Contents

Executive Summary

This report covers expanding wind power capacity with inclusion of battery energy storage in larger Alaska Village Electric Cooperative communities that have existing wind turbines presents an opportunity to not only save diesel fuel for electrical energy generation, but also save heating fuel for community thermal energy (water and space heating) needs. Toksook Bay presents an excellent opportunity to achieve this objective with the installation of 1,000 kW capacity EWT wind turbines at the wind farm. Modeling demonstrates favorable discounted benefit/cost ratios and short simple payback periods for several options including one or two EWT wind turbines and between two and eight remote electric wind-to-heat boilers at facilities in Toksook Bay, Tununak, and/or Nightmute.

The community could additionally benefit from selling power to the Alaska Village Electric Cooperative (AVEC) through a Power Purchase Agreement (PPA), which would pay for the additional jobs necessary to operate a wind system. To insulate Toksook Bay and intertied communities from fuel price volatility and create a more sustainable local economy, it is the recommendation of the authors that they consider the benefits of producing power through wind/battery systems.

Introduction

Alaska Native Tribal Health Consortium (ANTHC) contracted V3 Energy, LLC to prepare this analysis; its purpose is to demonstrate the technical and economic feasibility of substantially increasing the wind power penetration of the Toksook Bay-Tununak-Nightmute power system by installing one or more 1,000 kW capacity EWT wind turbines.[1] It is hoped that increased wind power capacity in Toksook Bay will encourage further efforts to expand renewable energy development and the electrification of thermal energy needs in all three communities.

Toksook Bay is an Alaska Native village on the Bering Sea coast of the central Yukon-Kuskokwim Delta approximately 115 miles northwest of Bethel. It has a population of 658 people. It is electrically intertied (connected via power transmission lines) to Tununak, a village of 411 people 6 miles to the northwest, and Nightmute, a village of 280 people 13 miles to the east. The three communities are members of Alaska Village Electric Cooperative (AVEC), a rural utility cooperative serving over 50 villages in rural Alaska.

Figure 1: Toksook Bay, Tununak, and Nightmute; Google Earth image

The Toksook Bay-Tununak-Nightmute power system is comprised of approximately 2.0 MW of diesel generation capacity augmented by 400 kW of wind power capacity, located in Toksook Bay. AVEC maintains standby diesel power generation capability in both Tununak and Nightmute in event of electrical intertie disruption. The Toksook Bay diesel powerplant includes a district (or recovered) heat system that routes engine jacket water waste heat to the nearby water treatment plant for co-generation capability.

For the most recently posted Power Cost Equalization[2] (PCE) period of July 1, 2020, to June 30, 2021, AVEC reported 3.21 GWh of diesel generation and 0.45 GWh of wind generation, for a total of 3.66

[1] EWT: Emergya Wind Technologies B.V., a Netherlands-based company; Home - EWT - Creating distributed energy champions (ewtdirectwind.com)

[2] Alaska Energy Authority > What We Do > Power Cost Equalization (akenergyauthority.org)

GWh. This represents 12.3% average annual wind power penetration, as a percentage of total load demand.

Wind Resource

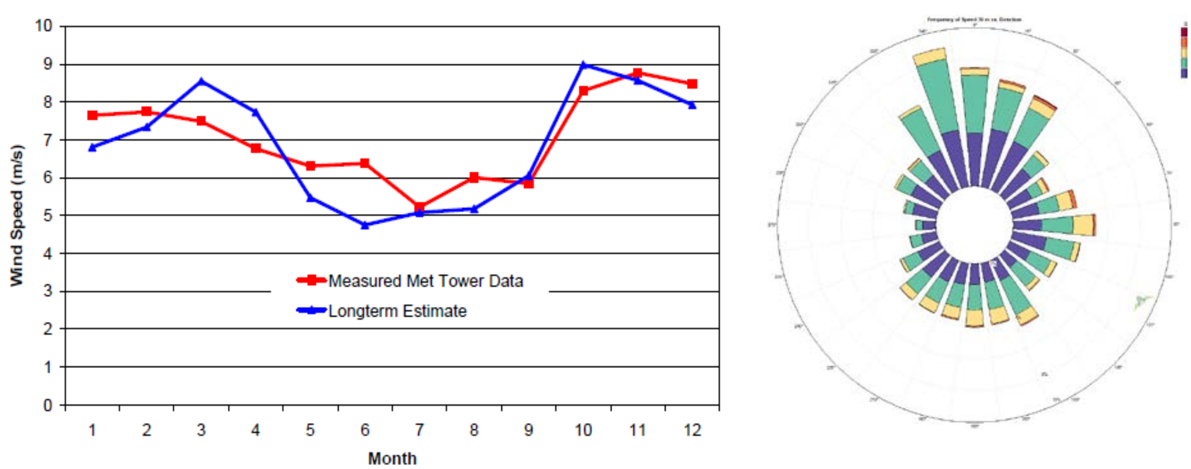
The Toksook Bay wind resource was measured from June 2004 to September 2005 with a 30-meter met tower located at the wind farm site (refer to Table 1 for summary data). The resource was documented in an Alaska Energy Authority report titled *Wind Resource Assessment for Toksook Bay, Alaska Site #0071* dated October 4, 2005.

Table 1: Met tower data set summary

Variable	Value
Latitude	N 60° 31 39.9"
Longitude	W 165° 6 28.5"
Elevation	20 m
Mean wind speed at 30 m	6.9 m/s
Mean temperature	0.8 °C (31 °F)
Mean air density	1.285 kg/m^3
Power density at 30 m	518 W/m^2
Wind power class	6 (Outstanding)
Power law exponent	0.13
IEC 61400-1 classification	Class IIC

In the AEA report, met tower data was adjusted against 20 years of Mekoryuk airport Automated Weather Observing Station (AWOS) data to yield a long-term representative data set. This yielded an adjustment of 30-meter mean wind speed from 7.3 m/s to 6.9 m/s (see Figure 2). The met tower wind rose indicates highly variable winds with a stronger predominance of northerly winds.

Figure 2: Toksook Bay monthly mean wind speed and wind rose, 30-meter level



Toksook Bay Electric and Thermal Load Demand

Energy demand in a community is comprised of three primary elements: electrical, thermal (or heat), and transportation. This analysis focuses on electrical and thermal energy demand, though transportation demand can also be accommodated with renewable energy resources through adoption of electric vehicles.

