard deviations. The mean TI is the mean value of all of the TI data at a particular wind speed.

Table 10 displays design wind speed and mean TI ratings for the different wind turbine design classes.

[4] International Electrotechnical Commission (IEC). "International Standard IEC 61400-1 Third Edition." Geneva, Switzerland: IEC, 2005.

Table 10. IEC Wind Turbine Classes, Ratings, and Characteristics of Turbulence Intensity[5]

WTG* Class	IEC I High Wind	IEC II Medium Wind	IEC III Low Wind	IEC IV Low Wind
V_{ave} average wind speed at hub-height (m/s)	10	8.5	7.5	6
V_{50} extreme 50-year gust (m/s)	70	59.5	52.5	42
Mean turbulence intensity at 15 m/s - turbulence Class A	14% - 16%			
Mean turbulenceiIntensity at 15 m/s - turbulence Class B	12% - 14%			
Mean turbulence intensity at 15 m/s - turbulence Class C	0 - 12%			

* Wind Turbine Generator

Figure 19 shows the representative and mean TI as a function of wind speed at 50-m (164-ft) at FC#2.

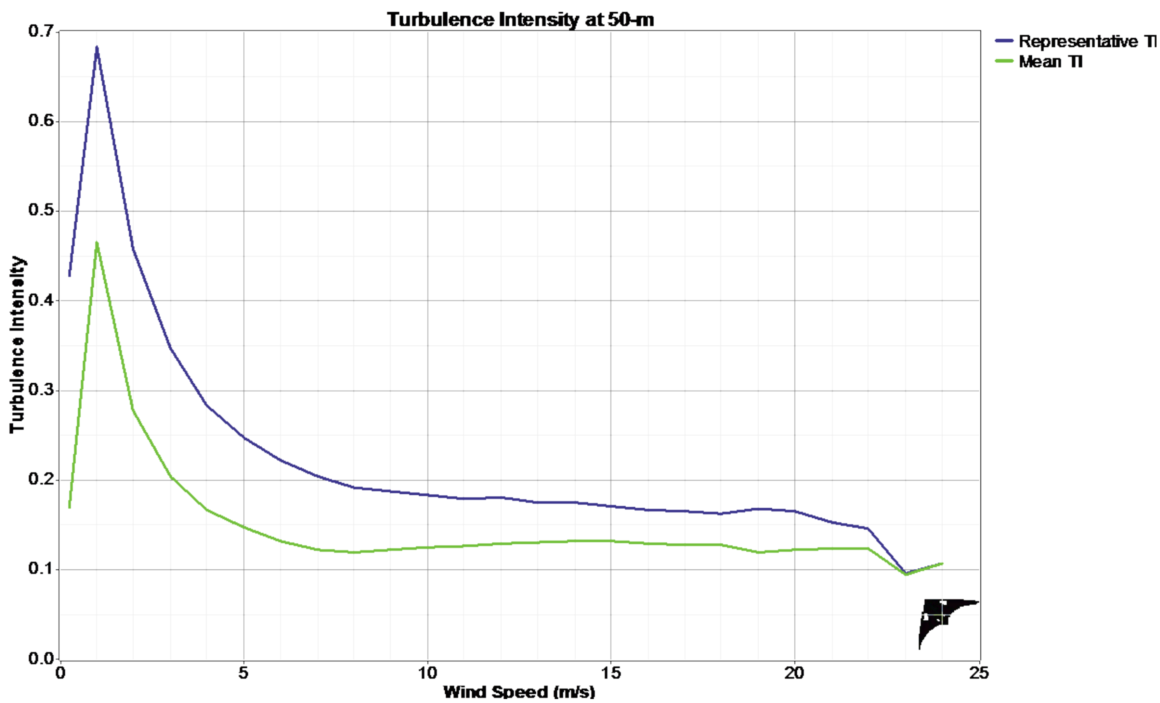

Figure 19. Representative and mean turbulence intensities at FC#2 for 1/1/2008-8/30/3009

Figure 20 shows the IEC turbulence ratings relative to the representative TI. A point of primary interest is the mean TI at 15 m/s, which is 0.13 (13%). This indicates low turbulence and that a Class B wind turbine is possible.

[5] IEC/TC88, 61400-1 ed. 3, Wind turbines - Part 1: Design Requirements, International Electrotechnical Commission (IEC), 2005.

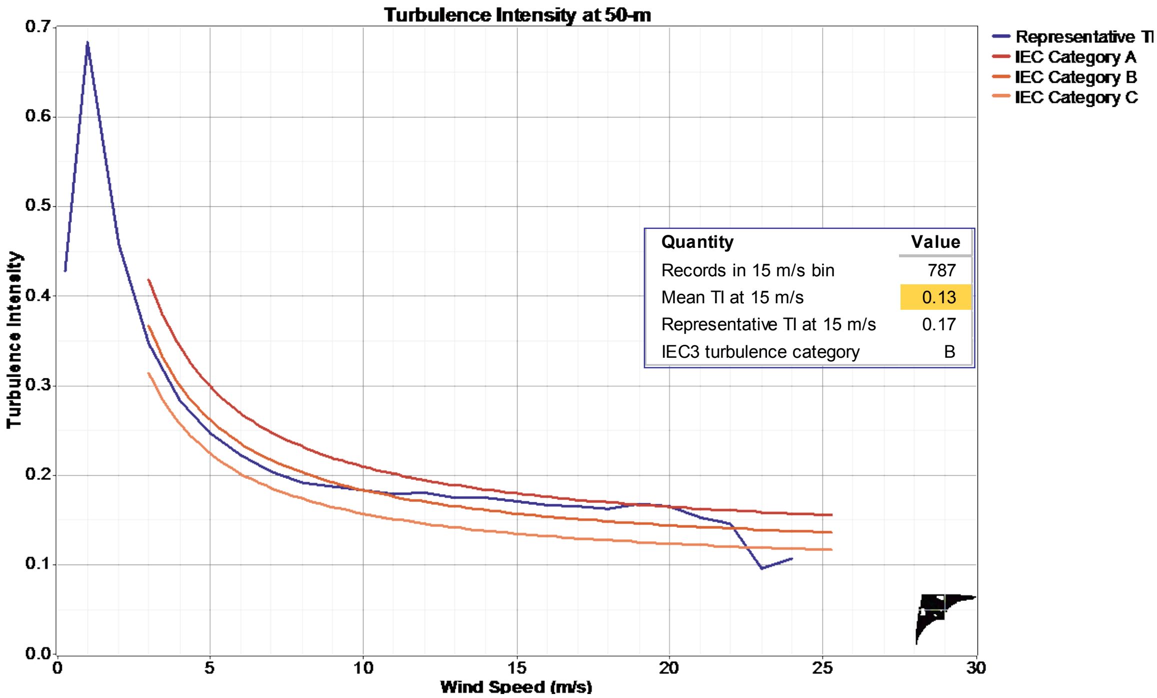

Figure 20. Turbulence intensity at FC#2 for 1/1/2008-8/30/3009

9 Long-Term Data Adjustment

It is important to determine if the data monitoring period is representative of the long-term wind resource at the site. Different methodologies are used to estimate the long-term wind resource at the site where the short-term met tower study was conducted. A standard industry approach with a number of variations is measure-correlate-predict (MCP), where a short-term dataset is correlated to a long-term wind dataset from a nearby monitoring station (reference site). The correlation relationship is then applied to the measured data at the site of interest to project the expected long-term wind resource. An industry-standard MCP method, the ratio of the mean of monthly means, was used in this analysis.

The purpose of this estimate is to provide a normalized, realistic estimate of the long-term wind resource and the resultant wind turbine energy production. Though wind turbine production at any site will vary year-to-year, the goal is to have the long-term energy production estimate minimize the uncertainty of the relatively short period of collected data.

9.1 Long-Term Datasets

The Federal Aviation Administration (FAA) and National Weather Service (NWS) own and operate automated surface observing systems (ASOS) for the purposes of aviation and weather observation. These datasets generally represent the most consistent weather observation data as the FAA and NWS are tasked with building a historical long-term surface weather observation record. Other long-term weather observation datasets include military airfield observations, ocean buoy observations, and other forms of surface observations.

The data from the following stations were accessed and analyzed for suitable, long-term correlation. For each of the stations, the r^2 correlation factors were low and were not used for MCP. Generally speaking, r^2 values of 0.75 or greater are required to have confidence that the two sites are comparable and wind trends observed for the long-term site apply to the short-term site of interest.

Table 11. Nearby ASOS Met Towers

Station ID #	Station Name	Mean Annual Wind Speed m/s (mph)	Distance to FC#2 km (mi)	Correlation Timeframe 1 hour r^2	8 hours r^2	1 day r^2
724680	FC BUTTS	3.7 (8.3)	27 (~17)	0.243	0.330	0.383
724640	Pueblo	3.6 (8.1)	21 (~13)	0.312	0.467	0.579
724660	Colorado Springs	4.3 (9.6)	43 (~27)	0.047	0.139	0.325

9.2 Regional Energy Deployment System (ReEDS) Data Set

NREL has purchased a wind data set from AWS Truepower[6] for a range of wind analysis purposes. This data represents a mix of meso-scale modeled data corrected and verified

[6] AWS Truepower, http://www.awstruepower.com/. Accessed 1/12/2012

with available met tower measurements. The data sets were created for specific regions and have 20-km (12.4-mi) resolution and vary in height above the ground. The data sets themselves are proprietary (AWS) and confidential (for NREL). This data was deemed more suitable for long-term correlation with FC#2 than the ASOS met tower data due to the low r^2 values during MCP correlation. The data trends/factors, based on elevation, terrain, and wind resource, were applied to a "typical meteorological year[7]" (TMY) data set at the 50-m (164-ft) level as this matches the height of the data collected at FC#2.

