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Executive Summary

Expanding wind power capacity with inclusion of battery energy storage in larger Alaska Village Electric Cooperative villages 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. Emmonak 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 one and six remote electric wind-to-heat boilers at facilities in Emmonak and/or Alakanuk.

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 Emmonak and Alakanuk 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 Emmonak-Alakanuk power system by installing one or more 1,000 kW capacity EWT wind turbines.[1] It is hoped that increased wind power capacity in Emmonak will encourage further development of renewable energy in the community, including the widespread electrification of it and Alakanuk's thermal energy needs.

Emmonak is an Alaska Native village on the lower Yukon River with a population of 836 people. It is electrically intertied (connected via overheard power transmission lines) to the village of Alakanuk, which has a population of 704 people and is located 8 miles to the southwest. Both communities are members of Alaska Village Electric Cooperative (AVEC), a rural utility cooperative serving over 50 villages in rural Alaska.

Figure 1: Emmonak and Alakanuk; Google Earth image

The Emmonak-Alakanuk power system is comprised of approximately 3.3 MW of diesel generation capacity augmented by 400 kW of wind power capacity, located in Emmonak. AVEC maintains standby diesel power generation capability in Alakanuk in event of electrical intertie disruption. The Emmonak 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.

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

For the most recently posted Power Cost Equalization[2] (PCE) period of July 1, 2020, to June 30, 2021, AVEC reported 5.14 GWh of diesel generation and 0.54 GWh of wind generation, for a total of 5.68 GWh. This represents 9.5% average annual wind power penetration, as a percentage of total load demand.

Wind Resource

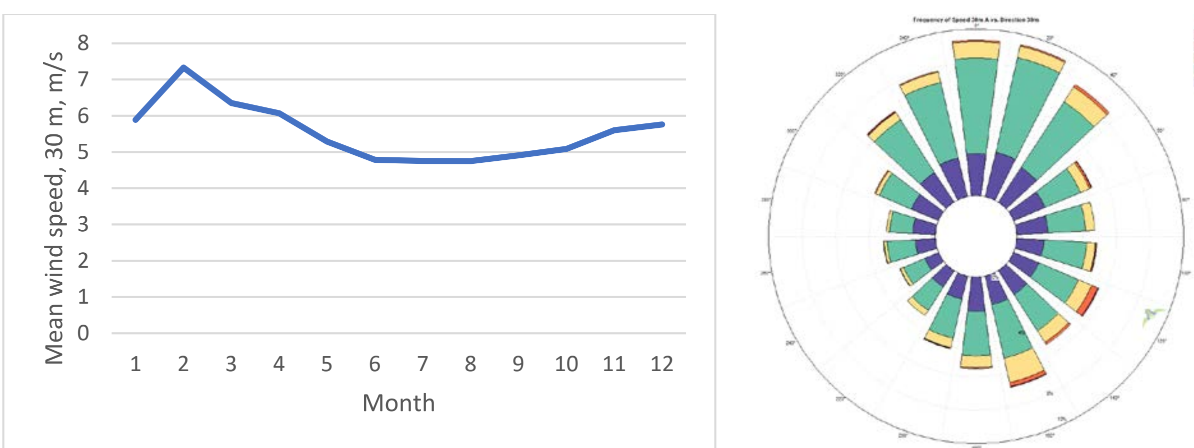
The Emmonak wind resource was measured from September 2007 to April 2010 with a 30-meter met tower located at the wind farm site (refer to Table 1 for summary data). The resource was documented in a V3 Energy LLC report titled *Emmonak, Alaska Wind Power Report* dated August 31, 2010.

Table 1: Met tower data set summary

Variable	Value
Latitude	N 62° 46' 57.840"
Longitude	W 164° 33' 26.820"
Elevation	3 m
Mean temperature	-1.80 °C (28 °F)
Mean wind speed at 30 m	5.55 m/s
Mean air density	1.270 kg/m^3
Power density at 30 m	171 W/m^2
Wind power class	2 (Marginal)
Wind shear exponent	0.185
IEC 61400-1 classification	Class IIIC

For the present analysis, the wind data was re-evaluated and adjusted against 40-years of Emmonak airport Automated Weather Observing Station (AWOS) data to yield a long-term representative data set applicable to the higher hub height of new, high-capacity wind turbines. The met tower wind rose indicates predominately northerly and south-southeasterly winds (see Figure 2).