Electric Load

Toksook Bay-Tununak-Nightmute electric power demand averages 418 kW with a peak electric demand of 700 kW and an approximate minimum demand of 300 kW. It exhibits typical northern-climate seasonal demand variation (see Figure 3) with a diurnal profile that peaks in early evening (see Figure 4).

Figure 3: Toksook Bay electric load seasonal profile

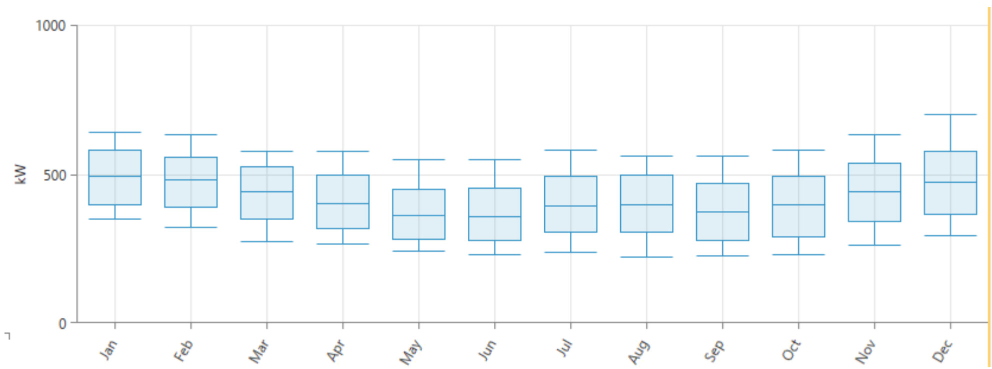
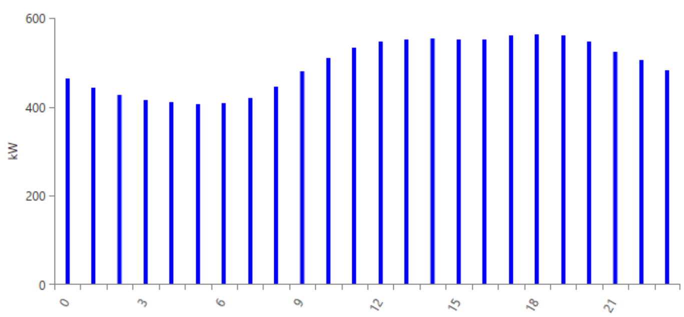


Figure 4: Toksook Bay electric load diurnal profile



Thermal Load, Recovered Heat Loop

Toksook Bay's total thermal load demand is difficult to comprehensively measure as it is comprised of three primary types: large facilities connected to recovered heat from the diesel generators, structures that employ hydronic (circulating hot water) heating, and generally smaller structures such as homes that are equipped with fuel oil-powered, air-driven stoves (e.g., Toyo) for heat. The larger structures are more readily characterized as they have often been audited for energy efficiency and usage, while the smaller structures with Toyo stoves are rarely audited and individual and aggregate energy usage are often uncertain.

The Toksook Bay water treatment plant (WTP) is the only structure connected to the power plant recovered heat system and as such benefits from the co-generation capabilities of the diesel generators. As documented in an AkWarm[3] file that documents an energy audit dated 15 August 2011, the WTP is augmented by two fuel oil boilers to meet the thermal load demand. Although the AkWarm file notes

[3] AkWarm is a specialty software designed to assess the efficiency and energy usage of infrastructure in rural Alaska.

usage of recovered heat, offtake of that heat was not documented, only fuel oil usage for the boilers. To create a thermal load profile for Homer software (see Figure 5 and Figure 6), recovered heat usage in the Hooper Bay WTP was used as a proxy with documented Toksook Bay WTP fuel oil usage added (from AkWarm files for Hooper Bay WTP and Toksook Bay WTP). Units were converted from million British Thermal Units (BTU) and gallons to kilowatt-hours (kWh).

Figure 5: Toksook Bay Water Treatment Plant thermal load seasonal profile

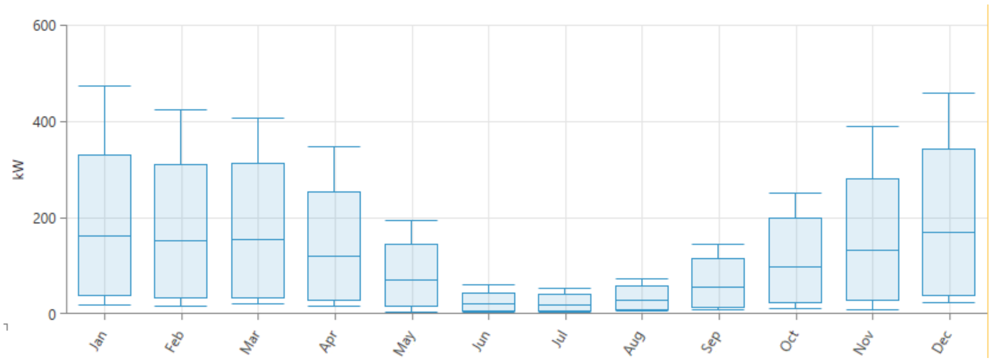
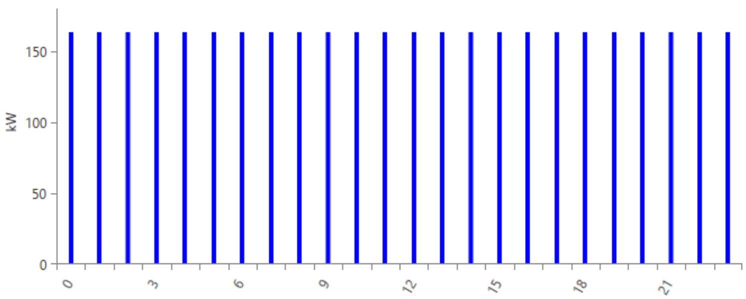


Figure 6: Toksook Bay Water Treatment Plant thermal load diurnal profile (assumed)



Toksook Bay Power System

Toksook Bay's power generation system is comprised of three diesel-electric generators and four wind turbines. Diesel generator information is detailed in Table 2. The four wind turbines are 20-meter rotor diameter, 100 kW capacity Northern Power Systems (NPS) Northwind 100 A models on 32-meter towers (400 kW total capacity) at a wind farm on the southwestern edge of the community (see Figure 7).

