Wind-Diesel System Design and Equipment

Wind-diesel power systems are categorized based on their average penetration levels, or the overall proportion of wind-generated electricity compared to the total amount of electrical energy generated. Commonly used categories of wind-diesel penetration levels are low penetration, medium penetration, and high penetration, as summarized below. The wind penetration level is roughly equivalent to the amount of diesel fuel displaced by wind power. Note however that the higher the level of wind penetration, the more complex and expensive a control system and demand-management strategy is required.

Categories of wind-diesel penetration levels

Penetration	Penetration Level		Operating characteristics and system requirements
	Instantaneous	Average	
Low	0% to 50%	Less than 20%	Diesel generator(s) run full time at greater than minimum loading level. Requires minimal changes to existing diesel control system. All wind energy generated supplies the village electric load; wind turbines function as "negative load" with respect to diesel generator governor response.
Medium	0% to 100+%	20% to 50%	Diesel generator(s) run full time at greater than minimum loading level. Requires control system capable of automatic generator start, stop and paralleling. To control system frequency during periods of high wind power input, system requires fast acting secondary load controller matched to a secondary load such as an electric boiler augmenting a generator heat recovery loop. At high wind power levels, secondary (thermal) loads are dispatched to absorb energy not used by the primary (electric) load. Without secondary loads, wind turbines must be curtailed to control frequency.
High (Diesels-off Capable)	0% to 150+%	Greater than 50%	Diesel generator(s) can be turned off during periods of high wind power levels. Requires sophisticated new control system, significant wind turbine capacity, secondary (thermal) load, energy storage such as batteries or a flywheel, and possibly additional components such as demand-managed devices.

Choosing the ideal wind penetration for Nunam Iqua depends on a number of factors, including load profile of the community, wind resource, construction cost and challenges, fuel price and also technical capability and experience of the utility with wind power and energy storage systems. There is no one "right" answer and the most optimal wind-diesel system for Nunam Iqua may not be the one that displaces the most fuel, nor even one that has the highest benefit-to-cost ratio. It is presumed for the purposes of this feasibility study that Nunam Iqua Electric Company's interest will be with a medium penetration option as that configuration provides a significant enough fuel savings to justify the high construction costs of a wind turbine project yet avoids the design complexity and operational challenges of high penetration.

Wind-diesel Integration Controls

Medium to high-penetration wind-diesel systems require fast-acting real and reactive power management to compensate for rapid variation in village load and wind turbine power output. A wind-diesel system master controller, typically referred to as a supervisory control and data acquisition (SCADA) system, is installed to select the optimum system component configuration based on village load demand and available wind power. Regardless of the supplier, a SCADA system is capable of controlling individual components and allowing those components to communicate status to the system. A typical SCADA will consist of the following:

- Station Controller: schedules and dispatches diesel generators, wind turbines and other components units, performs remote control functions, and stores collected component and system data
- Generation Controller: monitors and controls individual diesel generators
- Wind Turbine Controller: monitors and controls individual wind turbine and dispatches wind turbines
- Feeder Monitor: monitors vital statistics of an individual distribution feeder, including ground fault information
- Demand Controller: monitors, controls, and schedules demand-managed devices

Energy Storage Options

Although high penetration wind power is not proposed in this feasibility study, as reference for future development, electrical energy storage provides a means of storing wind generated power during periods of high winds and releasing that power to the electrical distribution system as winds subside.

Batteries are most appropriate for providing medium-term energy storage to allow a transition, or bridge, between the variable output of wind turbines, and diesel generation. This bridging period is typically between five and fifteen minutes. Storage for several hours or days is also possible with batteries, but requires more capacity and higher cost. In general, the disadvantages of batteries for energy storage, even for a small utility system, are high capital and maintenance costs and limited lifetime. Of particular concern to rural Alaska communities is that batteries are heavy and expensive to transport to the site, and many contain toxic material that requires disposal as hazardous waste at the end of a battery's useful life.

Because batteries operate on direct current (DC), a converter is required when connected to an alternating current (AC) system. A typical battery storage system includes a bank of batteries and a power conversion device. Recent advances in power electronics have made solid state converter (inverter/rectifier) systems cost effective and hence the preferred power conversion device.

Despite some drawbacks, electric power storage with batteries is a proven technology, but it has seen limited use in rural Alaska wind-diesel projects to date. Wales is equipped with a high penetration wind system with battery storage that is functional, but its operational history has been very disappointing and given the design age, it is not considered a reproducible system. Kokhanok has a recently-installed high-penetration wind-diesel system with lead-acid type battery storage, designed and constructed by

Marsh Creek LLC of Anchorage, although it is not yet operational. Of interest is a 250 kW flow battery that Kotzebue Electric Association plans to install in 2012 in Kotzebue to support their planned installation of two 900 kW EWT wind turbines.

Wind Turbines and HOMER Modeling

Considering Nunam Iqua Electric Company's goal of displacing as much diesel fuel for electrical generation as possible and yet recognizing the present limitations of high penetration wind power in Alaska and Nunam Iqua Electric Company's desire to operate a highly stable and reliable electrical utility in Nunam Iqua well within the confines of well-proven technology, only the medium penetration wind-diesel configuration scenario was modeled with HOMER software. Note that low penetration wind was not modeled as this would involve use of smaller farm-scale turbines that are not designed for severe cold climates. Additionally, a low penetration wind power configuration would not meet Nunam Iqua Electric Company's goal of significantly displacing fuel usage in Nunam Iqua.

As previously noted, a medium penetration wind-diesel configuration is a compromise between the simplicity of a low penetration wind power and the significant complexity and sophistication of the high penetration wind. With medium penetration, instantaneous wind input is sufficiently high (at 100 plus percent of the village electrical load) to require a secondary or diversion load to absorb excess wind power, or alternatively, to require curtailment of wind turbine output during periods of high wind/low electric loads. For Nunam Iqua, appropriate wind turbines for medium wind penetration are generally in the 50 to 200 kW range with more numbers of turbines required for lower output machines compared to larger output models.