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



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

Emmonak Electric and Thermal Load Demand

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

Electric Load

Emmonak-Alakanuk electric power demand averages 665 kW with a measured peak electric demand of 1,115 kW and an approximate minimum demand of 400 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: Emmonak electric load seasonal profile

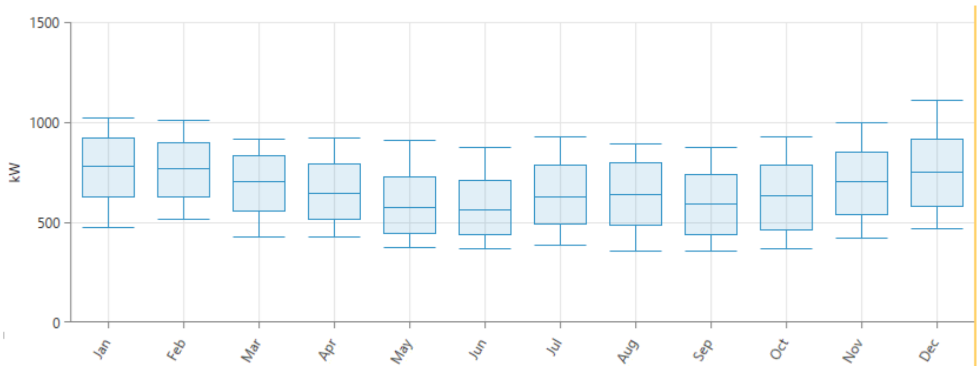
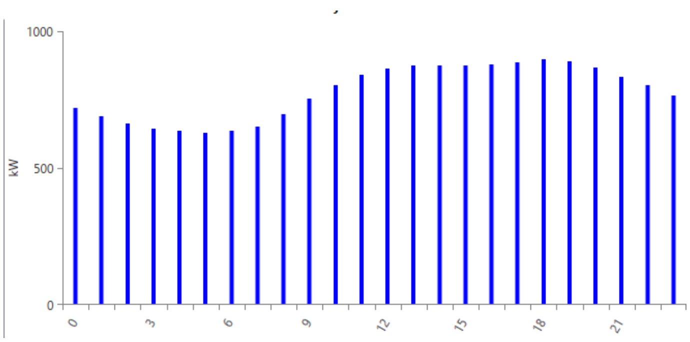


Figure 4: Emmonak electric load diurnal profile



Thermal Load, Recovered Heat Loop

Emmonak'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, such as the school, are more readily characterized as they have often been audited for energy efficiency and usage, while smaller, individual structures with Toyo stoves are rarely audited and energy usage is often uncertain.

The Emmonak water treatment plant (WTP) is the only structure connected to the powerplant recovered heat system and as such benefits from the co-generation capabilities of the diesel generators.

As documented in an AkWarm[3] file that records an energy audit dated 5 March 2013, the WTP is augmented by two fuel oil boilers to meet the thermal load demand. Although the AkWarm file notes usage of recovered heat, offtake of that heat was not documented, only fuel oil usage for the boilers. To create a synthetic 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 Emmonak WTP fuel oil usage added (from AkWarm files for Hooper Bay WTP and Emmonak WTP). Units were converted from million British Thermal Units (BTU) and gallons to kilowatt-hours (kWh) for modeling purposes.

Figure 5: Emmonak Water Treatment Plant thermal load seasonal profile

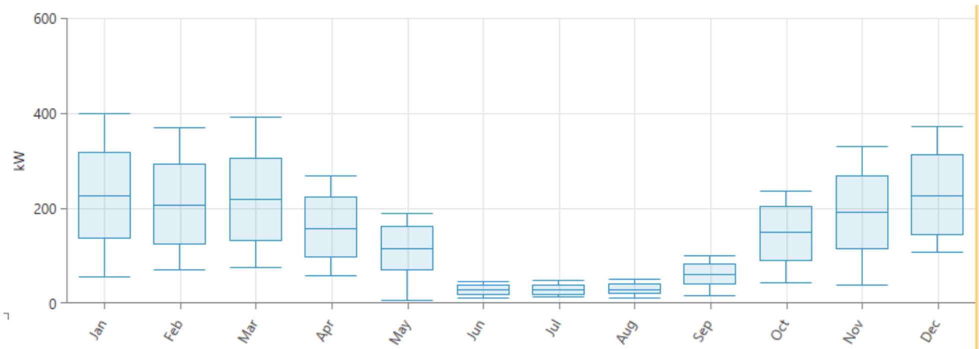
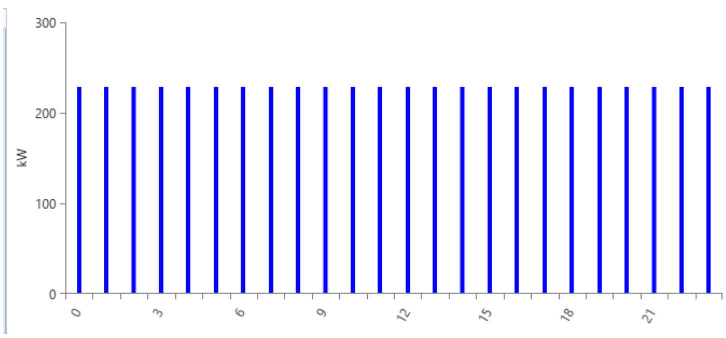