The blue line in Figure 21 shows the annual variation in wind speed over a 14-year period. The red line represents the long-term mean wind speed from the data set. The green shaded box represents the period of interest (2008) that wind speed and direction were measured at FC#2. The period of collection at FC#2 represents a higher than average wind period and the FC#2 data will need to be adjusted downward to reflect that.

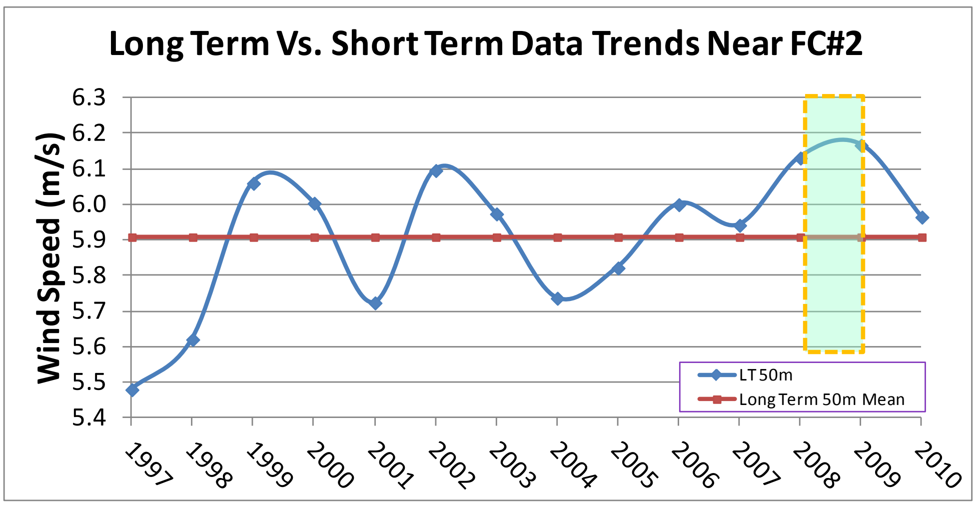

Figure 21. Long term mean wind speed using the ReEDS data for FC#2

For the adjustment of the FC#2 data, only the 2008 data was used. There were nine months of 2009 data with wide swings in wind speed that were not well suited for a partial-year analysis. The ratio of the mean wind speed of the given year (e.g., 2008) to the long-term mean wind speed can be seen in Table 12. The wind speed values for the data set are 3.76% higher than for the average wind year. Consequently, the collected data at FC#2 was adjusted downward 3.76%.

Table 12. Ratio of the Mean Wind Speed by Year to Long Term Mean at Site #101095

Year	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Ratio to Mean	0.927	0.951	1.026	1.016	0.969	1.032	1.011	0.971	0.985	1.015	1.006	1.038	1.044	1.010

After the adjustment of the measured data at FC#2 for 2008, the ratios in Table 9 were applied forward and backward from 2008 to obtain a 14-year data set representative of the long term wind speed at the site.

[7] National Solar Radiation Data base: 1991-2005 Update, Typical Meteorological Year 3. http://rredc.nrel.gov/solar/old_data/nsrdb/1961-1990/tmy2/ Accessed 5/24/2012.

9.3 Vertical Wind Shear Adjustment

To project the annual energy performance of wind turbines with hub heights in the 70 to 100-m (230-328-ft) range, vertical extrapolations were completed on the existing data from FC#2. The extrapolations were done beginning at 50 m (164 ft), increasing by 10-m (33-ft) increments to 110 m (361 ft). The miniSODAR measured data from 30 to 120 m (98 to 394 ft) above the ground. The ReEDS data set includes wind speed at 50 m, 80 m, 110 m, and 140 m (164 ft, 262 ft, 360 ft and 459 ft). All the wind speed data was compared at the 50 m, 80 m, and the 110 m level with the FC#2 serving as the base since its measurements were in between the ReEDS (lower than FC#2) and the miniSODAR (higher than FC#2). The results can be seen in Table 13.

Table 93. Comparison of Wind Speeds at Common Heights from Three Data Sources

Data Set	50-m	80-m	110-m	50-m	80-m	110-m
	m/s	m/s	m/s	%	%	%
ReEDS near FC#2	5.9	6.3	6.5	1.9%	1.6%	-1.1%
FC#2	5.8	6.2	6.6	100%	100%	100%
MiniSODAR	5.7	6.3	6.9	-1.8%	1.6%	4.3%

The data sets are in very close agreement at 80 m (262 ft), though the vertical wind shear profiles for each data set vary slightly resulting in variation in wind speeds both below and above 80 m (262 ft). The met tower data, conservatively representing actual on-site data at multiple heights and its calculated vertical wind shear, based on anemometer readings at 30 and 40 m (98 and 131 ft), were deemed suitable for use for the energy production analysis that follows.

10 Energy Production Estimates

This section discusses the potential energy generation from wind turbines at Fort Carson. Several layout scenarios and turbine sizes and types were evaluated. Per the preliminary screening results with the Federal Aviation Administration (FAA), Fort Carson must submit formal applications for the location of specific turbines at predetermined heights above ground (including rotor) in order to determine what size wind turbine will ultimately be allowed. On-site military operations are a primary concern in this part of the base. The results of the preliminary screening are located in Appendix C.

10.1 Site Layout

There may be transmission/distribution line limitations or mission/operations factors that impact the size of the wind project that is ultimately approved and installed at Fort Carson. Analysis was conducted for a larger build-out by assuming the siting of utility-scale turbines at every viable site on this ridge. A rough sketch of each potential wind turbine footprint is in Figure 22. A complete layout of scenarios with several suitable turbines is recommended as the number of 1.6-MW turbines that fit on this ridge is likely to be somewhat larger than the number of 3.0-MW turbines that will fit.

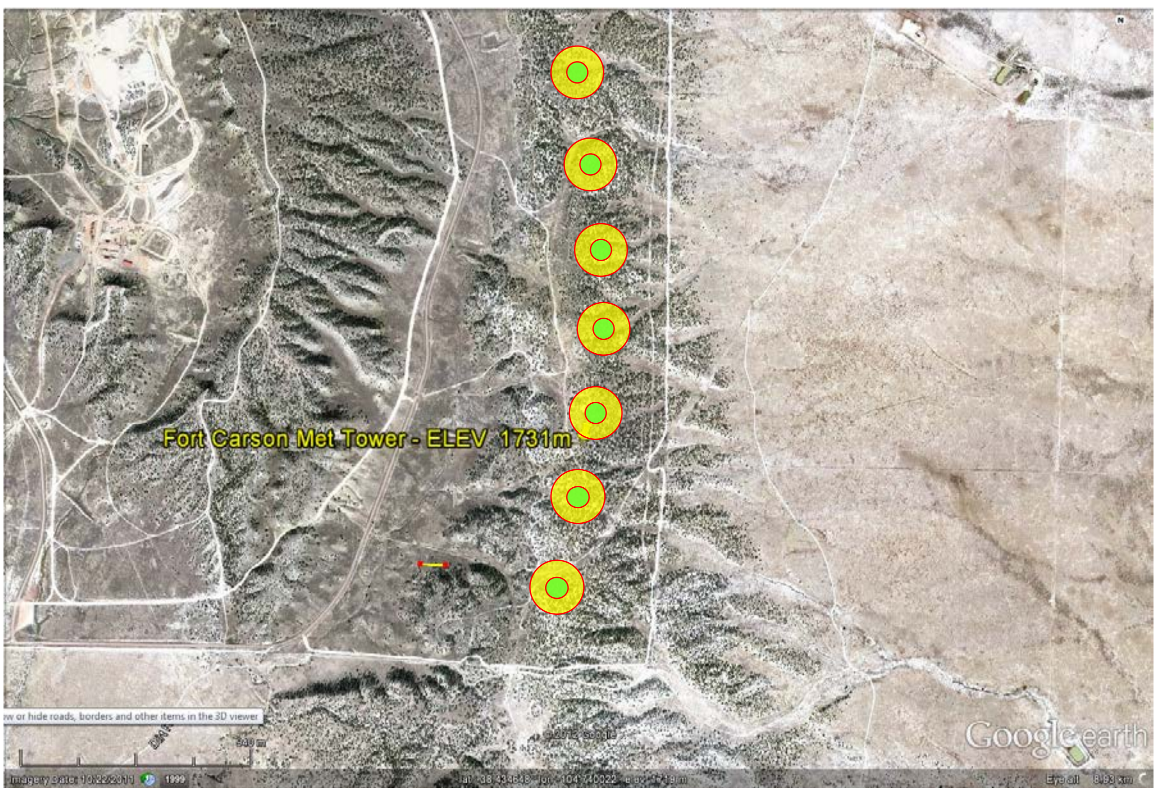

Figure 22. Potential wind turbine layout in southern half of southeast corner of Fort Carson.

Image Credit: Google Earth (edited by Robi Robichaud)

10.2 Wind Turbines Modeled

A broad range of utility-scale wind turbine models were selected to represent potential project scenarios at Fort Carson. These turbines were selected based upon IEC turbine type as well as general availability and access to the power curves. These turbines represent low-wind and moderate-wind classifications. The range of turbines is intended to showcase the available turbines with large nameplate capacities (1.6 MW or greater) as well as the new generation of low wind-speed machines, which couple an enlarged rotor with a standard generator. All power curves were for sea-level air density at 1.225 kg/m^3. The modeling accounts for the elevation increase and air density decrease at 1,731 m above sea level (5,679 ft). The turbine models are shown in Table 14. Many companies are continuing to increase their rotor size and turbine output so there may be even more economical wind turbine available in the not-too-distant future. The turbines modeled here do not reflect any endorsement on the part of NREL for any particular wind turbine.

