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Direct Testimony and Schedules
Paul B. Johnson

Before the North Dakota Public Service Commission
State of North Dakota

IN THE MATTER OF THE APPLICATION OF NORTHERN STATES POWER COMPANY FOR AN ADVANCE DETERMINATION OF PRUDENCE FOR THE 200 MW FOR THE COURTENAY WIND FARM PROJECT

Case No. PU-15_____
Exhibit ___(PBJ-1)

Resource Planning Testimony

May 6, 2015

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Northern States Power Company

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Schedules

I. INTRODUCTION

Q. PLEASE STATE YOUR NAME AND TITLE.

A. My name is Paul B. Johnson. I am Director of Resource Planning and Bidding for Xcel Energy.

Q. PLEASE DESCRIBE YOUR QUALIFICATIONS AND EXPERIENCE.

A. I have worked for Xcel Energy since July 2014 in the area of resource planning. In my current role, I am responsible for the direction and oversight of electric Resource Planning for the five-state integrated Northern States Power Company system (NSP System), which provides electric service to customers in North Dakota, South Dakota, Minnesota, Wisconsin, and Michigan.

My responsibilities include directing the development of resource plans, and working closely with modeling to complete the analyses required for those plans. In addition, I lead the effort in providing resource analysis and planning guidance for other Company planning activities and regulatory filings. I also oversee the development and execution of Requests for Proposals (RFP), the modeling for asset acquisition assessments, and provide long-term pricing guidance for purchased power negotiations. My resume is provided as Exhibit___(PBJ-1), Schedule 1.

Q. WHAT IS THE PURPOSE OF YOUR TESTIMONY?

A. I address the impact and benefits of adding the 200 MW Courtenay Wind Project to the Xcel Energy system as a Company-owned asset. I first describe how we used the Strategist resource planning model to evaluate and identify the benefits of the Project, including details about the cost inputs used and cost sensitivity tests conducted in the Strategist modeling. I then provide the results of our analysis including the benefits of adding the Project to our system as a Company-owned asset. These results include comparing the Company-owned asset to adding the Project to our system through a power purchase agreement (PPA) with Geronimo Energy as initially approved by the Commission, as well as a comparison to not adding the Project to our system at all.

II. STRATEGIST ANALYSIS OF COURTENAY PROJECT

Q. HOW DID THE COMPANY EVALUATE THE COST-EFFECTIVENESS OF THE PROJECT?

A. We used the Strategist resource planning model to evaluate the cost effectiveness of the Courtenay Wind Project as a Company-owned resource. The Strategist Planning model simulates the operation of the NSP System and estimates the total cost of energy over the life of the Project on a present value basis. We use the model to test results under a range of input assumptions. To assess the Project's impact on customer costs, we simulated the operation of the NSP System over the next 40 years, with and without the addition of the 200 MW of wind generation from the Courtenay Project, as well as in comparison to purchasing the output of the Project through the PPA.

Q. WHAT WERE THE PRINCIPAL MODELING INPUTS FOR THE STRATEGIST MODELING OF THE COURTENAY PROJECT?

A. For Company-owned projects, the upfront purchase price needs to be translated into a projection of annual revenue requirement associated with financing, operations, depreciation, and taxes, including the addition of allowance for funds used during construction (AFUDC). Projections of on-going capital investments and annual operating and maintenance expenses also need to be developed.

To create a total annual cost of ownership estimate, we used a spreadsheet model with the detailed project-level assumptions and transferred that annual total cost estimate directly into Strategist. The spreadsheet model used cost of capital assumptions consistent with the 2016-2030 Upper Midwest Resource Plan. In addition, the spreadsheet model assumed the Company's forecasted net operating loss (NOL), which is currently expected to dissipate in the 2019-2021 timeframe.

While the upfront capital investments are well defined, we conducted two sensitivity tests to assess the impact of variations in capital expenditures on the project's benefits. We refer to these as Capital Sensitivity 1, and Capital Sensitivity 2, which are respectively **[TRADE SECRET BEGINS… …TRADE SECRET ENDS]** approximately $300 million capital cost estimate for this project, plus about $12.5 million for AFUDC.

These two sensitivity tests also include the AFUDC associated with these higher capital outlays. And because on-going capital investments and O&M expenses are subject to some uncertainty due to unforeseen equipment failures and changing costs within the industry, we also conducted sensitivity tests for those costs coming in at +/- 25 percent of our projections.

The economic benefit of an owned wind project is also highly-dependent on the annual generation from the site and the number of years the project is anticipated to be in service. Each additional MWh produced by a Company-owned project increases the value of the project because the higher the production, the lower the average costs will be, and therefore, the larger the benefits. To test how average net capacity factors impact the benefits of the Courtenay Project, we conducted sensitivity tests of +/- 5 percent of the Courtenay Project's expected average annual capacity factor of 46.1 percent, based on our updated wind study which is attached to my testimony as Schedule 2.

This net capacity factor is higher than the generic net capacity factor assumption of **[TRADE SECRET BEGINS... ...TRADE SECRET ENDS]** provided in the RFP bid for the Courtenay Project since turbines had not yet been selected at the time the bid was submitted. The base assumption for the service life the Courtenay Project is 25 years (as compared to 20 years under the PPA), and sensitivities were performed for 20-year and 30-year lives for the Project.

Given the principal benefit of wind generation is the displacement of fossil-fueled generation, sensitivity testing was also performed on the Project's impact on system costs when natural gas prices are low and when they are high.

Q. PLEASE DESCRIBE THE OTHER PRINCIPLE ELEMENTS OF THE MODELING.

A. For the other modeling inputs we utilized our most recent resource planning model, which is the same one used for our 2016-2030 Upper Midwest Resource Plan. Consequently, several underlying assumptions have changed for our analysis of Company ownership of the Courtenay Project in addition to capacity factor and resource life.

The Strategist model included a wind integration cost to account for incremental operating reserves that may be required to support the intermittent nature of the projects. We performed a new wind integration study as part of our most recent Resource Plan, which showed integration costs of $1.10/MWh (2014$) applied to resources currently included to meet the Company's Load Obligations going forward.

In accordance with MISO's latest Effective Load Carrying Capability analysis, we modeled the Courtenay Project as having an accredited capacity value of 14.8 percent. However, per MISO's tariff and business practices, for the project to receive accreditation as a capacity resource it must have firm delivery rights either with Network Resource Interconnection Service or firm transmission service (Network Integration Transmission Service or Firm Point-to-Point Transmission Service). Our expectation is that this Project will not be given this designation until 2021 when various transmission system upgrades, including MISO's Multi-Value Portfolio projects, are complete. Our modeling efforts reflect the expected capacity accreditation in 2021.

The Strategist model does not explicitly model transmission congestion and line losses for new resources. To ensure that we are accounting for all the costs associated with our wind proposal, we included the congestion and line loss estimates from MISO's 2012 Promod model. The Promod model contains detailed information on the transmission topology in MISO, and has the ability to forecast hourly prices at individual nodes throughout the system. It is the same model that MISO used in their most recent round of transmission planning analysis, and contains all planned upgrades to the transmission system that may impact transmission congestion in the future. The difference in price between any two locations within MISO is interpreted at the combined impact of transmission system congestion and line losses.

Q. WHAT ARE THE COST BENEFITS OF THE PROJECT AS QUANTIFIED BY THE STRATEGIST ANALYSIS?

A. Wind generation produces financial benefits by reducing the costs of both fossil-fuel generation and purchased energy from the market. When wind resources are producing energy, generation from conventional resources such as natural gas plants can be reduced without impacting the reliability of service to our customers. Adding the energy from the 200 MW Courtenay Project to our system is expected to avoid the purchase of about 58 billion cubic feet of natural gas over the Project's service life, as well as avoid the purchase of approximately 8,173 gigawatt hours of energy. The Strategist analysis accounts for these cost savings, as well as the impact of the capital commitments associated with adding the Project to our system.

The results of our Strategist analysis in the tables below show that as compared to not adding it to the NSP system, the Courtenay Project will result in net savings for our customers under all sensitivity tests conducted.

Table 1: PVRR Results ($millions)

PVRR, Current Assumptions ($M)	Base	Low Gas	High Gas	Markets On	30 Year Operating Life	20 Year Operating Life	+5% Energy Production	-5% Energy Production	Capital Sensitivity 1	Capital Sensitivity 2	+25% On-Going Ownership Costs	-25% On-Going Ownership Costs
Base Case (No Project)	$46,015	$43,248	$50,002	$45,519	$46,015	$46,015	$46,015	$46,015	$46,015	$46,015	$46,015	$46,015
Courtenay Own	$45,918	$43,198	$49,844	$45,447	$45,909	$45,995	$45,872	$45,949	$45,935	$45,952	$45,939	$45,897

Table 2: Incremental PVRR from Base Case ($millions)

PVRR Delta, Current Assumptions ($M)	Base	Low Gas	High Gas	Markets On	30 Year Operating Life	20 Year Operating Life	+5% Energy Production	-5% Energy Production	Capital Sensitivity 1	Capital Sensitivity 2	+25% On-Going Ownership Costs	-25% On-Going Ownership Costs
Courtenay Own	($97)	($50)	($159)	($72)	($106)	($20)	($143)	($66)	($80)	($63)	($76)	($117)

Q. WHAT DID STRATEGIST SHOW THE COST BENEFITS ARE OF THE COURTENAY PROJECT AS A COMPANY-OWNED RESOURCE RATHER THAN AS A PPA?

A. Company ownership compares favorably to the PPA under any sensitivity other than a 20-year life (which is somewhat offset by the residual value of owning the assets comprising the Courtenay Project).