There are a number of comparative medium penetration village wind-diesel power systems presently in operation in Alaska. These include the AVEC villages of Toksook Bay, Chevak, Savoonga, Kasigluk, and Hooper Bay, among others. All are characterized by wind turbines directly connected to the AC distribution system. AC bus frequency control during periods of high wind penetration, when diesel governor control would be insufficient, is managed by the sub-cycle, high resolution, and fast-switching capability of the secondary load controller (SLC). Ideally, the SLC is connected to an electric boiler serving a thermal load as this will enhance overall system efficiency by augmenting the operation of the fuel oil boiler(s) serving the thermal load.

Diesel Power Plant

Electric power (comprised of the diesel power plant and the electric power distribution system) in Nunam Iqua is provided by Nunam Iqua Electric Company. The existing power plant in Nunam Iqua consists of two John Deering 6090HF485 diesel generators rated at 229 kW electrical power output and one John Deering 6125HF001 diesel generator rated at 250 kW electrical power output.

Additional generator

The existing diesel generators in Nunam Iqua are somewhat oversized for the present electrical load, even without considering wind turbines. If medium to high penetration wind turbine capacity is added, the generators would often be very lightly loaded and hence operating at a very inefficient point in their fuel curve. A possible solution to this problem is to add a small, 117 kW John Deere 4045 (or similar) generator that is better suited to operate in a combined wind-diesel mode servicing Nunam Iqua's approximately 105 kW average load. The estimated cost to install one new generator of this type is $60,000.

Nunam Iqua powerplant diesel generators (existing)

Bay No.	Generator Capacity	Diesel Engine Make/Model	Status
1	229 kW	John Deere PowerTech Plus 9.0 L 6090HF485 EPA Tier 3/Stage IIIA	prime
2	250 kW	John Deere PowerTech 12.5 L 6125AF001 EPA Tier 1	prime
3	229 kW	John Deere PowerTech Plus 9.0 L 6090HF485 EPA Tier 3/Stage IIIA	prime
4 (proposed)	117 kW	John Deere 4045 (proposed)	prime (proposed)

Generator sets in the Nunam Iqua power plant are manually controlled with no automatic paralleling capability, although generators can be manually paralleled.

Wind Turbines

For this study, the wind turbines considered are restricted to rated outputs of 50 to 150 kW as this range well matches Nunam Iqua's electric load. This eliminates battery-charging turbines and small grid-connect home and farm-scale turbines that are insufficient for village power needs, and large utility-scale turbines that would overwhelm the Nunam Iqua power system. Unfortunately though, the world wind turbine market offers very few new turbines in this mid or village-scale size range. Of new turbines, only the American-made 100 kW Northwind 100 is a possibility, but earlier work on this project determined that it would be too expensive for a wind power project in Nunam Iqua. Remanufactured wind turbines are a possible option for Nunam Iqua to consider, with the 110 kW Danish-made Vestas V19 available through Halus Power Systems of San Leandro, California (sold by Marsh Creek LLC in Alaska).

Whether new or remanufactured, the primary criteria for wind turbines suitable for Nunam Iqua are:

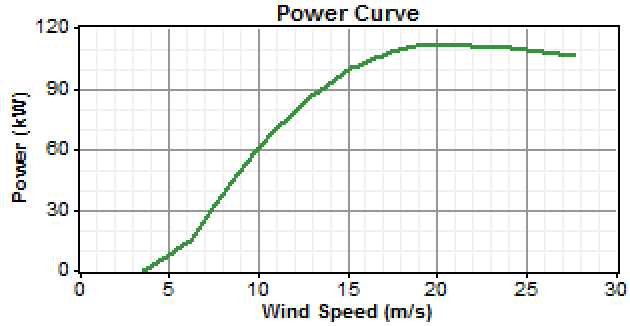
- Alternating current (AC) generator; synchronous or asynchronous are acceptable
- Cold-climate capable (rated to -40° C) with appropriate use of materials, lubricants and heaters
- IEC Class II rated
- A "known" turbine with an existing track record of installed operation
- Suitable for marine environments
- Established North American support capability, preferably with an Alaska presence
- Third party performance verification

Vestas V19

The Vestas V19 wind turbine was originally manufactured by Vestas Wind Systems A/S in Denmark and is now available as a remanufactured turbine through Halus Power Systems of San Leandro, California. The V19 turbines that Halus have available are sourced principally from California wind farms that are re-powered but others originate in Europe or other locations. In all cases, Halus remanufactured turbines are extensively rebuilt to like-new condition and are equipped with completely new and modern control systems. Note that the V19 turbine is essentially identical to the V17 turbine that Marsh Creek LLC installed in Kokhanok in 2010, except for a rotor blade extenders to increase power output at the more moderate wind speeds found in Nunam Iqua.

Vestas V19 wind turbine (similar V17 turbine in Kokhanok shown below)

Vestas V19 power curve

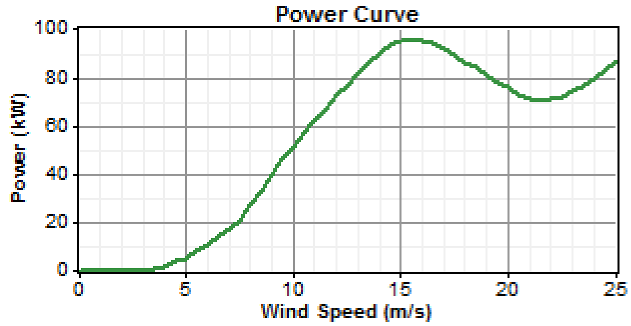


Wind Matic WM17S

The Wind Matic WM17S wind turbine was originally manufactured by Danish Windmill Company in Denmark as a successor to their popular 65 kW WM15S model, but are now only available used or remanufactured. The WM17S turbines available in the Unites States are sourced principally from California wind farms that are re-and can be remanufactured by Talk Inc. in Minnesota. In all cases, these remanufactured turbines are rebuilt to like-new condition and are equipped with completely new and modern control systems, including an inverter-based output that negates many of the undesirable characteristics of asynchronous generators operating on a small electrical grid.

