ENERGY
TRANSITIONS
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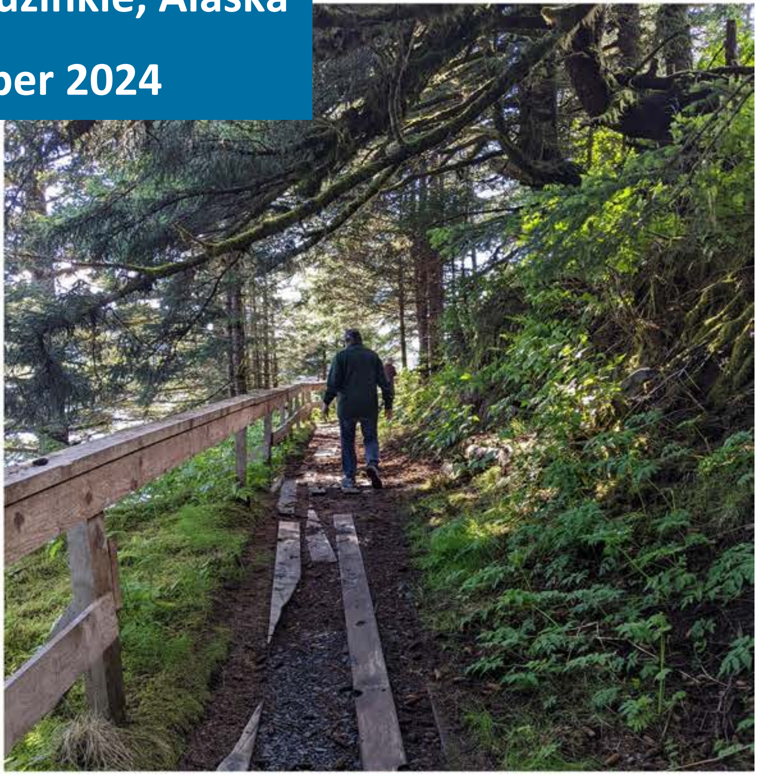
U.S. Department of Energy

# Resilient Energy Transition Planning for Ouzinkie, Alaska

September 2024



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# Contents

# Acronyms

| | |
|---|---|
| DER | distributed energy resource |
| DER-CAM | Distributed Energy Resources Customer Adoption Model |
| DOE | Department of Energy |
| ETIPP | Energy Transitions Initiative Partnership Project |
| ECMWF | European Centre for Medium-Range Weather Forecasts |
| FAA | Federal Aviation Administration |
| HOMER | Hybrid Optimization Model for Electric Renewables |
| KEA | Kotzebue Electric Association |
| kW | kilowatt |
| kWh | kilowatt-hour |
| LBNL | Lawrence Berkeley National Laboratory |
| met | meteorological |
| MILP | mixed-integer linear program |
| MW | megawatt |
| NOAA | National Oceanic and Atmospheric Administration |
| NPS | Northern Power System |
| NREL | National Renewable Energy Laboratory |
| NSRDB | National Solar Radiation Database |
| O&M | operations and maintenance |
| PNNL | Pacific Northwest National Laboratory |
| PV | photovoltaic |
| REAP | Renewable Energy Alaska Project |
| REPAIR | Risk-controlled Expansion Planning with Distributed Resources |
| SAM | System Advisory Model |
| SNL | Sandia National Laboratories |
| TA | technical assistance |
| UA | University of Alaska |

# Executive Summary

This report documents an energy system planning study for the village of Ouzinkie, Alaska, conducted by the U.S. Department of Energy's (DOE) Energy Transitions Initiative Partnership Project (ETIPP). Ouzinkie is a small remote community located on Spruce Island, Alaska, in the Kodiak Archipelago. The Ouzinkie community is served by a local electrical system powered by a combination of diesel generators and a hydroelectric turbine. Due to aging assets, however, the power system reliability has declined in recent years, while the cost of operating the diesel generators has increased significantly. To address these problems, Ouzinkie asked ETIPP to provide technical assistance to develop an updated integrated plan for improvements to the Ouzinkie power system, in order to transition to a more reliable and resilient system powered by renewable energy resources.

The national laboratory researchers on the ETIPP team considered three new energy technologies for addition to the Ouzinkie system—wind, solar, and battery storage—as well as upgrades to the hydropower system. The team compiled data on each technology from a variety of sources, and used these data as inputs to an optimization model that determined the optimal size and location of resources needed to meet the hourly demand for electricity on Ouzinkie's distribution system. The wind analysis considered the addition of one of six potential wind turbine models (ranging from 15 kilowatts (kW) to 100 kW in size), at sites across the Ouzinkie community. The solar analysis considered the addition of a photovoltaic (PV) array of up to 600 kW on the former airport runway site. Finally, the energy storage analysis considered a battery of up to 500 kilowatt-hour (kWh) capacity, located at the diesel generator powerhouse. The optimization model considered three different scenarios for the power system: no new investment, least cost (including both investment and operating cost), and spinning reserve (enhanced reliability with energy storage). In addition, the Ouzinkie community expressed interest in understanding how it can minimize use of diesel for power generation. Of the scenarios analyzed, the enhanced reliability scenario also resulted in the lowest annual diesel consumption.

The results of the analysis are shown in Table ES-1.

**Table ES-1. Summary of Preferred System Resources to Meet Different Community Goals.**

| Goal | New Resources | | | Cost ($) | | |
|---|---|---|---|---|---|---|
| | Wind (kW) | Solar (kW) | Battery (kWh) | Capital Investment | Total Annualized** | Annual Diesel |
| **No Investment*** | 0 | 0 | 0 | $0 | $92,660 | $92,660 |
| **Lowest Overall Cost** | 25 | 5 | 0 | $321,526 | $82,900 | $58,240 |
| **Enhanced Reliability** | 25 | 5 | 67 | $395,014 | $91,200 | $54,660 |

*All cases include upgrading the hydropower controls, which is not included in the capital costs for any of the scenarios.

**Including annualized investment and annual operating costs.

The optimal locations for the new energy resources are shown in Figure ES-1. The preferred site for the wind turbine is near the existing diesel generator powerhouse, along with the battery storage system, while the PV array would be installed on the former airport runway site.

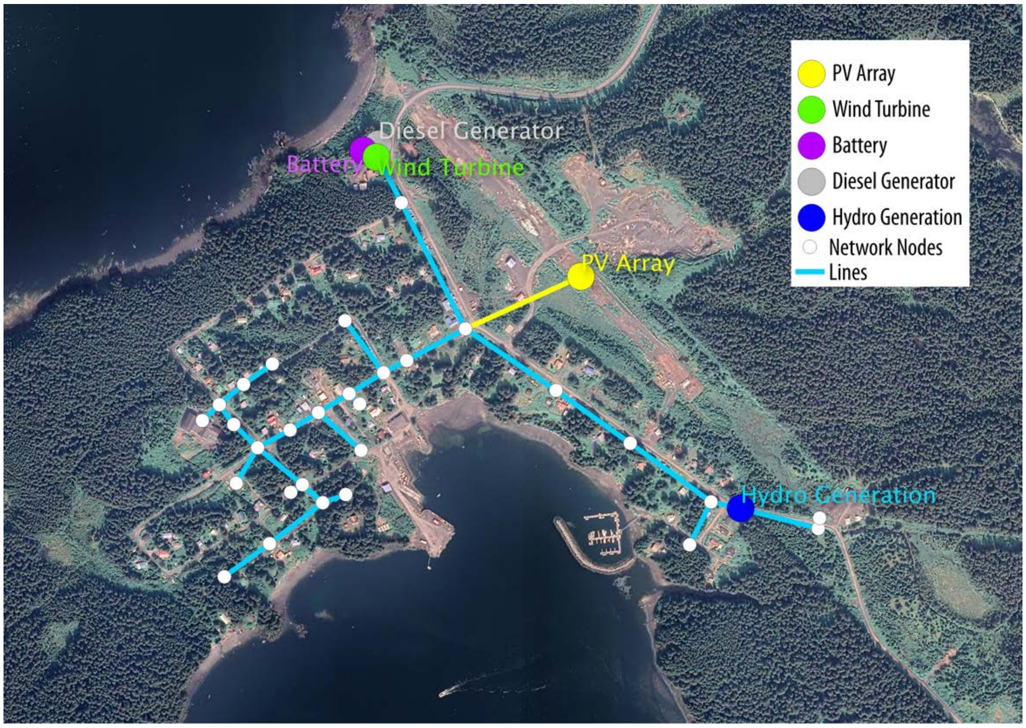

**Figure ES-1. Optimal location of new renewable generation sources within the Ouzinkie power grid. Image source: Google Maps.**

The renewable resources listed in Table ES-1, when operated over a typical year in Ouzinkie, would generate the annual share of Ouzinkie's electrical energy shown in Figure ES-2. The addition of wind, solar, and battery resources can reduce the diesel share of energy from about 50% in the current system to approximately 30% in a system with all four resources.

The findings from this analysis, and a preference for pursuing lower-cost options first, suggest the following priorities for implementation steps:

1. Complete the repairs and upgrades to the hydropower system to get it back online.
2. Design and install the enhanced controls for the hydropower generator.
3. Collect detailed wind meteorological (met) tower data for a minimum of one year.
4. Obtain funding and install a 25-kW wind turbine.
5. If additional power reliability is desired, fund and install the battery system and add either a PV array or a second wind turbine.

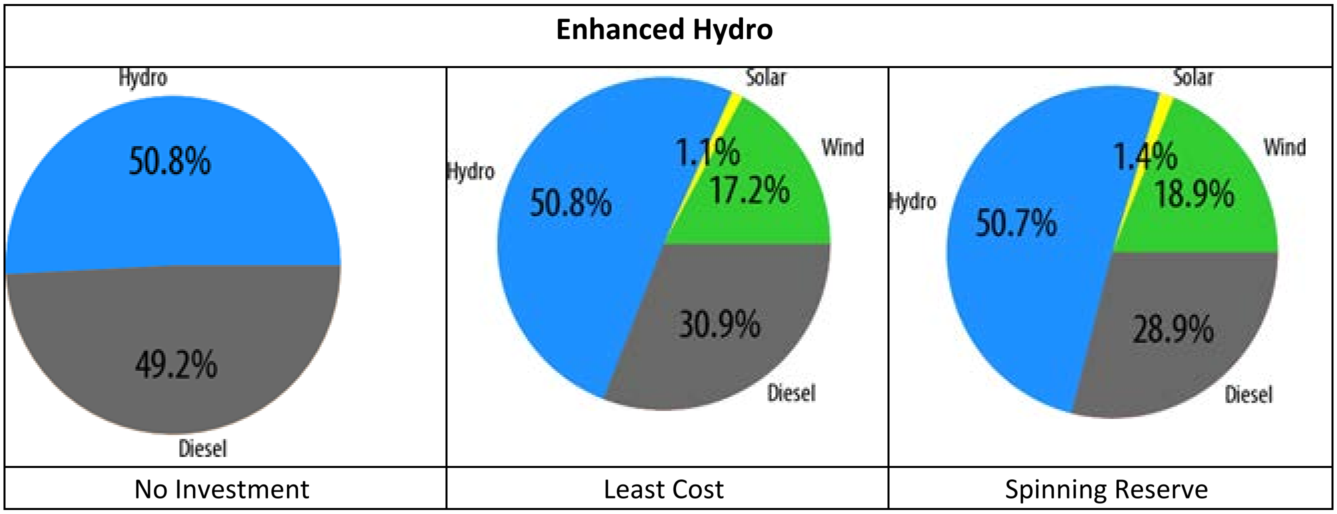

**Figure ES-2. Annual energy share by generating resource under different planning scenarios.**

# 1. Introduction

The U.S. Department of Energy (DOE) Energy Transitions Initiative Partnership Project (ETIPP) works with remote and island communities seeking to transform their energy systems and increase energy resilience. DOE national laboratories partner with local regional organizations to provide technical assistance (TA) to address selected communities' energy needs.

This report documents an energy system planning study for the village of Ouzinkie, Alaska, conducted under ETIPP TA by a national laboratory analysis team composed of the National Renewable Energy Laboratory (NREL), Lawrence Berkeley National Laboratory (LBNL), Pacific Northwest National Laboratory (PNNL), and Sandia National Laboratories (SNL). The national lab team was assisted by regional energy experts at the University of Alaska (UA) and the Renewable Energy Alaska Project (REAP).