Figure 6: Emmonak Water Treatment Plan thermal load diurnal profile (assumed)



Emmonak Power System

Emmonak's power generation system is comprised of four diesel-electric generators and four wind turbines. Diesel generator information is detailed in Table 2. The four wind turbines are 100 kW capacity, 21-meter rotor diameter, Northern Power Systems (NPS) Northwind 100 B models on 37-meter towers for 400 kW total capacity. The turbines are at a wind farm on the western edge of the community (see Figure 7).

Table 2: Emmonak diesel generators

Engine Data			Generator Data			Commissioning
Bay	Make	Model	Rating (kW)	Make	Model	Date
1	CAT	3456	505	Newage	HC I534F1	5/6/2016
2	CAT	3456	505	Newage	HC I534F1	5/6/2016

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

3	CAT	3512A 1200	908	Kato	6P4-2400	5/6/2016
4	CAT	3516B 1200	1,305	Kato	6P6-2650	5/6/2016

For the 2021 PCE report, AVEC reported a combined diesel generator efficiency of 14.5 kWh/gal (diesel generation only, exclusive of wind power input), which is outstanding for a village power system and indicates usage of appropriately sized generators, electronic governor control, and proper maintenance.

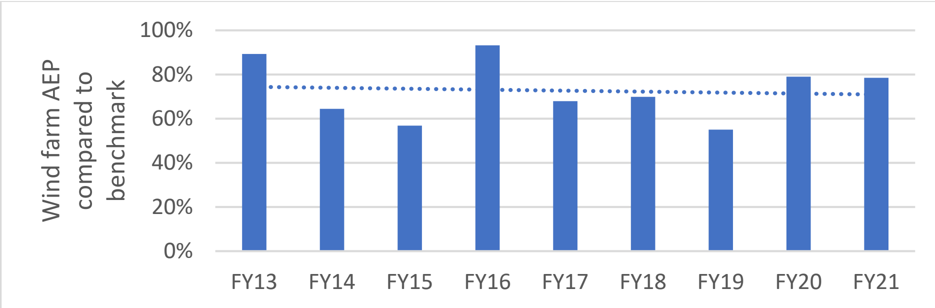
Figure 7: Emmonak wind farm location

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 nine-year period the four wind turbines in Emmonak operated at about 75 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, and the technical challenge of operating stall-controlled wind turbines at high instantaneous penetration in a wind-diesel power system without a battery energy storage system as a buffer.

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

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



Power Distribution

Emmonak'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 renewable energy to supply a significantly higher percentage of electrical load demand than the present 9.5 percent average penetration and concomitantly supply thermal load demand to the extent possible. It is widely understood that at present solar and wind power are the only realistic renewable energy options for Emmonak and Alakanuk. 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 the solar power resource/load demand match is 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 Emmonak despite its often-cloudy summer weather.

The proposed wind turbine of choice for Emmonak 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 maintain the Northwinds in service in lieu of decommissioning them during installation of the larger EWT turbine(s). With that in mind, the proposed project is assessed with both turbine models operational.