Wind Matic WM17S

WM17S power curve

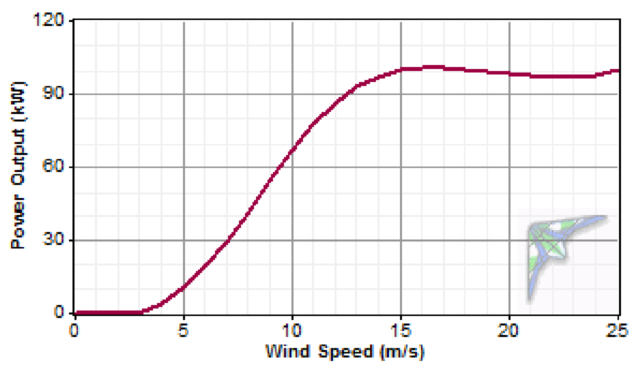


Northern Power Systems Northwind 100

The Northwind 100 (the NW100B/21 model) wind turbine is manufactured by Northern Power Systems in Barre, Vermont. The NW100 turbine is stall-regulated, has a direct-drive permanent magnet synchronous generator, active yaw control, a 21 meter diameter rotor, is rated at 100 kW power output, and is available only on a 37 meter tubular steel tower. The NW100B/21 is fully arctic-climate certified to -40° C and is the most represented village-scale wind turbine in Alaska at present with a significant number of installations in the Yukon-Kuskokwim Delta and on St. Lawrence Island. More information can be found at: http://www.northernpower.com/ and in Appendix C of this report.

NW100 wind turbine

NW100B/21 power curve



Wind Turbine Performance Comparison

In the table below is an analysis of turbine output and capacity factor performance of the turbines profiled above, with comparisons of manufacturer rated output power at 100%, 92% and 82% turbine availability (percent of time that the turbine is on-line and available for energy production). The Vestas V19, the Northwind NW100B/21 and the Wind Matic WM17S all perform well in the Nunam Iqua wind regime with good capacity factors and annual energy productions.

Turbine capacity factor comparison

					100% availability		92% availability		82% availability	
Turbine Model	Rated Output (kW)	Hub Height (m)	Tip Height (m)*	Tip Height (ft)*	Annual Energy (MWh)	Capacity Factor (%)	Annual Energy (MWh)	Capacity Factor (%)	Annual Energy (MWh)	Capacity Factor (%)
V19	110	26	35.5	116	213	21.9	196	20.1	175	18.0
NW100/21	100	37	47.5	156	268	29.7	247	27.3	220	24.4
WM17S	90	24	32.5	107	171	20.5	157	18.9	140	16.8

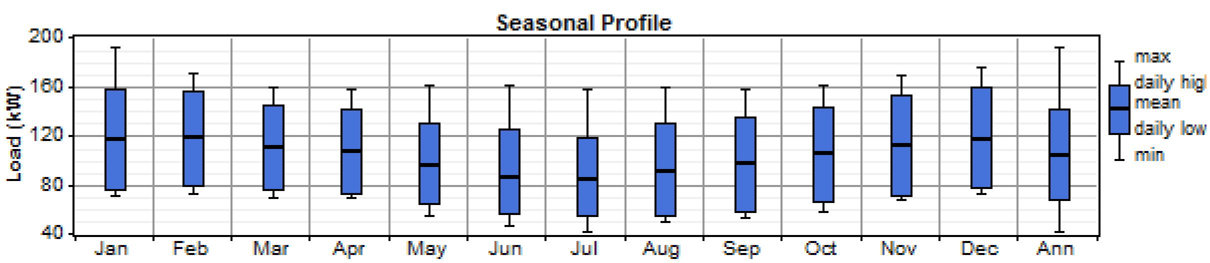
*Note: assumes base of turbine tower at ground level

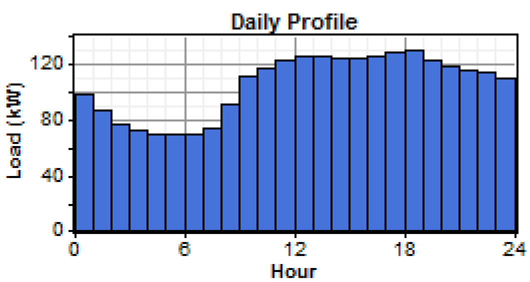
Modeling

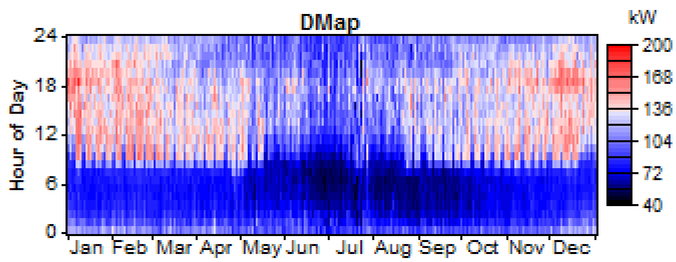
Wind turbine and system performance modeling of wind-diesel configurations in Nunam Iqua was accomplished with HOMER software. This software enables static modeling of a power system to demonstrate energy balances and fuel displacement with introduction of wind power. A limitation of the software is that it is not suitable for dynamic modeling. In other words, it cannot model voltage and frequency perturbations and power system dynamics, although it will provide a warning for systems that are potentially unstable.

Electric Load

The Nunam Iqua electric load was synthesized with the Alaska Electric Load Calculator Excel program (written in 2006 by Mia Devine of the Alaska Energy Authority). This spreadsheet allows one to create a "virtual" village load in one hour increments, suitable for import into HOMER software as average load for each hour of the year. For this study, 2011 PCE data of reported gross kWh generated, increased by approximately 8 percent to reflect anticipated growth in electrical demand at the half-way point (10 years) of the project, was used with the Alaska Load Calculator to synthesize a 105 kW average load with a 192 kW peak load and approximately 40 kW minimum load. Graphical representations of the electric load are shown below.