## 1.1 Ouzinkie, Alaska

Ouzinkie is located on Spruce Island, Alaska, in the Kodiak Archipelago. The community is remote, located 245 miles from Anchorage. It is only accessible by water or air. Ouzinkie has a year-round population of approximately 200 people (Ouzinkie 2019).

The Ouzinkie community is served by a local electrical system powered by a combination of diesel generators and a hydroelectric turbine. Due to aging assets, however, the power system reliability has declined in recent years. The hydroelectric turbine has been offline since December 2021 awaiting energy studies and parts to make repairs. The three electric diesel generators are all aging and will need replacement in the near future. According to Mayor Elijah Jackson, Ouzinkie spent over $17,000 a month on imported diesel fuel costs in 2021.

Over the previous decade, several assessments have been conducted of Ouzinkie's energy system, mainly focused on resource assessment in terms of security of supply and system economic performance under different scenarios of distributed energy resource (DER) investments. These past analyses identified important individual projects to decrease the operational diesel costs, such as the reinforcement of the current hydro power plant as well as the deployment of new renewable-based generation (e.g., wind and solar). Additionally, investment in electric storage to improve power system dynamic performance, namely frequency stability, was also considered. In general, these initial project studies evaluated new resources individually, and the cost-benefit analysis did not consider the cross-benefits between the new resources (i.e., how investments leverage each other). A 2018 microgrid assessment did attempt to produce a combined analysis through an economic planning exercise carried out with the Hybrid Optimization Model for Electric Renewables (HOMER) tool, which provided a "single-node" type of security of supply solution combining different renewable power sources with diesel generation.

## 1.2 Project Overview

The Ouzinkie community applied to ETIPP in 2021 and was selected as one of 11 communities across the country to receive ETIPP TA. The application noted that the "main challenge" for the community's energy system was to determine the next steps necessary to reduce reliance on expensive imported diesel fuel and pursue renewable energy technologies.

The goals of this ETIPP TA project were to develop an updated integrated plan for improvements to the Ouzinkie power system in order to transition to a renewably powered, reliable, and resilient system.[1] The technical analysis was intended to help the community prioritize DER investment projects and provide the documentation needed for grant or loan applications.

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[1] While reducing the cost of operating the power system is an important goal for the community, this goal is complicated by the fact that residential customers receive Power Cost Equalization (PCE) subsidies for their energy bills, thus reductions in operating costs would not necessarily result in lower residential energy bills. Schools and commercial customers would see lower bills, however.

Although the prior studies mentioned above helped the community with the first stage of energy resource assessment, to assess technology feasibility, it is important to account for the existence of a distribution network and any constraints in the ability of the system to distribute power from a generator in a secure and reliable manner. This is particularly important in a system like Ouzinkie's, where the candidate locations to place DERs (wind, solar, batteries) are limited, and distribution grid reliability is already a significant challenge. Thus, this TA project conducted an integrated techno-economic planning analysis, in which the most promising investments identified for Ouzinkie's system were evaluated together with the distribution grid as well as reliability and resilience targets. The outcome of this analysis was the identification of the optimal portfolio, sizing, and placement of DERs considering the economic, reliability, and resilience priorities of the community. The study also developed new renewable production scenarios (including extreme events) and generated a spatially-resolved resource assessment plan, which allows the community to understand the main locational aspects of DER deployment, the impact on the grid, and the trade-offs between costs and network reliability.

# 2. Energy Resources in Ouzinkie

Ouzinkie's electrical system is currently powered by a combination of diesel and hydroelectric generators. This section describes these existing resources in more detail, as well as potential new renewable resources, primarily wind and solar. This section also describes how the potential output of these generation resources was modeled for the analysis. In addition, this section reviews several other renewable energy resources that were briefly considered but excluded from detailed analysis due to either economic or technical feasibility.

## 2.1 Diesel

As described previously, Ouzinkie currently gets the majority of its electrical energy from three diesel generators located in a powerhouse near the village. The generators have an output capacity of 60 kW, 90 kW, and 190 kW, with an average annual consumption of 30,000 gallons per year, reported between 2014–2016. Ouzinkie burned 51,007 gallons of diesel fuel in 2021 for electric generation. The diesel generators were originally installed in 2007 and the community is starting to consider a replacement strategy.

## 2.2 Hydropower

### 2.2.1 Overview

In contrast with the diesel generators, which follow very well understood engineering principles for estimating their energy production, the hydro system depends on the variable hydrology of the watershed, making the process of estimating its output is more complex. This section reviews the hydropower system history and current characteristics, and describes the methods used to estimate energy production from the hydropower system. It also presents the results of the hydropower output modeling under several different sets of assumptions (scenarios). This analysis is based on three key information sources: previous engineering assessments, openly sourced datasets, and community discussions.

### 2.2.2 Hydropower System Characteristics

During community discussions, the national labs analysis team learned that the original hydropower dam was built in the 1980s using a wooden beam structure. The system's spillway was elevated by 8 inches to increase the storage capacity of the reservoir (circa 2012) as well as replaced with a concrete structure (circa 2014-2015). The community conducted engineering studies to evaluate the feasibility of a new generator and other hydro-power upgrades (ANTHC, 2014) as well as potential for a microgrid (Gamble, 2018). In June 2020, the community completed a penstock upgrade. The upgrade fixed cracks and conducted a proper burial of the penstock system. The community also upgraded the hydropower control system to improve the overall system efficiencies. Unfortunately, soon after the control system upgrade, the newly built penstock had misaligned elements that led to the system being offline completely (Figure 1).[2] At the time of this analysis (August 2022), the community had

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[2] The loss of penstock has also impacted the community's drinking water supply. So, the community has been relying on using surface water from the creek, which requires more chemical treatment to meet their needs.

been solely dependent on their diesel power generators (which are intended to serve as back-up) for almost two years.[3]

Figure 2. Picture of penstock taken during June 2022 visit. Photo from Thushara Gunda (SNL).

Brief statistics about the current hydropower system are captured below in Table 1. A picture of the outfall and maximum water height of the reservoir are captured in Figure 2. In addition to providing water for the hydropower system, water from the reservoir is also used to support drinking water for the community. A separate pipe diverts water from the penstock (before it reaches the hydropower station) to the water treatment plant. According to discussions with the community, approximately 30,000 gallons/day are used for drinking water. In addition, there may be an additional 40,000–70,000 gallons/day that are lost from distribution system leaks.

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[3] Community discussions revealed that diesel fuel costs are approximately $21,000/month.

## Table 1. Hydropower Details

| Characteristic | Value and Units |
|---|---|
| Hydropower turbine nameplate capacity | 125 kW |
| Elevation at dam crest | 282.32 feet (ft) |
| Elevation at base of dam | 263.43 ft |
| Difference between dam crest and base | approximately 20 ft |
| Maximum water height of the reservoir | 15 ft |
| Water height at the time of June 2022 visit | 13.5 ft (also see Figure 2) |
| Outflow height (i.e., minimum height of water needed) | 9 ft |
| Penstock length | 1 mile |

Figure 2. Pictures of outfall (left) and maximum water height of reservoir (right), taken during June 2022. Photos by Thushara Gunda (SNL).

The field visit in June 2022 also identified that the penstock volume or flow rate is manually controlled and is usually set to the maximum opening when working. In the winter the reservoir only freezes at the first few surface inches because the community installed an agitator that keeps outflow from freezing. For this reason, there is generally no risk of ice affecting hydropower generation. The community also indicated that even during high peak flow, there is often only water in the reservoir to support operations 5 days per week. Thus, the community has to monitor home water use for 2 days of the week to leave sufficient water for power production. These water resource limitations are often worse during the drier months (i.e., summer). This is because there is not often enough water stored in the reservoir to support both electricity generation and drinking water needs.

### 2.2.3 Methods of Hydropower Energy Estimation

Estimation of hydropower output involves two calculations: evaluating theoretical power available from falling water and then adjusting the theoretical values to those specific to the Ouzinkie hydropower system. More details about each of these steps and some of the values used for these calculations are captured below.

#### 2.2.3.1 THEORETICAL POWER

Theoretical estimation of hydropower output is driven by one primary equation, which estimates power as a function of water flow (Engineering Toolbox, 2008):

$$P_T = Q\rho g h, \tag{1}$$

where $P_T$ is the theoretical power available from falling water (measured in watts, W); $Q$ is the rate of water flow or discharge (in cubic meters per second, $m^3/s$); $\rho$ is the density of water (in kilograms per cubic meter, $kg/m^3$); $g$ is the acceleration due to gravity (in meters per squared seconds, $m/s^2$); and $h$ is the falling head (in meters, m). Two of these variables are constants that do not change between systems: $\rho$ is approximately 1,000 $kg/m^3$ for water while $g$ is 9.81 $m/s^2$. The remaining two variables are specific to each hydropower system. The microgrid assessment report notes that the available head ($h$ ) for the Ouzinkie hydropower system is 228 ft, which is equal to 69.5 m (Table 3 in Gamble, 2018).

Estimations for the discharge (i.e., water flow rate or $Q$ ) require understanding the rainfall available in the region. There was no local meteorological station data available at the time of this analysis. Therefore, the analysis team consulted online climate records available on U.S. Climate Data, a website developed by Weather Service, for the region (USCD, 2022). This website contains monthly average rainfall for Ouzinkie based on 1981–2010 values (Table 2).

**Table 2. Average Precipitation in Ouzinkie. Source: USCD (2022).**

| Month | Average Precipitation (inches) |
|---|---|
| January | 9.02 |
| February | 6.26 |
| March | 4.45 |
| April | 7.76 |
| May | 5.98 |
| June | 5.59 |
| July | 4.17 |
| August | 5.00 |
| September | 7.17 |
| October | 8.35 |
| November | 6.65 |
| December | 8.11 |

Once the rainfall depth values were collected, they were then converted to equivalent volume numbers and adjusted to reflect the amount of water that is captured by the reservoir. Calculation of total rainfall volume requires information about the watershed area. A previous engineering feasibility study notes that the drainage area is 0.84 square miles, which equates to approximately 537 acres (pg. 37 of ANTHC, 2014). The study also noted that losses such as evaporation and ground seepage account for 40% of the precipitation (pg. 36 of ANTHC, 2014). This means that 60% of the rainfall volume within the drainage area is what actually makes it to the reservoir. After multiplying total rainfall volume by 0.6, the TA team then subtracted community water needs (assumed to be 100,000 gallons/day[4]) to estimate total water available for hydropower generation. This value was divided by the number of seconds in a day to estimate the discharge values needed for Equation 1 above.[5]

In the calculations, a simple quality control check was implemented to make sure the amount of water being stored in the reservoir doesn't exceed the physical size of the reservoir. Specific measurements of the reservoir size were not available. Therefore, a back-of-the-envelope assessment was used to estimate the reservoir volume based on Google Earth imagery, where the surface area of the reservoir at different times of the year was traced using the Polygon feature within Google Earth. These images indicated that generally, the surface area of the reservoir ranged from 26 acres (in August 2015) to 36 acres (in July 2021). So, assuming an average of 30 acres in surface area and 6 feet of storage for the reservoir,[6] the system could store a maximum of 150 acre-feet of usable water at a given time.[7] These values were compared to the daily volume added to the reservoir (from rainfall) to make sure that the TA team was not assuming more water was stored in the reservoir than it was physically capable of

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[4] This number was estimated based on community discussions about drinking water needs and possible volumes lost to distribution system leaks (see "Hydropower System History" section above).

[5] Note: The team assumes that the travel time of water (after it rains) to the reservoir is negligible on a monthly scale.

[6] Difference between max reservoir height (15 ft) and height of the outfall (9 ft) – see Table 1 for more information.

[7] However, it is likely that the depth is not even across the reservoir itself. Therefore, future assessments may warrant revisiting the 150 acre-feet of storage assumption.

capturing. The associated Google Earth pdf and kmz files are provided in Attachment 2 (Reservoir Area Calculations using Google Earth).

Appendix D (Hydropower Energy Estimations Spreadsheet) summarizes the assumptions and unit conversions associated with the theoretical power calculations described above.

#### 2.2.3.4 ACTUAL POWER

Once the theoretical power values are calculated, the TA team then needed to estimate the actual power that can be generated for a given hydropower system. This typically involves scaling the theoretical values for turbine, generator, and transmission efficiencies. For the purpose of this analysis, the team used an overall system efficiency to capture turbine and generator related efficiencies as shown in Equation 2:

$$P_a = \eta_s P_T, \tag{2}$$

where $P_a$ is the actual power estimated for the hydropower system (in W), $P_T$ is the theoretical power available from falling water calculated in Equation 1 above (in W); and $\eta_s$ is the efficiency of the turbine and generator system combined (dimensionless). The microgrid assessment report notes that the system efficiency for the Ouzinkie hydropower system when operating is 0.57 (Table 3 in Gamble, 2018).