First, we compared Company ownership versus the PPA utilizing the estimated capacity factor assumed in the PPA. The estimated capacity factor was provided in Geronimo's RFP bid and developed before specific turbines were selected and our detailed wind study was completed. Second, we compared Company ownership to the PPA utilizing the updated turbine specific net capacity factor identified in our revised wind study. Utilizing the updated net capacity factor and assuming a 25-year life (consistent with our typical assumptions for a Company-owned project), Company ownership compares favorably to the PPA under any circumstance other than a 20-year life sensitivity as shown in the table below:

Table 3: Incremental PVRR from PPA ($ millions)

PVRR Delta, Current Assumptions ($M)	Base	Low Gas	High Gas	Markets On	30 Year Operating Life	20 Year Operating Life	+5% Energy Production	-5% Energy Production	Capital Sensitivity 1	Capital Sensitivity 2	+25% On-Going Ownership Costs	-25% On-Going Ownership Costs
Courtenay PPA	($62)	($29)	($103)	($42)	($62)	($62)	($82)	($57)	($62)	($62)	($62)	($62)
Courtenay Own	($97)	($50)	($159)	($72)	($106)	($20)	($143)	($66)	($80)	($63)	($76)	($117)
Own vs. PPA	($35)	($21)	($55)	($31)	($44)	$42	($60)	($9)	($18)	($1)	($14)	($55)

Q. DID THE COMPANY CALCULATE THE STRATEGIST RESULTS IN TERMS OF LEVELIZED COST?

A. Yes. An alternate way of presenting the Strategist results is by calculating the levelized price of the project and the other costs and benefits associated with it. Levelized prices are a fixed $/MWh price that have the same NPV as the actual cost streams generated by Strategist. For the sake of comparison, the 20 year levelized cost of the Courtenay PPA was **[TRADE SECRET BEGINS... ...TRADE SECRET ENDS]**. As mentioned previously, in addition to the direct project costs, the Strategist model also adds cost for wind integration, transmission congestion, and line losses. The primary benefit of the project is displaced generation from fossil fuel resources, but the model also tracks benefits from avoided CO_2 emissions and capacity credit. The table below illustrates how the levelized costs of the agreements are more than offset by the value of avoided generation.

Table 4: Levelized Costs Analysis - $/MWh

	[Trade Secret Begins
Revenue Requirements	
Wind Integration	
Congestion/Line Losses	
Avoided Fossil Fuel	
Capacity Credit	
	Trade Secret Ends]
Net Cost (Benefit)	($10.60)

Q. WHAT OTHER BENEFITS DOES THE COURTENAY PROJECT PROVIDE?

A. In addition to the economic benefits, adding additional wind at favorable pricing provides a hedge against future increases in natural gas prices, market energy costs, and CO_2 regulation. This is primarily because the wind displaces thermal generation or market purchases that are subject to volatility in fuel, power, and emissions costs. To illustrate the benefit of the Courtenay Project, the table below shows the base case volumes of natural gas, market purchases, and CO_2 emissions – and the deltas against these factors for the Project.

Table 5: Hedge Value

Total System 2016-2042	**CO2** *Million tons*	**Natural Gas** *bcf*	**Market Purchases** *GWh*
Base Case (No Project)	565	2,129	103,811
Add Courtenay	(15)	(58)	(8,173)

Q. WHAT IS THE ESTIMATED RATE IMPACT ON THE COMPANY'S NORTH DAKOTA CUSTOMERS?

A. The impacts to our customers will be different under the Company's ownership as opposed to through our purchase of the output of the Project's energy under a PPA. This is mainly due to the different rate treatment for Company-owned projects (through rate base or capital riders) and PPAs (through the Fuel Cost Recovery Rider). Due to this, there will be a slight increase in expenses during the interim period while cost recovery is accomplished through the Renewable Energy Rider (RER)) in the first few years of Company ownership of the Courtenay Project. Soon after initial operation, however, we expect that customers' overall bills will be lower than otherwise as a result of our proposed resource acquisition. Our Strategist dispatch simulation forecasts that the cost of the Courtenay Project proposed in this Petition will be more than offset by decreases in the cost of fossil fuel and other purchased energy.

The table below estimates how average rates will be affected by the proposed wind project. We used the output of our Strategist model divided by our forecasted sales volume to develop these rate impact estimates.

Table 6: Annual Rate Impact Analysis

	2015	2016	2017	2018	2019	2020
Base Rates	0.00¢/kWh	0.02¢/kWh	0.09¢/kWh	0.06¢/kWh	0.06¢/kWh	0.04¢/kWh
Fuel Clause	0.00¢/kWh	0.00¢/kWh	0.01¢/kWh	0.01¢/kWh	0.01¢/kWh	0.01¢/kWh
Avoided Fuel & Purchased Power	0.00¢/kWh	0.00¢/kWh	(0.05¢/kWh)	(0.05¢/kWh)	(0.06¢/kWh)	(0.05¢/kWh)
Net Rate Impact	**0.004¢/kWh**	**0.018¢/kWh**	**0.040¢/kWh**	**0.014¢/kWh**	**0.014¢/kWh**	**(0.008¢/kWh)**

	2021	2022	2023	2024	2025	2026
Base Rates	0.01¢/kWh	0.01¢/kWh	0.00¢/kWh	0.00¢/kWh	0.00¢/kWh	-0.01¢/kWh
Fuel Clause	0.01¢/kWh	0.01¢/kWh	0.01¢/kWh	0.01¢/kWh	0.01¢/kWh	0.01¢/kWh
Avoided Fuel & Purchased Power	(0.06¢/kWh)	(0.06¢/kWh)	(0.06¢/kWh)	(0.06¢/kWh)	(0.06¢/kWh)	(0.06¢/kWh)
Net Rate Impact	**(0.038¢/kWh)**	**(0.042¢/kWh)**	**(0.050¢/kWh)**	**(0.055¢/kWh)**	**(0.056¢/kWh)**	**(0.062¢/kWh)**

	2027	2028	2029	2030	2031	2032
Base Rates	0.08¢/kWh	0.08¢/kWh	0.08¢/kWh	0.08¢/kWh	0.08¢/kWh	0.07¢/kWh
Fuel Clause	0.01¢/kWh	0.01¢/kWh	0.01¢/kWh	0.01¢/kWh	0.01¢/kWh	0.01¢/kWh
Avoided Fuel & Purchased Power	(0.06¢/kWh)	(0.07¢/kWh)	(0.07¢/kWh)	(0.07¢/kWh)	(0.11¢/kWh)	(0.10¢/kWh)
Net Rate Impact	**0.028¢/kWh**	**0.023¢/kWh**	**0.018¢/kWh**	**0.018¢/kWh**	**(0.022¢/kWh)**	**(0.016¢/kWh)**

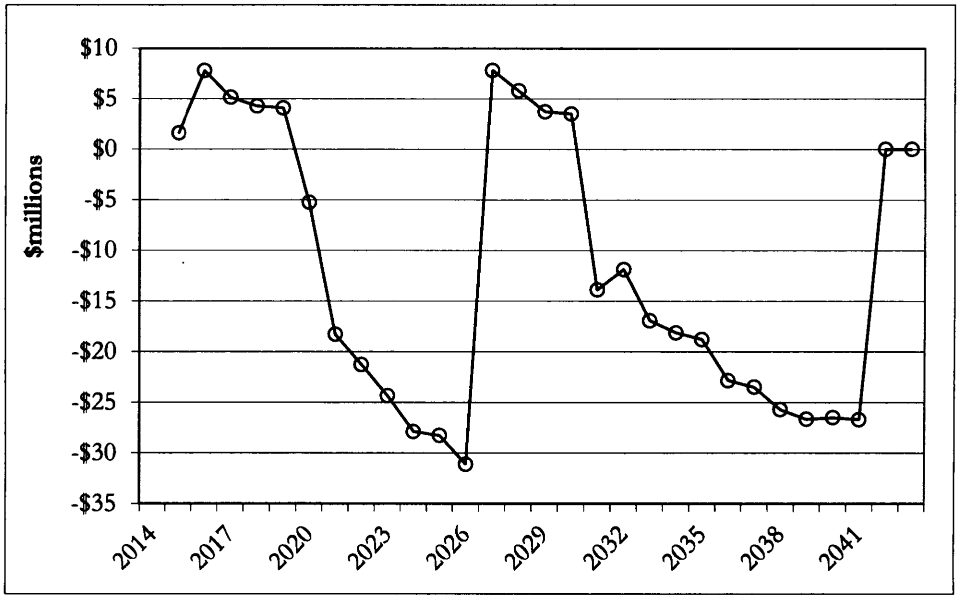
	2033	2034	2035	2036	2037	2038
Base Rates	0.07¢/kWh	0.07¢/kWh	0.07¢/kWh	0.07¢/kWh	0.07¢/kWh	0.06¢/kWh
Fuel Clause	0.01¢/kWh	0.01¢/kWh	0.01¢/kWh	0.01¢/kWh	0.01¢/kWh	0.01¢/kWh
Avoided Fuel & Purchased Power	(0.11¢/kWh)	(0.11¢/kWh)	(0.11¢/kWh)	(0.12¢/kWh)	(0.11¢/kWh)	(0.12¢/kWh)
Net Rate Impact	**(0.027¢/kWh)**	**(0.029¢/kWh)**	**(0.030¢/kWh)**	**(0.039¢/kWh)**	**(0.040¢/kWh)**	**(0.044¢/kWh)**

Q. PLEASE EXPLAIN THE VARIATION IN RATE IMPACTS ASSOCIATED WITH THE COURTENAY PROJECT.

A. As shown in Table 6, we estimate that there will be an initial base rate impact for Company ownership of the Courtenay Project in 2017, which will then rapidly decline through 2026 as the project is depreciated. The Project's costs are also further offset by avoided fuel and purchased power expenses beginning in 2017. Upon expiration of the Project's 10-year Production Tax Credit, which is discussed in the testimony of Company Witness Gregory Ford, there is another spike in base rates.

Figure 1 below details the $/MWh system costs/savings associated with the Courtenay Project, which shows a significant and growing net savings starting in 2020, after several years of higher revenue requirements, that grows through 2026 primarily due to increasing depreciation benefits. The spike in 2027 represents the first year of not having the benefit of the federal production tax credit, after which system costs significantly decline again.