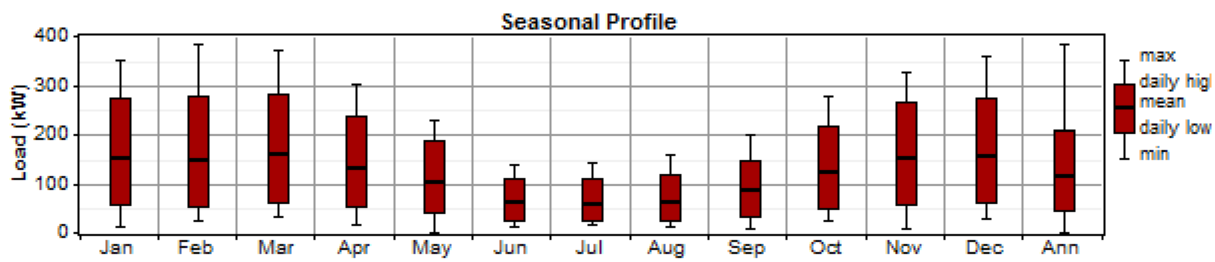
Electric load modeling statistics

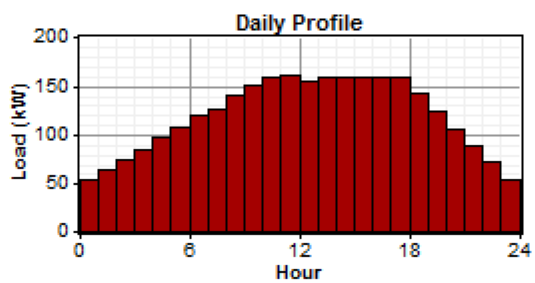
Annual (kWh)	919,800
Average (kWh/d)	2,520
Average (kW)	105
Peak (kW)	192
Load factor	0.548

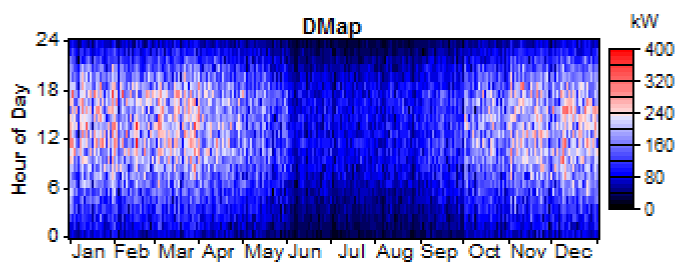
Thermal Load

The thermal load available to the diesel generator heat recovery system was estimated based on better-documented thermal loads in other villages and the size of Nunam Iqua's electrical load. Typically difficult to quantify as accurately as the electric load, the thermal load is nevertheless very important for a village wind-diesel system because it serves as the secondary load available to absorb excess electrical energy generated by wind turbines during periods of relatively high wind turbine output and low electric load demand. With a goal of displacing as much fossil fuel usage as possible, thermal loads must be integrated into the wind-diesel design.

Nunam Iqua reported heating fuel usage in 2010 at 3,850 gallons by Nunam Iqua Water Sewer (water plant) and 19,050 gallons by the school, a total of 22,900 gallons. Nunam Iqua also reported fuel savings of 9,000 gallons per year with waste heat from the generators used by the water plant via the generator recovered heat system. The thermal load was adjusted to result in heating fuel usage of 23,000 gallons per year in the base case assuming that the school were added to the recovered heat system (only reasonable if wind turbines are installed and an electric boiler is installed at the school) and fuel savings of approximately 10,000 gallons by the water plant per year with use of recovered heat versus no use of recovered heat.







Thermal load modeling statistics

Annual (kWh)	1,045,360
Average (kWh/d)	2,864
Average (kW)	119
Peak (kW)	382
Load factor	0.312

Diesel Generators

The HOMER model was constructed with Nunam Iqua's three diesel generators, all John Deere models, two with 229 kW output generators and one with a 250 kW generator. They are listed as numbers Gen 1, Gen 2, and Gen 3 to denote their bay positions in the Nunam Iqua powerplant. The proposed 117 kW John Deere 4045 is listed at Gen 4 in the Homer model. For cost modeling purposes, AEA assumes a generator O&M cost of $0.020/kWh. This was converted to $2.32/operating hour for each diesel generator for use in the HOMER software model (based on Nunam Iqua's modeled average electrical load of 105 kW).

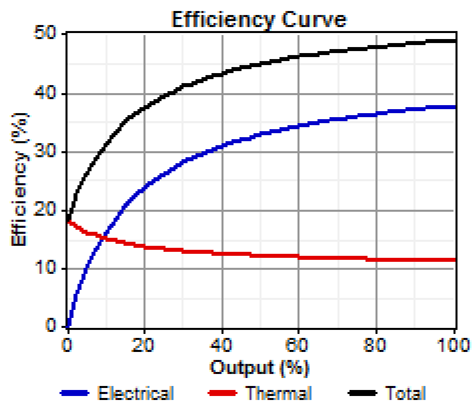
Manufacturer fuel curves for the diesel generators were used in the HOMER models. In addition, the diesel engines in the modeling runs were set to "optimize", which HOMER interprets as use of the most efficient diesel generator whenever possible.

Diesel generator HOMER modeling information

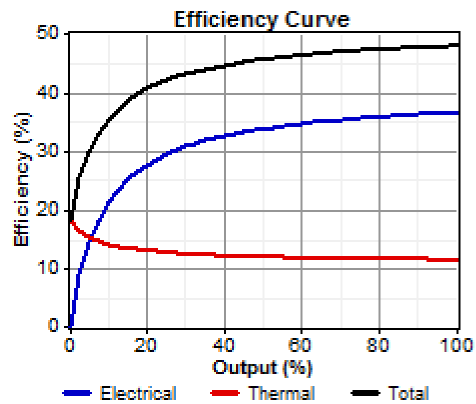
Diesel generator	John Deere 6090HF485	John Deere 6125AF001	John Deere 6090HF485	John Deere 4045
HOMER model identification	Gen 1 (Bay 1)	Gen 2 (Bay 2)	Gen 3 (Bay 3)	Gen 4 (Bay 4?)
Power output (kW)	229	250	229	117
Intercept coeff. (L/hr/kW rated)	0.030	0.030	0.030	0.022
Slope (L/hr/kW output)	0.240	0.240	0.240	0.256
Minimum electric load (%)	15	15	15	15
Heat recovery ratio (% of waste heat that can serve the thermal load)	18	18	18	18

Intercept coefficient – the no-load fuel consumption of the generator divided by its capacity
Slope – the marginal fuel consumption of the generator

John Deere 6090HF485 and John Deere 6125AF001 fuel efficiency curve



John Deere 4045 fuel efficiency curve



Wind Resource

The Nunam Iqua wind resource is documented in an Alaska Energy Authority report entitled *Wind Resource Assessment for Nunam Iqua, Alaska*, dated February 1, 2008.