Transmission-related efficiencies are assumed to be captured in the overall Distributed Energy Resources Customer Adoption Model (DER-CAM) assessment and thus are not reflected in the hydropower calculations. In other words, the actual power estimated for the hydropower system is at the point of the output of the hydro generator.

### 2.2.4 Hydropower Generation Scenarios

The TA team evaluated six hydropower scenarios to assess the impact and sensitivity of different climate conditions and turbine efficiencies on the electricity generation from hydropower.[8] As noted above, the hydropower model calculates energy generation for a given volume of water, which varies as a function of monthly rainfall. Climate change projections estimate a 15%–30% increase in precipitation across all seasons in Alaska (Chapin et al., 2014). Because more granular details aren't available, the TA team developed alternate conditions that vary from the baseline of average precipitation values captured in Table 2 above ("Normal Climate"). In particular, two other climate conditions were generated, one assuming a steady 20% increase ("Wet Climate") or another assuming a steady 20% decrease in monthly rainfall ("Dry Climate") from current averages. Note that only the normal climate conditions were used for planning purposes, whereas the wet and dry climate conditions were used to support operational scenario evaluations (Table 3).

Through community discussions, the ETIPP team learned that a recent evaluation of the hydropower system indicated that the turbine itself is in good working order but does need minor repairs. The low system efficiency (0.57 noted above) was primarily driven by control system issues, described further in Section 2.6 below. As of August 2022, the community had initiated efforts to upgrade the control system, which could significantly increase the hydropower system efficiency without the need for additional capital investments (such as replacement of the generator itself). Therefore, in addition to the current system efficiency, some of the scenarios presented here also include the effect of an improved turbine and generator efficiency (stemming from control system upgrades). For this analysis, the team assumed that the control system upgrades would result in a higher efficiency of 0.75[9] (Table 3). A more efficient control system would mean that more power is generated for a given volume of water, allowing more of the community's electricity needs to be met and potentially allowing for more water to be available for the community's drinking water needs.

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[8] Note: The team briefly considered including a scenario that considers using the reservoir as a storage system, with variable output that can ramp up and down with the demand on the power system. However, the team learned that there are no automated controls for the outflow valve that can govern the penstock flow rates. Therefore, this option was not considered further.

[9] This value is typically the lower end of hydropower system efficiencies. It is also equivalent to the Ossberger hydropower system value that the community evaluated in the feasibility study (pg. 7 of ANTHC, 2014).

**Table 3. Hydropower Scenarios Assessed**

| Scenario | Climate Condition | System Efficiency | Notes |
|---|---|---|---|
| 1 | Normal | Current | Used for Planning |
| 2 | Wet | Current | Only used for Operational Scenarios |
| 3 | Dry | Current | Only used for Operational Scenarios |
| 4 | Normal | Improved | Used for Planning |
| 5 | Wet | Improved | Only used for Operational Scenarios |
| 6 | Dry | Improved | Only used for Operational Scenarios |

The hydropower electricity generation estimates for these six scenarios are summarized in Figure 3. Figure 3 shows average daily generation per month. Generally, estimates for the "Wet Climate" are the greatest while values for the "Dry Climate" are the lowest.[10] Monthly power production values were assumed to be distributed evenly across the hours of a given month. These values are used as one of the inputs into the overall DER-CAM model.

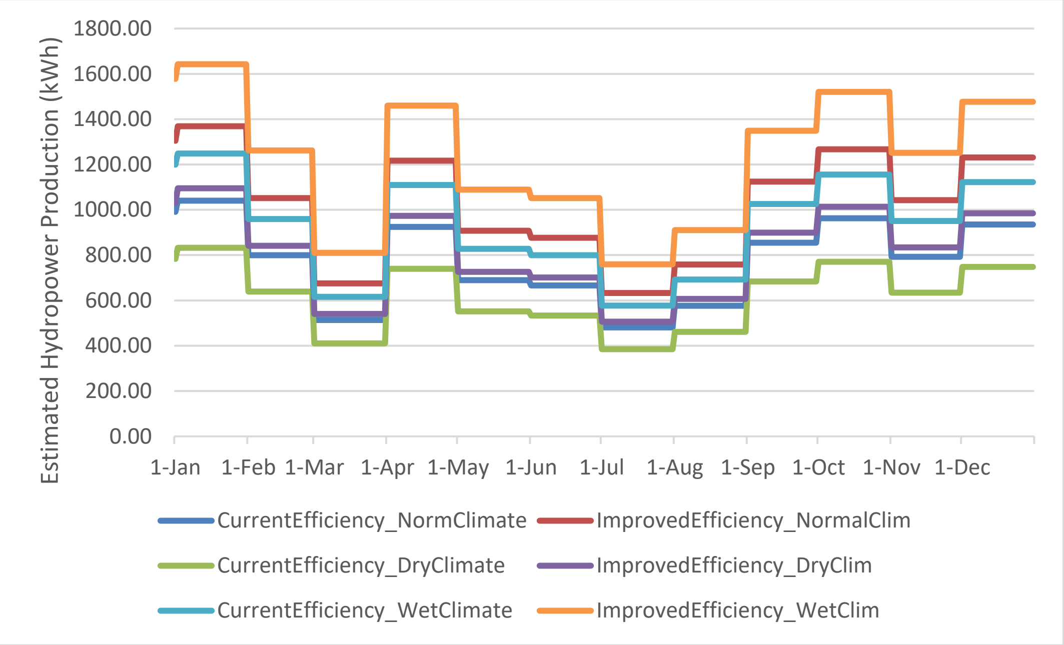

Figure 3. Hydropower electricity production estimates for the six assessed scenarios.

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[10] Studies are starting to indicate that the total runoff volume in catchments is not likely to increase in Alaska because precipitation increases for Alaska will be offset by increased temperatures (USGCRP, 2018). Therefore, it is likely that these observed patterns will serve as good estimations for future water availability as well.

## 2.3 Wind

This section summarizes the assumptions and data analysis used to create the wind energy inputs for the Ouzinkie DER-CAM distribution system model.

### 2.3.1 Potential Wind Locations

The TA team conducted a desktop review to identify locations suited for potential wind energy development, originally flagging seven areas of interest. Following a virtual meeting with the community to discuss these sites, the seven sites were down-selected to three for initial modeling purposes. Based on community feedback, one of the three was slightly modified from its original suggested location on the old airport runway (site #3) to the quarry adjacent to the runway (site #3.1). During the TA team's in-person visit to Ouzinkie, the team identified another potential location (site #9), modified the quarry site again (site #10), and identified a potential meteorological (met) tower location (site #11). These last three locations identified during the community visit were included in the final modeling. All proposed and selected turbine locations are documented in Table 4 and Figure 4. Asterisks in Table 4 indicate the sites that were selected to be included in the final modeling and analysis. Figure 5 shows the sites included in the final modeling and Figure 6 shows site #10.

As the community progresses with the planning for implementation, it is crucial to conduct a thorough analysis of the selected wind turbine location. Further studies should identify any nearby objects or terrain features that might create turbulence or sheltering effects, potentially impacting the turbine's generation capacity. This detailed assessment will help ensure optimal placement and enhance the efficiency of the wind energy system.

**Table 4. Proposed Wind Turbine Locations (asterisks indicate selected sites for modeling)**

| Proposed and Selected Sites | Coordinates (DD) | Elevation at coordinates (m) | Selection/Exclusion Notes |
|---|---|---|---|
| **Ouzinkie Point (1)** | 57.916296°, -152.518800° | 1 | Excluded because archaeological site and in flood plain. |
| **North Old Runway (2)** | 57.927017°, -152.499133° | 21 | Excluded because land is part of new community cemetery. |
| **Central Old Runway (3)** | 57.925583°, -152.496622° | 24 | Excluded because moved to off runway in quarry area. |
| **Old Runway – Rock Quarry (3.1)** | 57.925781°, -152.493647° | 31 | Initially modeled but excluded from final modeling because moved location farther west (#10). |
| **South Old Runway (4)** | 57.923839°, -152.493436° | 20 | Excluded because this part of the runway is no longer clear. |
| **Black Point (5)** | 57.916978°, -152.482483° | 29 | Initially modeled because of undeveloped land but excluded from final modeling because of remote location. |
| **Water Plant (6)** | 57.921205°, -152.487525° | 22 | Excluded because of siting constraints. |
| **Residential Clearing (7)** | 57.920494°, -152.511157° | 8 | Initially modeled because of quality wind resource, but excluded from final modeling |

| Proposed and Selected Sites | Coordinates (DD) | Elevation at coordinates (m) | Selection/Exclusion Notes |
|---|---|---|---|
| | | | because site visit revealed that the land is not cleared or accessible. |
| **Airport Rd. Clearing (8)** | 57.934385°, -152.484019° | 77 | Excluded because of distance from distribution system. |
| **Diesel Power Plant* (9)** | 57.926944°, -152.501944° | 6 | Included as an alternative to quarry location (#10) because of its proximity to power plant and prevailing winds off the coast. |
| **Quarry Clearing* (10)** | 57.926670°, -152.496009° | 28 | Included because of cleared, accessible location near distribution system and proposed location for solar PV. This could be considered an adjustment to site #3.1 (moved farther west). |
| **Met Tower* (11)** | 57.924957°, -152.495766° | 23 | Included for comparison to future met tower measurements and analysis. |

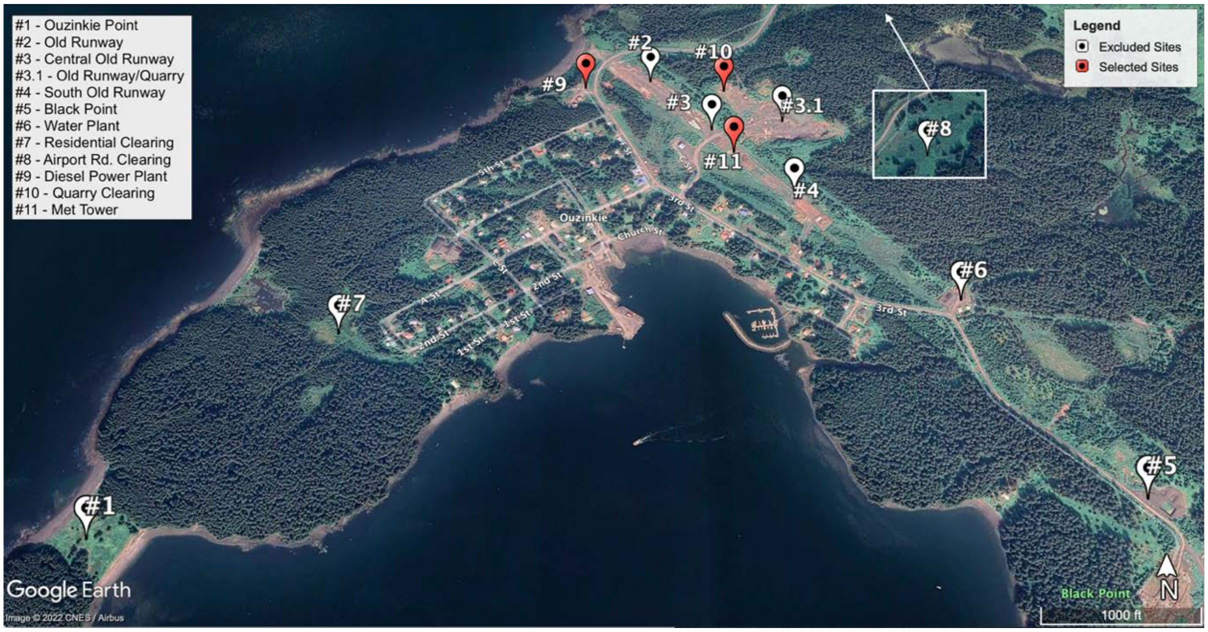

Figure 4. All locations considered for turbine siting. Image source: Google Earth (accessed August 2022).

Figure 5. Proposed locations for wind energy development from field visit included in final modeling. Image source: Google Earth (accessed July 2022).

Figure 6. Potential wind location at quarry clearing (site #10) looking west (top) and looking southwest (bottom). Photos by Alice Orrell (PNNL) and Thushara Gunda (SNL).