Table 104 Wind Turbine Specifications Used in Modeling

Turbine Manufacturer, Size, and Model	Nameplate Capacity	Turbine Class	Hub Height	Rotor Span	Max Height	Max Height	FC#2 Site Scenario	Wind Plant Capacity
	MW	#	m	m	m	ft	# turbines	MW
GE 1.6 XLE	1.6	III	80	100	130	427	7	11.2
Suzlon S97	2.1	III A	80	97	128.5	422	7	14.7
Siemens SWT-2.3 108	2.3	III	80	108	134	440	7	16.1
Siemens SWT-2.3 113	2.3	III	99.5	113	156	512	7	16.1
Nordex N117	2.4	II-III a	91	117	149.5	490	7	16.8
Vestas V112 - 3.0 MW	3.0	II a	84	112	140	459	7	21.0

Other factors to consider in the turbine selection process include cost, availability, constructability, transportability, warranty, the types of other proximal wind turbines, O&M, etc.

10.3 Energy Production Loss Factors

All energy projects will incur some type of energy loss due to real-world conditions differing from the idealized case. The resulting decrease in efficiency is accounted for with a series of estimated and calculated loss factors. The annual wind turbine energy production estimates were calculated assuming 17.7% losses, primarily due to wind turbine downtime, soiling/icing, electrical and other losses. A more detailed explanation of these production loss factors can be found in Appendix E.

10.4 Projected Wind Project Performance

Performance estimates were calculated for several suitable low wind-speed, utility-scale turbines using the Windographer software. Table 15 summarizes the annual wind turbine energy production estimates. The column at the far right, labeled "% of Base Energy" indicates how much of Fort Carson's load the potential wind projects will meet per year. As shown, these wind projects could meet 16-27% of Fort Carson's annual electric load which would make wind a solid contributor in the Net Zero Energy Initiative.

Table 115 Summary Wind Project Energy Performance of Sample Wind Turbines at Fort Carson

Turbine Manufacturer & Model	Rated Power	Mean Net Power	Mean Net Annual Energy /Turbine/Yr	Net Capacity Factor	FC#2 Site	Wind Plant Capacity	Wind Plant Annual Output	% of Base Energy
Turbine	MW	kW	kWh/yr	%	# Turb.	MW	MWh/yr	%
GE 1.6 XLE	1.6	415	3,634,101	25.9	7	11.2	25,439	15.7%
Suzlon S97	2.1	475	4,162,921	22.6	7	14.7	29,140	18.0%
Siemens SWT-2.3 108	2.3	572	5,014,293	24.9	7	16.1	35,100	21.6%
Siemens SWT-2.3 113	2.3	691	6,049,308	30.0	7	16.1	42,345	26.1%
Nordex N117	2.4	647	5,665,505	26.9	7	16.8	39,659	24.4%
Vestas V112 - 3.0 MW	3.0	677	5,933,315	22.0	7	21.0	41,533	25.6%

11 Economic Analysis

There are several financial paths that may be open to Fort Carson. In this section, primary options are investigated and their similarities and differences explained beginning with the potential impact of various incentives.

11.1 Incentives

Incentives can take many forms and each incentive may appeal to different parties to a wind turbine project depending upon their role in the project, their available resources, and the impact of the incentive on their resources. Incentives, such as the Production Tax Credit (PTC), have been strong drivers for equity partners in wind farms. Net metering has been an incentive that appeals to the local owner of a smaller, distributed generation-type of wind project as there are size limits well below commercial wind turbine range.

11.1.1 Production Tax Credit (PTC)

The PTC[8] has been a significant driver in the wind energy boom of the last seven years as it has been in place continuously since 2005. The PTC enables eligible taxpayers to receive a tax credit equal to $0.022/kWh for every kWh produced during the first ten years of operation of a wind (and other renewable energy technologies) project and sold to a third party. Depending on the wind resource and the competing cost of energy (COE), the PTC value may represent 15 to 40% of the cost of energy produced. Due to many factors, the net effect of the PTC is somewhat less than $0.022/kWh. In other words, if the COE for a wind turbine project was $0.096/kWh without the PTC incentive, utilizing the PTC does not typically result in the new COE being $0.074/kWh. It may be more likely in the range of $0.078 to $0.085/kWh depending on a range of other project cost factors.

The PTC is not available in the case where Fort Carson purchases the wind turbine outright with cash through the Energy Conservation Investment Program (ECIP) because neither Fort Carson nor the Army are taxpaying entities. In the case of energy savings performance contract (ESPC) or power purchase agreement (PPA) scenarios, a third party would take advantage of the PTC to enhance the overall project economics.

The PTC is scheduled to expire on Dec 31, 2012. It is not certain if Congress will extend the PTC for one or more years. It has been extended retroactively several times in the past but the economics of wind without incentives has improved considerably since the early 2000s. At this point in time (8/2012), indications from Senate Finance Committee are that the PTC will be extended for one year.[9]

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[8] Renewable Energy Production Tax Credit (PTC), FEDERAL Incentives/Policies for Renewables & Efficiency, DESIRE Database of State Incentives for Renewables & Efficiency. http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=US13F&re=1&ee=1, accessed January 2012 and Renewable Electricity, Refined Coal, and Indian Coal Production Credit, IRS Form 8835 2009, http://www.irs.gov/pub/irs-pdf/f8835.pdf, accessed January 2012.

[9] Colman, Z., E2 Wire, THE HILL'S Energy & Environment Blog, 08/07/2012. http://thehill.com/blogs/e2-wire/e2-wire/242559-reid-very-confident-wind-credit-will-clear-senate

11.1.2 Targeted Incentives

There are several other types of incentives available for renewable energy systems in Colorado. Unfortunately, they target sectors such as residential, commercial, industrial, state, or community renewable energy projects, not the federal government. Many of these incentives have size restrictions limiting systems to 10, 25, or 100 kW. As such, they will not help Fort Carson in regards to a multi-megawatt wind project.

One utility incentive that may have implications that could be of value to Fort Carson is an aspect of the Renewable Portfolio Standard (RPS) that Colorado instituted in 2004 and adopted modifications in 2007.

Municipal utilities, such as Colorado Springs Utilities, must have a certain percentage of their retail sales come from either wholesale distributed generation or retail distributed generation, regardless of technology type, according to the following schedule[10]:

- 1% of its retail electricity sales in Colorado for the years 2008-2010;
- 3% of its retail electricity sales in Colorado for the years 2011-2014;
- 6% of its retail electricity sales in Colorado for the years 2015-2019; and
- 10% of its retail electricity sales in Colorado for the year 2020 and each following year.

There are credit multipliers for four types of projects that apply to the utilities as an incentive to work with entities to accomplish certain renewable energy goals. One project can only receive one multiplier and they cannot be combined. They include:

- Each kilowatt-hour (kWh) of eligible electricity generated in state, other than retail distributed generation, can receive 125% credit for RPS-compliance purposes.
- Electricity generated at a "community-based project," a project not greater than 30 megawatts (MW) in capacity that is located in Colorado and owned by individual residents of a community or by an organization or cooperative that is controlled by individual residents, or by a local government entity or tribal council, can receive 150% credit for RPS-compliance purposes.
- Solar electricity located in the territory of a cooperative or municipal utility and generated by a facility that begins operation before July 1, 2015, can receive 300% credit for RPS-compliance purposes. (Solar electricity generated by a facility that begins operation on or after July 1, 2015, receives 100% credit.)
- Projects up to 30 MW that are interconnected to electrical transmission or distribution lines owned by a cooperative or municipal utility, which are

[10] Colorado Incentives/Policies for Renewables & Efficiency, Renewable Energy Standard, DESIRE Database of State Incentives for Renewables & Efficiency. http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=CO24R&re=1&ee=1. Accessed Feb 2012.

installed prior to December 31, 2014 can receive 200% credit for RPS-compliance purposes. With the exception of investor-owned utilities using this multiplier, it is only available for the first 100 MW of projects statewide.

It appears that either the first (with no time limit) or the fourth (must be installed by Dec 31, 2014 and is available only for the first 100 MW statewide) might serve as an incentive for Colorado Spring Utilities to support the development of a wind project at Fort Carson in some way and it merits further exploration. The RPS may be a driving force for Colorado Springs Utilities to want/need to develop a utility energy services contract (UESC) for wind and other energy services with Fort Carson.

11.1.3 Renewable Energy Certificates

Renewable energy projects generate additional value in the form of Renewable Energy Certificates (RECs). RECs capture the beneficial renewable energy attributes of the project (i.e., electricity produced with no greenhouse gas production). In many renewable energy projects, the RECs can provide a small, additional revenue stream to enhance the project economics. There are organizations that verify the green attributes for the existence of RECs with particular projects and there are markets for buying and selling RECs. Some states have programs whereby the value of RECs is considerable and they play a vital part in the economics of renewable projects.