Economic Analysis

Selected wind turbines in medium penetration mode are modeled in this report to demonstrate the economic viability of various configurations and fuel price points.

Wind Turbine Costs

Capital and installation costs of wind turbines are somewhat difficult to estimate without detailed consideration of shipping fees, foundation design, cost efficiencies with installation of multiple turbines, identification of constructor, mobilization fees, etc. Although the cost assumptions detailed below should be considered tentative, they are generally in-line with other rural Alaska wind projects of the past few years.

Wind turbine cost assumptions

- Vestas V19, two turbines: $1.6 million
- Wind Matic WM17S, two turbines: $1.2 million
- Northwind NW100B/21: $1.2 million

Fuel Cost

A fuel price of $6.32/gallon ($1.67/Liter) was selected for the initial HOMER analysis by reference to *Alaska Fuel Price Projections 2011-2035*, prepared for Alaska Energy Authority by the Institute for Social and Economic Research (ISER), dated July 7, 2011. The $6.32/gallon price reflects the average value of all fuel prices between the 2014 (assumed project start year) fuel price of $5.14/gallon and the 2033 (20 year project end year) fuel price of $7.15/gallon using the medium price projection three-year moving average (MA3) analysis.

Additional analyses with ISER's low price projection MA3 and high price projection MA3 are included in the economic analysis of this report. For the high price projection, the median 2013 to 2032 three-year moving average price is $10.24/gallon ($2.71/Liter). For the low price projection, the average 2013 to 2032 three-year moving average price is $2.76/gallon ($0.73/Liter). Note also that heating fuel in HOMER is priced equal to diesel fuel.

Fuel cost table

Cost Scenario	2014 (/gal)	2033 (/gal)	Average (/gallon)	Average (/Liter)
Medium	$5.14	$7.15	$6.32	$1.67
High	$7.46	$11.85	$10.24	$2.71
Low	$3.34	$2.51	$2.76	$0.74

ISER, 2011, MA3 cost projections

HOMER Modeling Assumptions

HOMER modeling assumptions are listed in the table below. Note that in the HOMER modeling simulations, the wind speed of 6.48 m/s (at 30 meters above ground level) was reduced to 6.25 m/s to simulate 92 percent turbine availability and to 5.96 m/s to simulate 82 percent turbine availability. Eighty-two percent availability is in-line with AEA assumptions of turbine availability in their economic models, but other wind projects in Alaska have experienced better turbine availability, hence 92 percent availability is presented as the base turbine availability to compare the effects of fuel price on project economics. One hundred percent turbine availability is not a realistic goal but is shown for boundary or comparison purposes.

Basic modeling assumptions

Economic Assumptions	
Project life	20 years
Discount rate	3%
System fixed O&M cost	$60,000/year (2011 PCE Report)
Operating Reserves	
Load in current time step	10%
Wind power output	25%
Fuel Properties (both types)	
Heating value	43.2 MJ/kg
Density	820 kg/m^3
Diesel Generators	
Generator capital cost	$0 for existing generators; $60,000 installed cost for John Deere 4045
O&M cost	$2.32/hour ($0.02/kWh, all generators)
Time between overhauls	20,000 hours
Overhaul cost	$40,000 existing generators; $25,000 new J. Deere 4045
Minimum load ratio	15%
Schedule	Optimized (most efficient during any one hour period)
Wind Resource	
Annual mean wind speed (30 meters)	6.48 m/s
Weibull k	2.2
Power law exponent	0.14 (assumed)
Wind Turbines	
Availability	100%, 92%, 82%
Scaled annual average wind speed	6.48 m/s measured at 30 meters; scaled to 6.25 m/s for 92% turbine availability and 5.96 m/s for 82% turbine availability
Capital cost	
• Vestas V19	• $1.6M, 2 turbines
• Northwind NW100B/21	• $1.2M, 1 turbine
• Wind Matic WM17S	• $1.5M, 2 turbines
O&M cost	$0.0469/kWh (translated to $/year based on 92% turbine availability)
• Vestas V19	• $9,207/yr/turbine
• Wind Matic WM17S	• $7,325/yr/turbine
• NW100B/21	• $10,000/yr/turbine

Project Economics, Vestas V19 turbine

V19, Present Powerplant Configuration

92% Turbine Availability

High Fuel Price Projection

V19	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction	Diesel (L)	Heating oil arctic (L)	Total fuel use (gal)	Fuel use avoided (gal)	Gen 1 (hrs)	Project B/C ratio
2	$1,600,000	914,330	$15,202,924	0.737	0.19	211,738	84,937	78,382	18,839	8,760	1.07
3	$2,400,000	864,581	$15,262,781	0.742	0.26	199,516	75,371	72,625	24,595	8,760	1.06
	$0	1,088,866	$16,199,578	0.81	0	280,933	87,046	97,220	0	8,760	1.00

Medium Fuel Price Projection

V19	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction	Diesel (L)	Heating oil arctic (L)	Total fuel use (gal)	Fuel use avoided (gal)	Gen 1 (hrs)	Project B/C ratio
	$0	707,272	$10,522,415	0.538	0	280,933	87,046	97,220	0	8,760	1.00
2	$1,600,000	606,678	$10,625,843	0.546	0.19	211,738	84,937	78,382	18,839	8,760	0.99
3	$2,400,000	579,523	$11,021,832	0.575	0.26	199,516	75,371	72,625	24,595	8,760	0.95

Low Fuel Price Projection

V19	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction	Diesel (L)	Heating oil arctic (L)	Total fuel use (gal)	Fuel use avoided (gal)	Gen 1 (hrs)	Project B/C ratio
	$0	364,181	$5,418,087	0.295	0	280,933	87,046	97,220	0	8,760	1.00
2	$1,600,000	329,922	$6,508,401	0.375	0.19	211,738	84,937	78,382	18,839	8,760	0.83
3	$2,400,000	323,124	$7,207,262	0.426	0.26	199,516	75,371	72,625	24,595	8,760	0.75