Figure 1: Annual Cost (Savings) of Company Ownership



III. CONCLUSION

Q. DOES THIS CONCLUDE YOUR TESTIMONY?

A. Yes, it does.

Paul B. Johnson

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PROFESSIONAL EXPERIENCE

Director Resource Planning and Bidding **July 2014 –Present**

Xcel Energy, Minneapolis, MN

- Develop and direct the systems, processes and personnel required to prepare effective and prudent long term system plans for each of the four Xcel Energy operating utilities.
- Develop and direct the systems, processes and personnel required to conduct effective and fair power solicitation processes to procure needed power and energy to meet native load demand and energy requirements and achieve cost reductions in the Xcel supply portfolios.
- Direct acquisition of up to 800 MW per year of additional capacity and for management of the various state resource planning processes in a manner to fulfill requirements and meet company objectives meeting native load requirements and company asset growth goals.

Manager Power Supply Planning **March 2012—June 2014**

Old Dominion Electric Cooperative (ODEC), Glen Allen, VA, a large G&T Cooperative serving 11 distribution cooperative members located in VA, MD and DE who serve over 1.3 million customers with a peak load of about 3000 MW.

- Directed long term power supply area of ODEC managing all ongoing power supply analysis, requests for proposals, PPA negotiations for renewable and thermal resources and planning analysis and issue or hot topic updates responsive to ODEC Board requests which meets monthly.
- Directed selection, implementation and ongoing management and updates of all planning models and data sources used for long term planning.
- Worked effectively and collaboratively with all areas of ODEC to successfully fulfill corporate and business unit objectives for current budget year.
- Actively develop staff providing growth opportunities within power supply planning and with other areas of ODEC.
- Kept abreast of developments and trends in PJM and electric industry and evaluate potential impact as a part of long term planning efforts and updates to executive management and Board members.

President, S&P Energy, LLC **October 2011--February 2012**

I formed S&P Energy LLC October 2011in response to interest by others in my network to work with other consulting firms and development companies with all aspects of renewable project development and marketing (permitting, interconnection, off-take prospects and contracting, RFP responses, etc.).

- Worked as contract consultant with Bridge Energy Group as key resource for interconnection report development and filing support for large Californian utility to the California ISO involving over 120 reports (November 2011through January 2012)
- Pursued consulting contract negotiations for work with a couple renewable project developers and biomass fuel production facility developers.

Sr. Manager, Development North central and Eastern Regions **April 2009—May 2011**

RES Americas, Minneapolis, MN, a national wind and solar project development and construction company. I have management responsibility of regional office in Minneapolis under Regional Vice

President Minneapolis Office has active project pipeline of nearly 2000 MW.

- Direct project management responsibility for development and power marketing of 300 MW Wind Project in southeastern, MN Successfully initiated and navigated permitting to advanced stage resulting in MPUC unanimous October 2010 approval of site permit and certificate of need. Led effort to successfully gain unanimous Mower County Commissioner approval of permits for two transmission routes and three substation sites. Provided direction and support for project interconnection options and study evaluation and effective and timely interaction with Midwest Independent System Operator (MISO) staff.
- As member of company-wide management team participated in 2010 effort to evaluate and refine RES Americas business strategy and identify key implementation efforts.
- Established and maintained project marketing relationships and RFP follow-up with electric utilities in MN, WI, IA, OH and TN.
- Actively monitored renewable market project development and sale opportunities which resulted in relationships with new power purchase prospects in upper Midwest and Eastern US.
- Led effort to evaluate potential biomass fuel opportunity and led effort to develop a biomass fuel business plan for generation market in US and Europe. This effort relied on extensive biomass fuel and biomass power market research.
- Identified and completed initial due diligence for potential acquisition of biomass fuel planting, harvesting and combustion technologies for utility-scale greenfield and retrofit biomass power generation projects.
- Completed preliminary work on strategic approach for wind project development in eastern US based on current and projected changes in renewable market and electric utility generation plans.

Several key positions with Minnesota Power, Duluth, MN June 1999—April 2009

An 1800 MW investor-owned electric utility serving 140,000 customers.

Renewable Energy Project Development Manager October 2006—April 2009

- Developed and led turbine 2008 purchase solicitation, screening and contract negotiation process which resulted in executed contract for 33 turbine project in North Dakota.
- Developed and gained management support for capital budget and project development plan for several 100 MW of wind generation development. Supported executive management's effort to secure budget and initial project approval.
- Initiated and continued to direct multi-year wind prospecting effort which resulted in met tower siting and installation on several project site in northeastern Minnesota. Prospecting effort also identified large area with high average winds within economic distance of grid interconnection. Oversaw successful wind option acquisition effort with sufficient land and wind rights to support substantial wind project development.
- Provided site control and project information necessary to maintain interconnection study process and avoid higher study costs.
- Developed and directed 2004 and 2007 All Source Request for Proposals through bid completeness, evaluation, short-list, contract negotiation and filing with state public utilities commission (all filed contracts approved).
- Successfully led negotiation team for four wind-based power purchase agreements totally 156 MW.
- Developed, maintains and directs implementation of renewable strategy responsive to corporate strategy and direction of key state and federal policies.
- Developed and managed relationships with major wind developers, turbine suppliers and regulators essential for continuing to increase wind portion of Minnesota Power renewable power supply.
- Managed hand-off to project construction team of permitted, sited projects with turbines.
- Provided liaison as needed with MP executive management, outside consultants and key landowners to resolve issues and keep wind generation project progress on schedule.

Strategic Initiatives—Project Leader **September 2002—October 2006**

- Directed development and implementation of long term power supply request for proposals for renewable, bridge transactions and long tern purchases; evaluation and PPA negotiation completion by mid-2005.
- Led multi-area effort to develop and maintain MP's long term plan and develop and defend MP's biennial 15-year Resource Plan filed in September 2004.
- Developed long term power sales responses to RFPs and manage post-bid submittal follow-up through buyer screening and short-list announcement
- Identified long term power market and generation technology developments, trends, events and provide assessment executive management.
- Led and manage multi-area generation strategy development to support executive management decisions.
- Managed long term generation asset sale process including buyer due diligence and definitive agreement development.
- Tracked and provided assessments of regional generation development and performance of existing regional generation.

Generation Development –Project Leader **June 1999—August 2002**

- Managed internal generation development agreement compliance.
- Identified and screened generation development opportunities as key member of generation development team and lead project due diligence under executive management direction.
- Led effort to deploy and integrate price forecasting and generation opportunity evaluation tools into management decision processes.
- Monitored electric industry and key data sources for competitive intelligence and use this information to improve timing and focus of generation development.

ELECTRIC UTILITY INDUSTRY COMMITTEE LEADERSHIP OPPORTUNITIES

- Edison Electric Institute Renewables Committee. Committee developed policy proposals on federal renewable policy initiatives to reflect position of member investor-owned utilities)
- EPRI Storage and Renewables Task Force (Biomass/Waste Fuel Working Group Chair) Efforts resulted in gaining $85 million DOE funding commitment to complete engineering and build first 100 MW biomass power using "whole tree energy" technology. Also chaired national biomass technology symposium jointly hosted by EPRI and DOE in Washington, DC.

EDUCATION

Bachelor of Science and **Master of Arts** Environmental Studies
Bemidji State University. Bemidji, MN

Completed extensive graduate studies in organic chemistry, ecology, macro/micro economics, environmental law, politics of pollution and many special topic research papers requiring peer defense. Degree was designed to prepare students to understand industrial environmental issues and regulatory requirements, pollution control and renewable technologies, law and associated environmental impacts. Served as a graduate assistant in the library and physics lab. Completed graduate internship with regional development commission providing technical support to environmental projects.

AWS Truepower®

PREPARED FOR
NORTHERN STATES POWER COMPANY

ENERGY PRODUCTION SUMMARY

Calibrated Assessment of the Wind Resource and Energy Production Using the SiteWind System

APRIL 1, 2015

FOR THE COURTENAY WIND PROJECT

STUTSMAN COUNTY, NORTH DAKOTA

CLASSIFICATION
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DOCUMENT HISTORY

ISSUE	DATE	SUMMARY
A	1 April 2015	Initial Report

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1. INTRODUCTION

AWS Truepower, LLC, was retained by Northern States Power Company (NSPC) to evaluate the long-term wind resource and energy production potential of the proposed Courtenay Wind Project, located in North Dakota, about 30 km to the north-northeast of Jamestown, North Dakota, and 140 km west-northwest of Fargo, North Dakota. This report presents the results of our analysis and briefly describes the methods used to develop the wind resource and energy estimates.

2. WIND MEASUREMENTS

Wind monitoring at the Courtenay project began in July 2010 with the installation of a single monitoring mast, designated Mast 2612. One additional mast, designated Mast 2611, was installed in January 2013. Both masts remain in operation. Table 1 presents basic information about the masts including their geographic coordinates, elevations, periods of record, and sensor heights. NSPC provided the data to AWS Truepower in their raw binary format via ftp. Each data file contained 10-minute average wind speed, direction, and temperature records, along with their standard deviations.

The observed 60-m mean wind speeds are 7.59 m/s at Mast 2611 and 7.67 m/s at Mast 2612. The 60-m annualized mean wind speeds, which take into account repeated months in the data record and weight each calendar month by its number of days, are 7.62 m/s at Mast 2611 and 7.74 m/s at Mast 2612. The annualized wind shear exponents, which represent the rate of wind speed increase with height above ground according to the power law, are 0.213 at Mast 2611 and 0.225 at Mast 2612. The shear was calculated from the mean wind speeds at the highest and lowest monitoring levels based on concurrent valid records at both heights. Only wind speeds greater than 4 m/s, the range of interest for energy production, were used in the calculations.

The Weibull function is an analytical curve that describes the wind speed frequency distribution, or number of observations in specific wind speed ranges. Its two adjustable parameters allow a reasonably good fit to a wide range of actual distributions. *A* is a scale parameter related to the mean wind speed while *k* controls the width of the distribution. Values of *k* typically range from 1 to 3.5, the higher values indicating a narrower distribution. The observed 60-m *k* values, which are 2.30 at Mast 2611 and 2.49 at Mast 2612, are indicative of a reasonably steady wind resource with occasional high wind events. Figure 1 contains a chart showing the observed frequency distribution and the fitted Weibull curve for Mast 2612.