Table 2: Toksook Bay diesel generators

	Engine Data		Generator Data			Commissioning
Bay	Make	Model	Rating (kW)	Make	Model	Date
1	Cummins	QST30	755	Cummins	-	10/5/2019
2	Cummins	QSX15 G9	499	Newage	HC I534F1	8/23/2005
3	MTU	3512A 1200	756	MAR	575 RSL 4044	12/8/2021

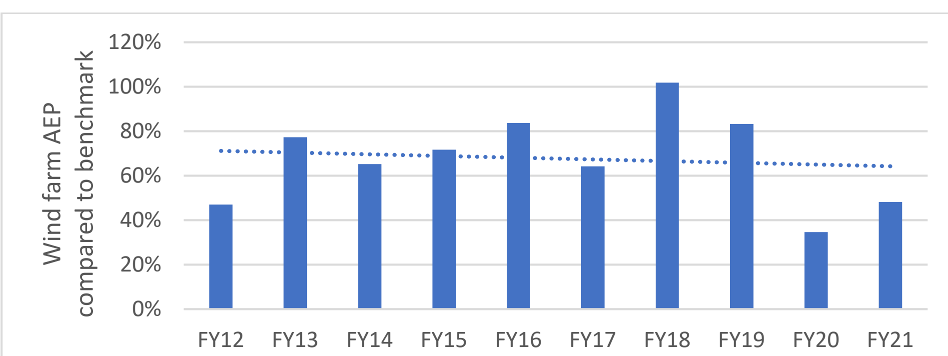
For the 2021 PCE report, AVEC reported a combined diesel generation efficiency of 13.9 kWh/gal (diesel generation only, exclusive of wind power input), which is very good for a village power system and indicates usage of appropriately sized generators, electronic governor control, and proper maintenance.

Figure 7: Toksook Bay wind farm location

Excess wind energy production is presently controlled via a secondary (or thermal) load controller (SLC) and electric boiler in the recovered heat system that supplies jacket water waste heat to the water treatment plant. To help the diesel generators maintain power system frequency, the SLC absorbs excess wind energy regardless of thermal load need. Recovered heat system energy not absorbed by the WTP, whether from the diesel generators or the wind turbines, returns to the powerplant to be ejected into the atmosphere via radiators.

As noted in Figure 8, over a ten-year period the four wind turbines in Toksook Bay operate at about 70 percent of the benchmark performance established by AVEC several years ago.[4] Several factors influence this underperformance, including the financial difficulties and eventual bankruptcy of the turbine manufacturer, curtailment, age of the turbines, the technical challenge of operating stall-controlled wind turbines at high instantaneous penetration in a wind-diesel power system without a battery storage as a buffer, and recent failure of one of the turbines.

Figure 8: Wind farm annual energy production as ratio of benchmark performance



[4] From AVEC fleetwide wind turbine baseline performance study; internal review; 2014

Power Distribution

Toksook Bay's electrical three-phase distribution system, to which the wind farm connects to the powerplant, operates at 7,200 volts phase-to-neutral and 12,470 volts phase-to-phase. The conductors are no. 2 ACSR (aluminum conductor, steel reinforced) with a capacity of 175 amps, equating to approximately 3,800 kW of power transfer capability.

Proposed Project

The proposed project will use additional wind power to supply a significantly higher percentage of electrical load demand than the present 14.1 percent average penetration and concomitantly to supply as much thermal load demand as reasonably achievable. It is widely understood that at present solar and wind power are the only realistic renewable energy options for Toksook Bay, Tununak, and Nightmute. Wind power is the primary focus of this study as its seasonal resource availability matches the seasonal energy demand of the community (i.e., high winter winds match high winter load demand), whereas solar power is the opposite. Solar power though has seen important gains in recent years as a significant renewable energy supply option in rural Alaska and may have excellent applicability in Toksook Bay despite its often-cloudy summer weather.

The proposed wind turbine of choice for Toksook Bay is the 1,000-kW capacity Emergya Wind Technologies (EWT) Direct Wind (DW) series models.[5] This turbine is in wide use in rural Alaska with operational installations in Kotzebue, Nome, Delta Junction, Bethel, and St. Mary's, with many more planned. The EWT DW series occupies a market niche between home and farm-scale turbines in the 5 to 100 kW capacity range and the much larger utility-scale turbines in the 2 to 6 (and even higher for offshore installations) MW range.

Although the existing Northwind 100 wind turbines are nearing the end of their 20-year operational life, AVEC has stated that they prefer to leave the Northwinds in service in lieu of decommissioning them during installation of the larger EWT turbine(s). With that in mind, the proposed project was assessed with both turbine models operational.

Site Location

The existing wind farm (refer to Figure 7) is the preferred location to install one or more EWT wind turbines due to landownership, existing electrical distribution connection to the site, known geotechnical conditions, and relatively far distance from Toksook Bay Airport. The existing wind farm site and surrounding land, where an EWT turbine site appears to be most suitable, belong to Nunakauiak Yupik Corporation (see Figure 9). Nunakauiak Yupik Corp. provided AVEC a contractual land use permit for installation of the Northwind 100 turbines and it is assumed they would support installation of EWT wind turbine(s) near the Northwind turbines.

[5] Emergya Wind Technologies B.V. is based in Amersfoort, The Netherlands. Website: [Home - EWT - Creating distributed energy champions (ewtdirectwind.com)](ewtdirectwind.com)

Figure 9: Toksook Bay wind site land ownership, DCRA[6] community profile map; red circle; wind farm site

The new version EWT turbines are available with 46- and 69-meter height towers, with the lower tower acceptable considering Toksook Bay's strong wind resource (note that 46 meters is significantly higher than the existing Northwind turbine hub heights).

As with nearly all rural Alaska wind power projects, installation of turbines near an airport poses potential air safety concerns for Federal Aviation Administration (FAA). Use of FAA's notice criteria tool on its obstruction evaluation website indicates that an EWT DW58-1000 at a 46-meter hub height (a tip height of 75 meters or 246 ft.), located immediately west of the existing Northwind turbines, exceeds notice criteria for CFR Title 14 Part 77, subpart B, Notice Requirements, for construction exceeding an imaginary sloped surface from Toksook Bay Airport, specifically Part 77.9(b) (see Figure 10). Exceeding Part 77.9 criteria is not uncommon for proposed wind power projects in rural Alaska and does not necessarily indicate FAA objection to the proposed project. Further review is required by formal submission of the project to FAA for evaluation.