Due to the requirements of the Energy Policy Act of 2005 (EPAct 2005), for Fort Carson to meet the renewable energy requirements of the law, it must retain the RECs associated with the production of wind energy in this project. In cases where the market value for RECs are high, some federal entities and others have sold the RECs that are associated with their on-site renewable energy project and purchased replacement RECs at a much reduced cost to gain capital advantage to enhance project economics. Solar RECs are often ones that have a high value. If one was worth $0.15/kWh, it would be possible to sell it and purchase a cheaper renewable REC for $0.002/kWh (typically from a landfill methane-type project) and use the net difference of $0.148/kWh to help finance the project with an initial cash infusion to help buy down the cost of the renewable energy project. If the project involved tens of millions of kWh per year, the economic advantages of this approach become more apparent.

The value of RECs varies over time. Estimates for national wind RECs in 2011 were in the $2 to $8/megawatt-hour (MWh) ($0.002-0.008/kWh) range.[11] Realistically, there may not be a large enough margin for wind RECs to justify trading them. The more easily realized value is keeping them with the project owner. If Fort Carson were not to own the wind turbine project, it could consider structuring its PPA or ESPC such that Fort Carson would obtain the ownership of RECs to meet EPAct 2005 renewable energy goals.

11.2 Wind Turbine Project Cost Factors

There are many economic factors to consider in a wind turbine project. Factors such as the wind turbine cost, balance of system, foundation, interest rates, discount factors, interconnection, environmental impacts, etc. all have a role to play in the analyses. Many of these factors vary from project to project and there is not an effective predictor of what

[11] http://apps3.eere.energy.gov/greenpower/markets/certificates.shtml?page=5. Accessed Feb 2012.

the costs will be at a given site in the future. It is usually more effective to analyze the cost and performance parameters of actual bids that developers submit responding to a request for proposal (RFP) than to develop a full range of expected cost and performance parameters from developers' speculations. The developers understand they can't be held to speculative estimates and also that it might not be in their best interests to divulge competitive pricing information short of an official response to an RFP. Even the best intentioned speculative bid will be impacted by dynamic market forces affecting the turbine supply chain, raw material costs, regulatory timeframes and cost, etc. such that the bid may be unrepresentative of actual expected costs three to six months later.

A reasonable sampling of historical wind farm project data has been collected, analyzed, and summarized in the annual Wind Technologies Market Report[12]. Economic cost data for modeling purposes was obtained from this report with the focus on comparable wind projects in the 5 to 20 MW range, utilizing 1.5 to 3 MW turbines and installed in the Mountain West. The average installed cost in this scenario was ~$2,200/kW.

Gearbox and blade replacement and annual O&M costs were derived from cost ratio figures in the series of WindPACT[13] studies that NREL completed during the early 2000s. The figures cited for blade replacement were applied at a 75% factor due to low turbulence at Fort Carson.

Recent utility summary data provided to NREL by Fort Carson indicated an annual electric load of 191,804 MWh/yr (excluding the solar phovoltaic system production) with an estimated cost of $11.3 million/year resulting in a blended rate of $0.059/kWh for electrical energy. These figures were used for the economic modeling.

Two primary driving factors for economically viable wind turbine projects are wind power density (derived from wind speed) and competing COE. A high wind power density and high COE ensure solid economics. Most other scenarios require a detailed investigation. The mean annual wind speed of 6.2 m/s at 80 m at Fort Carson is a moderate wind resource. Fort Carson has a relatively low COE at $0.059/kWh. These driving factors suggest a potentially viable wind project, but not one with a large profit margin that would enable a large range of financing scenarios.

For analysis purposes, a "typical" 1.6 MW wind turbine designed for low wind speeds was selected. The key factor in the economic analysis is how many kWh/year a turbine will produce to offset the installation and O&M costs. As project costs vary depending upon a number of factors, some of which may change considerably between now and the issuance of an RFP, attempting to project the installation and O&M costs for a number of turbines fraught with uncertainty.

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[12] Wiser, Ryan and Bolinger, Mark - 2010 Wind Technologies Market Report, U.S. Department of Energy, Energy Efficiency & Renewable Energy, June 2011.

[13] Wind Partnership for Advanced Component Technology, Department of Energy, Office of Energy Efficiency and Renewable Energy, National Renewable Energy Laboratory. http://www.nrel.gov/wind/windpact.html. Accessed Feb 2012.

11.2.1 Financing Scenarios

There are typically several financing approaches available to DoD facilities for energy projects. They include:

- Business as usual – continue to purchase electricity from the utility as is currently done
- Cash purchase of wind turbines by Fort Carson utilizing ECIP cash grant
- ESPC or UESC funded purchase of wind turbines
- PPA by third party owner/operator of wind turbines.

As stated above, the existing driving factors limit economic financing options. To provide Fort Carson with effective decision-making information, the economic analyses focused on three project scenarios:

- Business as usual – no wind turbines
- Seven 1.6 MW Class III wind turbines purchased/installed using an ECIP grant for funding
- Seven 1.6 MW Class III wind turbines purchased/installed using a PPA

There are numerous variations to the wind farm scenario that could be investigated and optimized, but the intent of this analysis is to frame the economics to provide realistic expectations for moving forward.

11.2.2 General Modeling Assumptions

Several assumptions were made concerning the parameters of the economic modeling. These assumptions included:

- Annual averaged wind turbine output (3,634,101 kWh/yr) for a 1.6-MW turbine was used for all energy production calculations. Overall loss factor of 17.7% was assumed.
- Purchase/installation and annual O&M, contract, insurance and warranty costs were modeled using estimated figures obtained for each scenario from industry sources or partners, all are estimates for an "unknown" project and they varied, but represent the best available figures for that segment of the industry.
- Fort Carson would complete the required NEPA permitting and the contractor would not be expected to conduct nor pay for any part of the NEPA approval process.
- The project life is assumed to be 20 years. The wind turbine useful life is estimated to be 20 to 30 years. This generation of 1+ MW turbines is not yet 20 years old so there is little field experience to point to for verification.

To enable smooth continuous operations with minimal downtime, in the event of a catastrophic equipment failure, it is prudent to put aside an annual self-imposed fee from the beginning of the project. An escrow account for capital repairs (blade failure, gearbox failure, etc.) is often used for this purpose. Though it is not possible to predict exactly when repairs will be necessary, having this fund ready will enable Fort Carson to have repairs taken care of quickly as there will be no need to search for funding to pay for them, the funds will be in escrow waiting. The funding and expense stream are not possible to match, but the escrow fund should prepare Fort Carson to meet any capital repair expenses that may arise.

The Capital Repair Escrow Fund may work differently depending on the finance scenario. In the ECIP - Cash Purchase model, Fort Carson should have the funds from savings set aside in escrow so they can be deployed immediately for a repair. This was not captured in the model. It is assumed that in the PPA scenario the capital repair cost would be "built-in" to the energy cost being charged to Fort Carson though there was no accounting for this in the model.

The expected salvage value of the wind turbine with significant components made of steel, copper, etc. is expected to have enough residual value to cover the demolition costs. What is occurring in many sites that have smaller, older wind turbines 15-20 years old is a process called "re-powering", that is the existing turbine nearing the end of its useful life is replaced with a newer, sometimes larger turbine since the permitting, electrical, etc. issues have already been addressed. Full turbine/foundation demolition and site restoration are not common.

11.2.3 Business as Usual

The business-as-usual scenario pits the EPAct 2005 annual 2% energy reduction requirement against electricity price inflation to keep the annual electricity expense under control. Commercial electricity rates in Colorado have increased an average of 5.1% per year from 2000 to 2010.[14] The "Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis – 2011[15]" predicts annual project inflation of 0.9% over the next 20 years. The Energy Escalation Rate Calculator estimates the nominal energy escalation factor to be 2.99% over the next 20 years. If the historical increasing electricity price trend continues, even while doing the business-as-usual scenario with energy consumption declines, Fort Carson will likely see its annual electricity expenditure increasing over the next 20 or 25 years.

11.2.4 ECIP Funding

Economic analysis was completed assuming no finance charges through an ECIP-funded project. Though the overall cost for a 7-turbine wind farm may be outside the range of ECIP project budget, it is useful to set the cost parameter framework. Since Fort Carson is not a tax-paying entity, no PTC was used for these initial calculations. The simple payback results can be seen in Table 1612. The first line is labeled "ECIP – 20 yr life." The simple payback is 21.7 years and the Life Cycle Cost (LCC) is negative. However, the effect of extending the project life 25 years can be seen in the second line of the table

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[14] Department of Energy, Energy Information Agency. http://www.eia.gov/electricity/data.cfm#sales. Accessed March 2012.

[15] Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis – 2011, U.S. Department of Commerce. http://www1.eere.energy.gov/femp/pdfs/ashb11.pdf. Accessed March 2012.

in the orange-shaded boxes. The LCC becomes positive and savings-to-investment (SIR) exceeds 1.0.

Table 16 Economic Comparison of 20- and 25-year ECIP-funded Wind Project

Sensitivity Factor	Annual Energy Output	Net CF *	Annual Energy Savings	Annual O&M **	% of FC Energy	Estimated Installed Cost	Life Cycle Cost Savings	Cost of Wind Energy	SIR ***	Simple Payback
	MWh/yr	%	$	$	%	$	$	$/kWh	-	yrs
ECIP - 20 yr Life	25,439	25.9%	$1,500,962	$331,130	13.3%	$25,345,600	($1,027,270)	$0.061	0.96	21.7
ECIP - 25 yr Life	25,439	25.9%	$1,500,962	$331,130	13.3%	$25,345,600	$5,808,288	$0.051	1.23	21.7

* CF = Capacity Factor; ** O&M = Operations & Maintenance; *** SIR = Savings to Investment Ratio

11.3 ECIP Sensitivity Analysis

A sensitivity analysis was undertaken to illustrate the relative importance of key project factors. The economics were re-run against the ECIP 20-year life case (labeled ECIP – Original in the table) to provide a constant barometer of relative impact. In the first scenario, beneficial factors were applied as the mean annual wind speed was increased by 10%, the installed cost per kW was decreased by 10% and the competing COE was increased by 10%. The results can be seen in Table 17. The shaded boxes indicate factors that have changed compared to the ECIP – Original case. In each case, the LCC becomes positive, Savings to Investment (SIR) exceeds 1.0 and Simple Payback falls below 20 years.