The directional distribution of the wind resource is an important factor to consider when designing the wind project to minimize the wake interference between turbines. Annual wind frequency and energy distribution by direction plots (wind roses) for the onsite masts are presented in Figure 2. The wind roses indicate that the prevailing wind directions are west-northwest through north-northwest.

3. ESTIMATION OF LONG-TERM MEAN WIND SPEED

We obtained historical wind speed data from several nearby potential reference stations operated by the National Weather Service (NWS) and Federal Aviation Administration (FAA), as well as datasets from three reanalysis datasets (CFSR[1], ERA-I[2], and MERRA[3]), and assessed them for suitability as long-term references.

Mast 2612 was chosen as the primary mast for the analysis because it has the longest data record. Linear regression equations were established using concurrent daily mean wind speeds at Mast 2612 and each potential reference station. Following reviews of the correlations and the time series of reference station annual mean speeds, we selected the Jamestown NWS surface station and the ERA-I dataset to estimate the long-term annual mean speed at Mast 2612. Substitution of the annualized mean wind speeds at the reference stations into the regression equation listed in Table 2 yields a 60-m long-term mean wind speed of 7.70 m/s at Mast 2612.

The climate-adjusted wind speed at Mast 2611 was estimated using a similar technique, but with Mast 2612 now serving as the reference. The regression was performed using concurrent hourly wind speeds; the r-squared value is 0.98. Substitution of the estimated long-term speed at Mast 2612 into the regression equation yields a long-term 60-m mean wind speed of 7.63 m/s at Mast 2611.

Extrapolation of these long-term mean wind speeds using the annualized wind shear exponents yields mean wind speeds of 8.11 m/s at Mast 2611 and 8.21 m/s at Mast 2612 at the 80-m hub height. A summary of the climate adjustments and extrapolation is included in Table 2.

4. ESTIMATION OF LONG-TERM ENERGY PRODUCTION

The energy production of the proposed Courtenay Wind Project was estimated using the Openwind® software. Openwind was developed by AWS Truepower as an aid for the design, optimization, and assessment of wind power projects.[4] The primary input is a wind resource grid generated by a numerical wind flow model, in this case the SiteWind® system. Other inputs include elements of the project design such as the turbine locations, hub height, power curve, and thrust coefficients, as well as the mast data. The SiteWind system and Openwind software and their applications in this project are briefly described below.

The SiteWind System

Numerical wind flow models are used to calculate the wind resource variation across a project area due to changes in terrain and surface roughness. AWS Truepower has developed the SiteWind system to perform these calculations. SiteWind employs both mesoscale and microscale models to simulate the wind climate over a wide range of scales. The mesoscale model assesses regional climate conditions and simulates complex meteorological phenomena such as katabatic (downslope) mountain winds, channeling through mountain passes, lake and sea breezes, low-level jets, and temperature inversions. The microscale model accounts for the localized influences of topography and surface roughness

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[1] Climate Forecast System Reanalysis (CFSR), which was developed by the National Centers for Environmental Prediction (NCEP), is a global atmosphere-ocean-land-sea ice system which produces 6-hourly outputs at a horizontal resolution of 1/2° latitude and 1/2° longitude. CFSR extends through 2010, while an operational version of CFSR has been employed beginning in 2011.

[2] ERA-Interim (ERA-I), which was developed by the European Centre for Medium-Range Weather Forecasts (ECMWF), utilizes a variety of observing systems which have been assimilated into a global three-dimensional grid by numerical atmospheric models at a spectral resolution of T255, or an approximate horizontal resolution of 79 km.

[3] Modern-Era Retrospective Analysis for Research and Applications (MERRA), which was developed by the National Aeronautics and Space Administration (NASA), utilizes a variety of observing systems which have been assimilated into a global three-dimensional grid by numerical atmospheric models at a horizontal resolution of 1/2° latitude and 2/3° longitude.

[4] Openwind – Theoretical Basis and Validation, Version 1.3, AWS Truewind, LLC, April 2010.

changes and produces a detailed wind resource map and grid. As a final step, the predicted speed and direction are adjusted with on-site data from masts within the project area. This method has been found to be more accurate on the whole than microscale wind flow models on their own.[5]

The mesoscale model used for this analysis was the Mesoscale Atmospheric Simulation System (MASS[6]), a non-hydrostatic weather model used in commercial and research applications. MASS was run in a series of nested grids, with the innermost grid having a spatial resolution of 1.2 km. Using regional weather data, MASS simulated historical weather conditions for a representative sample of days. The MASS output was then coupled to WindMap – a mass-conserving model – which was run on a grid scale of 50 m.[7] Finally, the output of WindMap was adjusted to the wind speed and direction distribution at the two masts within the project area. This last step was performed within Openwind, as described below. The resulting wind resource map is shown in Figure 3.

Openwind

Once the wind resource model has been run, the resource grid file is imported into Openwind to define the wind resource for the project area. The Weibull parameters in the file are converted to directional speed-up ratios relating the wind speed at each grid point to the speed at a reference mast. By associating the model data to a wind speed histogram file for the reference mast, the program is able to adjust the modeled speed distribution to the true speed distribution observed at a point. This method usually produces a more accurate estimate of the energy production than relying on the modeled distributions alone.

A number of reference masts can be used to reduce errors in the predicted spatial variation of the wind resource across the project area. Conventionally, the project area is broken up into sub-regions, each of which is associated with a different mast using the distance-weighted interpolation between masts, as previously described. This avoids discontinuities in wind speeds across the boundaries of areas assigned to different masts and produces a more realistic picture of the spatial variation of the wind resource. Within Openwind, the adjusted wind resource grid is divided into sub-regions associated with different masts to capture variations in the observed speed frequency distribution, although the corresponding impact on energy production estimates is usually relatively small.

AWS Truepower uses the Openwind Deep Array Wake Model (DAWM) to calculate wake losses. This model actually contains two separate wake models operating independently. The first is the Eddy Viscosity model, which is based on the thin-shear-layer approximation of the Navier-Stokes equations assuming axisymmetric wakes of Gaussian cross-sectional form, as originally postulated by Ainslie.[8] The model equations ensure that momentum and mass conservation are observed simultaneously. As inputs, the wake model requires the ambient turbulence intensity at hub height, which influences the initial wake deficit behind each turbine and the rate of wake dissipation; the speed and direction frequency distribution, based on a wind resource grid and associated mast files; the locations of the

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[5] Beaucage, Philippe and Brower, Michael C, Wind Flow Model Performance – Do More Sophisticated Models Produce More Accurate Wind Resource Estimates?, 6 February 2012

[6] Developed for NASA, the US Air Force, and commercial and research applications, MASS is similar to and has been verified against other mesoscale weather models such as MM5 and WRF. For further information, see http://www.meso.com/mass.html.

[7] WindMap, developed by AWS Truepower, is a mass-conserving model that adjusts an initial wind field, here supplied by MASS, in response to local variations in topography and surface roughness. See, e.g., Michael Brower, "Validation of the WindMap Model," Proceedings of WindPower 1999, American Wind Energy Association, June 1999.

[8] Ainslie, J.F., 1988, Calculating the flowfield in the wake of wind turbines." Journal of Wind Engineering and Industrial Aerodynamics, 27. Pages 213-224.

turbines; and the turbine thrust coefficient curves. Validation of the Openwind Eddy Viscosity model is described elsewhere.[4]

In response to evidence that conventional wake models like the Eddy Viscosity model underestimate wake losses in deep (multi-row) arrays of wind turbines, especially offshore, AWS Truepower implemented a second model designed to handle such situations. This model is loosely based on a theory developed by Frandsen,[9] who postulated that the effect of a deep array of wind turbines on the atmosphere could be represented as a region of increased surface drag, represented by a surface roughness length. Where the wind first impinges on the array, an internal boundary layer (IBL) is created, within which the wind profile is determined by the array roughness rather than by the ambient roughness. This IBL grows with downwind distance, and once its height exceeds the turbine hub height, the hub-height speed impinging upon turbines farther downwind is progressively reduced. According to the Frandsen theory, the effective array roughness is in the range of 1 m to 3 m, or typical of a forest, for mid-range speeds and typical turbine spacings. AWS Truepower modified the Frandsen model to treat each turbine as an isolated island of roughness, a necessary change to permit rapid modifications to the turbine layout for array optimization. In addition, the IBL created by each turbine is assumed to be centered on the turbine's hub height.

In combining the two models, the DAWM implicitly defines "shallow" and "deep" zones within a turbine array. In the shallow zone, the direct wake effects of individual turbines dominate, and the unmodified Eddy Viscosity (EV) model is used to calculate wake deficits; in the deep zone, the deep-array effect is more prominent, and thus, the roughness model is employed. The DAWM has been validated at several offshore and onshore projects.[10]

Results

The energy production was simulated for the Vestas V100-2.0 MW with a 100-m rotor diameter and an 80-m hub height. The turbine layout[11], which was provided by NSPC, is shown on the wind resource map in Figure 3. Each turbine in the layout was associated with the wind speed and direction distribution file from one of the on-site masts.

The average air density was calculated from the wind speed and temperature data from Mast 2612 and adjusted to the mean elevation of the turbines using a standard atmospheric lapse rate. The result was 1.198 kg/m^3.

Plant losses aside from turbine wake losses were estimated from AWS Truepower's experience with other projects and an analysis of site-specific data.[12] The wake loss was estimated by the Openwind program to be 8.0%. Including combined plant losses totaling 11.8%, the total loss is estimated to be 18.8%.

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[9] Sten Tronæs Frandsen, Turbulence and turbulence-generated structural loading in wind turbine clusters, Risø-R-1188(EN), Risø National Laboratory (January 2007).

[10] Brower, Michael C. and Robinson, Nicholas M., "The openWind Deep Array Wake Model – Development and Validation", May 2012.