[6] Division of Community and Regional Affairs, Alaska Department of Commerce, Community, and Economic Development

Figure 10: FAA obstruction evaluation result and Toksook Bay Airport Layout Plan overlay on Google Earth imagery

Electrical Upgrade

In a preliminary review, AVEC's engineering department noted the following to add one or two EWT wind turbines to the Toksook Bay wind farm:

"A #2 ACSR three-phase overhead distribution line feeds out of the AVEC power plant from a 480 volt, 600 amp feeder breaker to a step-up transformer bank consisting of 3-75 kVA transformers connected Y-ground to Y-ground. The #2 ACSR overhead distribution line that extends to the wind farm also serves an elementary school, homes, fish plant, tank farm, and the city office. At the edge of Toksook Bay, the existing four 100 kW Northwind turbines connect to the overhead #2 ACSR line via a 4/0 AL underground distribution.

To accommodate one new 1,000 kW EWT at Toksook Bay located adjacent to the existing Northwind turbines, the existing 480 volt, 600 amp feeder breaker and the existing three 75 kVA step-up transformers would require upgrading at the power plant. The existing 480 volt, 600 amp breaker could be upsized to a 1,600 amp breaker to interconnect up to 1,400 kW (1000 + 400 kW) and the pad-mount 75 kVA transformers must be upgraded to three 500 kVA units with a spare unit and their associated 480 volt conductors replaced to meet the capacity requirements of 1300 kW on Circuit #3 out of the power plant.

The addition of two 1,000 kW turbines at the existing wind farm would require substantial switchgear replacement and infrastructure improvements that would warrant further investigation."

AVEC estimated $150,000 of upgrades to support one EWT turbine and $500,000 of upgrades to support two EWT turbines.

Evaluation Method

The proposed project was evaluated using UL's Hybrid Optimization of Multiple Energy Resources (HOMER) Pro software. From UL's Homer Energy website: *HOMER Pro® microgrid software by HOMER Energy is the global standard for optimizing microgrid design in all sectors, from village power and island utilities to grid-connected campuses and military bases. Originally developed at the National Renewable*

Energy Laboratory, and enhanced and distributed by HOMER Energy, HOMER (Hybrid Optimization Model for Multiple Energy Resources) nests three powerful tools in one software product, so that engineering and economics work side by side.

The HOMER project evaluation model was constructed using the existing diesel generators, existing Northwind 100 wind turbines, recent electric load demand, water treatment plant thermal load demand, re-evaluated wind resource data, one and two EWT DW58-1000 wind turbines at 46-meter hub height, and a battery energy storage system (BESS) equivalent to AVEC's planned battery installation in St. Mary's. Given EWT's large capacity compared to the load, a BESS comprised of Li-ion batteries and a grid-forming inverter is necessary to control system frequency and to enable diesel-off operations.

Cost Estimates

HOMER software is an economic optimization tool and as such requires cost data for capital expenses, fuel, and operations and maintenance (O&M). Installing a wind turbine in rural Alaska is a complex task with barge access challenges, road and distribution connection needs, and foundation design as primary variables. Default capital and O&M cost assumptions from AEA's Renewable Energy Fund (REF) Round 14 (Nov. 2021) were used in Table 3, and actual costs reported by AVEC. Project capital costs were further evaluated at -20% and +25% of those noted in Table 3 for use in a sensitivity analysis.

Table 3: AEA REF14 cost assumptions

		REF14 assumptions		Other assumptions		
Type	Capacity	Capital ($/kW)	O&M ($/hr)	O&M ($k/yr)	Overhaul ($K/90K hours)	Add'l Capital ($K)
Wind	1,000 kW	8,379		58		
	2,000 kW	6,498		116		
Diesel	361-600 kW		9.95		150	
	601-1,300 kW		15.16		250	
Distribution	for 1 EWT					150
	for 2 EWT					500
BESS	935 kWh			9.3		1,020
Inverter	900 kW					
Note: Turbine O&M data from EWT, + 30% per ANTHC; add'l capital from AVEC						

Project Results and Optimization

Homer software evaluates cost optimization for each scenario requested. There can be many scenarios depending on sensitivity cases. For instance, two fuel costs entail two cost scenarios with all other variables held constant. Should two wind turbine costs be considered, that yields four cost scenarios, all other variables constant, and so on. Results for each cost scenario are ranked by net present cost (NPC), which generally tracks levelized cost of energy (LCOE), which is also calculated.

For this analysis, Table 4 details the chosen cost assumptions. Renewable energy capital expense assumptions are as noted in Table 3. Fuel costs were chosen to reflect the average price of fuel listed in the 2021 PCE Statistical Report ($2.76/gal), this year's anticipated market rate fuel cost recently communicated to AVEC from their fuel provider ($5.37/gal), and a possible near-term higher fuel cost should energy markets remain unstable ($6.50/gal).

Table 4: Homer software modeling assumptions

Real discount rate	3%
Fuel escalation rate	1.5%
Project life	25 years EWT turbines; BESS replaced at 20 years
Fuel price	$2.76, $5.37 and $6.50/gal ($0.73, $1.42 and $1.72/Liter)
Fixed system O&M cost (excludes component-specific O&M in the model)	$689.9K Toksook Bay, Tununak, and Nightmute (2021 PCE report)

Modeling results with assumptions as noted above are presented in simplified form in Table 5. These indicate that the proposed project – constructing one or two EWT DW58 wind turbines with a BESS to maximize the offset of diesel fuel for electrical energy production – has lower NPC and LCOE than the existing energy generation system of diesel generators and four NPS100 wind turbines. Hence, installing EWT wind turbine(s) at the wind farm site is an economically advantageous project to develop. Note that the benefit cost ratios of 1.11 for 1 EWT turbine and 1.02 for 2 EWT turbines both reference the existing power system as the base case.