### 2.3.2 Wind Turbine Model Options

The TA team considered six different turbine models, with nameplate capacities ranging from 15 kW to 100 kW and hub heights ranging from 23 m to 37 m, to be considered in the analysis, as shown in Table 5 and Figure 7.[11]

The TA team considered two 100-kW Northern Power Systems (NPS) 100 turbine models. The NPS 100C-28 turbine model is a newer turbine model. The NPS 100C-24 could be installed with a tilt-up tower and ballast foundation. The tilt-up tower with ballast foundation is a newer option from NPS and recommended by the manufacturer for remote locations because it eliminates the need to mobilize a large crane for the installation and the need to source a lot of concrete for the foundation. There are many NPS turbines in operation in Alaska.

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[11] The TA initially also considered the 900-kW EWT DW 54-900 turbine model because of its performance track record in Alaska, but excluded it from the analysis because it is greatly oversized for Ouzinkie's average load of 100 kW (even if paired with a battery).

The 75-kW refurbished Vestas V17 and the 50-kW refurbished Endurance E3120 turbine models were included to provide options between 25 kW and 100 kW. As there are currently no newly manufactured turbine models in this size range, refurbished turbines had to be selected.

The 25-kW EOX S-16 turbine model is produced by Eocycle, a Canadian company with turbines deployed in Alaska and other cold weather states such as Minnesota. The Excel 15 is a newer model from Bergey Windpower Co., a manufacturer with a long history that was selected so the analysis could have a small wind turbine option.

It is crucial to validate the availability and conditions of O&M services for any turbine under consideration before finalizing the selection. Ensuring the presence of robust local support is essential for maintaining long-term turbine efficiency and operational reliability.

**Table 5. Turbine Models Considered for Ouzinkie Wind Deployment**

| Turbine Model | Excel 15 | EOX S-16 | Endurance E3120 | V17 | NPS 100C-24 | NPS 100C-28 |
|---|---|---|---|---|---|---|
| **Manufacturer** | Bergey Windpower | Eocycle | All Energy Management | Vestas | Northern Power Systems | Northern Power Systems |
| **Nameplate Capacity (kW)** | 15 | 25 | 50 | 75 | 100 | 100 |
| **Hub Height (m)** | 37 | 24 | 37 | 31 | 23 | 37 |
| **Rotor Diameter (m)** | 9.6 | 15.8 | 19.2 | 17 | 24.4 | 28 |
| **Tip Height[12] (m)** | 41.8 | 31.9 | 46.6 | 39.5 | 35.2 | 51 |

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[12] Tip height is the sum of the hub height and half of the rotor diameter (i.e., the length of a blade). When one blade is pointed directly up, this is the tallest the wind turbine system will be.

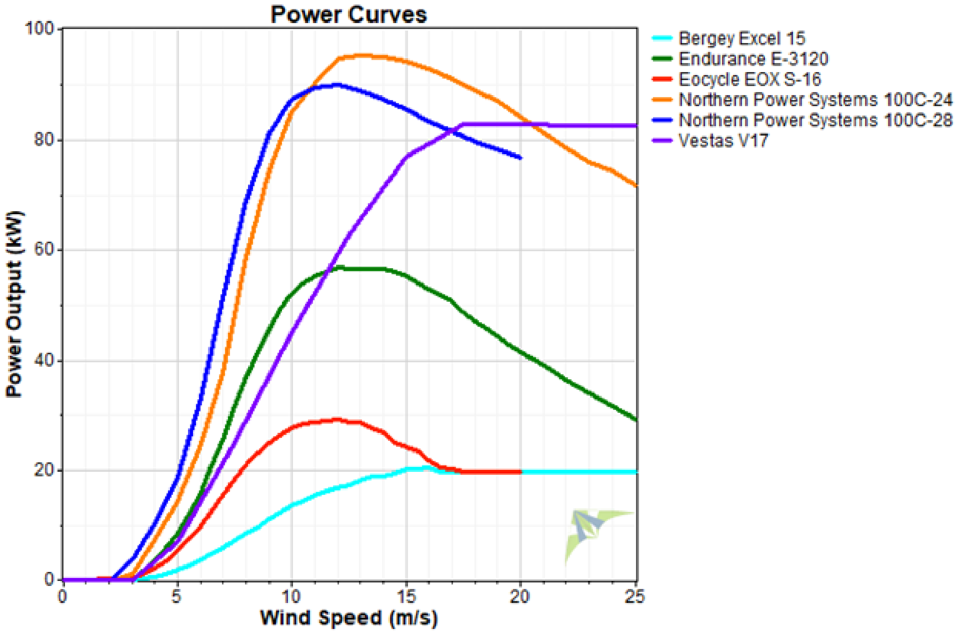

**Figure 7. Power curves for turbine assessed in this wind energy assessment. Curves displayed using Windographer Version 4.2.19.**

### 2.3.4 Federal Aviation Administration Evaluation of Potential Locations

The siting of a wind energy project can be subject to many regulatory considerations, including potential airspace obstruction and radar and military compatibility. In order to preserve navigable airspace, wind energy developers must file a Notice of Construction with the Federal Aviation Administration (FAA) if the wind turbine structure is expected to exceed height, airport proximity, or slope ratio requirements.

The FAA's Notice Criteria tool[13] is used to determine if a structure exceeds these requirements and whether a notice of construction must be filed. The tool prompts the user to identify the coordinates, site elevation, wind turbine tip height, and whether the structure is located on an airport. A developer must file with the FAA at least 90 to 120 days prior to the proposed construction if the structure exceeds 200 feet above ground level, the structure is in proximity to an airport and exceeds the slope ratio, or the structure activates other filing requirements.

Once the Notice of Construction is filed, the FAA reviews the proposed project and determines whether it meets the eligibility criteria for construction. A Determination of No Hazard is required from the FAA in order to proceed with ground work. If the applicant does not receive this ruling, the FAA will instead propose changes to the project, such as additions of markings or lighting or the reduction of the structure height, in order to allow the project to proceed and be safe for airspace.

The TA team used the FAA's Notice Criteria tool to evaluate the wind turbine model option with the shortest tip height (i.e., the Eocycle EOX S-16) and the option with the tallest tip height (i.e., the NPS 100C-28) at the three sites included in the final modeling. The NPS 100C-28, the tallest option, exceeds the FAA's criteria limits at each of the three sites. The shortest option, the Eocycle EOX S-16, does not exceed notification criteria at the Diesel Power Plant (#9) location, but it does at the Quarry Clearing (#10) and Met Tower (#11) sites.

Because of elevation variation on the island and the proximity of the most likely locations to the airfield, if the Ouzinkie community pursues a wind turbine installation it will likely need to file a Notice of Construction. A requirement to file does not mean the project will not be able to go forward, but the FAA may require adjustments,

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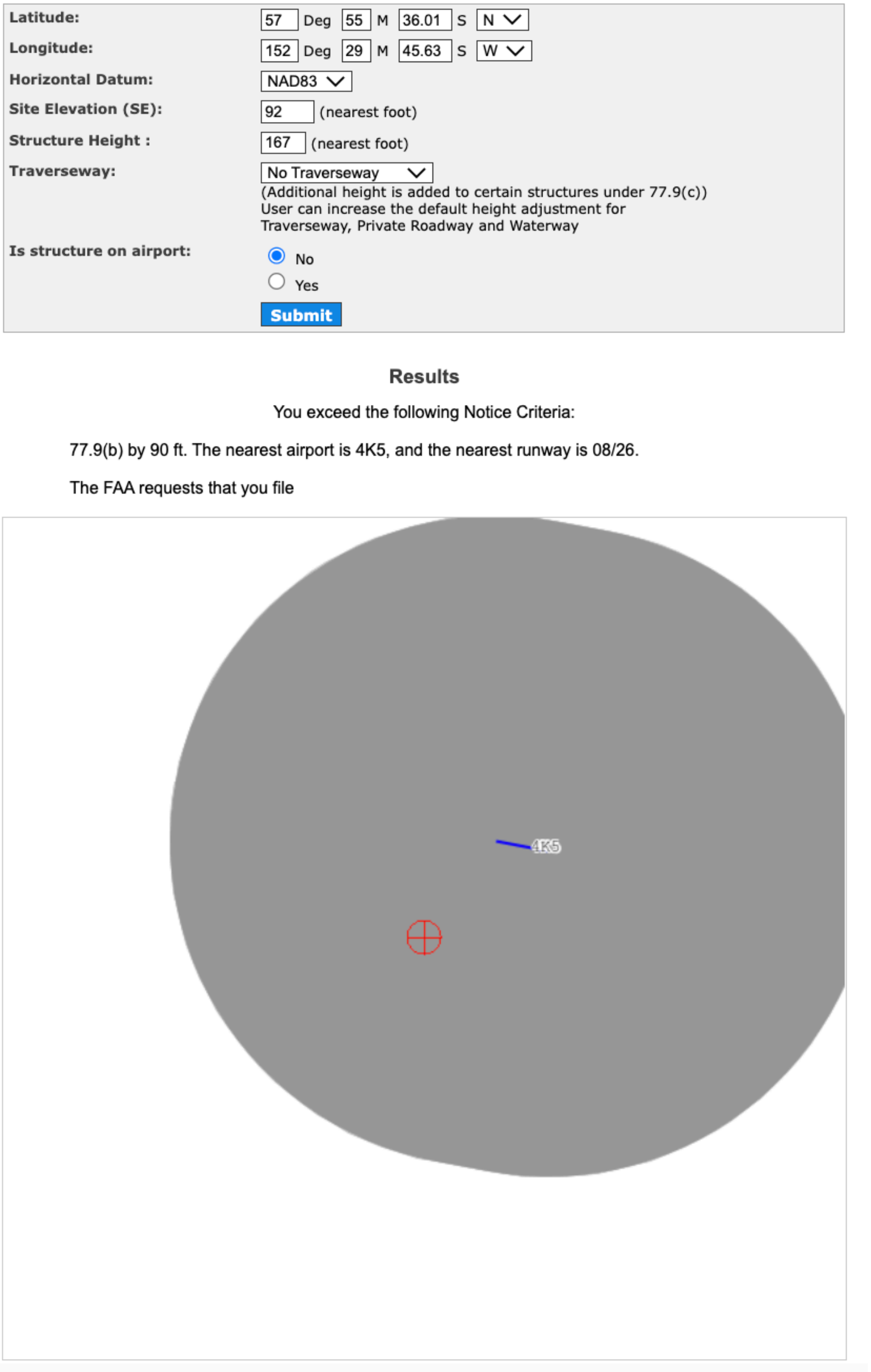
[13] The FAA is developing a new version of the Notice Criteria Tool, which is available for preview on its website.

such as adding lighting. While the notification requirement will ultimately depend on the site and turbine model selected, the community may still want to file a Notice of Construction as a "good neighbor" best practice. An example FAA evaluation for the Quarry Clearing site (#10) with ~~an~~ the NPS 100C-28 turbine model is shown in Figure 8.



| | |
|---|---|
| **Latitude:** | 57 Deg 55 M 36.01 S N |
| **Longitude:** | 152 Deg 29 M 45.63 S W |
| **Horizontal Datum:** | NAD83 |
| **Site Elevation (SE):** | 92 (nearest foot) |
| **Structure Height :** | 167 (nearest foot) |
| **Traverseway:** | No Traverseway<br>(Additional height is added to certain structures under 77.9(c))<br>User can increase the default height adjustment for<br>Traverseway, Private Roadway and Waterway |
| **Is structure on airport:** | ● No<br>○ Yes |

**Results**

You exceed the following Notice Criteria:

77.9(b) by 90 ft. The nearest airport is 4K5, and the nearest runway is 08/26.

The FAA requests that you file

Figure 8. FAA Notice Criteria Tool results for the selected Quarry Clearing Site (#10) (FAA OE/AAA Tool, accessed August 2022).

### 2.3.5 Wind Turbine Loss Rate

A wind turbine installation in Ouzinkie may be subjected to a variety of factors that will reduce the turbine's production. The TA team used a loss rate of 20% in the net generation calculations based on the loss categories outlined in Table 6 provided by DNV (Comstock 2009).

**Table 6. Potential Wind Turbine Production Losses**

| Losses Category | Typical Range | Notes | Ouzinkie Assumption |
|---|---|---|---|
| Availability | 4%–6% | Downtime for maintenance. | 4% |
| Wake (Array) | 0%–15% | Not applicable to single turbine installations. | 0% |
| Turbine Performance | 1%–3% | Assume high performance. | 1% |
| Electrical | 2%–3% | Standard electrical losses. | 2% |
| Environmental | 1%–10% | Assume weather may disrupt production, similar to the experience of the Pillar Mountain project on Kodiak Island. | 10% |
| Curtailment | 0%–3% | Balance with diesel and hydro may necessitate curtailment. | 3% |
| **Total** | 12%–25% | | 20% |

### 2.3.6 Wind Resource Analysis

In this subsection, we present an analysis of the wind resources available in different sites in around the Ouzinkie system.