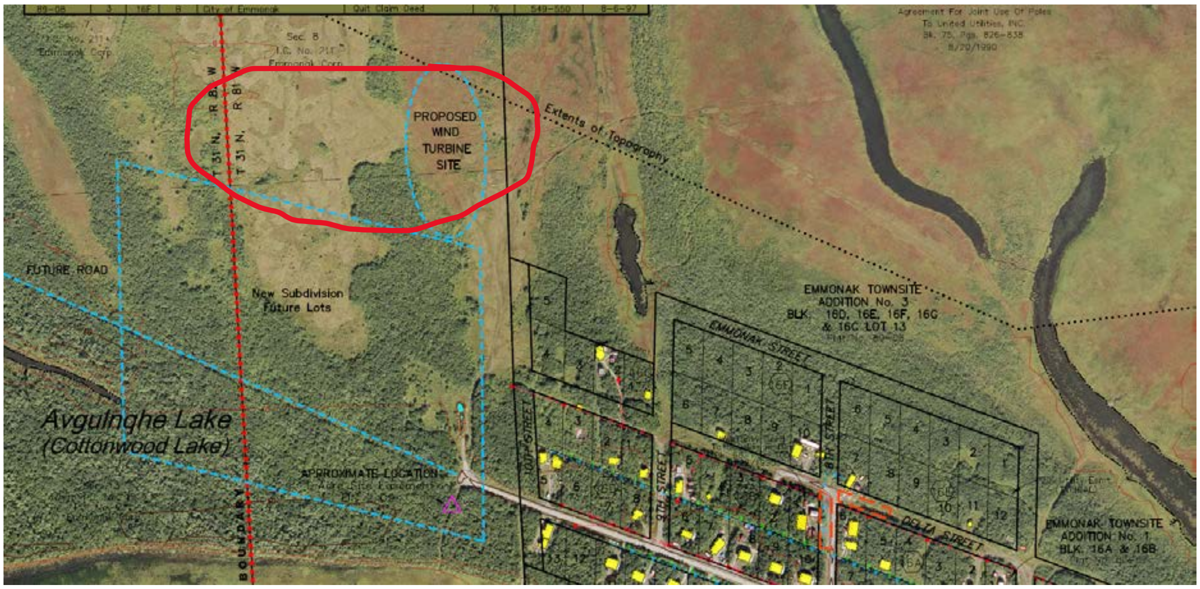
Site Location

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

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

geotechnical conditions, and relatively far distance from Emmonak Airport. The existing wind farm site and land immediately west where an EWT turbine site appears to be most suitable belongs to Emmonak Corporation (see Figure 9). Emmonak Corporation provided AVEC with a 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.

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

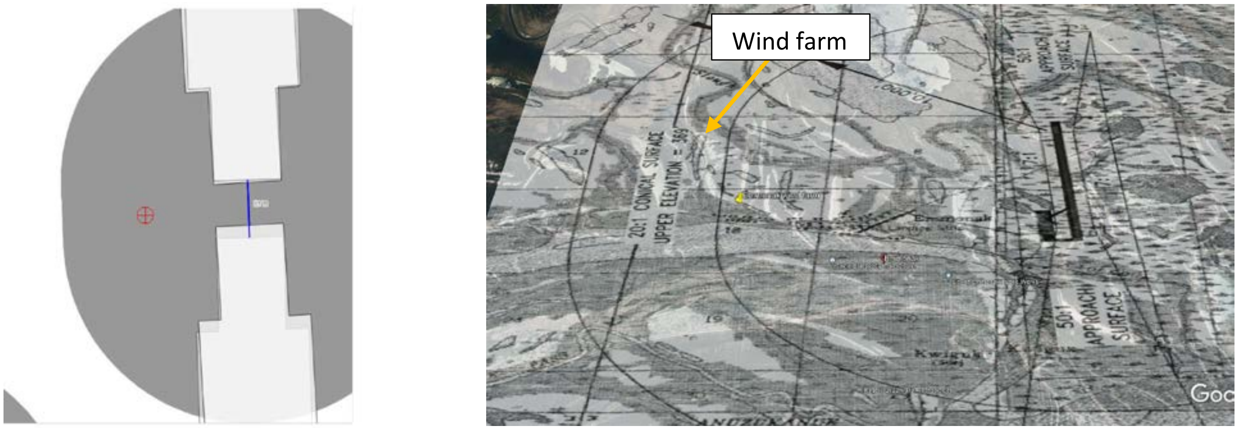


The new version EWT turbines are available with 46- and 69-meter height towers, with the latter preferred in Emmonak to capture stronger winds at higher heights above ground level. Note that 69 meters is significantly higher than hub heigh of the existing Northwind turbines.

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 DW61-1000 at a 69-meter hub height (a tip height of 100 meters or 328 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 Emmonak 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 Emmonak 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 Emmonak wind farm:

"A 4/0 ACSR three-phase overhead tie-line to Alakanuk feeds out of the AVEC powerplant from a 480 volt, 1,200 amp breaker to a step-up transformer bank of three 250 kVA transformers. This 4/0 ACSR distribution line is a dedicated tie-line to serve Alakanuk. At the edge of Emmonak, the four existing 100 kW wind turbines are tapped off the 4/0 ACSR tie-line with #2 ACSR line to interconnect the turbines.