Table 5: Simplified Homer modeling results, $5.37/gal fuel

Scenario	Capital Cost ($M)	Wind Penet. (electric) (%)	Benefit/ Cost Ratio	LCOE ($/kWh)	Net Present Value ($M)	Fuel Saved (diesels) (gal/y)	Excess Energy (MWh/y)	Diesels Off Time (hr/y)
4 Northwind (base case)	0.00	20.7	1.00	0.582	40.0	-	2	-
1 EWT, 4 Northwind, BESS	9.55	112.0	1.11	0.524	36.3	125,649	1,516	5,193
2 EWT, 4 Northwind, BESS	14.50	209.0	1.02	0.570	39.3	156,005	4,512	6,290

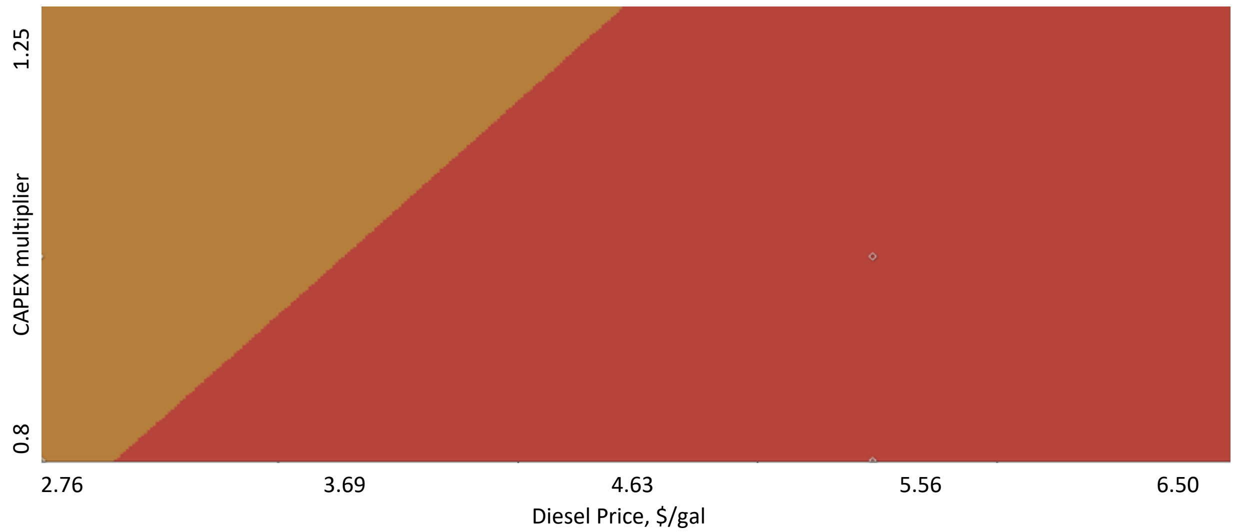
Several assumptions are contained within Table 5, including:

- All scenarios include diesel generation.
- The ABB-PSC battery storage system, included with the EWT DW58-1000 options, enables diesel-off capability. This results in lower diesel generator O&M costs and longer diesel overhaul cycles.
- To reflect that the Northwind turbines have been operational for over 10 years, they are modeled with 15 years of remaining life. The EWT DW61 is modeled with a 25-year life.
- The scenario with a 1.0 benefit/cost ratio is the base case, or existing power system.
- Minimum 10% diesel generator loading with BESS; 25% without BESS
- Assumed turbine losses (all causes): 10% for EWT, 45% for Northwind

Sensitivity Analysis

A sensitivity analysis provides insight into conditions where the proposed project may no longer have the lowest projected NPC/LCOE/benefit-to-cost ratio. Figure 11 demonstrates a sensitivity of fuel cost (x axis) vs. capital cost (y axis) with the proposed project in red and the existing system configuration in brown. Notably, the proposed project returns a 1.0 benefit-to-cost ratio with fuel price as low as approximately $3.00/gal and a capital cost 80% of nominal (see cost assumptions in Table 3). The minimum fuel price rises to approximately $4.60/gal with a capital cost 125% of nominal to achieve a 1.0 benefit-to-cost ratio.

Figure 11: Sensitivity analysis of optimal system type; gold color is existing base case; brick color includes 1 or 2 EWT wind turbines and battery energy storage system



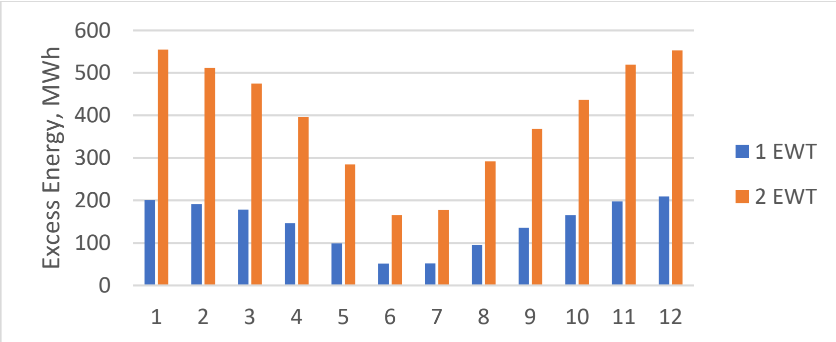
Wind-to-Heat

The benefit-to-cost ratio presented in Table 5 represents the perspective of AVEC as the electric utility of the community or perhaps that of an independent power producer with AVEC as the primary customer. Another benefit however of installing high-capacity EWT wind turbine(s) in Toksook Bay is the option to make use of excess energy via wind-to-heat.

Excess energy occurs when wind turbines produce more energy than the electric load, battery capacity to accept a charge, and/or water treatment plant thermal load (served by a thermal load controller) collectively demand. Because electricity generation must equal electrical load demand to maintain stable power system frequency, excess wind power must be curtailed, disposed of, or directed to beneficial use. The latter option has economic value beyond that demonstrated in Table 5 (see Figure 12) and can be accomplished, depending on the heating system design of the building, with an electric boiler connected to a hydronic (hot water) heat system or via an electric-thermal storage heater such as manufactured by Steffes.[7]

[7] Electric Thermal Storage - Steffes

Figure 12: Monthly distribution of excess energy for 1 or 2 EWT wind turbines in Toksook Bay, Homer modeling result



There are several large structures in Toksook Bay, Tununak, and Nightmute that are potentially suitable for remote node wind-to-heat. A review of ANTHC audit reports and an April 2020 report by CRW Engineering Group of heat recovery options for Toksook Bay[8] revealed a partial list of thermal loads (see Table 6 and Table 7).