Table 137 Sensitivity Analysis of Beneficial Changes to Project Parameters

Sensitivity Factors	Annual Energy Output	Net CF *	Annual Energy Savings	Annual O&M **	% of FC Energy	Estimated Installed Cost	Life Cycle Cost Savings	Cost of Wind Energy	SIR ***	Simple Payback
	MWh/yr	%	$	$	%	$	$	$/kWh	-	yrs
ECIP - Original	25,439	25.9%	$1,500,962	$331,130	13.3%	$25,345,600	($1,027,270)	$0.061	0.96	21.7
Wind Speed - 10% ?	29,686	30.3%	$1,751,465	$331,130	15.5%	$25,345,600	$4,333,656	$0.052	1.17	17.8
Installed Cost -10% ?	25,439	25.9%	$1,500,962	$331,130	13.3%	$22,811,040	$1,230,460	$0.057	1.05	19.5
COE - 10% ?	25,439	25.9%	$1,651,059	$331,130	13.3%	$25,345,600	$2,185,195	$0.061	1.09	19.2

* CF = Capacity Factor; ** O&M = Operations & Maintenance; *** SIR = Savings to Investment Ratio

A second sensitivity analysis was completed with the same factors moving in a negative manner relative to the ECIP – Original case. That is, the wind speed decreased by 10%, the installed cost per kW increased by 10% and the competing COE decreased by 10%. As shown in Table 18, a negative trend applied to any of these factor results in the SIR moving below 1.0 and Simple Payback extending beyond 20 years.

Table 148 Sensitivity Analysis of Negative Changes to Project Parameters

Sensitivity Factors	Annual Energy Output	Net CF *	Annual Energy Savings	Annual O&M **	% of FC Energy	Estimated Installed Cost	Life Cycle Cost Savings	Cost of Wind Energy	SIR ***	Simple Payback
	MWh/yr	%	$	$	%	$	$	$/kWh	-	yrs
ECIP - Original	25,439	25.9%	$1,500,962	$331,130	13.3%	$25,345,600	($1,027,270)	$0.061	0.96	21.7
Wind Speed - 10% ?	21,123	20.5%	$1,186,522	$331,130	11.0%	$25,345,600	($6,478,596)	$0.073	0.74	27.7
Installed Cost - 10% ?	25,439	25.9%	$1,500,962	$331,130	13.3%	$27,880,160	($3,285,002)	$0.065	0.88	23.8
COE - 10% ?	25,439	25.9%	$1,350,866	$331,130	13.3%	$25,345,600	($4,239,735)	$0.061	0.83	24.9

* CF = Capacity Factor; ** O&M = Operations & Maintenance; *** SIR = Savings to Investment Ratio

11.3.1 Power Purchase Agreement (PPA)

Another option to consider is to sign a long-term PPA with a wind developer where Fort Carson would purchase energy generated by the wind project at a negotiated price. This option has the potential to provide the best value to Fort Carson, but the contracting vehicle for federal agencies to sign PPA’ s for wind is not well-established at this time.

The assumptions applied here include:

- Equity partner could vary equity position from 0 – 100%
- 5% interest rate for a loan
- The offset cost of electricity was $0.059/kWh
- PTC of $0.022/kWh was in place for the project.

The results are in Table 19. The ROI for equity partner is below current rates (~9 to 12%) and it may be difficult to attract an equity partner for a PPA. The 100% debt financing option is not financially feasible as modeled. The shorter Simple Payback (14.7 yrs vs. 21.7 in other tables) is due to the third party owner-operator being able to take advantage of the PTC.

Table 159 PPA - Sensitivity Analysis of Financing Factors

Sensitivity Factors	Annual Energy Output	Net CF *	Annual Energy Savings	Annual O&M **	% After-Tax ROI to Equity Partner	Estimated Installed Cost	Life Cycle Cost Savings	Cost of Wind Energy	SIR ***	Simple Payback
	MWh/yr	%	$	$	%	$	$	$/kWh	-	yrs
PPA - 20 yr; 0% debt	25,439	25.9%	$1,500,962	$331,130	3.5%	$25,345,600	$1,292,988	$0.056	1.05	14.7
PPA - 20 yr; 30% debt	25,439	25.9%	$1,500,962	$331,130	3.4%	$25,345,600	$777,496	$0.057	1.04	14.7
PPA - 20 yr; 80% debt	25,439	25.9%	$1,500,962	$331,130	2.6%	$25,345,600	($209,976)	$0.060	0.96	14.7
PPA - 25 yr; 0% debt	25,439	25.9%	$1,500,962	$331,130	4.9%	$25,345,600	$5,735,813	$0.047	1.23	14.7
PPA - 25 yr; 30% debt	25,439	25.9%	$1,500,962	$331,130	5.4%	$25,345,600	$5,150,676	$0.049	1.29	14.7
PPA - 25 yr; 80% debt	25,439	25.9%	$1,500,962	$331,130	8.2%	$25,345,600	$3,994,369	$0.051	1.79	14.7

* CF = Capacity Factor; ** O&M = Operations & Maintenance; *** SIR = Savings to Investment Ratio

ESPC and UESC approaches were not modeled given the low ROI’s calculated under the PPA. Generally, ESPC and UESC have higher ROI expectations so it was assumed that if the ESCO or utility had a fixed ROI of 15 to 25% (upfront fee often charged for ESPC contracts), that the resultant COE to Fort Carson would be unacceptably high.

12 Conclusions and Recommendations

12.1 Conclusions

Wind data was collected from a 50-m met tower on a small ridge in the southeastern part of the Fort Carson base. A miniSODAR unit was also deployed at this site to measure wind speeds at elevations 30 to 140 m (98 to 459 ft) above ground. The data collected provided an effective dataset for comparative analysis of wind speed, turbulence intensity, and energy production of several wind turbines suitable for the wind conditions at the site.

The mean annual wind speed during the period of investigation was 5.9 m/s (13.2 mph) at 50 m. After normalizing this figure to account for the long-term wind trends with a modeled 14-year data set (ReEDS), the adjusted mean annual wind speed was 5.7 m/s (12.7 mph).

Applying vertical wind shear factors obtained from the miniSODAR unit resulted in a mean annual wind speed of 6.2 m/s (13.9 mph) at 80 m. The mean turbulence intensity factor at 15 m/s was 0.13 which makes the site suitable for the newer low wind speed turbines (i.e., Class III IEC rating).

Table 20 shows the summary results of annual wind speeds, estimated annual energy production (AEP) figures, capacity factors, and the percent of Fort Carson's electricity load generated.

Table 20. Summary of Wind Project Energy Performance of Sample Wind Turbines

Turbine Manufacturer & Model	Rated Power	Mean Net Power	Mean Net Annual Energy /Turbine/Yr	Net Capacity Factor	FC#2 Site	Wind Plant Capacity	Wind Plant Annual Output	% of Base Energy
Turbine	MW	kW	kWh/yr	%	# Turb.	MW	MWh/yr	%
GE 1.6 XLE	1.6	415	3,634,101	25.9	7	11.2	25,439	15.7%
Suzlon S97	2.1	475	4,162,921	22.6	7	14.7	29,140	18.0%
Siemens SWT-2.3 108	2.3	572	5,014,293	24.9	7	16.1	35,100	21.6%
Siemens SWT-2.3 113	2.3	691	6,049,308	30.0	7	16.1	42,345	26.1%
Nordex N117	2.4	647	5,665,505	26.9	7	16.8	39,659	24.4%
Vestas V112 - 3.0 MW	3.0	677	5,933,315	22.0	7	21.0	41,533	25.6%

A comparison of the various financing scenarios modeled shows the tradeoffs between each approach. A 7-turbine wind plant rated at 11.2 MW was assumed with constant annual energy output of 25,439 MWh/yr, net capacity factor of 25.9%, annual energy savings of $1.5 million, installed cost of $25.4 million, and annual O&M of $331,000.

Given the wind resource and the current cost of electricity at Fort Carson, the most viable option for a small wind farm appears to be ECIP funding, which is compared to other funding options in Table 21. The estimated purchase/installation cost of $25 million may be a barrier, but it provides the most compelling economic advantages to Fort Carson.

Table 21. Comparison of Financing Scenarios

Sensitivity Factors	% After-Tax ROI to Equity Partner	Life Cycle Cost Savings	Cost of Wind Energy	SIR *	Simple Payback
	%	$	$/kWh	-	yrs
ECIP - 20 yr Life	N/A	($1,027,270)	$0.061	0.96	21.7
ECIP - 25 yr Life	N/A	$5,808,288	$0.051	1.23	21.7
PPA - 20 yr; 0% debt	3.5%	$1,292,988	$0.056	1.05	14.7
PPA - 20 yr; 30% debt	3.4%	$777,496	$0.057	1.04	14.7
PPA - 20 yr; 80% debt	2.6%	($209,976)	$0.060	0.96	14.7
PPA - 25 yr; 0% debt	4.9%	$5,735,813	$0.047	1.23	14.7
PPA - 25 yr; 30% debt	5.4%	$5,150,676	$0.049	1.29	14.7
PPA - 25 yr; 80% debt	8.2%	$3,994,369	$0.051	1.79	14.7

* SIR = Savings to Investment Ratio

One possible approach within the ECIP scenario would be to request funds for 40-60% of the wind farm with the caveat that the annual savings could be saved over time to purchase the remainder of the farm at a future date. This approach, though not currently allowed by DoD, would enable Fort Carson to self-fund future renewable energy projects using savings from installed renewable energy projects. This approach could prove to be a model worth replicating after obtaining the necessary permission to pursue it.