100% Turbine Availability

Medium Fuel Price Projection

V19	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction	Diesel (L)	Heating oil arctic (L)	Total fuel use (gal)	Fuel use avoided (gal)	Gen 1 (hrs)	Project B/C ratio
2	$1,600,000	598,266	$10,500,679	0.537	0.2	207,764	83,870	77,050	20,170	8,760	1.00
	$0	707,272	$10,522,415	0.538	0	280,933	87,046	97,220	0	8,760	1.00
3	$2,400,000	569,820	$10,877,477	0.564	0.28	195,788	73,286	71,090	26,131	8,760	0.97

82% Turbine Availability

Medium Fuel Price Projection

V19	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction	Diesel (L)	Heating oil arctic (L)	Total fuel use (gal)	Fuel use avoided (gal)	Gen 1 (hrs)	Project B/C ratio
	$0	707,272	$10,522,415	0.538	0	280,933	87,046	97,220	0	8,760	1.00
2	$1,600,000	617,694	$10,789,725	0.558	0.17	217,117	86,158	80,125	17,095	8,760	0.98
3	$2,400,000	592,409	$11,213,556	0.589	0.24	204,673	77,936	74,666	22,555	8,760	0.94

V19, with new John Deere 4045 diesel generator

92% Turbine Availability

High Fuel Price Projection

V19	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction	Diesel (L)	Heating oil arctic (L)	Total fuel use (gal)	Fuel use avoided (gal)	Gen 1 (hrs)	Gen 4 (hrs)	Project B/C ratio
3	$2,460,000	784,600	$14,132,870	0.659	0.28	163,368	84,461	65,477	31,744	2,242	6,363	1.15
2	$1,660,000	852,691	$14,345,895	0.675	0.20	182,994	93,082	72,939	24,281	2,711	6,039	1.13
	$0	1,088,866	$16,199,578	0.81	0	280,933	87,046	97,220	0	8,760	n/a	1.00

Medium Fuel Price Projection

V19	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction	Diesel (L)	Heating oil arctic (L)	Total fuel use (gal)	Fuel use avoided (gal)	Gen 1 (hrs)	Gen 4 (hrs)	Project B/C ratio
2	$1,660,000	566,401	$10,086,613	0.507	0.20	182,994	93,082	72,939	24,281	2,711	6,039	1.04
3	$2,460,000	527,601	$10,309,372	0.523	0.28	163,368	84,461	65,477	31,744	2,242	6,363	1.02
	$0	707,272	$10,522,415	0.538	0	280,933	87,046	97,220	0	8,760	n/a	1.00

Low Fuel Price Projection

V19	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction	Diesel (L)	Heating oil arctic (L)	Total fuel use (gal)	Fuel use avoided (gal)	Gen 1 (hrs)	Gen 4 (hrs)	Project B/C ratio
	$0	364,181	$5,418,087	0.295	0	280,933	87,046	97,220	0	8,760	n/a	1.00
2	$1,660,000	308,719	$6,252,965	0.356	0.20	182,994	93,082	72,939	24,281	2,711	6,039	0.87
3	$2,460,000	296,275	$6,867,824	0.401	0.28	163,368	84,461	65,477	31,744	2,242	6,363	0.79

100% Turbine Availability

Medium Fuel Price Projection

V19	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction	Diesel (L)	Heating oil arctic (L)	Total fuel use (gal)	Fuel use avoided (gal)	Gen 1 (hrs)	Gen 4 (hrs)	Project B/C ratio
2	$1,660,000	556,118	$9,933,630	0.495	0.21	177,461	92,500	71,324	25,896	2,593	6,157	1.06
3	$2,460,000	514,800	$10,118,918	0.509	0.30	157,668	82,655	63,494	33,727	2,138	6,416	1.04
	$0	707,272	$10,522,415	0.538	0	280,933	87,046	97,220	0	8,760	n/a	1.00

82% Turbine Availability

Medium Fuel Price Projection

V19	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction	Diesel (L)	Heating oil arctic (L)	Total fuel use (gal)	Fuel use avoided (gal)	Gen 1 (hrs)	Gen 4 (hrs)	Project B/C ratio
2	$1,660,000	579,744	$10,285,125	0.521	0.18	190,326	93,683	75,035	22,185	2,854	5,898	1.02
	$0	707,272	$10,522,415	0.538	0	280,933	87,046	97,220	0	8,760	n/a	1.00
3	$2,460,000	544,345	$10,558,477	0.541	0.25	171,181	86,501	68,080	29,141	2,428	6,220	1.00

Project Economics, Wind Matic WM17S turbine

WM17S, Present Powerplant Configuration

92% Turbine Availability

High Fuel Price Projection

WM17	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction	Diesel (L)	Heating oil arctic (L)	Total fuel use (gal)	Fuel use avoided (gal)	Gen 1 (hrs)	Project B/C ratio
2	$1,520,000	944,924	$15,578,080	0.765	0.15	222,204	87,167	81,736	15,484	8,760	1.04
3	$2,280,000	898,734	$15,650,898	0.770	0.22	208,900	80,695	76,511	20,709	8,760	1.04
	$0	1,088,866	$16,199,578	0.810	0	280,933	87,046	97,220	0	8,760	1.00

Medium Fuel Price Projection

WM17	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction	Diesel (L)	Heating oil arctic (L)	Total fuel use (gal)	Fuel use avoided (gal)	Gen 1 (hrs)	Project B/C ratio
	$0	707,272	$10,522,415	0.538	0	280,933	87,046	97,220	0	8,760	1.00
2	$1,520,000	624,106	$10,805,119	0.559	0.15	222,204	87,167	81,736	15,484	8,760	0.97
3	$2,280,000	598,425	$11,183,045	0.587	0.22	208,900	80,695	76,511	20,709	8,760	0.94

Low Fuel Price Projection

WM17	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction	Diesel (L)	Heating oil arctic (L)	Total fuel use (gal)	Fuel use avoided (gal)	Gen 1 (hrs)	Project B/C ratio
	$0	364,181	$5,418,087	0.295	0	280,933	87,046	97,220	0	8,760	1.00
2	$1,520,000	335,519	$6,511,676	0.375	0.15	222,204	87,167	81,736	15,484	8,760	0.83
3	$2,280,000	328,295	$7,164,193	0.423	0.22	208,900	80,695	76,511	20,709	8,760	0.76