Table 6: Toksook Bay, Tununak, and Nightmute thermal loads, partial listing, monthly heating fuel usage (gallons)

	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
Toksook Bay												
Nelson Is. School	739	512	557	471	331	171	153	199	258	412	591	795
NYC Corp. Office	820	737	711	491	263	128	99	120	205	407	597	821
Armory	369	256	278	235	165	86	77	99	129	206	295	397
Health Clinic	132	118	116	60	23	22	23	23	22	52	49	133
Bayview Store	220	196	189	131	72	34	22	30	56	118	163	221
NYC Store	220	196	189	131	72	34	22	30	56	118	163	221
Tununak												
Paul Albert School	739	512	557	471	331	171	153	199	258	412	591	795
Armory	220	196	189	131	72	34	22	30	56	118	163	221
Water Treatment Plai	314	280	274	198	155	54	54	54	54	184	239	315
Police office	118	106	102	71	39	19	12	17	30	63	87	119
Health Clinic	132	118	116	60	23	22	23	23	22	52	49	133
Native Store	220	196	189	131	72	34	22	30	56	118	163	221
Nightmute												
Nightmute School	739	512	557	471	331	171	153	199	258	412	591	795
Health Clinic	143	128	119	78	41	22	23	23	35	72	103	143
Store	220	196	189	131	72	34	22	30	56	118	163	221
Traditional Council	126	113	107	73	40	20	15	19	33	67	93	127

[8] *Heat Recovery Feasibility Study Toksook Bay, Alaska*, CRW Engineering Group, LLC, April 17, 2020

Table 7: Toksook Bay, Tununak, and Nightmute thermal load data source

Toksook Bay	
Nelson Is. School	CRW Heat Recovery Report
NYC Corp. Office	ANTHC audit report, space heating and DHW
Armory	CRW Heat Recovery Report
Health Clinic	Assume same as Tununak
Bayview Store	Assume same as Tununak Armory
NYC Store	Assume same as Tununak Armory
Tununak	
Paul Albert School	CRW Heat Recovery Report, assume same as Toskook Bay
Armory	ANTHC audit report, space heating
Water Treatment Pl	ANTHC audit report, space heat, DHW, and water storage heat
Police office	ANTHC audit report, space heating
Health Clinic	ANTHC audit report, space heating and DHW
Native Store	Assume same as Tununak Armory
Nightmute	
Nightmute School	CRW Heat Recovery Report, assume same as Toskook Bay
Health Clinic	ANTHC audit report, space heating
Store	Assume same as Tununak Armory
Traditional Council	ANTHC audit report, space heating

Cost Estimate

A December 2021 analysis by ANTHC for the expansion of wind-to-heat in Kotzebue estimated a capital cost of $700K to engineer, permit, and install a 300-kW boiler in a hydronic heating system to use excess wind energy to offset heating fuel for the system boilers, or $657K for a 200-kW boiler. ANTHC has indicated though that those cost estimates included elements not normally required for a typical wind-to-heat installation, hence for this analysis $500K is assumed for one 300 kW boiler in Toksook Bay, Tununak, or Nightmute with additional 300 kW boilers costing $450K each – 90% of the first boiler cost – as economies of scale are presumed. Later detailed analyses may reveal that smaller or larger boilers are required for individual facilities, with attendant lower or higher costs. This analysis is intended to demonstrate the economic potential of excess energy for wind-to-heat in Toksook Bay, Tununak, and Nightmute.

Economic Evaluation

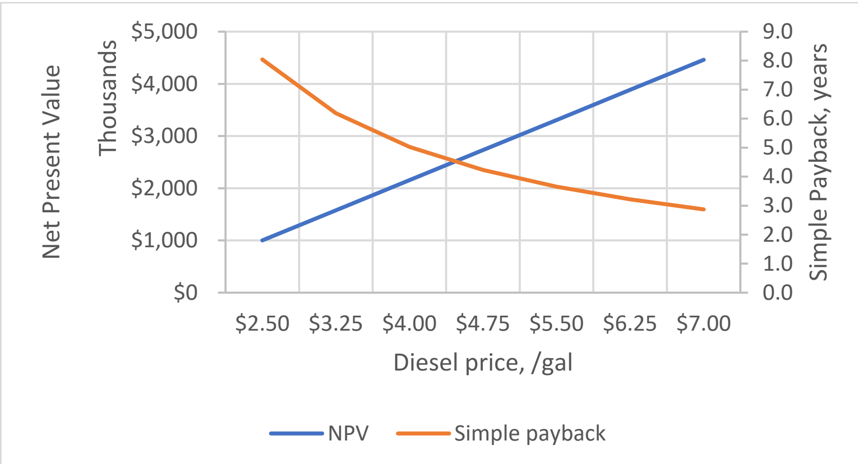
The prospective economic valuation of wind-to-heat is evaluated with the assumption that all excess wind energy can be used by remote node electric boilers or Steffes-type heaters to displace no. 1 diesel for fuel oil boilers. This may be idealized but provides a reference point for subsequent analysis to match excess heat availability with thermal load demand. A project life of 25 years, like the EWT wind turbine, is assumed, with a 3% real discount rate applied for a net present value (NPV) evaluation. Boiler capital costs are applied to year 0 and fuel savings are tabulated over the following 25 years beginning with an initial fuel cost and adding a 1.5% per year fuel price escalation. It is assumed that AVEC will charge 30% of avoided fuel cost for wind-to-heat electric energy and that the efficiency of the companion fuel oil boiler is 80%.[9] Besides NPV, simple payback period (where NPV is not considered) is also calculated.