[11] AWST has completed a high-level review of the layout provided and has determined that two turbines within the layout are within 1000 feet of a possibly occupied structure. As these turbines are closer than AWST standard setbacks, it is recommended that Northern States Power Company verify the locations with local authorities.

[12] Dan Bernadett, et al., 2012 Backcast Study: A Review and Calibration of AWS Truepower's Energy Estimation Methods, AWS Truepower May 2012.

The gross and net annual energy production estimates for the project are 994.9 GWh and 807.8 GWh, respectively. The net capacity factor is predicted to be 46.1%, and the estimated array-average free-stream wind speed at hub height is 8.24 m/s. A summary of the estimated average free-stream wind speed and gross and net energy production for each turbine is presented in Table 3.

5. UNCERTAINTY ESTIMATE

The uncertainty in the projected long-term hub height wind speed across the project is estimated to be 2.7%. This value incorporates the uncertainties associated with field verification, the onsite measurements, the wind shear extrapolation, the historical climate adjustment, the evaluation period, and the wind flow modeling. The sensitivity of the project output to changes in wind speed was determined to be approximately 3.4% for the given 2.7% uncertainty in mean wind speed. The uncertainties in wind speed frequency distribution and plant losses were combined with the previous total to yield an overall energy production uncertainty of 5.0%, or 40.7 GWh/yr. Table 4 presents the estimated net annual energy production and capacity factor at five confidence levels assuming a 9-year mature operation evaluation period and the same for the first year and for any single year thereafter.

6. SUMMARY

The long-term wind resource at the proposed Courtenay Wind Project was estimated using data from two monitoring masts and correlation with Jamestown and the ERA-I dataset. The energy production was simulated using a wind resource grid developed using SiteWind system, the Openwind software, a wind turbine layout provided by NSPC, and the Vestas V100-2.0 MW turbine with a 100-m rotor diameter at an 80-m hub height, and site average air density of 1.198 kg/m^3. The total wind plant loss is estimated to be 18.8%. The expected average annual net production and capacity factor for the project are 807.8 GWh and 46.1%, respectively, and the predicted array-average wind speed is 8.24 m/s.

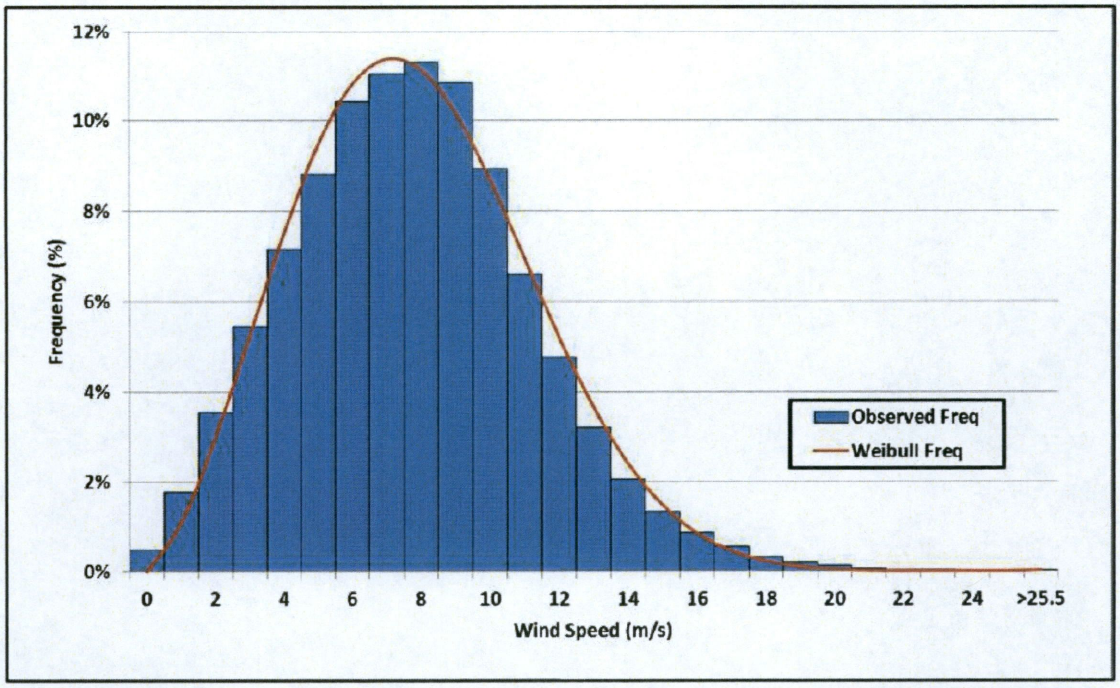

Figure 1. Mast 2612 Observed Wind Speed Frequency Distribution and Fitted Weibull Curve

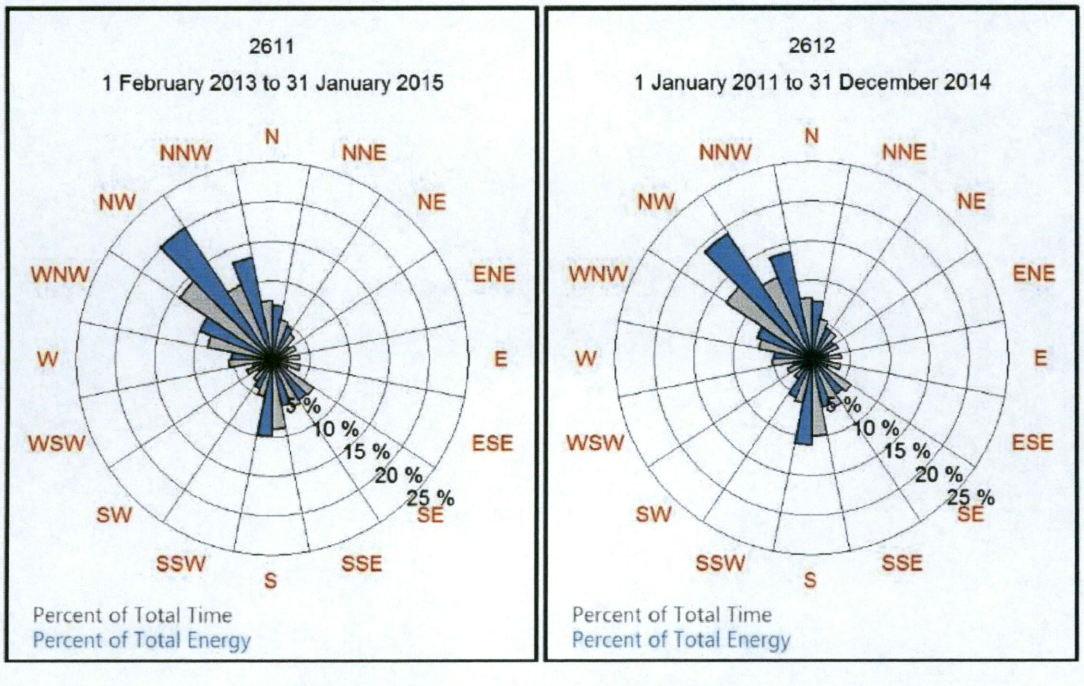

Figure 2. Monitoring Mast Annual Wind Roses

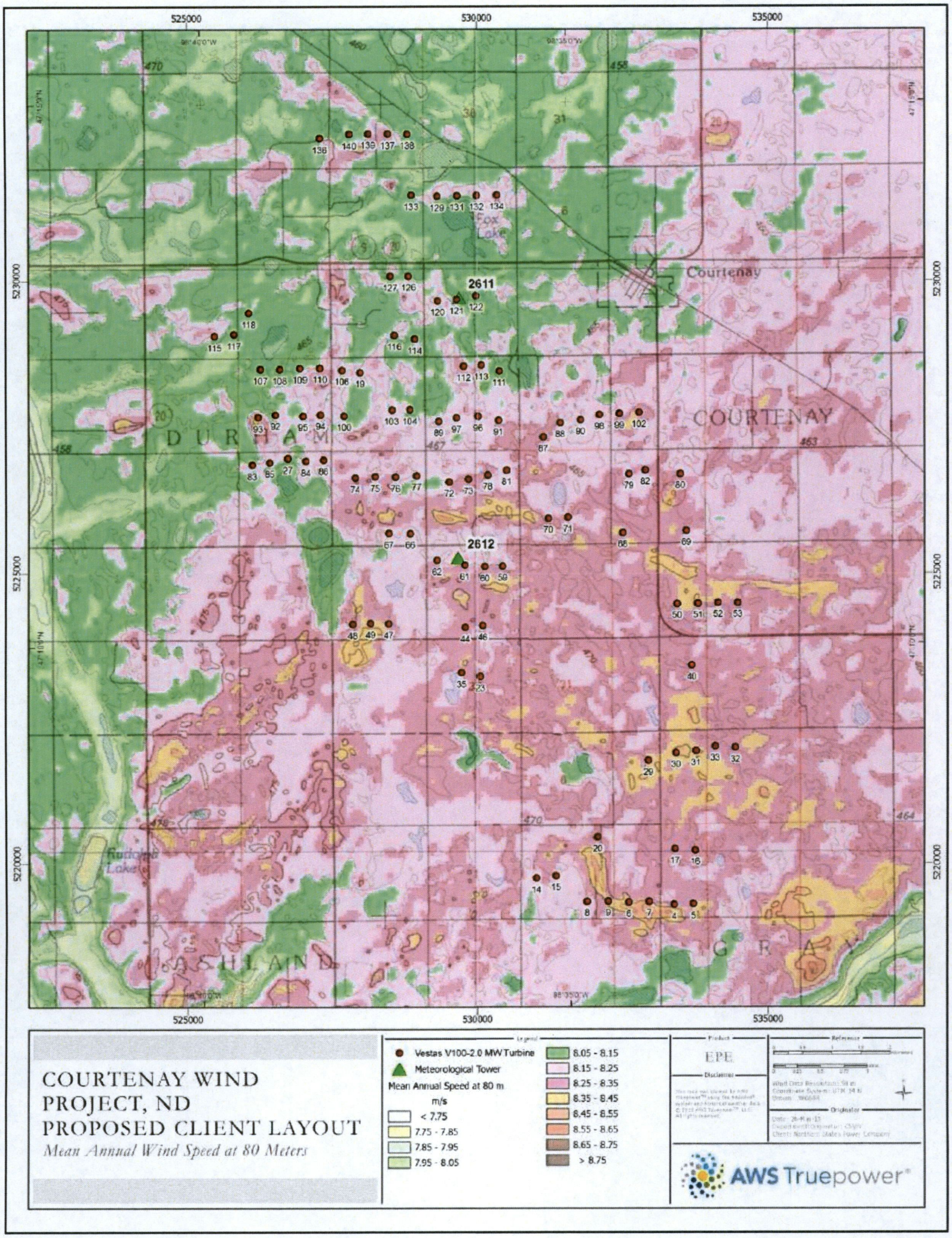

Figure 3. Proposed Courtenay Vestas V100-2.0 MW Turbine Layout

Table 1. Mast Summary

Mast	Site UTM Coordinates (WGS84, Zone 14)		Elevation (m)	Period of Record	Monitoring Heights (m)		
	Easting	Northing			Wind Speed	Wind Direction	Temp
2611	529687	5229709	465	1/29/2013 – 1/31/2015	60, 47, 32	58, 45	59, 2
2612	529671	5225265	471	7/16/2010 – 1/19/2015	60, 47.3, 32	58, 45.5	59, 2