The economic conditions for a PPA do not generally appear to be attractive to an investor at this time due to the relatively low COE ($0.059/kWh) that Fort Carson pays. The longer the project life, greater the overall ROI is expected to be. There is some uncertainty in this concept, as turbines in the size considered for this project have not been operating in the field for 20 to 25 years so the true O&M costs and turbine viability at that later stage is somewhat speculative. It is reasonable to expect that if Fort Carson is willing to pay a premium for its wind-generated electricity, then a third-party investor could obtain a viable ROI.

12.2 Recommendations

Overall, the wind resource at the selected sites at Fort Carson is sufficient for a wind turbine project, though the specific approach (financing and ownership) and size still need more refinement. There are a number of other factors to consider before turbine selection is undertaken, including cost, availability, constructability, and transportability. There are also a number of other factors still to be explored as the parameters of this project become more clearly defined, including on-site military operations, FAA restrictions and requirements, financing, NEPA restrictions and requirements, constructability, subsoil and foundations, impact on neighbors, and transportation planning and logistics.

There are a number of proposed tasks to continue to move this project forward, including:

- Fort Carson to complete the NEPA evaluation already underway
- Complete an electrical interconnection study specifically assessing a distribution voltage possibility as well as the transmission voltage option

- Determine the most appropriate financing mechanism and secure project funding/finance
- Complete the transportation and logistics study
- Complete the visual and sound impact study
- Develop and implement a public information plan.

Appendix A. Wind Sensors & Tower

Met tower components for Fort Carson at FC#2:

- **NRG Systems 50 m XHD Tower:**
  - Six NRG Systems #40C anemometers (item 1899)
  - Two NRG Systems #200P wind vanes (item 1904)
  - One NRG Systems #110S temperature sensor (item 1906)
  - One Symphonie*PLUS*® data logger (item 4289).
- **NRG Systems #40C Anemometer** (item: 1899). The NRG Systems #40C anemometer is the industry standard anemometer used worldwide. NRG Systems #40C anemometers have recorded wind speeds of 96 m/s (214 mph). Their low moment of inertia and unique bearings permit very rapid response to gusts and lulls. Because of their output linearity, these sensors are ideal for use with various data retrieval systems. A four-pole magnet induces a sine wave voltage into a coil producing an output signal with a frequency proportional to wind speed. The #40C is constructed of rugged Lexan cups molded in one piece for repeatable performance. A rubber terminal boot is included.

Figure A-1. Anemometer #40C NRG Systems (item 1899)[16]

- **NRG Systems #200P Wind Direction Vane, 10K** (item: 1904). The NRG Systems #200P wind direction vane is the industry standard wind direction vane used worldwide. The thermoplastic and stainless steel components resist corrosion and contribute to a high strength-to-weight ratio. The vane is connected directly to a precision conductive plastic potentiometer located in the main body. An analog voltage output directly proportional to the wind

[16] Photo courtesy of NRG Systems, Inc.
http://www.nrgsystems.com/AllProducts/SensorsandTurbineControl.aspx

direction is produced when a constant DC excitation voltage is applied to the potentiometer. A rubber terminal boot is included.

Figure A-2. Wind vane NRG Systems #200P (item 1904)[17]

- **Mounting booms.** NRG side-mounting booms allow you to easily mount sensors to your tower or mast at any height. Mounting hardware is included. Heavy-duty mounting booms are designed specifically for icing environments and mounting NRG IceFree sensors.

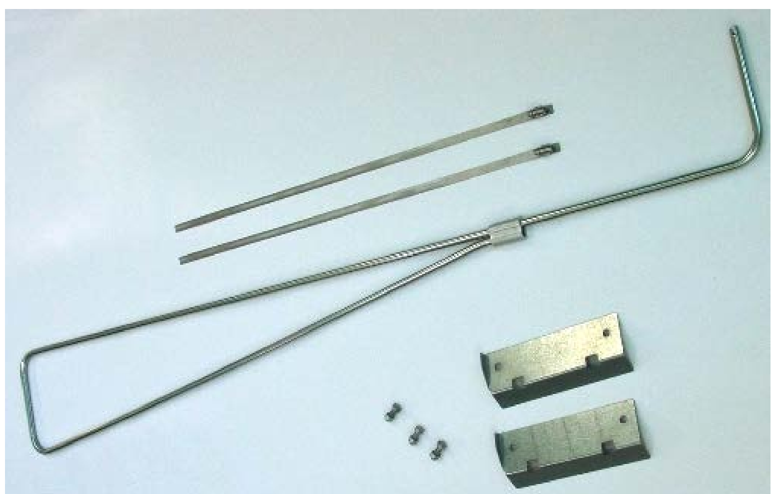

Figure A-3. Boom, side, 1.53m (60.5"), galvanized, with clamps (item: 3390)[18]

[17] Photo courtesy of NRG Systems, Inc. http://www.nrgsystems.com/AllProducts/SensorsandTurbineControl.aspx

[18] Photo courtesy of NRG Systems, Inc. http://www.nrgsystems.com/AllProducts/SensorsandTurbineControl.aspx

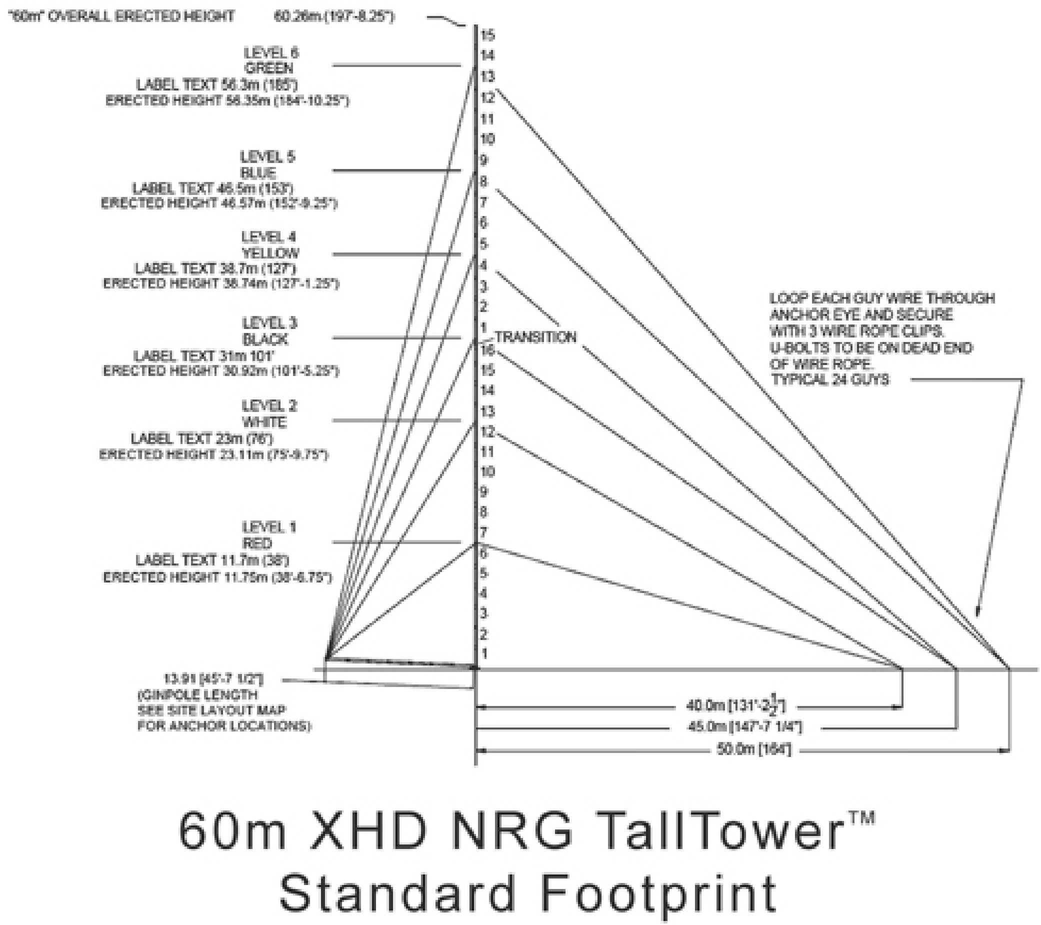

Figure A-4. 50m and 60m XHD Tower configuration[19]

[19] Diagram courtesy of NRG Systems, Inc. http://www.nrgsystems.com/sitecore/content/Products/4063-4290-4199.aspx.

Appendix B. Fort Carson Met Tower Commissioning Report

The following was submitted by the installer, Advanced Turbine Service, Inc., to Brett Jackson of the Army National Guard.