#### 2.3.6.1 PRELIMINARY WIND RESOURCE SCREENING

The high-resolution Global Wind Atlas 3 was utilized to assess the 12 unique locations considered for potential wind deployment on Spruce Island (Table 7). The annual average wind speed was found to vary minimally across the 12 sites, with a standard deviation of 0.4 m/s. Furthermore, the estimated annual average wind speed at 50 m at each site exceeds 6.5 m/s at 50 m, the recommended minimum wind speed for distributed wind deployment interpolated from the minimum recommended wind speed of 4 m/s at a height of 30 m and 6.5 m/s at a height of 80 m (DOE 2011), indicating viability for wind deployment on Spruce Island. The free online Global Wind Atlas (version 3) was selected to identify average wind speeds for the different locations (DTU 2022). Global Wind Atlas has a high spatial resolution and modeled wind speed data for Alaska; however, all wind resource models are subject to inaccuracies and data validations of such models for Alaska are limited.

As presented in the Potential Locations section, the different site options were discussed with the Ouzinkie community and the DER-CAM modelers and three sites (#9, #10, and #11) were selected for the final modeling. The following sections present the characteristics of the wind resource on and near Spruce Island and provide the simulated annual average wind speeds and energy production estimates for average, high, and low wind resource years for sites #9, #10, and #11.

**Table 7. Annual Average 50 m Wind Speeds at Locations on Spruce Island According to Global Wind Atlas 3 (https://globalwindatlas.info)**

| Site | Annual Average Wind Speed at 50 m (m/s) |
|---|---|
| (1) Ouzinkie Point | 7.46 |
| (2) North Old Runway | 7.04 |
| (3) Central Old Runway | 6.82 |
| (3.1) Old Runway – Rock Quarry | 7.00 |
| (4) South Old Runway | 6.67 |
| (5) Black Point | 6.93 |
| (6) Water Plant | 6.64 |
| (7) Residential Clearing | 7.77 |
| (8) Airport Rd. Clearing | 6.81 |
| (9) Diesel Power Plant | 7.41 |
| (10) Quarry Clearing | 7.00 |
| (11) Met Tower | 6.67 |

Note: Interannual variability in the wind resource can cause annual average wind speeds to vary by ±0.4 m/s per the Global Wind Atlas data.

#### 2.3.6.2 LONG-TERM TREND

The wind resource assessment for Ouzinkie employed the European Centre for Medium-Range Weather Forecasts (ECMWF) Reanalysis v5 (ERA5) (ECMWF 2022) to provide the long-term hourly trends in wind speed and direction and the Global Wind Atlas 3 to provide more localized wind information for the 12 sites of interest (Table 8).

**Table 8. Characteristics of the Models That Provided Wind Resource Data for This Study**

| Model | ERA5 | Global Wind Atlas 3 |
|---|---|---|
| Developer | ECMWF | DTU Wind and Energy Systems, World Bank Group |
| Temporal Coverage (years) | 1950–Present | 2008–2017 |
| Temporal Output Frequency | 1 hour | Annual |
| Horizontal Spatial Coverage | Global | Global |
| Horizontal Grid Spacing | 0.25° | 0.25 km |
| Wind Speed Output Heights | 10 m, 100 m | 10 m, 50 m, 100 m, 150 m, 200 m |

Wind speed data at 10 m and 100 m above ground level at the nearest neighbor ERA5 grid point at 58°N, 152.5°W were extracted over the period of 1980–2020. In order to produce wind speed timeseries at the various hub heights of interest $z_{HH}$, the power law shown in Equation 3, in conjunction with a dynamic shear exponent ($\alpha$), as shown in Equation 4, calculated using the simulated wind speeds $v_{10}$ and $v_{100}$ from the two surrounding model heights 10 m and 100 m, was employed. This vertical interpolation scheme for simulation of the wind speed at the measurement height was selected because it considers multiple levels in the wind speed profile and does not rely on static stability assumptions (Olauson and Bergkvist 2015).

$$v_{ERA,HH} = v_{10}\left(\frac{z_{HH}}{10}\right)^{\alpha} \tag{3}$$

$$\alpha = \ln\left(\frac{v_{100}}{v_{10}}\right)/\ln\left(\frac{100}{10}\right) \tag{4}$$

It is important to note that two pre-construction meteorological towers deployed on nearby Kodiak Island during the periods of November 2005–August 2006 and November 2005–February 2007 yielded drastically different average shear exponents of 0.129 and 0.023, respectively. The average ERA5-based shear exponent was 0.139. Higher shear exponents correspond to higher estimated wind speeds. Without on-site multi-level wind speed measurements, it is impossible to exactly quantify the local wind shear at Ouzinkie, but the first Kodiak Island and ERA5 shear exponents fall into the category of moderate wind shear, while the second Kodiak Island shear exponent is categorized as low wind shear (Wharton and Lundquist 2012).

### 2.3.6.3 GEOLOCATION TO SELECTED SITES AND HUB HEIGHTS

Using the overlapping grid cell to the site from the high-resolution Global Wind Atlas 3 (GWA3) (Table 7) (DTU 2022), the ERA5 wind speed timeseries $v_{ERA,HH}$ was geolocated to the each of the latitude/longitudinal sites in Table 4 for each of the hub heights in Table 5 via Equation 5:

$$v_{Site,HH} = v_{ERA,HH} \cdot \frac{\overline{v_{GWA,50}} \cdot \overline{v_{GWA,50,norm}}}{\overline{v_{ERA,50}}} \tag{5}$$

where $\overline{v_{GWA,50}}$ is the mean GWA3 50 m wind speed for a year of interest, $\overline{v_{ERA,50}}$ is the mean ERA5 50 m wind speed for a year of interest, and $\overline{v_{GWA,50,norm}}$ is the mean GWA3 50 m wind speed for a year of interest normalized by the mean GWA3 50 m wind speed for all years.

### 2.3.6.4 AVERAGE, HIGH, AND LOW WIND RESOURCE YEARS

In order to select average, high, and low wind resource years for modeling within the DER-CAM framework, the annual average wind speeds from a GWA3 grid point at Ouzinkie, from surrounding ERA5 grid points, and from observations from the Kodiak airport (Iowa State University 2022) were normalized by their respective averages of all annual averages (Figure 9). Normalized annual wind speeds of 1.0 correspond to average wind resource years, normalized annual wind speeds greater than 1.0 correspond to above average (high) wind resource years, and normalized annual wind speeds less than 1.0 correspond to below average (low) wind resource years. Based on GWA3 and ERA5, 2011 was identified as an average wind resource year, 2014 as a low wind resource year, and 2015 as a high wind resource year.

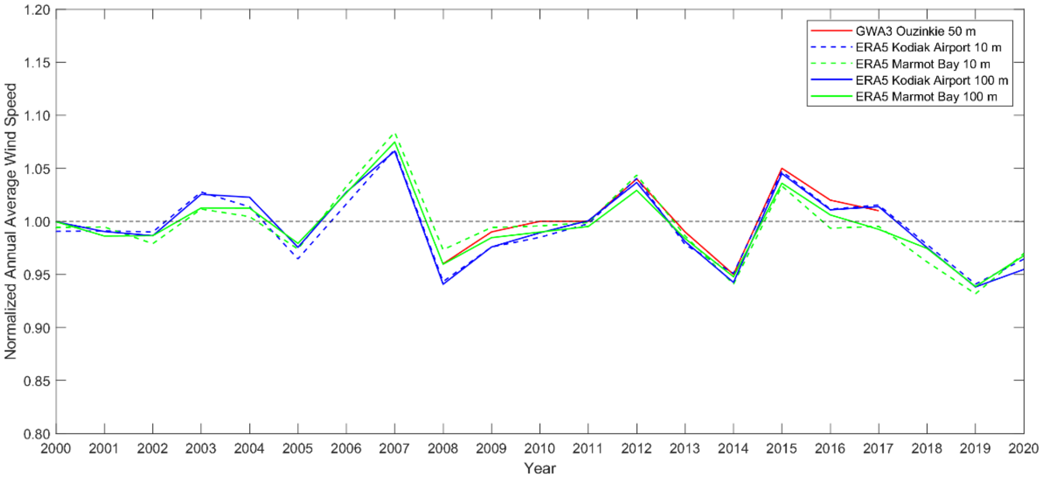


Figure 9. Normalized annual average wind speed near Ouzinkie from GWA3 and ERA5.

Analysis of the average wind resource year, 2011, shows that the Diesel Power Plant site provides the highest annual average wind resource among the three analyzed sites at both hub heights (Table 9). The range of wind speeds for all sites and heights during the average year, between 6.0 m/s and 7.1 m/s, lie on the steep portion of the two power curves considered (Figure 7).

**Table 9. Annual Average 24 m and 37 m Wind Speeds at the Potential Wind Site, the Potential Met Tower Location, and the Alternative Site Near the Diesel Plant for Average, High, and Low Wind Resource Years.**

| Site | Height | Average Wind Speed: Average Wind Year (2011) | Average Wind Speed: High Wind year (2015) | Average Wind Speed: Low Wind Year (2014) |
|---|---|---|---|---|
| (9) Diesel Power Plant | 23 m | 6.66 m/s | 6.97 m/s | 6.30 m/s |
| (9) Diesel Power Plant | 24 m | 6.70 m/s | 7.02 m/s | 6.34 m/s |
| (9) Diesel Power Plant | 31 m | 6.94 m/s | 7.27 m/s | 6.57 m/s |
| (9) Diesel Power Plant | 37 m | 7.11 m/s | 7.46 m/s | 6.74 m/s |
| (10) Quarry Clearing | 23 m | 6.29 m/s | 6.59 m/s | 5.95 m/s |
| (10) Quarry Clearing | 24 m | 6.32 m/s | 6.63 m/s | 6.00 m/s |
| (10) Quarry Clearing | 31 m | 6.55 m/s | 6.87 m/s | 6.21 m/s |
| (10) Quarry Clearing | 37 m | 6.71 m/s | 7.04 m/s | 6.37 m/s |
| (11) Met Tower | 23 m | 5.99 m/s | 6.28 m/s | 5.67 m/s |
| (11) Met Tower | 24 m | 6.03 m/s | 6.32 m/s | 5.71 m/s |
| (11) Met Tower | 31 m | 6.24 m/s | 6.55 m/s | 5.92 m/s |
| (11) Met Tower | 37 m | 6.40 m/s | 6.71 m/s | 6.07 m/s |

### 2.3.7 Wind Direction

An examination into the predominant wind directions at Ouzinkie yielded westerly and southeasterly flow (Figure 10). Given Ouzinkie's exposure to open ocean in both of these directions (Figure 5), consistent wind speeds suitable for wind energy production are expected.

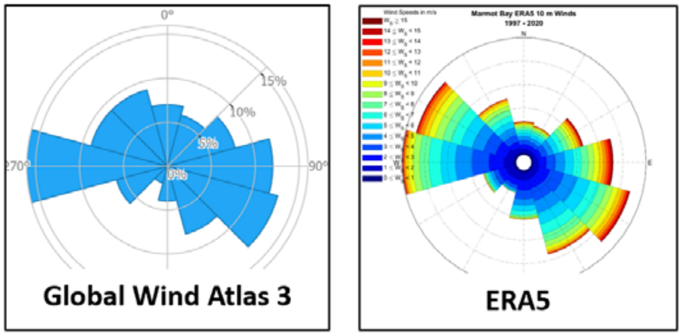


Figure 10. Long-term wind roses near Ouzinkie from GWA3 and ERA5.

### 2.3.8 Seasonal and Diurnal Trends

The monthly wind resource from models and observations near Ouzinkie indicated a seasonally dependent pattern in the wind resource, with the fastest speeds occurring in winter and the slowest speeds occurring in summer (Figure 11). In addition to the Kodiak airport wind observations, additional wind observations were sourced for this analysis at Alitak, Kodiak (Pillar Mountain), Port Lions, Womens Bay (Alaska Energy Authority 2022; FAA 2021) and from on-site Ouzinkie measurements taken at the old airport.