Table 2. Monitoring Mast Long-Term Wind Speed Projection Summary

Mast	Monitoring Height (m)	Reference	Regression Equation	r^2	Long-Term Wind Speed (m/s)	Effective Wind Shear	Projected 80-m Speed (m/s)
2611	60	Mast 2612	y = 0.988x + 0.027	0.98	7.63	0.213	8.11
2612	60	Jamestown, ERA-I	y = 0.683*Jamestown + 0.423*ERA-I + 1.543	0.90	7.70	0.225	8.21

Table 3. Courtenay Wind Speed and Energy Production Detail

Project:	Northern States Power Company - Courtenay Wind Project, ND	
Date:	26-Mar-15	
Comments:	Client Layout	
Turbine Manufacturer/Model:	Vestas V100-2.0 MW	
Turbine Rated Power:	2.00	MW
Hub Height:	80	m
Number of Turbines:	100	
Plant Capacity:	200	MW
Site Air Density:	1.198	kg/m^3

AWS Truepower®
Where science delivers performance.

Loss Accounting	
Wake Effect	8.0%
Availability	4.5%
Electrical	3.1%
Turbine Performance	1.2%
Environmental	3.6%
Curtailments	0.0%
Average Total Loss	**18.8%**

Overall Wind Plant Summary	
Average Free Wind Speed (m/s)	8.24
Gross Plant Production (MWh/yr)	994,937
Net Plant Production (MWh/yr)	807,813
Net Capacity Factor	46.1%

Per Turbine Summary

Turbine ID	Mast Association	Coordinates (WGS84 UTM14) Easting (m)	Northing (m)	Free Speed (m/s)	Gross MWh/yr	Array Eff. (%)	Array Loss (%)	Total Loss (%)	Net MWh/yr	Turbine Rank	Net Capacity Factor (%)	Total TI at 15m/s (%)
4	2612	533382	5219293	8.33	10,076	93.8	6.2	17.3	8,336	19	47.5	8.2
5	2612	533712	5219306	8.34	10,091	94.4	5.6	16.7	8,403	5	47.9	8.2
6	2612	532601	5219337	8.40	10,178	93.0	7.0	18.0	8,346	18	47.6	8.1
7	2612	532949	5219349	8.39	10,153	93.5	6.5	17.5	8,377	14	47.8	8.1
8	2612	531887	5219349	8.18	9,866	94.3	5.7	16.8	8,206	35	46.8	8.3
9	2612	532247	5219355	8.38	10,159	92.9	7.1	18.0	8,327	20	47.5	8.1
14	2612	531014	5219751	8.20	9,879	96.3	3.7	15.0	8,393	8	47.9	8.2
15	2612	531352	5219794	8.22	9,923	94.4	5.6	16.7	8,263	27	47.1	8.3
16	2612	533743	5220232	8.30	10,034	93.1	6.9	17.9	8,240	30	47.0	8.2
17	2612	533396	5220256	8.34	10,082	93.6	6.4	17.4	8,323	21	47.5	8.0
19	2611	527984	5228437	8.20	9,912	90.7	9.3	20.0	7,932	68	45.2	8.5
20	2612	532067	5220456	8.31	10,036	95.4	4.6	15.9	8,444	3	48.2	8.1
23	2612	530047	5223219	8.28	10,022	92.5	7.5	18.4	8,183	37	46.7	8.2
27	2612	526743	5226968	8.17	9,850	90.3	9.7	20.4	7,844	84	44.7	8.7
29	2612	532939	5221783	8.36	10,118	95.5	4.5	15.7	8,527	1	48.6	8.0
30	2612	533413	5221916	8.45	10,228	94.0	6.0	17.1	8,482	2	48.4	7.9
31	2612	533760	5221949	8.39	10,150	92.8	7.2	18.1	8,314	23	47.4	8.0
32	2612	534437	5222008	8.32	10,042	94.6	5.4	16.6	8,379	13	47.8	8.1
33	2612	534089	5222029	8.31	10,036	92.9	7.1	18.0	8,229	31	46.9	8.1
35	2612	529727	5223282	8.24	9,958	94.0	6.0	17.1	8,258	29	47.1	8.2
40	2612	533687	5223411	8.29	10,011	94.9	5.1	16.2	8,384	10	47.8	8.0
44	2612	529790	5224071	8.31	10,062	92.4	7.6	18.5	8,203	36	46.8	8.1
46	2612	530095	5224101	8.27	9,996	91.5	8.5	19.3	8,066	51	46.0	8.2
47	2612	528472	5224135	8.32	10,050	93.4	6.6	17.6	8,284	25	47.3	8.2
48	2612	527861	5224126	8.27	9,985	95.9	4.1	15.4	8,443	4	48.2	8.2
49	2612	528166	5224139	8.38	10,136	92.8	7.2	18.2	8,294	24	47.3	8.1
50	2612	533436	5224475	8.35	10,095	94.4	5.6	16.8	8,403	6	47.9	8.0
51	2612	533799	5224480	8.36	10,125	92.5	7.5	18.4	8,266	26	47.1	8.1
52	2612	534140	5224492	8.30	10,034	92.3	7.7	18.6	8,169	38	46.6	8.2
53	2612	534480	5224492	8.32	10,069	94.2	5.8	16.9	8,365	15	47.7	8.2
59	2612	530435	5225120	8.25	9,960	91.5	8.5	19.3	8,039	59	45.9	8.4
60	2612	530131	5225111	8.26	9,980	89.5	10.5	21.0	7,882	75	45.0	8.4
61	2612	529785	5225137	8.23	9,950	90.9	9.1	19.8	7,982	63	45.5	8.4
62	2612	529304	5225220	8.22	9,934	92.3	7.7	18.6	8,089	46	46.1	8.3
66	2612	528846	5225680	8.20	9,897	90.3	9.7	20.4	7,880	76	44.9	8.5
67	2612	528480	5225683	8.21	9,907	92.1	7.9	18.8	8,048	55	45.9	8.3
68	2612	532500	5225693	8.34	10,099	94.3	5.7	16.8	8,402	7	47.9	8.0
69	2612	533596	5225726	8.26	9,975	94.5	5.5	16.6	8,316	22	47.4	8.1
70	2612	531227	5225940	8.26	9,978	92.3	7.7	18.5	8,128	42	46.4	8.3
71	2612	531563	5225956	8.25	9,963	91.7	8.3	19.1	8,059	52	46.0	8.2
72	2612	529516	5226563	8.22	9,915	90.6	9.4	20.1	7,924	69	45.2	8.4
73	2612	529848	5226610	8.28	10,000	89.5	10.5	21.0	7,898	73	45.0	8.3
74	2612	527906	5226636	8.25	9,977	90.9	9.1	19.8	7,996	61	45.6	8.4
75	2612	528248	5226654	8.26	9,978	89.3	10.7	21.2	7,859	80	44.8	8.4
76	2612	528594	5226650	8.25	9,969	89.4	10.6	21.2	7,859	81	44.8	8.5