The initial wind-to-heat evaluation is one EWT wind turbine (plus the existing four Northwind wind turbines), a BESS, and two remote-node wind-to-heat boilers in facilities in Toksook Bay, Tununak,

[9] ANTHC assumption

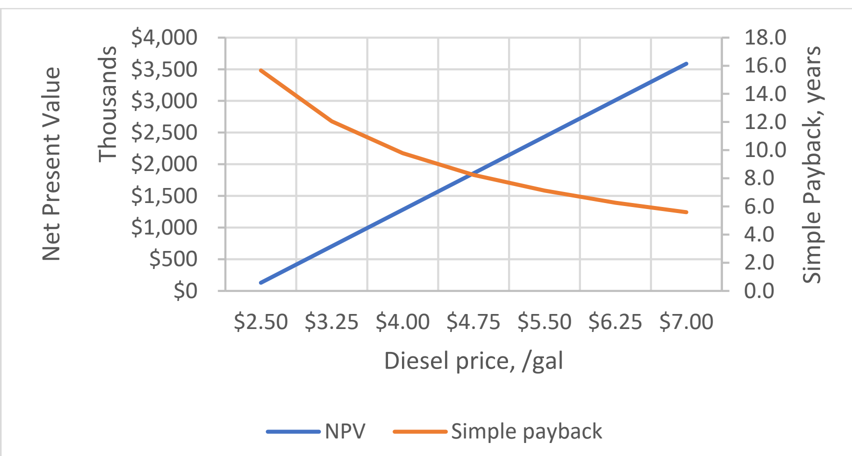
and/or Nightmute. As demonstrated in Table 5, 1,516 MWh/year of excess wind energy is projected. With that, positive NPV and short simple payback periods are anticipated for all fuel prices modeled, though likely only high heat load facilities like water plants or schools can absorb this much excess energy (see Figure 13).

Figure 13: One EWT turbine, two wind-to-heat boilers, NPV and payback period (25 yr. project, 3% real discount rate)



One EWT wind turbine and four remote node electric boilers would provide more flexibility with facilities in which to install remote node electric boilers and yet still demonstrate desirable economic benefit (see Figure 14).

Figure 14: One EWT turbine, four wind-to-heat boilers, NPV and payback period (25 yr., 3% real discount rate)



Two new EWT wind turbines provide considerably more flexibility with wind-to-heat. Table 5 demonstrated that two EWT's generate three times more excess wind energy compared to one EWT. This enables heating fuel displacement in many facilities with sufficient heat loads to absorb the cost of multiple wind-to-heat boilers. Figure 15 demonstrates the economic valuation with six boilers, which is excellent even at low fuel prices.

Figure 15: Two EWT turbines, six wind-to-heat boilers, NPV and payback period (25 yr., 3% real discount rate)

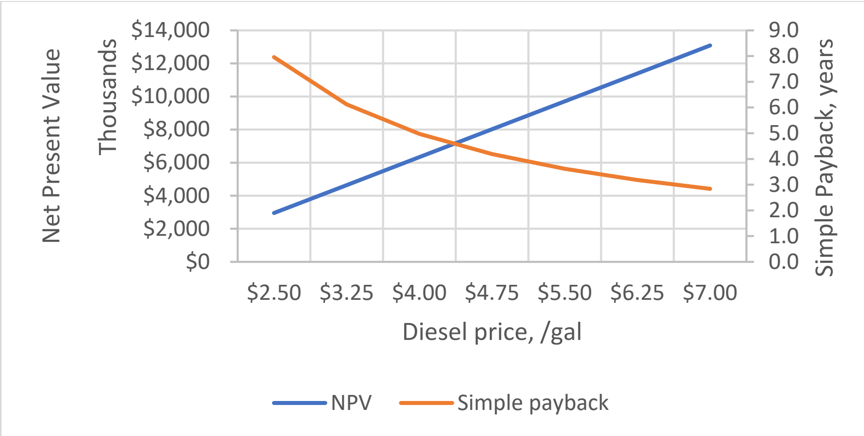
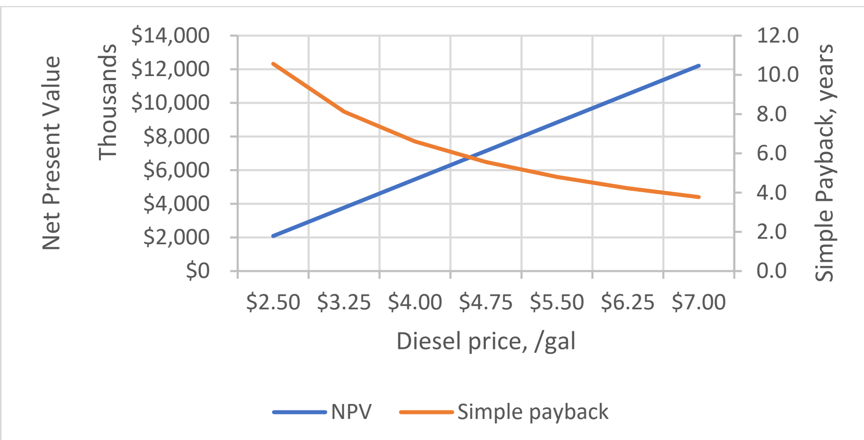


Figure 16 demonstrates that even eight wind-to-heat boilers absorbing all excess energy of two EWT wind turbines also demonstrates excellent economic potential, including at very low fuel prices.

Figure 16: Two EWT turbines, eight wind-to-heat boilers, NPV and payback period (25 yr., 3% real discount rate)



Discussion

This report separates the economic analysis of new EWT wind turbines in Toksook Bay into two parts: the first a utility perspective of displacing diesel fuel for electricity generation and the second a community or facility owner perspective of displacing heating oil for thermal needs via wind-to-heat. Table 5 demonstrates that installing one or two EWT turbines are economically advantageous with discounted benefit-to-cost ratios of 1.11 and 1.02 respectively.

The benefit/cost evaluation however is before consideration of wind-to-heat potential. Including wind-to-heat improves the economic valuation for all scenarios. Of the four turbine and wind-to-heat boilers scenarios presented, at $5.50 per gallon fuel cost two EWT wind turbines and six wind-to-heat boilers demonstrates the lowest simple payback period in the isolated context of wind-to-heat only (see Table 8), assuming the thermal loads are sufficient to absorb all excess wind energy generated. When aggregating wind-to-heat with installation of the wind turbines to provide a more holistic perspective, the resulting combined simple payback periods improve but are dominated by the higher expense of turbine development, as one would expect.