To accommodate one new EWT turbine in Emmonak adjacent to the existing Northwind turbines, the existing 480 volt, 1,200 amp feeder breaker and the existing three 250 kVA step-up transformers would require upgrading at the powerplant. The breaker would be upsized to 1,600 amps to interconnect up to 1,400 kW (1,000 kW + 400 kW) of wind power and the three 250 kVA transformers would be replaced with 500 kVA units. Associated conductors would be replaced to meet the capacity requirements of 1,300 kW wind turbine capacity on the tie-line.

The addition of two 1,000 kW turbines at the same location as the existing 100 kW wind turbines 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 DW61-1000 wind turbines at 69-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: 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					

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, combining with two fuel costs yields four cost scenarios, all other variables constant, and so on. Results for each cost scenario are ranked by net present cost (NPC), which 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)	\$1.066M Emmonak and Alakanuk (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 DW61 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 1.09 for 1 or 2 EWT turbines both reference the existing power system as the base case.

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

Scenario	Capital Cost (\$M)	Wind Penet. (electric) (%)	Benefit/ Cost Ratio	LCOE (\$/kWh)	Net Present Value (\$M)	Fuel Saved (diesels) (gal)	Excess Energy (MWh)	Diesels Off Time (hrs)
4 Northwind (base case)	0.00	11.0	1.00	0.601	65.0	-	-	-
1 EWT, 4 Northwind, BESS	9.55	52.2	1.09	0.550	59.9	137,663	492	2,175
2 EWT, 4 Northwind, BESS	14.50	93.5	1.09	0.549	59.7	190,096	2,161	3,535

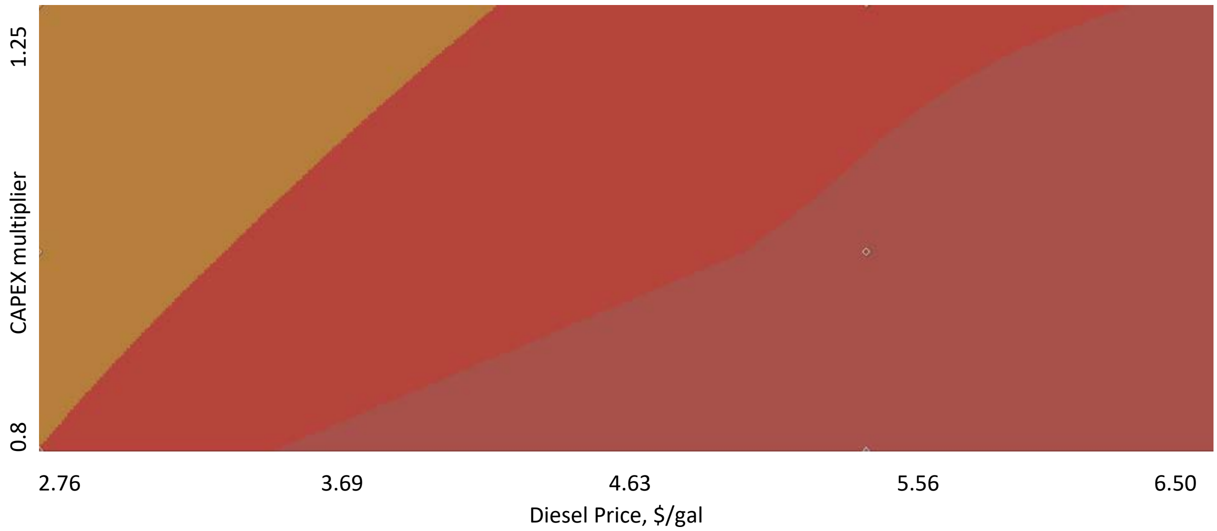
Several assumptions are contained within Table 5, including:

- All scenarios include diesel generation.
- The ABB-PSC battery storage system, included with the EWT DW61-1000 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, 25% 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 \$2.76/gal and a capital cost 80% of nominal (see cost assumptions in Table 3). The minimum fuel price rises to \$4.50/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; red and brick colors are 1 or 2 EWT wind turbines and battery energy storage system