Table 3 Continued. Courtenay Wind Speed and Energy Production Detail

Per Turbine Summary												
Turbine ID	Mast Association	Coordinates (WGS84 UTM14) Easting (m)	Northing (m)	Free Speed (m/s)	Gross MWh/yr	Array Eff. (%)	Array Loss (%)	Total Loss (%)	Net MWh/yr	Turbine Rank	Net Capacity Factor (%)	Total TI at 15m/s (%)
77	2612	528960	5226672	8.20	9,904	90.0	10.0	20.6	7,864	78	44.9	8.6
78	2612	530182	5226685	8.27	9,981	89.4	10.6	21.1	7,875	77	44.9	8.4
79	2612	532607	5226699	8.25	9,951	92.0	8.0	18.9	8,073	50	46.0	8.2
80	2612	533494	5226703	8.27	9,980	94.9	5.1	16.3	8,352	16	47.6	8.1
81	2612	530504	5226767	8.22	9,915	91.0	9.0	19.7	7,960	66	45.4	8.5
82	2612	532889	5226766	8.27	9,994	91.6	8.4	19.2	8,074	49	46.1	8.3
83	2612	526122	5226857	8.16	9,835	95.2	4.8	16.0	8,259	28	47.1	8.5
84	2612	527054	5226921	8.18	9,865	88.6	11.4	21.8	7,710	96	44.0	8.7
85	2612	526421	5226898	8.18	9,869	91.6	8.4	19.2	7,973	64	45.5	8.5
86	2612	527355	5226943	8.23	9,951	89.5	10.5	21.1	7,853	82	44.8	8.5
87	2611	531134	5227331	8.28	10,016	92.3	7.7	18.5	8,160	39	46.5	8.3
88	2611	531427	5227572	8.23	9,938	92.3	7.7	18.6	8,094	43	46.2	8.4
89	2611	529341	5227597	8.23	9,946	89.4	10.6	21.1	7,845	83	44.7	8.5
90	2611	531775	5227623	8.21	9,923	91.9	8.1	19.0	8,042	57	45.9	8.4
91	2611	530367	5227617	8.21	9,929	89.3	10.7	21.2	7,819	88	44.6	8.6
92	2611	526525	5227712	8.16	9,848	89.0	11.0	21.5	7,733	93	44.1	8.6
93	2611	526223	5227672	8.34	10,111	92.0	8.0	18.8	8,209	34	46.8	8.3
94	2611	527306	5227712	8.20	9,907	87.0	13.0	23.3	7,601	100	43.4	8.6
95	2611	527002	5227694	8.18	9,877	88.3	11.7	22.1	7,695	98	43.9	8.7
96	2611	530018	5227684	8.23	9,953	89.1	10.9	21.4	7,822	87	44.6	8.6
97	2611	529644	5227659	8.20	9,899	88.9	11.1	21.6	7,763	90	44.3	8.6
98	2611	532103	5227708	8.24	9,965	92.6	7.4	18.3	8,140	40	46.4	8.5
99	2611	532442	5227730	8.22	9,929	92.3	7.7	18.6	8,078	48	46.1	8.4
100	2611	527711	5227694	8.16	9,859	89.4	10.6	21.2	7,772	89	44.3	8.6
102	2611	532781	5227746	8.36	10,116	93.9	6.1	17.1	8,383	11	47.8	8.2
103	2611	528537	5227794	8.17	9,863	90.1	9.9	20.5	7,837	85	44.7	8.5
104	2611	528842	5227799	8.15	9,841	89.1	10.9	21.4	7,737	92	44.1	8.6
106	2611	527672	5228474	8.20	9,901	90.3	9.7	20.3	7,890	74	45.0	8.5
107	2611	526259	5228491	8.13	9,807	91.5	8.5	19.3	7,918	71	45.2	8.6
108	2611	526600	5228491	8.12	9,794	89.1	10.9	21.4	7,700	97	43.9	8.7
109	2611	526948	5228509	8.14	9,817	89.3	10.7	21.3	7,731	94	44.1	8.6
110	2611	527293	5228512	8.19	9,891	90.1	9.9	20.5	7,863	79	44.8	8.5
111	2611	530380	5228459	8.12	9,791	89.0	11.0	21.5	7,690	99	43.9	8.7
112	2611	529765	5228540	8.27	10,014	90.5	9.5	20.2	7,991	62	45.6	8.4
113	2611	530070	5228561	8.19	9,884	88.5	11.5	21.9	7,721	95	44.0	8.5
114	2611	528926	5229005	8.14	9,821	90.4	9.6	20.3	7,831	86	44.7	8.5
115	2611	525466	5229055	8.21	9,919	95.9	4.1	15.4	8,388	9	47.8	8.3
116	2611	528579	5229071	8.16	9,845	92.6	7.4	18.3	8,042	58	45.9	8.4
117	2611	525804	5229088	8.13	9,811	93.1	6.9	17.9	8,058	53	46.0	8.4
118	2611	526058	5229448	8.15	9,829	94.9	5.1	16.3	8,227	32	46.9	8.3
120	2611	529317	5229656	8.20	9,903	90.7	9.3	20.0	7,924	70	45.2	8.4
121	2611	529650	5229681	8.13	9,807	89.7	10.3	20.9	7,759	91	44.3	8.5
122	2611	529979	5229744	8.13	9,802	92.2	7.8	18.7	7,973	65	45.5	8.6
126	2611	528818	5230081	8.15	9,829	91.1	8.9	19.6	7,899	72	45.1	8.5
127	2611	528509	5230078	8.12	9,800	93.0	7.0	18.0	8,035	60	45.8	8.5
129	2611	529311	5231442	8.21	9,922	91.9	8.1	18.9	8,044	56	45.9	8.4
131	2611	529653	5231452	8.16	9,843	91.6	8.4	19.2	7,956	67	45.4	8.5
132	2611	529994	5231459	8.20	9,908	92.2	7.8	18.7	8,054	54	45.9	8.4
133	2611	528871	5231463	8.12	9,797	93.6	6.4	17.4	8,090	45	46.1	8.5
134	2611	530342	5231464	8.27	10,001	94.6	5.4	16.5	8,348	17	47.6	8.3
136	2611	527300	5232427	8.11	9,780	97.2	2.8	14.3	8,381	12	47.8	8.3
137	2611	528466	5232501	8.29	10,036	92.8	7.2	18.1	8,219	33	46.9	8.3
138	2611	528803	5232499	8.10	9,760	94.0	6.0	17.1	8,091	44	46.1	8.5
139	2611	528134	5232506	8.18	9,875	92.8	7.2	18.1	8,087	47	46.1	8.3
140	2611	527807	5232497	8.09	9,745	94.6	5.4	16.5	8,134	41	46.4	8.3

Table 4. Estimated Energy Production and Net Capacity Factor at Five Confidence Levels (Evaluation Period [Years 2-10], Annual, and First Year)

Probability of Exceedance	Evaluation Period Average Energy Production (GWh)	Evaluation Period Average Capacity Factor (%)	Annual Energy Production (GWh)	Annual Capacity Factor (%)	First Year Energy Production (GWh)	First Year Capacity Factor (%)
P50	807.8	46.1	807.8	46.1	788.4	45.0
P75	780.3	44.5	770.5	43.9	738.3	42.1
P90	755.6	43.1	736.9	42.0	693.2	39.5
P95	740.8	42.3	716.8	40.9	666.2	38.0
P99	713.1	40.7	679.1	38.7	615.6	35.1

APPENDIX A – ENERGY PRODUCTION LOSSES

Table A1. Courtenay Vestas V100-2.0 MW Detailed Energy Production Loss Accounting

Wake Effect	**First Year**	**Long-Term**
Internal Wake Effect of the Project	8.0%	8.0%
Wake Effect of Existing or Planned Projects	0.0%	0.0%
Wake Effect Total	**8.0%**	**8.0%**
Availability		
Contractual Turbine Availability*	3.0%	3.0%
Non-Contractual Turbine Availability*	0.7%	0.7%
Long-term Availability Correlation with High Wind Events*	0.1%	0.1%
Availability of Collection & Substation	0.2%	0.2%
Availability of Utility Grid	0.3%	0.3%
Plant Re-start after Grid outages	0.2%	0.2%
First-Year Plant Availability*	2.9%	0.0%
Availability Total	**7.2%**	**4.5%**
Electrical		
Electrical Efficiency**	2.5%	2.5%
Power Consumption of Extreme Weather Package	0.6%	0.6%
Electrical Total	**3.1%**	**3.1%**
Turbine Performance		
Sub-Optimal Operation*	0.5%	0.5%
Power Curve Adjustment	0.6%	0.6%
High Wind Control Hysteresis	0.1%	0.1%
Inclined Flow	0.0%	0.0%
Turbine Performance Total	**1.2%**	**1.2%**
Environmental		
Icing	2.0%	2.0%
Blade Degradation	0.7%	1.2%
Low/High Temperature Shutdown	0.0%	0.0%
Site Access	0.2%	0.2%
Lightning	0.2%	0.2%
Environmental Total	**3.1%**	**3.6%**
Curtailments		
Directional Curtailment	0.0%	0.0%
PPA Curtailment	0.0%	0.0%
Environmental Curtailment	0.0%	0.0%
Curtailment Total	**0.0%**	**0.0%**
Total Losses	**20.8%**	**18.8%**

*Reduced from AWS Truepower standards based on the use of the AOM 5000 availability warranty.

**Increased from AWS Truepower standard based on provided electrical studies.

Wake Effect

Wind turbines alter the free stream wind flow which may reduce the energy production of a wind project. Losses due to this wake effect are divided into the following categories:

- **Internal Wake Effect of the Project:** This loss accounts for the wake effect from turbines within the project being analyzed.
- **Wake Effect of Existing or Planned Projects:** This loss accounts for the wake effect of existing or planned projects located adjacent to the project being analyzed for which sufficient information was available to make a precise estimate of their impact on the project being studied.

Availability

A plant or turbine is said to be available when it is capable of generating its full rated output, given sufficient wind. Availability losses occur when some turbines in a project, or an entire project, are inoperative for some reason. Availability losses assume that the Vestas AOM5000 contract (as described in the documents downloaded from the Geronimo Energy Sharefile dataroom[13]) is in place for a 10-year term.

- **Contractual Availability of Wind Turbines:** Turbine downtime traditionally covered under availability warranties (while in effect); AWS Truepower typically assumes a baseline time-weighted turbine availability of 97%. The AOM5000 contract has a 97% production-based availability guarantee.
- **Non-Contractual Availability of Wind Turbines:** AWS Truepower attributes an additional 1.3% of turbine downtime as a result of force majeure events, scheduled maintenance, and repair delays due to high winds or lack of spare parts, which are typically not covered under traditional warranties. The AOM5000 contract is a long-term full service contract, which eliminates exclusions due to maintenance-based events, such as repair delays and spare parts. As such, the non-contractual availability has been reduced to 0.7%.
- **Long-term Availability Correlation with High Wind Events (LACHWE):** This factor accounts for the likelihood that the turbines will experience shutdowns more often in high winds than at other times, resulting in energy losses not accounted for by downtime alone. Shutdowns tend to occur in high winds because that is when turbine components are most likely to exceed limits specified in the control software. AWS Truepower's estimate of this loss, which depends upon the turbine type, expected downtime, and capacity factor, is based on detailed study of losses in operating wind projects. As the AOM5000 contract has a production-based availability guarantee, the LACHWE loss has been reduced to only account for the time-to-energy component of the remaining non-contractual availability.
- **Availability of Collection and Substation:** This loss accounts for outages of the collection system and substation. It is typically assigned a value of 0.2%, which corresponds to 2 events per year of 8 hours average duration.
- **Availability of Utility Grid:** This loss accounts for outages of the utility grid. It is typically assigned a value of 0.3%, which corresponds to 4 events per year of 6 hours average duration.
- **Plant Restart after Grid Outage:** This loss is typically assigned a value of 0.2%, which assumes that 4 utility grid outages per year are accompanied by a 5-hour average standby

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[13] Vestas. "VAWT_ Enel FSMA Ex. D Availability Covenants.DOCX."

period while the turbine components are brought within temperature, humidity, and other operating specifications.