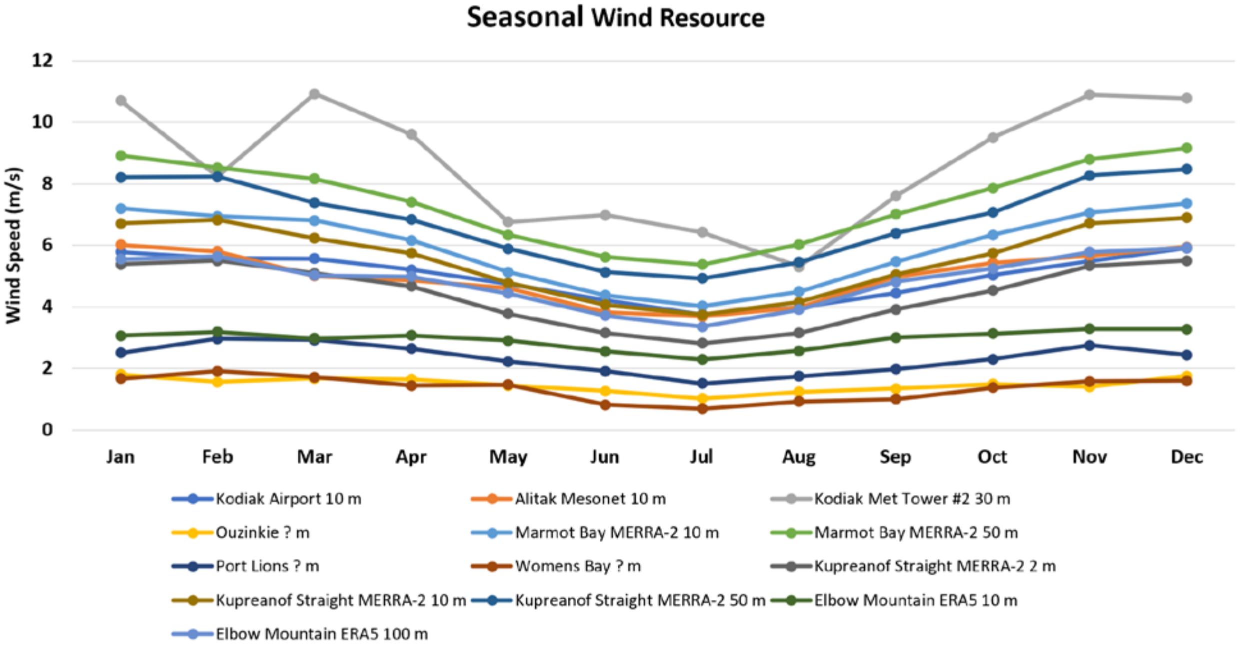


Figure 11. Seasonal wind resource at modeled and observational locations near Ouzinkie (when heights are unknown, the character '?' is added to the respective item legend).

Conversely, no significant diurnal signal in wind speed was noted for locations around Ouzinkie, indicating consistent flow throughout the day and night (Figure 12).

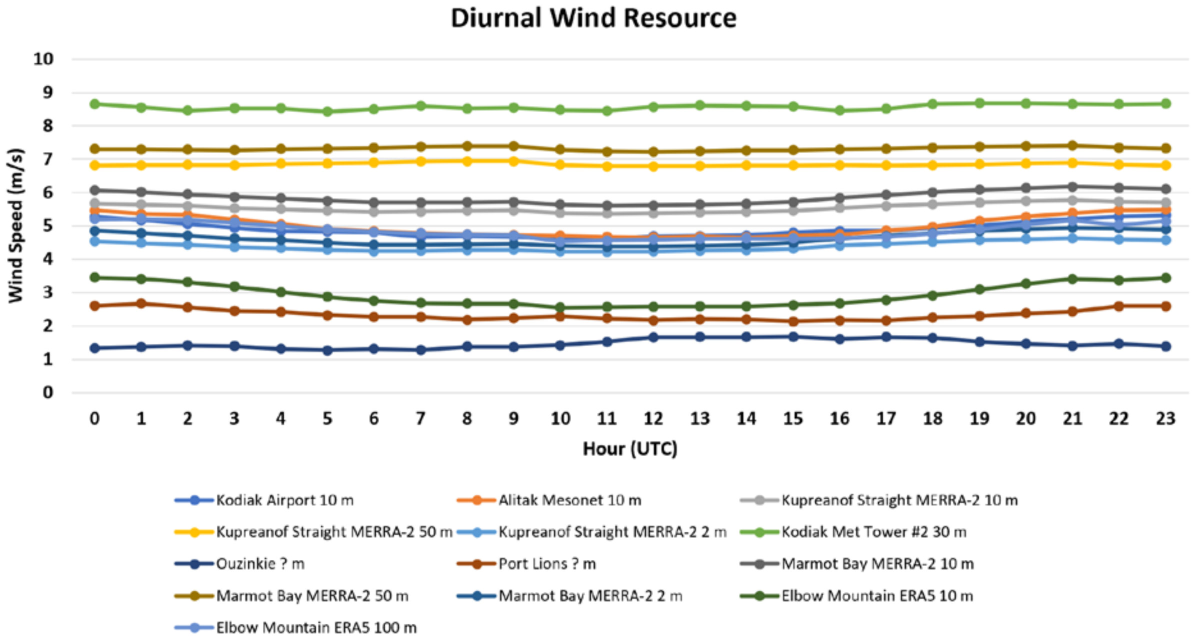


**Figure 12. Diurnal wind resource in modeled and observed locations near Ouzinkie (when heights are unknown, the character '?' is added to the respective item legend).**

### 2.3.9 Net Generation Profiles

For each considered site, the simulated hourly wind speeds for average (2011), high (2015), and low (2014) wind resource years were applied to all the analyzed power curves at their respective hub heights (Table 5), resulting in annual timeseries of gross power generation. In order to create the annual timeseries of net generation, a constant 20% reduction was applied to the gross generation at each hour. Realistically, the generation reduction will fluctuate throughout time, but the simulations cannot provide temporal insight on all the loss categories discussed in Table 6, maintenance downtime in particular. The gross and net simulated wind energy generation values for average, high, and low wind resource years for the Bergey Excel 15 at 37 m and the NPS 100C-28 turbine at 37 m are presented in Tables 10, 11, and 12, respectively to show the range of possible energy generation values for the turbine models included in the assessment. The gross and net simulated wind energy generation values for average, high, and low wind resource years for all of the analyzed sites, turbines, and hub heights are provided as data files.

The Ouzinkie DER-CAM distribution system model is designed to use input data for the net generation profiles as csv files. A generation profile is created by applying the wind resource time series of a given location to a turbine model's power curve to calculate the generation at each unit of time of the time series (in this analysis, the generation profile is kW per hour). The generation profiles used in this analysis are provided with this report as detailed in data files.

### Table 10. The Range of Possible Gross and Net Simulated Wind Energy Generation for an Average Wind Resource Year

| Site | Bergey Excel 15 Gross Generation (kWh) | NPS 100C-28 Gross Generation (kWh) | Bergey Excel 15 Net Generation (kWh) | NPS 100C-28 Net Generation (kWh) |
|---|---|---|---|---|
| (9) Diesel Power Plant | 56,616 | 384,085 | 45,292 | 307,268 |
| (10) Quarry Clearing | 53,470 | 362,642 | 42,776 | 290,113 |
| (11) Met Tower | 50,407 | 343,910 | 40,326 | 275,128 |

### Table 11. The Range of Possible Gross and Net Simulated Wind Energy Generation for a High Wind Resource Year

| Site | Bergey Excel 15 Gross Generation (kWh) | NPS 100C-28 Gross Generation (kWh) | Bergey Excel 15 Net Generation (kWh) | NPS 100C-28 Net Generation (kWh) |
|---|---|---|---|---|
| (9) Diesel Power Plant | 61,364 | 413,178 | 49,091 | 330,542 |
| (10) Quarry Clearing | 57,954 | 391,869 | 46,363 | 313,495 |
| (11) Met Tower | 54,565 | 371,917 | 43,652 | 297,534 |

### Table 12. The Range of Possible Gross and Net Simulated Wind Energy Generation for a Low Wind Resource Year

| Site | Bergey Excel 15 Gross Generation (kWh) | NPS 100C-28 Gross Generation (kWh) | Bergey Excel 15 Net Generation (kWh) | NPS 100C-28 Net Generation (kWh) |
|---|---|---|---|---|
| (9) Diesel Power Plant | 49,535 | 347,775 | 39,628 | 278,220 |
| (10) Quarry Clearing | 46,692 | 328,598 | 37,354 | 262,878 |
| (11) Met Tower | 44,315 | 310,252 | 35,452 | 248,202 |

### 2.3.10 Wind Installed and Operations and Maintenance Costs

The TA team reviewed the PNNL distributed wind project dataset and interviewed representatives from multiple turbine manufacturers and suppliers; the project manager at Kotzebue Electric Association, Matt Bergan; Elan Edgerly with Alaska Native Tribal Health Consortium; and an Alaska-based renewable energy installer to estimate the Alaska-specific installed costs for the proposed turbine models. These costs are presented in Table 13.

Because renewable energy projects, especially wind projects, have site-specific costs, particularly in Alaska, due to transportation and installation challenges in remote locations, the TA team used conservative installed cost estimates for the proposed wind turbines included in the model that are intended to be inclusive of distribution, integration, and development costs. These costs are generally twice the cost for the installation of the same turbine model in the lower 48 states.

### Table 13. Wind Turbine Model Installed Costs

| Turbine Models | Bergey Excel 15 | Eocycle EOX S-16 | Endurance E3120 refurbished | Vestas V17 refurbished | NPS 100C-24 | NPS 100C-28 |
|---|---|---|---|---|---|---|
| Turbine Capacity (kW) | 15 | 25 | 50 | 75 | 100 | 100 |
| Hub height (m) | 37 | 24 | 37 | 23 | 23 | 37 |
| Potential Alaska-Specific Estimated Installed Cost ($/kW) | 12,000 | 12,000 | 15,200 | 6,900 | 12,000 | 12,000 |

*Wind power project size and component costs: An Alaska case study* (VanderMeer et al. 2017) reports that the average predicted wind maintenance cost based on Alaska Energy Authority Renewable Energy Fund grant applications at the time of the study was $0.036/kWh. The TA team applied this rate to the estimated production values of some of turbine models considered for Ouzinkie and converted the amounts to dollars per kW rates. The rates averaged to about $100/kW/year. The $100/kW/year estimate is in line with the expectation that costs can be at least double in Alaska compared to the lower 48. In addition, NPS has provided that $10,000 per year is a fair estimate for scheduled and unscheduled maintenance of its 100-kW turbine models. The company also recommends that remote locations keep $10,000 of spare parts on site. Collaboration with local energy experts before implementation will be essential to validate these cost estimates, ensuring they reflect the unique conditions and challenges of operating in Alaska.

## 2.4 Solar

This section summarizes the assumptions and data analysis used to create the solar PV inputs for the Ouzinkie DER-CAM distribution system model.

### 2.4.1 Potential Locations

In early scoping discussions, the Ouzinkie stakeholders indicated they were interested in siting a centralized solar PV array on Spruce Island's former airport runway. As this location is already level, graveled, and near interconnection points on the distribution system, it was the only location considered in the analysis.

### 2.4.2 Maximum PV Array Sizing

Ouzinkie has more than sufficient land availability on the former runway to site ground-mounted solar PV arrays.

To determine the maximum PV array that could be sited on the former runway, the TA team reviewed power density data. Empirical data from Lawrence Berkeley National Laboratory (LBNL) states that one acre of land can house 0.35 MW of solar PV panels while accounting for module efficiency and array spacing (Bolinger and Bolinger 2022). This value is for a median latitude, and power density decreases with an increase in latitude. The furthest north latitude data collected by LBNL is 45 degrees latitude, which changes the power density number to 0.3 MW per acre. The TA team used this value to estimate the amount of PV that could fit on Ouzinkie's former runway. Ouzinkie's latitude is 58 degrees, so the 0.3 MW per acre is likely too generous, but a reasonable approximation.

Using just the middle of the former runway (two acres), near the former rock quarry that avoids the new cemetery on the north end of the old runway, up to 600 kW of PV could be installed (Figures 13 and 14). The middle of the runway is the first-choice location identified by the Ouzinkie community. If up to five acres of the former runway are used, 1,500 kW of PV is possible. Ouzinkie's energy needs are significantly lower than what 600 kW or 1,500 kW of solar PV could produce (current system peak is below 200 kW), so land availability is not expected to be an issue.

Figure 13. Potential solar PV array location on former runway map, aerial photo. Image source: Google Maps (accessed 2022).

Figure 14. Potential solar PV array location on former runway. Photo from Alice Orrell, PNNL.