Table 8: Summary of wind-to-heat simple payback period with $5.50/gal diesel fuel cost

	Turbine/BESS Only			Wind-to-Heat Only*			Combined
Scenario	No. EWT turbines	Capital Expense ($M)	Simple Payback (yr.)	Wind-to-Heat Boilers	Capital Expense ($M)	Simple Payback (yr.)	Simple Payback** (yr.)
1 EWT, BESS, 2 WTH	1	9.55	13.1	2	0.95	3.7	12.3
1 EWT, BESS, 4 WTH	1	9.55	13.1	4	1.85	7.3	12.2
2 EWT, BESS, 6 WTH	2	14.5	16.6	6	2.75	3.6	14.5
2 EWT, BESS, 8 WTH	2	14.5	16.6	8	3.65	4.8	14.2
*Presumes new turbines (considered independently of turbine)							
**Calculated as a weighted average of capital expense and associated payback periods							

The objective with wind-to-heat is to match appropriate thermal loads with available excess electrical energy to maximize both the investment of wind-to-heat boilers and use of the projected availability of excess wind energy. Toksook Bay, Tununak, and Nightmute thermal load fuel usage documented in Table 6 was converted to kWh and the excess energy presented in Figure 12 are listed in Table 9. As one can see, there are several options to use the excess energy from installation of one EWT wind turbine but using all excess energy from two EWT wind turbines may prove challenging. Even if full utilization of excess energy is not possible for either scenario, installing one or two EWT wind turbines in Toksook Bay is nevertheless economically advantageous from the perspectives of fuel savings for electrical energy generation and reduced generator maintenance with frequent diesel-off operations.

Table 9: Thermal loads compared to modeled excess wind energy, monthly kWh

	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
Toksook Bay												
Nelson Is. School	22,638	15,684	17,063	14,428	10,140	5,238	4,687	6,096	7,903	12,621	18,104	24,353
NYC Corp. Office	25,119	22,577	21,780	15,041	8,056	3,921	3,033	3,676	6,280	12,468	18,288	25,150
Armory	11,304	7,842	8,516	7,199	5,054	2,634	2,359	3,033	3,952	6,310	9,037	12,161
Health Clinic	4,044	3,615	3,553	1,838	705	674	705	705	674	1,593	1,501	4,074
Bayview Store	6,739	6,004	5,790	4,013	2,206	1,042	674	919	1,715	3,615	4,993	6,770
NYC Store	6,739	6,004	5,790	4,013	2,206	1,042	674	919	1,715	3,615	4,993	6,770
Tununak												
Paul Albert School	22,638	15,684	17,063	14,428	10,140	5,238	4,687	6,096	7,903	12,621	18,104	24,353
Armory	6,739	6,004	5,790	4,013	2,206	1,042	674	919	1,715	3,615	4,993	6,770
Water Treatment Plai	9,619	8,577	8,393	6,065	4,748	1,654	1,654	1,654	1,654	5,636	7,321	9,649
Police office	3,615	3,247	3,125	2,175	1,195	582	368	521	919	1,930	2,665	3,645
Health Clinic	4,044	3,615	3,553	1,838	705	674	705	705	674	1,593	1,501	4,074
Native Store	6,739	6,004	5,790	4,013	2,206	1,042	674	919	1,715	3,615	4,993	6,770
Nightmute												
Nightmute School	22,638	15,684	17,063	14,428	10,140	5,238	4,687	6,096	7,903	12,621	18,104	24,353
Health Clinic	4,381	3,921	3,645	2,389	1,256	674	705	705	1,072	2,206	3,155	4,381
Store	6,739	6,004	5,790	4,013	2,206	1,042	674	919	1,715	3,615	4,993	6,770
Traditional Council	3,860	3,462	3,278	2,236	1,225	613	459	582	1,011	2,052	2,849	3,890
Total	167,593	133,928	135,980	102,131	64,391	32,349	27,417	34,462	48,523	89,724	125,596	173,935
Excess energy, 1 EWT	193,305	182,983	171,233	140,293	97,208	49,538	52,241	92,949	132,174	161,217	189,911	200,066
Excess energy, 2 EWT	545,577	503,731	465,991	386,652	281,876	164,343	178,289	285,843	362,815	430,265	510,271	541,853

Independent Power Producer Option to Lower Water and Sewer Rates

The community of Toksook Bay could capitalize on the revenue generating opportunity of owning the proposed wind turbines and selling the electricity to AVEC through a Power Purchase Agreement (PPA) to create a revenue generating asset and local jobs. This model has been implemented in Shungnak for their community sized solar system, which has allowed for diesel off operation during the spring and summer season and has generated $100,000 in nearly passive revenue for the Tribe in 12 months. If a local or regional entity acted as an Independent Power Producer (IPP) to own and operate the renewable assets, AVEC would buy the power through a PPA at a fuel-avoided rate equal to roughly 80% of an equivalent cost of a gallon of diesel bought locally. Given that AVEC prefers to charge a fluctuating annual rate related to diesel price for renewable energy purchased from an IPP, this means that annual profits are variable. If the fuel price is high, profits from the wind systems are high, and will proportionally change annually with a change in fuel price. AVEC's avoided fuel rate method ensures that total electricity costs borne of renewable assets stay below the base case of diesel, lowering electrical costs pre-PCE no matter what the bulk fuel cost or global fuel price instability. While this makes financial planning slightly harder for an IPP, it ensures the lowest possible electricity costs for the community.

To give an example for Toksook Bay, which illustrates the revenue generating ability had the system been online for 2022, the current fuel price was multiplied by AVEC's fuel avoided rate and again multiplied by the annual amount of power generated by the system. Operations and Maintenance costs were subtracted along with the cost of two part time jobs that would be created locally. Wind to Heat systems are not included in this scenario and only identify revenue from wind production at the turbines. Thirty dollars an hour was estimated for two part time operators working an average of 10 hours per week year round, alternating two week shifts. If the annual revenue was set aside to reduce the billed rates for water and sewer, this would mean a $2,540.00 annual reduction in each of the 172 households in Toksook. When taking equity into account and sharing the benefit between all intertied household connected to water/sewer, a $1,649.00 annual reduction in water bills for each household of Toksook (172), Nightmute (30) and Tununak (63) would be possible with these revenues. Given the high percentage of families living below the poverty line, this revenue would ensure clean water was not shut off for non-payment and the critical sanitation infrastructure that ANTHC built would continue to be sustainable.

Table 10: 2022 IPP Earnings from 1 EWT Energy Sales to AVEC

Fuel Price 2022/gallon	Annual Gallons Diesel Avoided	80% of Avoided Gallon = AVEC Purchase Price	Two Part Time Operators	Annual O + M Costs for 1 EWT & BESS	Net 2022 Revenue	Annual Household Savings if Applied to Water and Sewer Bills
$5.37	124,649	$4.296	-$31,200	-$67,300	$436,992	$1,649