- **First-Year Plant Availability:** This value is typically set to 4% to account for the additional turbine and plant downtime that is often observed during the first year of operation The First-Year Plant Availability has been reduced to reflect the production-based nature of the AOM5000 and the reduction in non-contractual availability.

Electrical

- **Electrical Efficiency:** Losses are experienced in all electrical components of the wind project, including the padmount transformer, electrical collection system, and substation transformer. These losses are established in the electrical system design. An electrical loss study[14] was provided for the proposed wind project. This study has been reviewed by AWS Truepower and the resulting electrical loss value has been increased from the AWS Truepower typical assumption of 2.0% to 2.5% based on additional transmission and step-up transformers required for project interconnection.
- **Power Consumption of Extreme Weather Package:** This loss is intended to account for the energy consumed by the equipment included in an extreme weather package, if the turbines are so equipped. Power consumption for site lighting, O&M facilities, and other site facilities not associated with the turbines are not included as loss items and should be considered in the project's financial modeling.

Turbine Performance

- **Sub-Optimal Operation:** This factor accounts for shortfalls from ideal performance due to suboptimal turbine settings. Typical examples include yaw misalignments, control anemometer calibration, blade pitch inaccuracies or misalignments, and other control setting issues. AWS Truepower was provided the Vestas AOM 5000 full-service contract with production based availability for the project. Based on the excerpts provided and understanding of the services from Vestas, the sub-optimal operation loss was reduced to 0.5%.
- **Power Curve Adjustment:** This loss accounts for expected turbine performance relative to the modeled performance using the advertised power curve.[15] Vestas supplied AWS Truepower with tabular, unfiltered power performance test results for turbines in similar site conditions[16,17]. The power performance test results were used in conjunction with the site specific climatic conditions and power frequency distribution to adjust the loss.
- **High Wind Control Hysteresis:** For most turbines, once the wind speed exceeds the turbine's design cut-out speed and the machine shuts down, the control software waits until the speed drops below a lower speed threshold (the reset-from-cut-out speed) before allowing the turbine to restart. This loss accounts for the energy lost in this hysteresis loop. It is calculated from wind data collected at the site and the manufacturer's specified cut-out and reset-from-cut-out speeds.

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[14] INTERCONNECTION OVERVIEW - COURTENAY 131127.pdf, 2014 January 21_Revision_ColorByFeeder.pdf

[15] Dan Bernadett, et al., 2012 Backcast Study: A Review and Calibration of AWS Truepower's Energy Estimation Methods, AWS Truepower May 2012.

[16] Vestas. "North American Power Performance Results for Active-Pitch Turbines." 130405dejae Vestas Active-Pitch Power Performance Summary.doc. 5 April 2013.

[17] Vestas. Data. 130719dejae Vestas V90 and V100 PPPT Results__EXTERNAL.xlsx. 23 September 2013.

- **Inclined Flow:** This loss has been included to account for the estimated impact of inclined (non-horizontal) flow on power production.

Environmental

- **Icing:** This loss reflects decreased rotor aerodynamic efficiency caused by the accumulation of ice on the turbines during plant operation, as well as turbine shutdowns caused by excessive ice accumulation. The icing losses are estimated from site weather data, including the expected frequency and duration of freezing precipitation and rime ice formation.
- **Blade Degradation:** This loss reflects changes to the aerodynamic efficiency of the turbine blades over time and consists of long- and short-term components. Long-term impacts result from normal wear and are caused by factors such as the permanent effects of sun exposure, wind-blown sand, and the freeze/thaw cycle of moisture within micro-cracks on the blades. These factors typically affect the leading edge of the blade and result in performance degradation over time. Short-term effects generally result from the accretion of insects and dirt. This factor is estimated from the expected dust and insect accumulation in the area and the frequency of precipitation, which cleans the blades.
- **Low/High Temperature Shutdown:** This loss value is calculated based on the energy that will be lost when the turbine shuts down due to temperatures outside the operating design envelope.
- **Site Access:** Severe weather can limit access to some sites, which can reduce energy production because response times for repairs are increased. This situation often occurs in areas prone to heavy snow. However, offshore projects may also be strongly affected. This loss is estimated based on weather data and other site specific information.
- **Lightning:** Lightning can damage turbine components and cause electrical faults resulting in shutdowns. This loss is estimated from meteorological data indicating the likely frequency of lightning at the site.

Curtailments

Directional Curtailment: AWS Truepower has reviewed the Wind Power Plant Assessment (WPPA) for the Courtenay wind project which indicated that directional curtailment was not required for the layout in its current configuration when utilizing the Vestas V100-2.0 MW turbine model.

- **PPA Curtailment:** If the wind farm is forced to curtail production, loss of revenue could result from the sale of energy and or loss of production incentives. Typically, AWS Truepower does not have sufficient information to assign a value to this loss. Consequently, it is typically set to zero unless loss data is supplied by the client.
- **Environmental Curtailment:** If the wind farm is required to comply with certain operational standards due to environmental constraints, an environmental curtailment loss may be estimated. Production may be curtailed due to habitat concerns, noise restraints, shadow flicker, and other such environmental issues. Typically, AWS Truepower does not have sufficient information to assign a value to this loss. Consequently, it is normally set to zero unless specific restrictions are supplied by the client.

APPENDIX B – INDIVIDUAL UNCERTAINTY DESCRIPTIONS

- **Site Documentation and Verification**: This uncertainty addresses the quality and independence of the available information describing the site characteristics and monitoring equipment. Specific items considered include the quality and comprehensiveness of tower commissioning and verification documents; the quality and number of photographs depicting each mast and its surroundings; and information regarding obstacles potentially affecting the wind flow at each mast.

- **Wind Speed Measurements**: This is the uncertainty in anemometer readings of the free-stream wind speed. It reflects not just uncertainty in the sensitivity of the instruments when operating under wind-tunnel conditions, but also uncertainty in their performance in the field, where they may be subject to turbulent and off-horizontal winds, tower effects, and problems such as icing that may be missed in the validation. In addition, where applicable, the uncertainty in empirical adjustments applied to account for factors such as turbulence or the impact of wakes from existing turbines on observed wind speeds is considered.

- **Long-Term Average Speed**: This uncertainty addresses how accurately the site data, after the MCP adjustment, may represent the historical average wind resource. AWS Truepower has undertaken a study of wind speed interannual variability and has produced an interannual variability map using the global ERA-Interim reanalysis dataset.[18] The map suggests that the standard deviation of annual mean wind speeds for the Courtenay Project is about 3.1%. It is assumed that the annual mean varies randomly according to the normal distribution, and thus the error margin varies inversely with the square root of the number of years. The estimated uncertainty accounts also for the degree of correlation between the target and reference station, the length of the reference period of record, and the data recovery at each mast.

- **Evaluation Period Wind Resource**: This uncertainty is associated with how closely the wind resource over the evaluation period may match the long-term site average. The estimated value assumes a 10-year evaluation period, 3.1% interannual variation in the mean speed, and 0.5% uncertainty associated with possible climate oscillations and trends.

- **Wind Shear**: The wind shear uncertainty includes the uncertainty in the observed shear due to possible measurement errors and the uncertainty in the change in shear above mast height. The estimated value considers the site conditions, anemometer heights, hub height(s), and measurement uncertainties at each mast.

- **Wind Flow Modeling**: The uncertainty in the array-average free-stream wind speed at the turbines, relative to the masts, depends on the wind climate, terrain complexity and vegetation density and variation, characteristics of the wind flow model, and number of masts used to adjust the resource grid and their representativeness of the turbine layout.

- **Wind Speed Frequency Distribution**: Like the mean wind speed, the wind speed frequency distribution varies over time. Our research indicates that the interannual variability of the energy production directly related to the wind speed frequency distribution is typically about 1.4%. The estimated uncertainty in the long-term energy production estimate

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[18] Michael C. Brower, et al., "A Study of Wind Speed Variability Using Global Reanalysis Data", AWS Truepower, May 2013.

considers this factor along with the on-site period of record and the length of the evaluation period.

- **Plant Losses**: AWS Truepower has used operational data to quantify the uncertainties associated with our estimates for plant availability, electrical, and turbine performance losses for the evaluation period, as well as for the first year and any subsequent year. When these values are combined with the estimated uncertainties due to environmental factors and directional curtailment, the plant operational loss uncertainty is estimated to be 3.2% over the 10-year evaluation period. (Uncertainties associated with grid curtailment losses are not considered here.) In addition, based on the DAWM validation findings, we estimate the uncertainty in the wake loss calculations to be 20% of the total wake loss. The operational and wake loss uncertainties are combined as the square root of the sum of their squares.

STATE OF NORTH DAKOTA
BEFORE THE
PUBLIC SERVICE COMMISSION

In the Matter of the Application of
Northern States Power Company
for an Advance Determination of
Prudence for the 200 MW
Courtenay Wind Farm Project

Case No. PU-15-_____

STATE OF MINNESOTA)
) ss
COUNTY OF HENNEPIN)

Paul B. Johnson, being first duly sworn on oath, deposes and says that he is the Director of Resource Planning and Bidding for Xcel Energy Services Inc., the service company subsidiary of Xcel Energy, in the above captioned matter, that he has read the testimony and schedules submitted in the above captioned matter under his name, that they were prepared under his direction, that he knows the contents thereof, and that the same is true and correct to the best of his knowledge and belief.

Paul B. Johnson
Paul B. Johnson

Subscribed and sworn to before me
this 5th th day of May, 2015.

Notary Public
My Commission Expires: 1-31-2020

CYNTHIA D. HARRINGTON
Notary Public, State of Minnesota
My Commission Expires
January 31, 2020