### 2.4.3 PV Array Loss Rate

There is an existing 7-kW rooftop solar PV array installed on the Ouzinkie Cultural Center (Figure 15). Using PVWatts Version 6.3.2 (NREL 2022) and actual recorded production data for the 7-kW rooftop array, the TA team was able to estimate an appropriate loss rate for solar PV production in Ouzinkie.

Per Google Earth, the rooftop array at the Ouzinkie Cultural Center is oriented at 155 degrees. PNNL assumed a typical roof pitch for the building of 4:12 (18.4 degrees) and PVWatts' standard rooftop panel installation characteristics (Table 14). Using these assumptions, a 23% loss rate was needed to match PVWatt's estimated production value to the actual production value of the array (Table 15). The loss rate accounts for soiling, shading, electrical losses, degradation, age, nameplate capacity, and availability.

#### Table 14. PVWatts Model Inputs

| | |
|---|---|
| DC System Size (kW) | 7 |
| Module Type | Standard |
| Array Type | Fixed (roof mount) |
| System Losses (%) | 23% |
| Tilt (deg) | 18.4 |
| Azimuth (deg) | 155 |
| Inverter Efficiency (%) | 96% |
| DC to AC Size Ratio | 1.2 |

**Table 15. PVWatts Results Compared to Actual Production**

| | |
|---|---|
| PVWatts Estimated Annual Output (kWh/yr) | 5,322 (4,871 kWh to 5,560 kWh) |
| Actual Annual Output, June 2015–June 2016 (kWh/yr) | 5,280 |
| Actual Annual Output, March 2016–March 2017 (kWh/yr) | 5,422 |

Figure 15. Solar PV array on the Ouzinkie Cultural Center. Photo from Alice Orrell, PNNL.

### 2.4.4 Optimal Azimuth and Panel Tilt

Typically, the latitude of the site is used as the tilt of the solar panels, but this can be adjusted for optimization. The latitude of Ouzinkie is 58 degrees. In the Solar Watts Contour Plot tool (Tandem Labs 2017), the closest location to Ouzinkie available in the tool is Kodiak. An optimized tilt for Kodiak is 45 degrees per the tool.

*A Solar Design Manual for Alaska* (Nash et al. 2018) states that the ideal panel orientation in Alaska is “slightly less than latitude.” But because a latitude tilt (based on the Kodiak location in the tool) would only reduce the estimated production by 1.5%, and “slightly less” is ambiguous, the TA team used the standard assumption of a latitude tilt of 58 degrees for the Ouzinkie modeling. The optimal azimuth is slightly southeast at 165 degrees. Figure 16 below shows the contour plot for solar availability in Kodiak.

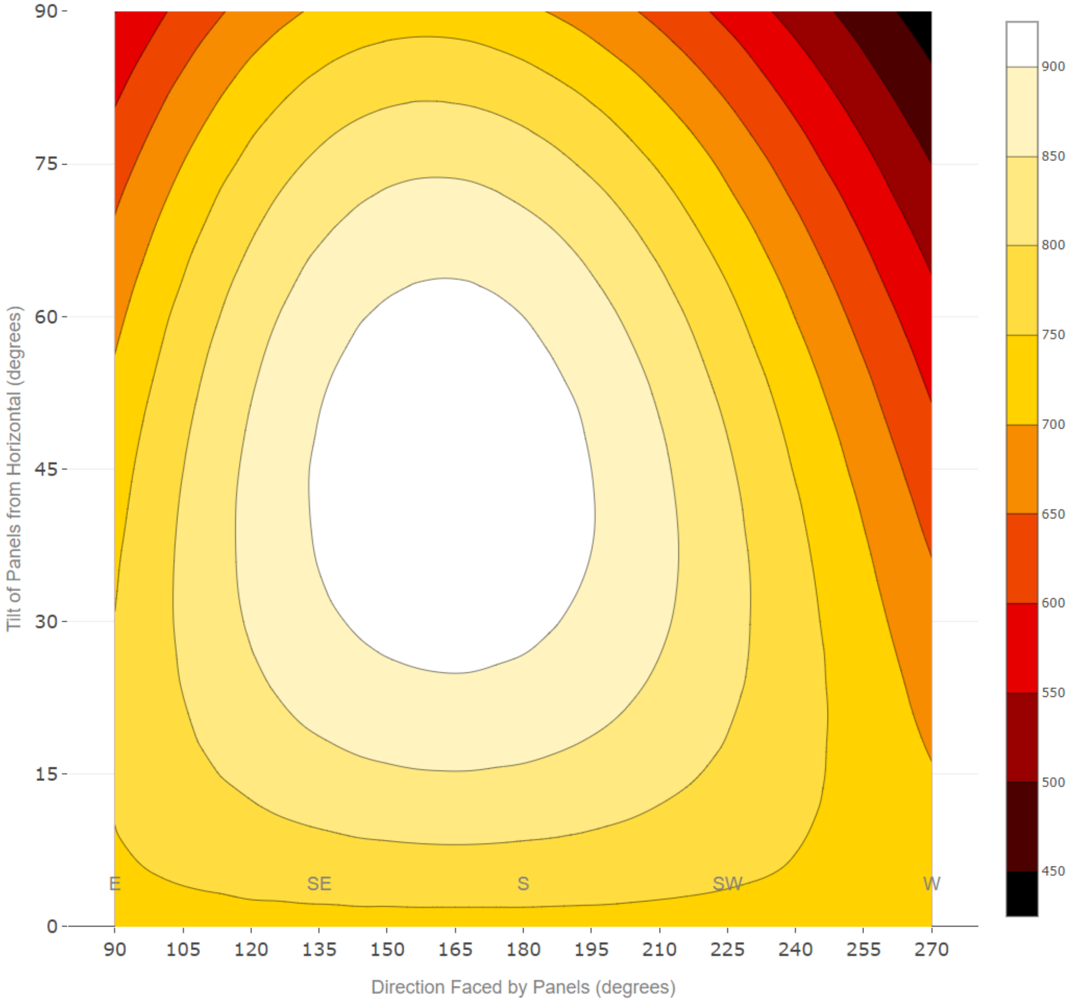


**Figure 16. Annual kWh produced per DC kW for various tilts/azimuths for Kodiak, Alaska (Tandem Labs 2017).**

### 2.4.5 Average, High, and Low Solar Resource Years

The TA team downloaded data from the National Solar Radiation Database (NSRDB) (NREL 2021) for the years 1998 to 2020 for Ouzinkie to examine average, high, and low solar resource years. To get the normalized annual average solar resource, the TA team calculated the average of each year and divided that by the average of all the years. The NSRDB data is given in 30-minute intervals. To get a singular data point for every hour, the TA team averaged every two 30-minute data points. Figure 17 below shows the results of the normalized annual average. A normalized annual average of 1.0 corresponds to an average solar resource year, a normalized annual average greater than 1.0 correspond to an above average (high) solar resource year, and a normalized annual average less than 1.0 corresponds to a below average (low) solar resource year. This process identified that 2018 is an average solar resource year, 2017 is a high resource year, and 2010 is a low resource year.

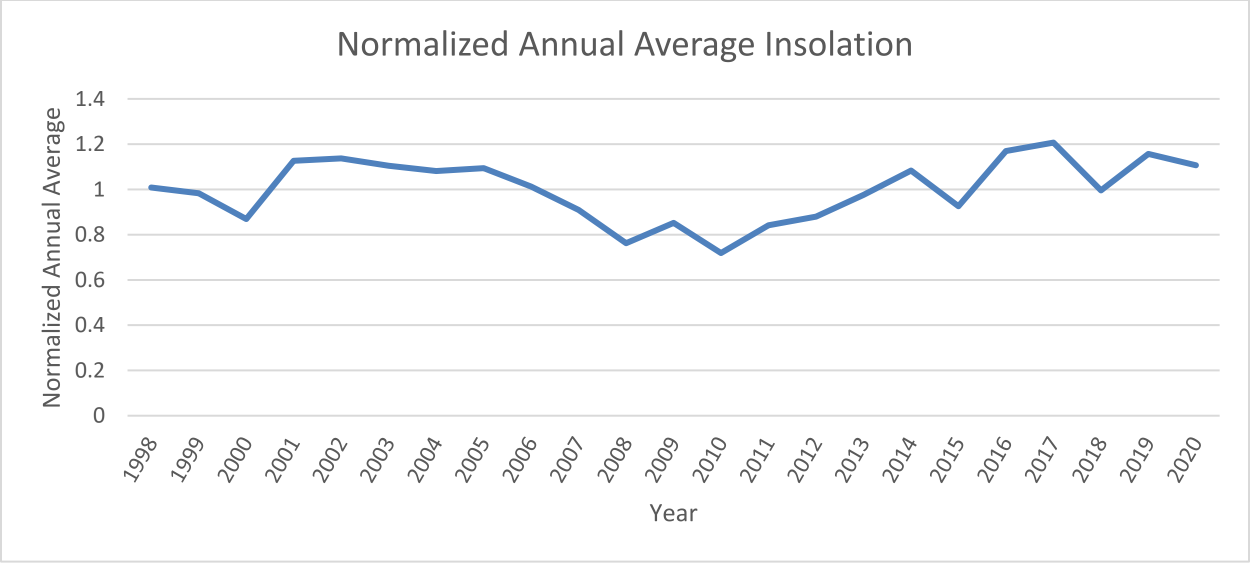


**Figure 17. Normalized annual average solar insolation (NREL 2021).**

### 2.4.6 Generation Profiles

The TA team used the PVWatts tool within NREL's System Advisor Model (SAM) Version 2020.11.29 Revision 1 (NREL 2020) to create the net generation profiles for the Ouzinkie distribution system DER-CAM model. The TA team used SAM, rather than just using PVWatts directly, because SAM lets a user create and download csv generation profile files, while PVWatts does not.

To create the generation profiles in SAM, a solar resource data file from the NSRDB was downloaded for each of three types of solar years (average, high, and low solar) and the assumptions listed in Table 16 were input to create a solar energy net generation profile for each year. The assumptions in Table 16 are therefore embedded into the generation output results summarized in Table 17.

**Table 16. Solar PV Inputs Used to Create Solar Generation Profiles for the DER-CAM Model**

| Input | Value | Source |
|---|---|---|
| System Losses (%) | 23% | See Loss Rate section |
| Azimuth (degrees) | 165 | See Optimal Azimuth and Panel Tilt section |
| Tilt (degrees) | 58 | See Optimal Azimuth and Panel Tilt section |
| Module Type | Standard | PVWatts default |
| Module Efficiency (%) | 15 | PVWatts default |
| Inverter Efficiency (%) | 96 | PVWatts default |

**Table 17. Solar PV Generation**

| Year Type | Net Generation (kWh per kW per Year) |
|---|---|
| Average Solar | 793 |
| High | 987 |
| Low | 669 |

### 2.4.7 Solar PV Installed and Operations & Maintenance Costs

The TA team selected a conservative installed cost estimate of $4,500/kW for solar PV in the model that is intended to be inclusive of distribution, integration, and development costs. Empirical installed cost data for solar PV installations in Alaska are difficult to obtain. According to the 2021 Edition of Tracking the Sun (Barbose et al. 2021), which includes no Alaska data, the average price of large non-residential PV arrays (defined as greater than 100 kW in size) in 2020 in the lower 48 was $2.20/Watt. It is important to acknowledge that the capital expenditures (CAPEX) for smaller solar PV systems are generally higher per kilowatt installed. This analysis assumes constant CAPEX per kW; however, future studies might need to adjust financial models to reflect the increased costs associated with smaller installations

Matt Bergan, project engineer with Kotzebue Electric Association (KEA), reported to the TA team that KEA’s 532-kW PV array installed in 2020 cost $3.50/Watt. The TA team confirmed with Bergan that this cost includes foundation and engineering costs. However, Bergan said that for budgeting of future projects, KEA is using $4/Watt due to market and pricing uncertainty.

Cost research conducted by Becki Meadows of NREL, to support other Alaska communities participating in ETIPP, found that 553 kW of solar PV in Selawik cost $4.34/kW and 223 kW in Shungnak and Kobuk cost

$4.82/kW. These and the KEA costs are about double the average lower 48 price, which is in line with the expectation that costs can be double in Alaska compared to the lower 48.

A $20 per kW per year operations and maintenance (O&M) expense rate estimate is typical for the lower 48(Feldman et al. 2021). *An Alaskan Case Study* (Whitney and Pike 2017) suggests an O&M cost of $100 per kW per year for remote communities based on expert opinion. Even though this is an Alaska-specific estimate, it still may be too high and outdated as solar PV maintenance is better understood now than 6 years ago, when the case study was completed. Consequently, the TA team chose $40/kW/year as the default O&M cost for solar PV in the model.