Met Tower Site Data Sheet

Site Information

Project Fort Carson Site 001 Met Tower Height 50m HD Manufacturer: NRG	Property Owner: U.S. Gov Vince E. Guthrie Work Phone No.: 719-526-2927	Contact Name: Brett Jackson Cell Phone No.: 303-916-0730
Site Location: Fort Carson	City, State: Colorado Springs, CO	County: El Paso
Installation Date: 12/29/07	Removal Date:	Inspection Date:
Installation Crew:	1. Ruben 2. Juan	3. Randy 4. David
Company:	Advance Turbine Service, Inc.	
Contact Person:	Bob Ochoa	
E-mail Address:	bob_ochoa@earthlink.net	
Address:	1506 East Broadway Ave, Sweetwater TX 79556	

Data Logger Information

I-Pack Type:	N/A	Logger Type:	Symphonle
I-Pack ESN:	N/A	Logger Serial Number:	309015378
I-Pack Serial Number:	N/A	Time Zone:	MST
Modem Min No:	N/A	Daylight Savings Time Adjustment	Yes or No

Location Information

Coordinate System/Datum:	NAD27	Magnetic Declination (degrees relative to true North):	009° E
Latitude (DMS):	N 38° 26.001	Prevailing Winds (magnetic degrees):	
Longitude (DMS):	W104° 44.372	Elevation (ft/in):	5,675'
Primary Units of Measure:	Ft/In		
Latitude (DMS): GPS	N 38.43333		
Longitude (DMS): GPS	W104.73952	Elevation (ft/in): GPS	1,731 m

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Site Description Information

Site description (tree types, hills, etc.):	Cedar trees,hill
Terrain Features (obstructions, distances from tower):	
Soil Type:	Rocky

Anemometers

Attach calibration sheets for any calibrated anemometers

Monitoring height (ft/in):	159'.5"	159'.5"	133'.10"	98'.9"		
Manufacturer/model:	MAX NRG 40	MAX NRG 40	MAX NRG 40	MAX NRG 40	MAX NRG 40	MAX NRG 40
Anemometer Serial Number:	51337	513333	51335	51336		
Boom Height (ft/in):	159'	159'	133'.5"	98'.4"		
Boom Length (ft/in):	3'.9"	3'.9"	3'.9"	3'.9"		
Boom Orientation (mag. deg.):	315°	225°	270°	270°		
Calibration Date:	11/20/07	11/20/07	11/20/07	11/20/07		
Slope/Scale Factor:	0.765	0.765	0.765	0.765		
Offset:	0.350	0.350	0.350	0.350		
Primary or Redundant (P/R)?	R	R	P	P		
Logger Channel Number:	1	2	3	4	5	6

Wind Vanes

Monitoring Height (ft/in):	157'.5"	96'.9"				
Manufacturer/model:	P-200	P-200				
Wind Vane Serial Number:	N/A	N/A				
Boom Height (ft/in):	157'	96'.4"				
Boom Length(ft/in):	3'.9"	3'.9"				
Boom Orientation (mag. deg.):	0°	0°				
Dead band Orientation (mag. deg.)	0°	0°				
Slope/Scale Factor:	0.351	0.351				
Offset:	0.000	0.000				
Logger Channel Number:	7	8				

Other Sensors

Sensor Type:	Temp					
Monitoring Height (ft/in):	10'					
Manufacturer/model:	110S					
Sensor Serial Number:	N/A					
Boom/mounting Orientation (mag. deg.):	0°					
Slope:	0.136					
Offset:	-86.383					
Logger Channel Number:	9	10	11	12		

Tower Information

Manufacturer/model:	NRG 50m HD
Type (mast/lattice):	mast
Purpose (prospecting/permanent)	Prospecting
Height (ft/in):	159'.2"
Diameter/width (ft/in):	8"
10 Digital Pictures?: Page: 3 [0] Eight from base of tower facing out at increments of 45 degrees each, plus one straight up from base of tower (facing North), and one of entire tower from a distance (10 total)	Yes or No
Comments:	Tower was used, pressure sensor and pressure card was not installed because it was not delivered with tower, Sensor cables were also used · Installed Bird Diverters

Other

Equipment Rental Company : (Drilling Anchors or repairs)	
Did you install cattle guards:	No
Did you install F.A.A. Marker Balls:	No
Installed F.A.A. Light	Yes A601
Comments:	

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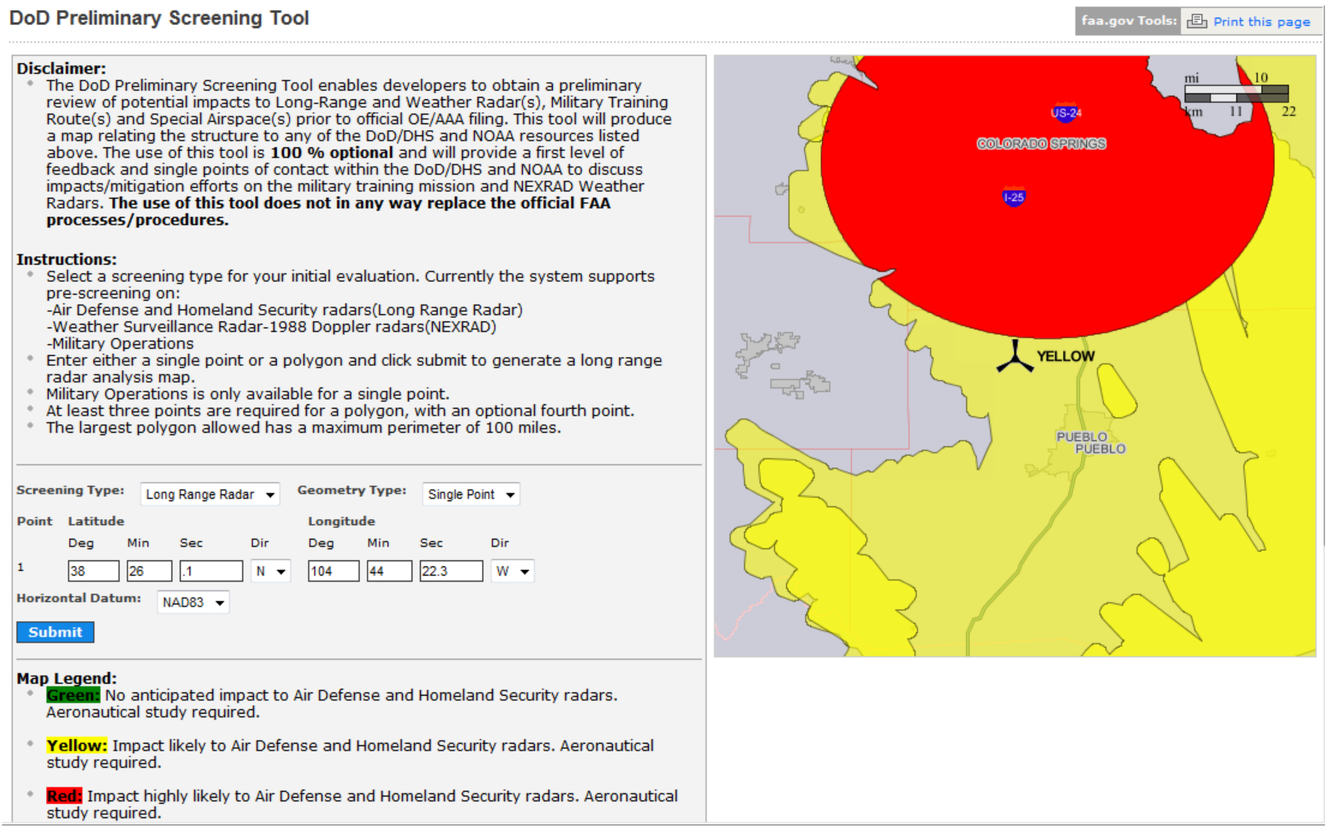
Appendix C. Preliminary FAA Screening

FAA Long Range Radar Screening Results


DoD Preliminary Screening Tool

faa.gov Tools: Print this page

Disclaimer:

- The DoD Preliminary Screening Tool enables developers to obtain a preliminary review of potential impacts to Long-Range and Weather Radar(s), Military Training Route(s) and Special Airspace(s) prior to official OE/AAA filing. This tool will produce a map relating the structure to any of the DoD/DHS and NOAA resources listed above. The use of this tool is **100 % optional** and will provide a first level of feedback and single points of contact within the DoD/DHS and NOAA to discuss impacts/mitigation efforts on the military training mission and NEXRAD Weather Radars. **The use of this tool does not in any way replace the official FAA processes/procedures.**

Instructions:

- Select a screening type for your initial evaluation. Currently the system supports pre-screening on:
  -Air Defense and Homeland Security radars(Long Range Radar)
  -Weather Surveillance Radar-1988 Doppler radars(NEXRAD)
  -Military Operations
- Enter either a single point or a polygon and click submit to generate a long range radar analysis map.
- Military Operations is only available for a single point.
- At least three points are required for a polygon, with an optional fourth point.
- The largest polygon allowed has a maximum perimeter of 100 miles.

Screening Type: Long Range Radar **Geometry Type:** Single Point

Point	Latitude Deg	Min	Sec	Dir	Longitude Deg	Min	Sec	Dir
1	38	26	.1	N	104	44	22.3	W

Horizontal Datum: NAD83

Submit

Map Legend:

- **Green:** No anticipated impact to Air Defense and Homeland Security radars. Aeronautical study required.
- **Yellow:** Impact likely to Air Defense and Homeland Security radars. Aeronautical study required.
- **Red:** Impact highly likely to Air Defense and Homeland Security radars. Aeronautical study required.