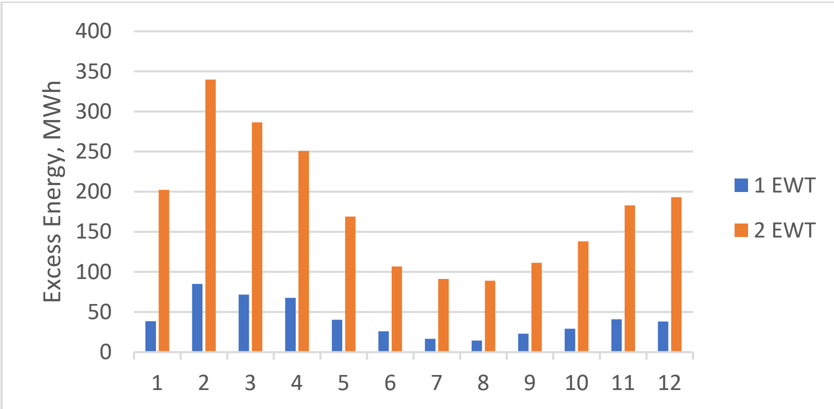
Wind-to-Heat

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 Emmonak 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 Emmonak, Homer modeling result



There are several large structures in Emmonak and Alakanuk 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] a village that share similarities with Emmonak and Alakanuk, revealed a partial list of thermal loads (see Table 6 and Table 7).

Table 6: Emmonak and Alakanuk thermal loads, partial listing, monthly heating fuel usage (gallons)

	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
Emmonak school	739	512	557	471	331	171	153	199	258	412	591	795
Emmonak washeteria	394	354	345	254	193	174	180	180	180	243	304	395
Emmonak clinic	125	112	104	67	37	23	22	24	32	61	88	125
Emmonak tribal office	451	404	385	266	150	71	50	68	123	244	335	453
Emmonak store	369	256	278	235	165	86	77	99	129	206	295	397
Alakanuk school	739	512	557	471	331	171	153	199	258	412	591	795
Alakanuk clinic	125	112	104	67	37	23	22	24	32	61	88	125
Alakanuk washeteria	461	421	415	126	225	-	-	-	-	66	354	460
Alakanuk tribal office	451	404	385	266	150	71	50	68	123	244	335	453
Alakanuk WTP	1,422	1,287	1,350	1,152	47	-	-	-	-	616	1,223	1,423
Alakanuk store	369	256	278	235	165	86	77	99	129	206	295	397

Table 7: Emmonak and Alakanuk thermal load data source

Emmonak school	Toksook Bay school and head start as stand-in (CRW report)
Emmonak washeteria	ANTHC audit report, space heating and hot water
Emmonak clinic	Assume same as Alakanuk clinic
Emmonak tribal office	Assume same as Alakanuk tribal office
Emmonak store	Toksook Bay armory as stand-in (CRW report)
Alakanuk school	Assume same as Emmonak school
Alakanuk clinic	ANTHC audit report, space heating and water storage
Alakanuk washeteria	ANTHC audit report, space heating and water storage
Alakanuk tribal office	ANTHC audit report, space heating
Alakanuk WTP	ANTHC audit report, water circ heat and water storage heat
Alakanuk store	Assume same as Emmonak

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

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

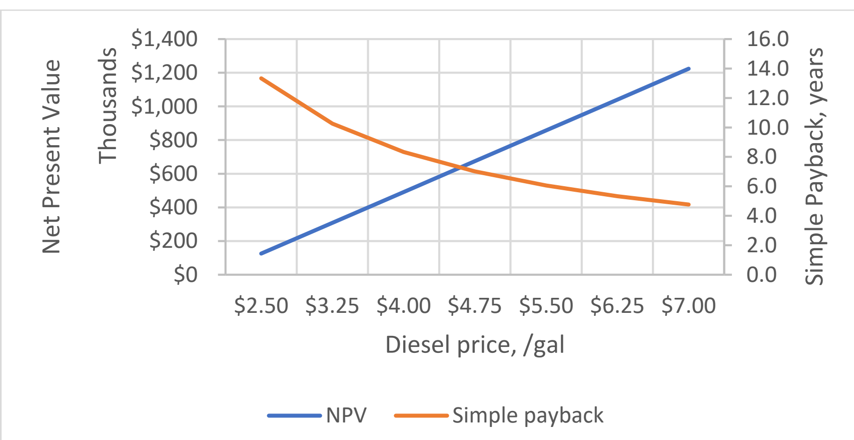
wind energy to offset heating fuel for the system boilers, or $657K for a 200-kW boiler. ANTHC has indicated though that those cost estimates included elements not normally required for a typical wind-to-heat installation, hence for this analysis $500K is assumed for one 300 kW boiler in Emmonak or Alakanuk 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 Emmonak and Alakanuk.