100% Turbine Availability

Medium Fuel Price Projection

WM17	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction	Diesel (L)	Heating oil arctic (L)	Total fuel use (gal)	Fuel use avoided (gal)	Gen 1 (hrs)	Project B/C ratio
	$0	707,272	$10,522,415	0.538	0	280,933	87,046	97,220	0	8,760	1.00
2	$1,520,000	616,283	$10,688,740	0.551	0.17	218,251	86,433	80,498	16,723	8,760	0.98
3	$2,280,000	589,094	$11,044,233	0.577	0.23	204,977	79,028	75,034	22,186	8,760	0.95

82% Turbine Availability

Medium Fuel Price Projection

WM17	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction	Diesel (L)	Heating oil arctic (L)	Total fuel use (gal)	Fuel use avoided (gal)	Gen 1 (hrs)	Project B/C ratio
	$0	707,272	$10,522,415	0.538	0	280,933	87,046	97,220	0	8,760	1.00
2	$1,520,000	634,169	$10,954,829	0.570	0.14	227,407	87,993	83,329	13,891	8,760	0.96
3	$2,280,000	610,598	$11,364,160	0.600	0.19	214,217	82,671	78,438	18,782	8,760	0.93

WM17S, with new John Deere 4045 diesel generator

92% Turbine Availability

High Fuel Price Projection

WM17	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction	Diesel (L)	Heating oil arctic (L)	Total fuel use (gal)	Fuel use avoided (gal)	Gen 1 (hrs)	Gen 4 (hrs)	Project B/C ratio
3	$2,340,000	830,606	$14,697,325	0.700	0.23	178,174	88,554	70,470	26,751	2,611	6,060	1.10
2	$1,580,000	890,947	$14,835,044	0.710	0.16	197,567	93,954	77,020	20,200	3,028	5,724	1.09
	$0	1,088,866	$16,199,578	0.810	0	280,933	87,046	97,220	0	8,760	n/a	1.00

Medium Fuel Price Projection

WM17	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction	Diesel (L)	Heating oil arctic (L)	Total fuel use (gal)	Fuel use avoided (gal)	Gen 1 (hrs)	Gen 4 (hrs)	Project B/C ratio
2	$1,580,000	588,640	$10,337,476	0.525	0.16	197,567	93,954	77,020	20,200	3,028	5,724	1.02
	$0	707,272	$10,522,415	0.538	0	280,933	87,046	97,220	0	8,760	n/a	1.00
3	$2,340,000	554,010	$10,582,266	0.543	0.23	178,174	88,554	70,470	26,751	2,611	6,060	0.99

Low Fuel Price Projection

WM17	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction	Diesel (L)	Heating oil arctic (L)	Total fuel use (gal)	Fuel use avoided (gal)	Gen 1 (hrs)	Gen 4 (hrs)	Project B/C ratio
	$0	364,181	$5,418,087	0.295	0	280,933	87,046	97,220	0	8,760	n/a	1.00
2	$1,580,000	316,586	$6,290,001	0.359	0.16	197,567	93,954	77,020	20,200	3,028	5,724	0.86
3	$2,340,000	305,067	$6,878,633	0.402	0.23	178,174	88,554	70,470	26,751	2,611	6,060	0.79

100% Turbine Availability

Medium Fuel Price Projection

WM17	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction	Diesel (L)	Heating oil arctic (L)	Total fuel use (gal)	Fuel use avoided (gal)	Gen 1 (hrs)	Gen 4 (hrs)	Project B/C ratio
2	$1,580,000	579,049	$10,194,785	0.514	0.17	192,191	93,642	75,517	21,703	2,894	5,857	1.03
3	$2,340,000	542,204	$10,406,620	0.530	0.25	172,477	87,274	68,626	28,594	2,488	6,162	1.01
	$0	707,272	$10,522,415	0.538	0	280,933	87,046	97,220	0	8,760	n/a	1.00

82% Turbine Availability

Medium Fuel Price Projection

WM17	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction	Diesel (L)	Heating oil arctic (L)	Total fuel use (gal)	Fuel use avoided (gal)	Gen 1 (hrs)	Gen 4 (hrs)	Project B/C ratio
2	$1,580,000	600,813	$10,518,582	0.538	0.14	204,534	94,192	78,924	18,297	3,175	5,582	1.00
	$0	707,272	$10,522,415	0.538	0	280,933	87,046	97,220	0	8,760	n/a	1.00
3	$2,340,000	569,317	$10,809,997	0.559	0.20	185,688	90,084	72,859	24,361	2,755	5,948	0.97

Project Economics, NW100B/21 turbine

NW100B/21, Present Powerplant Configuration

92% Turbine Availability

High Fuel Price Projection

NW100	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction	Diesel (L)	Heating oil arctic (L)	Total fuel use (gal)	Fuel use avoided (gal)	Gen 1 (hrs)	Project B/C ratio
2	$2,400,000	872,524	$15,380,949	0.750	0.24	198,853	81,786	74,145	23,075	8,760	1.05
1	$1,200,000	962,151	$15,514,370	0.760	0.13	226,238	91,218	83,872	13,348	8,760	1.04
	$0	1,088,866	$16,199,578	0.810	0	280,933	87,046	97,220	0	8,760	1.00

Medium Fuel Price Projection

NW100	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction	Diesel (L)	Heating oil arctic (L)	Total fuel use (gal)	Fuel use avoided (gal)	Gen 1 (hrs)	Project B/C ratio
	$0	707,272	$10,522,415	0.538	0	280,933	87,046	97,220	0	8,760	1.00
1	$1,200,000	632,949	$10,616,675	0.545	0.13	226,238	91,218	83,872	13,348	8,760	0.99
2	$2,400,000	581,501	$11,051,265	0.577	0.24	198,853	81,786	74,145	23,075	8,760	0.95