NEXRAD Radar Preliminary Screening Results

Disclaimer:

- The DoD Preliminary Screening Tool enables developers to obtain a preliminary review of potential impacts to Long-Range and Weather Radar (s), Military Training Route(s) and Special Airspace(s) prior to official OE/AAA filing. This tool will produce a map relating the structure to any of the DoD/DHS and NOAA resources listed above. The use of this tool is **100 % optional** and will provide a first level of feedback and single points of contact within the DoD/DHS and NOAA to discuss impacts/mitigation efforts on the military training mission and NEXRAD Weather Radars. **The use of this tool does not in any way replace the official FAA processes/procedures.**

Instructions:

- Select a screening type for your initial evaluation. Currently the system supports pre-screening on:
  -Air Defense and Homeland Security radars(Long Range Radar)
  -Weather Surveillance Radar-1988 Doppler radars(NEXRAD)
  -Military Operations
- Enter either a single point or a polygon and click submit to generate a long range radar analysis map.
- Military Operations is only available for a single point.
- At least three points are required for a polygon, with an optional fourth point.
- The largest polygon allowed has a maximum perimeter of 100 miles.

Screening Type: NEXRAD **Geometry Type:** Single Point

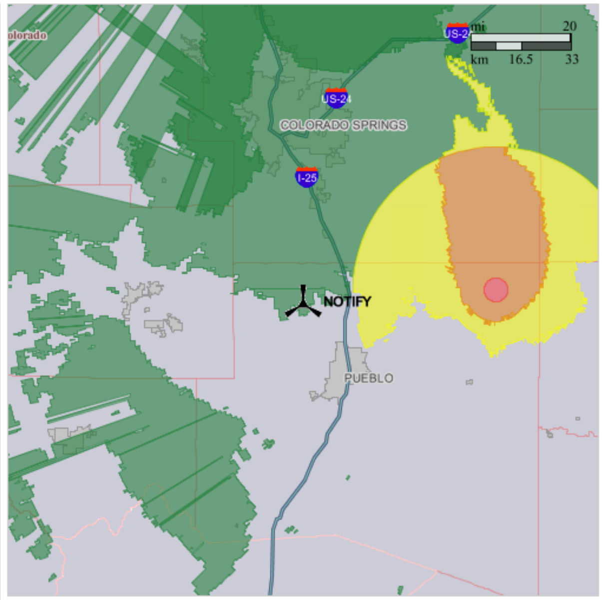
Point	Latitude Deg	Min	Sec	Dir	Longitude Deg	Min	Sec	Dir
1	38	26	.1	N	104	44	22.3	W

Horizontal Datum: NAD83

Submit

Map Legend:

- **Green: No Impact Zone.** Impacts not likely. NOAA will not perform a detailed analysis, but would still like to know about the project.
- **Dk Green: Notification Zone.** Some impacts possible. Consultation with NOAA is optional, but NOAA would still like to know about the project.
- **Yellow: Consultation Zone.** Significant impacts possible. NOAA requests consultation to discuss project details and to perform a detailed impact analysis. NOAA may request mitigation of significant impacts.
- **Orange: Mitigation Zone.** Significant impacts likely. NOAA will likely request mitigation if a detailed analysis indicates that the project will cause significant impacts.
- **Red: No-Build Zone.** Severe impacts likely. NOAA requests developers not build wind turbines within 3 km of the NEXRAD. Detailed impact analysis required.



Because the NEXRAD can detect wind turbines occasionally at great distance, NOAA would like to know the location of all wind farm projects so that corrupted radar data can be flagged. Send project information directly to NOAA at wind.energy.matters@noaa.gov or through the National Telecommunications & Information Administration (NTIA) in the Dept. of Commerce. NOAA protects all wind project information as proprietary and sensitive.

Military Operations Preliminary Screening Results

DoD Preliminary Screening Tool

faa.gov Tools: Print this page

Disclaimer:

- The DoD Preliminary Screening Tool enables developers to obtain a preliminary review of potential impacts to Long-Range and Weather Radar(s), Military Training Route(s) and Special Airspace(s) prior to official OE/AAA filing. This tool will produce a map relating the structure to any of the DoD/DHS and NOAA resources listed above. The use of this tool is **100 % optional** and will provide a first level of feedback and single points of contact within the DoD/DHS and NOAA to discuss impacts/mitigation efforts on the military training mission and NEXRAD Weather Radars. **The use of this tool does not in any way replace the official FAA processes/procedures.**

Instructions:

- Select a screening type for your initial evaluation. Currently the system supports pre-screening on:
  -Air Defense and Homeland Security radars(Long Range Radar)
  -Weather Surveillance Radar-1988 Doppler radars(NEXRAD)
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- Enter either a single point or a polygon and click submit to generate a long range radar analysis map.
- Military Operations is only available for a single point.
- At least three points are required for a polygon, with an optional fourth point.
- The largest polygon allowed has a maximum perimeter of 100 miles.

Screening Type: Military Operations **Geometry Type:** Single Point

Point	Latitude Deg	Min	Sec	Dir	Longitude Deg	Min	Sec	Dir
1	38	26	.1	N	104	44	22.3	W

Horizontal Datum: NAD83

Submit

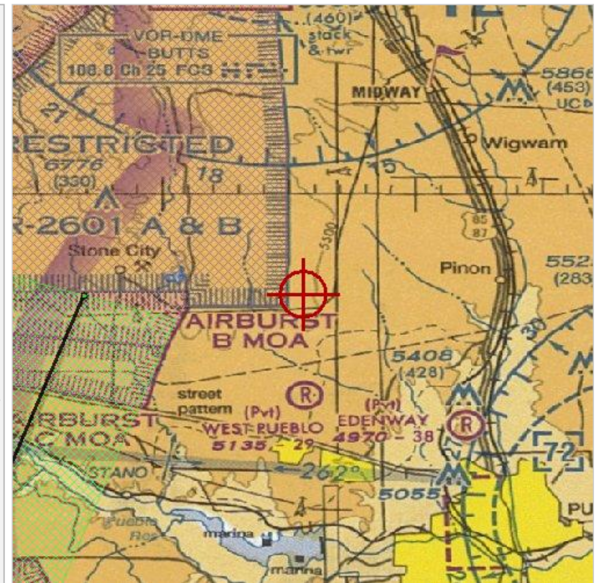
The preliminary review of your proposal does not return any likely impacts to military airspace. Please contact Gary Munsterman at the USAF Regional Enviromental Coordinator at (415)977-8884 for confirmation and documentation.

The preliminary review of your proposal does not return any likely impacts to military airspace. Please contact the US Navy Representative, FAA Western Service Area at the USN Regional Enviromental Coordinator at (425) 227-2740 for confirmation and documentation.

The preliminary review of your proposal does not return any likely impacts to military airspace. Please contact LTC Thomas C. Petty at the USA Regional Enviromental Coordinator at (425) 227-2955 for confirmation and documentation.

The preliminary review of your proposal does not return any likely impacts to military airspace. Please contact the US Marine Corps Representative, FAA Western Service Area at the USMC Regional Enviromental Coordinator at (425) 227-2665 for confirmation and documentation.

This is a preliminary review of your proposal and does not preclude official FAA processes.
Your search data is not retained and the privacy of all your searches is assured.



Any questions interpreting the map, please email Steve Sample with your question/s and phone number at steven.sample@pentagon.af.mil

Appendix D. Fort Carson Met Tower

Below are photos of the met tower and the met tower site.

Figure 23 Fort Carson 50m met tower with bird diverters. Photo credit: Robi Robichaud, NREL

Figure 24 Fort Carson 50m met tower – view from the northwest. Photo credit: Robi Robichaud, NREL

Appendix E. Wind Turbine Energy Production Loss Factors

The annual wind turbine energy production estimates were calculated assuming 17.7% losses, primarily due to wind turbine downtime, soiling/icing, electrical and other losses. The components of this loss factor include:

- **Array efficiency:** This loss parameter is associated with the wakes created by the turbines. This results in a decrease in wind speed and increase in turbulence as the wind moves through the wind farm array. This is a value estimated at 5%.
- **Turbine availability:** This term accounts for the expected downtime a wind turbine will experience during its annual operation. This includes routine maintenance, faults, and any component failures. Turbine availability or uptime is typically covered in the manufacturer's warranty terms with a value of 95% or greater. 97% was assumed.
- **Electrical:** Electrical losses occur in the process of collecting and transmitting the project energy across the site. As the power moves through the transformers and collection system, a certain percentage will be lost as heat. This value is typically estimated at 2%.
- **Hysteresis:** This is the term for when a turbine shuts down to protect itself from ambient climate events that are outside of the design envelope. This typically involves a high wind event that forces the turbine to shut down for a period of time. Based on on-site data, these are expected to be negligible.
- **Environmental:** Environmental losses occur because of ambient conditions that may affect blade aerodynamics or turbine operation. This includes icing, blade soiling, insect accumulation, and extreme cold or hot events. This is expected to happen at Fort Carson and is estimated to be on the order of 4%.
- **Operational:** Operational energy requirements such as power for the control system, heating system, and other parasitic loads are estimated at 2%.
- **Power curve variation:** The power curve may deviate from the manufacturer-stated designation due to yaw system misalignment, incorrect programming, or ambient weather events such as high turbulence or variations in atmospheric stability. This is not believed to be an issue for Fort Carson.
- **Substation downtime:** The collection substation on the Fort Carson side of the utility interconnection will likely require some downtime for routine maintenance. This is estimated at 0.5% for Fort Carson.
- **Utility downtime:** Utility transmission and distribution uptime or availability is generally very high. However, there are certain areas of the country or seasons of the year with more risk. The Fort Carson site is assumed to experience energy loss of 0.5% due to the utility electrical system being unavailable for power transmission.