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 one remote-node wind-to-heat boiler in a facility in either Emmonak or Alakanuk. As demonstrated in Table 5, 490 MWh/year of excess wind energy is projected. With that, positive NPV is anticipated for all fuel prices modeled, though the NPV is somewhat low and the simple payback period relatively high with a very low ($2.50/gal) fuel price. At $5.50/gal, there is a NPV of $900K with accompanying 5-year simple payback period (see Figure 13).

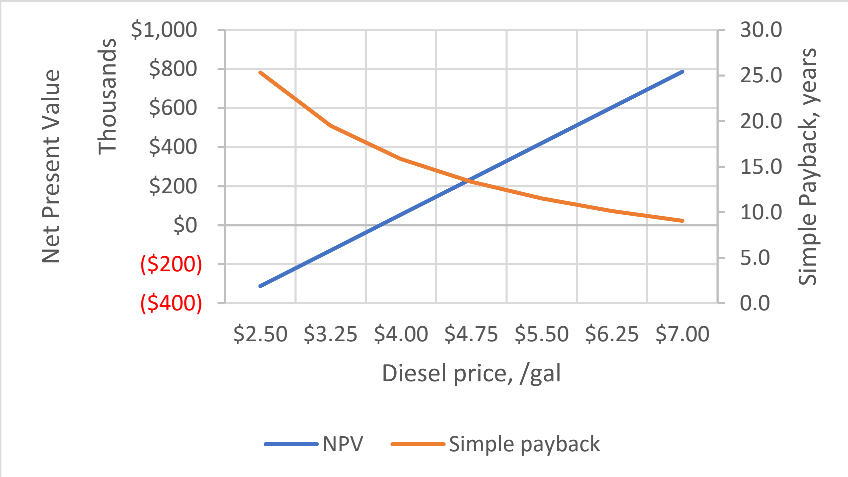
Figure 13: One EWT turbine, one wind-to-heat boiler, NPV and payback period (25 yr. project, 3% real discount rate)



One EWT wind turbine and two remote node electric boilers may be more challenging economically as there is less excess wind energy to offset the relatively high cost of two remote node electric boilers, except at higher fuel costs (see Figure 14).

[9] ANTHC assumption

Figure 14: One EWT turbine, two 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 over four times more excess wind energy compared to one EWT. This enables heating fuel displacement in many facilities with sufficient heat demand to absorb the cost of several wind-to-heat boilers. Figure 15 demonstrates the economic valuation with four boilers, which is excellent even at low fuel prices.

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

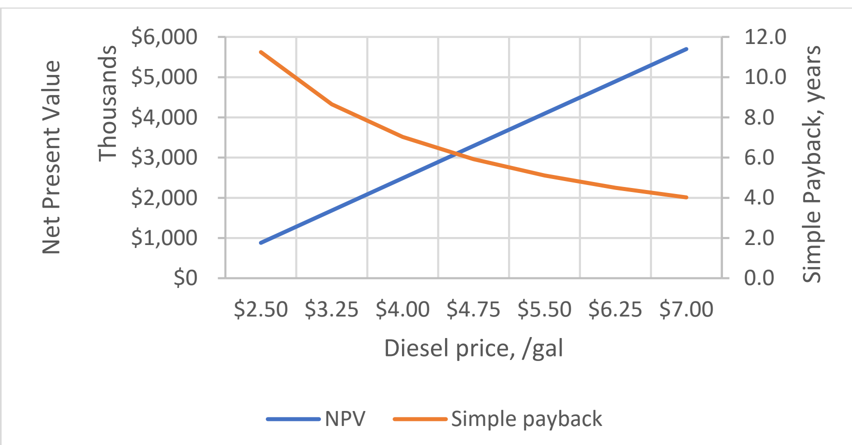
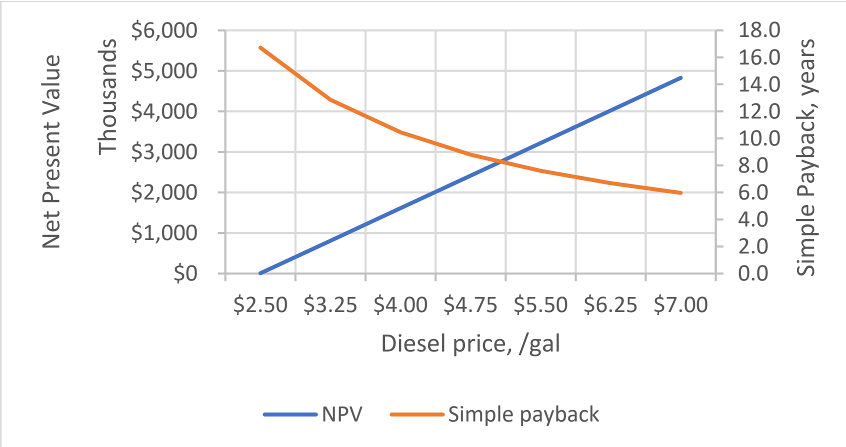