Low Fuel Price Projection

NW100	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction	Diesel (L)	Heating oil arctic (L)	Total fuel use (gal)	Fuel use avoided (gal)	Gen 1 (hrs)	Project B/C ratio
	$0	364,181	$5,418,087	0.295	0	280,933	87,046	97,220	0	8,760	1.00
1	$1,200,000	336,802	$6,210,767	0.353	0.13	226,238	91,218	83,872	13,348	8,760	0.87
2	$2,400,000	319,689	$7,156,162	0.422	0.24	198,853	81,786	74,145	23,075	8,760	0.76

100% Turbine Availability

Medium Fuel Price Projection

NW100	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction	Diesel (L)	Heating oil arctic (L)	Total fuel use (gal)	Fuel use avoided (gal)	Gen 1 (hrs)	Project B/C ratio
	$0	707,272	$10,522,415	0.538	0	280,933	87,046	97,220	0	8,760	1.00
1	$1,200,000	627,099	$10,529,650	0.539	0.13	222,714	91,237	82,946	14,274	8,760	1.00
2	$2,400,000	572,994	$10,924,700	0.568	0.25	195,207	80,335	72,798	24,422	8,760	0.96

82% Turbine Availability

Medium Fuel Price Projection

NW100	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction	Diesel (L)	Heating oil arctic (L)	Total fuel use (gal)	Fuel use avoided (gal)	Gen 1 (hrs)	Project B/C ratio
	$0	707,272	$10,522,415	0.538	0	280,933	87,046	97,220	0	8,760	1.00
1	$1,200,000	640,552	$10,729,802	0.554	0.11	230,871	91,141	85,076	12,145	8,760	0.98
2	$2,400,000	592,810	$11,219,508	0.589	0.22	203,874	83,540	75,935	21,285	8,760	0.94

NW100B/21, with new John Deere 4045 diesel generator

92% Turbine Availability

High Fuel Price Projection

NW100	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction	Diesel (L)	Heating oil arctic (L)	Total fuel use (gal)	Fuel use avoided (gal)	Gen 1 (hrs)	Gen 4 (hrs)	Project B/C ratio
2	$2,460,000	807,995	$14,480,928	0.684	0.25	168,603	90,292	68,400	28,820	2,970	5,790	1.12
1	$1,260,000	918,394	$14,923,383	0.717	0.13	206,718	96,461	80,100	17,120	3,699	5,061	1.09
	$0	1,088,866	$16,199,578	0.810	0	280,933	87,046	97,220	0	8,760	n/a	1.00

Medium Fuel Price Projection

NW100	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction	Diesel (L)	Heating oil arctic (L)	Total fuel use (gal)	Fuel use avoided (gal)	Gen 1 (hrs)	Gen 4 (hrs)	Project B/C ratio
1	$1,260,000	603,998	$10,245,959	0.518	0.13	206,718	96,461	80,100	17,120	3,028	5,724	1.03
2	$2,460,000	539,521	$10,486,704	0.536	0.25	168,603	90,292	68,400	28,820	2,611	6,060	1.00
	$0	707,272	$10,522,415	0.538	0	280,933	87,046	97,220	0	8,760	n/a	1.00

Low Fuel Price Projection

NW100	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction	Diesel (L)	Heating oil arctic (L)	Total fuel use (gal)	Fuel use avoided (gal)	Gen 1 (hrs)	Gen 4 (hrs)	Project B/C ratio
	$0	364,181	$5,418,087	0.295	0	280,933	87,046	97,220	0	8,760	n/a	1.00
1	$1,260,000	321,077	$6,036,811	0.340	0.13	206,718	96,461	80,100	17,120	3,699	5,061	0.90
2	$2,460,000	297,845	$6,891,183	0.403	0.25	168,603	90,292	68,400	28,820	2,970	5,790	0.79

100% Turbine Availability

Medium Fuel Price Projection

NW100	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction	Diesel (L)	Heating oil arctic (L)	Total fuel use (gal)	Fuel use avoided (gal)	Gen 1 (hrs)	Gen 4 (hrs)	Project B/C ratio
1	$1,260,000	597,345	$10,146,979	0.511	0.14	202,417	96,798	79,053	18,168	3,643	5,117	1.04
2	$2,460,000	529,100	$10,331,675	0.524	0.26	163,435	89,255	66,761	30,459	2,872	5,888	1.02
	$0	707,272	$10,522,415	0.538	0	280,933	87,046	97,220	0	8,760	n/a	1.00

82% Turbine Availability

Medium Fuel Price Projection

NW100	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Wind fraction	Diesel (L)	Heating oil arctic (L)	Total fuel use (gal)	Fuel use avoided (gal)	Gen 1 (hrs)	Gen 4 (hrs)	Project B/C ratio
1	$1,260,000	612,550	$10,373,193	0.528	0.11	212,286	95,992	81,447	15,773	3,763	4,997	1.01
	$0	707,272	$10,522,415	0.538	0	280,933	87,046	97,220	0	8,760	n/a	1.00
2	$2,460,000	553,327	$10,692,106	0.551	0.22	175,608	91,488	70,567	26,653	3,112	5,648	0.98

Conclusion and Recommendations

Given the geographic location and local topography of Nunam Iqua, wind power appears to be the most viable renewable energy option to reduce the community's dependence on the use of fossil fuel to generate electricity and to serve thermal (heat) loads. Modeling indicates that a wind-diesel power system can be constructed in a high penetration/no electrical energy storage configuration that will be both economically advantageous for the community and manageable to operate, compared to more sophisticated battery storage configuration designs.

The project economics tables indicate that all three turbines modeled – the Vestas V19, the Windmatic WM17S, and the Northwind 100B/21 – are suitable for Nunam Iqua and provide positive economic benefit over the life of the project. It is notable however that inclusion of a smaller, more efficient 117 kW John Deere 4045 series diesel generator significantly enhances the economic viability of wind-diesel in Nunam Iqua. This is because, despite the initial capital cost of a new generator, the John Deere 4045 is appropriately sized for the Nunam Iqua load, especially when considering that it will operate in parallel with wind turbines at a 15 percent load ration at times.

Although modeling indicates that the Vestas V19 turbine is the most economical for Nunam Iqua, project costs should be considered only as reasonable estimates. Should Nunam Iqua continue with wind power planning into the conceptual design phase, refinement of cost estimates is warranted, as well as discussion with the turbine suppliers regarding control systems, warranty and support.