Figure 16 demonstrates that even six wind-to-heat boilers absorbing all excess energy of two EWT wind turbines has excellent economic potential except perhaps at very low fuel prices.

Figure 16: Two EWT turbines, six 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 Emmonak 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 installation of both one and two EWT turbines are economically advantageous with 1.09 benefit-to-cost ratios for both.

The benefit/cost evaluation however is before consideration of wind-to-heat potential. Including wind-to-heat improves the economic valuation for all scenarios except with very low fuel prices. Of the four turbine and wind-to-heat boilers scenarios presented, at $5.50 per gallon fuel cost two EWT wind turbines and four wind-to-heat boilers demonstrate 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 of wind-to-heat 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 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, 1 WTH	1	9.55	12.2	1	0.5	6.1	11.9
1 EWT, BESS, 2 WTH	1	9.55	12.2	2	0.95	11.5	12.1
2 EWT, BESS, 4 WTH	2	14.5	13.2	4	1.85	5.1	12.3
2 EWT, BESS, 6 WTH	2	14.5	13.2	6	2.75	7.6	12.3

*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. Emmonak and Alakanuk thermal load fuel usage documented in Table 6 was converted to kWh and the excess energy presented in Figure 12 are listed in Table 8. As one can see, there are several options to use all excess energy from installation of one EWT wind turbine but using all excess energy from two EWT wind turbines may not be economically viable. Even if full utilization of excess energy is not possible for either scenario, installing one or two EWT wind turbines in Emmonak 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
Emmonak 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
Emmonak washeteria	12,069	10,844	10,568	7,781	5,912	5,330	5,514	5,514	5,514	7,444	9,312	12,100
Emmonak clinic	3,829	3,431	3,186	2,052	1,133	705	674	735	980	1,869	2,696	3,829
Emmonak tribal office	13,816	12,376	11,794	8,148	4,595	2,175	1,532	2,083	3,768	7,474	10,262	13,877
Emmonak store	11,304	7,842	8,516	7,199	5,054	2,634	2,359	3,033	3,952	6,310	9,037	12,161
Alakanuk 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
Alakanuk clinic	3,829	3,431	3,186	2,052	1,133	705	674	735	980	1,869	2,696	3,829
Alakanuk washeteria	14,122	12,897	12,713	3,860	6,892	-	-	-	-	2,022	10,844	14,091
Alakanuk tribal office	13,816	12,376	11,794	8,148	4,595	2,175	1,532	2,083	3,768	7,474	10,262	13,877
Alakanuk WTP	43,560	39,425	41,355	35,289	1,440	-	-	-	-	18,870	37,464	43,591
Alakanuk store	11,304	7,842	8,516	7,199	5,054	2,634	2,359	3,033	3,952	6,310	9,037	12,161
Total	172,924	141,831	145,752	110,585	56,089	26,835	24,016	29,408	38,720	84,884	137,818	178,223
Excess energy, 1 EWT	38,454	84,958	71,667	67,722	40,384	25,880	16,638	14,338	22,964	29,246	40,964	38,163
Excess energy, 2 EWT	202,341	339,731	286,536	250,818	168,975	106,841	91,157	88,988	111,321	138,145	183,066	193,091

Independent Power Producer Option to Lower Water and Sewer Rates

The community of Emmonak 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 new 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 if the Power Cost Equalization endowment were to disappear.

To give an example for Emmonak, 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 this annual revenue of nearly half a million dollars was set aside to reduce the billed rates for water and sewer, this would mean a $1,792.00 annual reduction in each of the 275 households in Emmonak. When taking equity into account and sharing the benefit between all 503 intertied household connected to water/sewer, a $980.00 annual reduction in water bills for each household of both intertied communities 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 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	137,663	$4.296	-$31,200	-$67,300	$492,900	$980