## 2.5 Stationary Battery

In order to provide reserve power that can quickly fill in for the loss of other generating assets on the grid, the analysis team considered the addition of a battery energy storage system. It was assumed that the batteries use a lithium-ion chemistry and have a cost of $2,000/kWh of energy storage capacity. This is significantly higher than battery costs in the lower 48 states and is meant to reflect higher costs for transportation and construction in Alaska. This estimate is based on personal communication with Ingemar Mathiasson of the Northwest Arctic Borough by both the TA team and Becki Meadows. The storage was assumed to have a roundtrip efficiency of 90% and a 15-year lifetime. The optimal location for the battery system is to be co-located at the powerhouse with the diesel generators.

## 2.6 Technologies not Considered

The Ouzinkie community expressed interest in a number of other renewable energy resources and technologies, in particular tidal energy, biomass, rooftop solar PV, and residential wind. The analysis team conducted a screening assessment of these energy resources but did not evaluate them further due to reasons of either cost or feasibility in the Ouzinkie area. The screening assessments for these resources and technologies are provided in Appendix A.

## 2.7 Control and Operations

The output of the Ouzinkie hydropower plant and the diesel generators is coordinated in a very simple way. The hydropower system runs at a fixed output that is set manually by the city maintenance staff. Output settings are maintained at a level to maximize hydropower production and are not typically adjusted. The diesel generators then modulate their output to pick up the remaining load and maintain frequency and voltage on the distribution system. When the hydropower system is producing power, only diesel generator #3 has the appropriate controls to run at the same time. Diesel generators #1 and #2 do not have these more advanced controls and thus do not operate when the hydro is producing. There is a micro-second lag that occurs when shifting power sources from hydro to diesel generator, which causes hydropower curtailment. This, and the need for minor hydro turbine repairs, results in a 57% efficiency rating for the hydropower system when operating. When the hydropower system is not operating, all three diesel generators are operated together to serve the entire load of the system.

## 2.8 Electrical Distribution System

The community of Ouzinkie is served by a power distribution system that transmits power from the generating sources (hydro and diesel generator powerhouses) to the buildings in the town. The layout and characteristics of the distribution system were obtained from as-built drawings provided by the City of Ouzinkie. The main bus voltage is approximately 12 kV, with approximately 32 service transformers to step down the voltage for service to the 105 customers of the system. The line lengths were estimated by calculating geographical distances, using Google Maps estimates. Conductors were assumed to be 4 AWG copper, with an impedance of 1.503 Ω /mile (Kersting 2018). The topology of the distribution system is shown in Figure 19. The city also provided historical monthly electrical energy consumption data for each of the service transformers. An hourly load profile (Figure 20) was estimated by scaling a load profile from a previous analysis (Gamble 2018) to match each transformer monthly energy consumption. The peak hourly load of the power system is 107 kW.

Figure 19. Ouzinkie electrical distribution system. Transformer locations are indicated by yellow dots. Image from Google Maps.

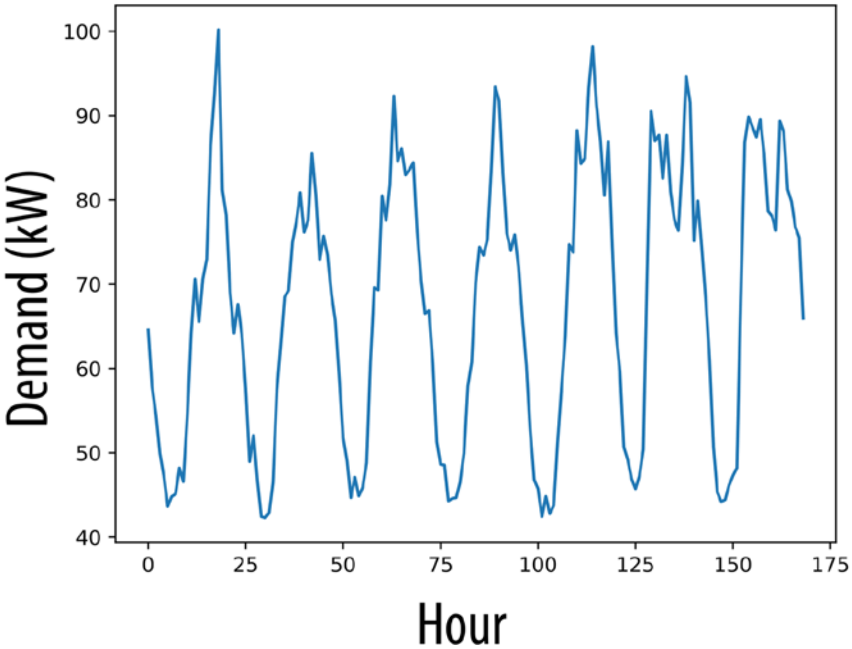


Figure 20. Total hourly power demand on the Ouzinkie power system for a typical week.

## 2.9 Planned System Upgrades

The City of Ouzinkie plans to install a new controller that integrates the diesel and hydro operations and would be compatible with possible wind energy, solar energy, and/or battery storage additions in the future. As described above, the city cannot run diesel generators #1 and #2 with the hydropower plant without the installation of a "D-slick engine control module" (which will be part of the controller upgrade scope of work). The planned upgrade to the control system could also significantly increase the hydropower system efficiency without the need for additional capital cost investments (such as replacement of the generator itself).

Before this control system upgrade project can be initiated, a number of other actions must be completed. Now that the penstock has been repaired (as of November 2022), the turbine repair can proceed. Also, an upgrade of the switchgear on the diesel power plant is funded, but that project has not started because of contractor difficulties. Once these issues are resolved, the city will seek funding and a contractor for a new controller.

Other upgrades or improvements to the distribution grid may also be required to accommodate the addition of wind energy, solar energy, and or battery storage to the distribution system. This consideration can be addressed once the other issues described above have been resolved and the city is ready to pursue implementation of new distributed energy resources.

# 3. Community Meeting Feedback

While in Ouzinkie, the TA team hosted a community-wide gathering to introduce the ETIPP project and share what had been learned to date in the community. After sharing that information, attendees were invited to participate in an exercise designed to capture their views on and goals for different energy options for the community. Using Post-It notes and stickers, the TA team asked participants to respond to four questions:

1. Currently, Ouzinkie gets energy from diesel & hydro (when working). What else would you like to see? (choices: wind, solar, tidal, and biomass)
2. What is more important to you: more energy from renewable sources, lower energy costs, more reliable energy, or residential energy efficiency upgrades?
3. If (when) energy becomes more affordable and reliable, what is your vision for Ouzinkie's future?
4. Please share your thoughts on energy in Ouzinkie (needs, hopes, anything we all should know).

It is important to note that the data presented here is not a representative sample; this was a sample of convenience—anyone who attended the community gathering and chose to respond to the questions. The TA team did not ask respondents to identify themselves, and the team made sure to remove any identifiable information when the team recorded their answers. Thus, these responses only provide a window into what a select group of community members thought. However, there was a diverse group of respondents from elders to young adults and some students, and the answers provide some guidance for what community leaders should continue to ask.

The energy sources community members wanted to see in addition to diesel and hydro were, in descending order, wind (24), tidal (11), and solar (8). No one selected biomass. The preferences in terms of energy improvements were in the following order: lower energy costs (13), more energy from renewable sources (10), and then more reliable energy and residential energy efficiency upgrades each received seven votes.

Only 10 people wrote out responses to the third question, but of those, seven mentioned that they hoped more affordable and reliable energy would result in families moving back to Ouzinkie and/or that the population would grow. Two wrote specifically of hoping it would result in there being a local store, and two expressed hope for there being more jobs. The raw answers are included in Appendix E.

The final question was open-ended, and intended to capture thoughts that participants hadn't shared elsewhere and perhaps hadn't felt comfortable sharing in other settings (e.g., verbally). Eleven responded with comments varying from the need for redundancy in renewable energy systems, as well as to keep diesel as a backup system, to wanting energy costs to drop to zero, and for residents to be more responsible in consuming energy. These comments are not representative of Ouzinkie as a whole but allow leaders to see some of the concerns and goals for improvements to the energy system. The full text of these responses is included in Appendix E.

# 4. Analysis Methodology and Results

The methodology used in the Ouzinkie Resource Planning analysis is illustrated in Figure 21 below. The renewable resource scenarios of wind, solar, and hydro, described above, were combined with additional information on energy resource planning, including technology costs, loads, distribution network characteristics, and existing generation infrastructure. This information was used as an input to an optimal resource planning model, which was developed to calculate the best mix of distributed energy resource investment, considering different objectives and constraints of the planning exercise. After determining the optimal technology mix, the operational conditions of the Ouzinkie system were evaluated under different scenarios by calculating the hourly dispatch of the system resources for an entire year.

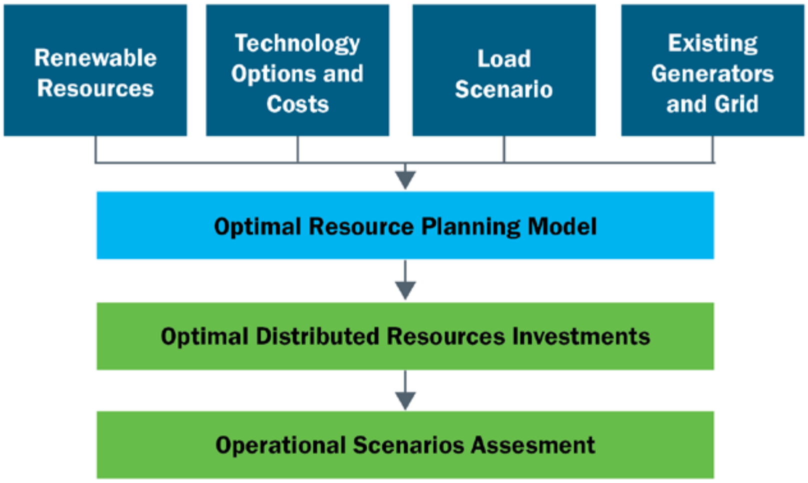


Figure 21. Methodology overview.

## 4.1 Resource Planning Model

The TA team developed a resource planning model for this analysis, considering the particular needs and conditions of the Ouzinkie community and the objectives of this study, which included elements of a typical microgrid energy resource investment analysis combined with distribution grid planning. The main technical challenges regarding the optimal resource planning model were the following: (1) make the input structure of the existing models compatible with the horizon and granularity of the loads and renewable scenario deployment data built for Ouzinkie's system; (2) model operational characteristics in the planning horizon, including distribution network security of operation, i.e. voltage and line limits; (3) add explicit reliability metrics to the analysis (e.g. allowing spinning reserve); (4) perform a separate assessment of the operational scenarios, considering the hourly dispatch for an entire year.

Given that there is no "off-the-shelf" commercial tool to address a problem with these characteristics, LBNL built a specific model for this analysis by adapting and combining two existing models, the Distributed Energy Resources-

Customer Application Model (DER-CAM) and the Risk-controlled Expansion Planning with Distributed Resources (REPAIR), described below:

- DER-CAM, developed by LBNL is one of the most comprehensive optimization-based tools used in community-level grid design and DER investment. The core application of DER-CAM is microgrid energy resources planning to supply all energy services required by a community, while optimizing the energy flows to minimize costs of the system. DER-CAM finds the optimal portfolio of resources (renewable-based generators, thermal units, electric storage, etc.) that minimizes the cost of the system, while considering steady-state constraints (voltage/current) of the power network. Inputs to DER-CAM include electric loads; utility tariffs; DER techno-economic data (capital costs, O&M costs, and efficiency, among others); and circuit topology, electric model, and outage data. Outputs include optimal technology investment portfolios, sizing, placement within the microgrid topology, and the dispatch of all DERs present in the solution, including any load management decisions such as load-shifting, peak-shaving, or load prioritized curtailments in the event of outages.
- REPAIR, developed by LBNL, is an innovative tool to support decisions around utility grid planning to prevent and mitigate the impact of outages caused by routine equipment failures (reliability) or by extreme events (resilience). REPAIR is a risk-based optimization and decision-making model allowing informed and transparent "cost versus risk" decisions regarding infrastructural planning of electric utilities. The model considers long-term resilience and reliability planning strategies that rely on traditional infrastructure upgrades or new investment alternatives, such as DERs.

The final model was formulated as a mixed integer linear program (MILP), considering the inputs and outputs illustrated in Figure 22 below.

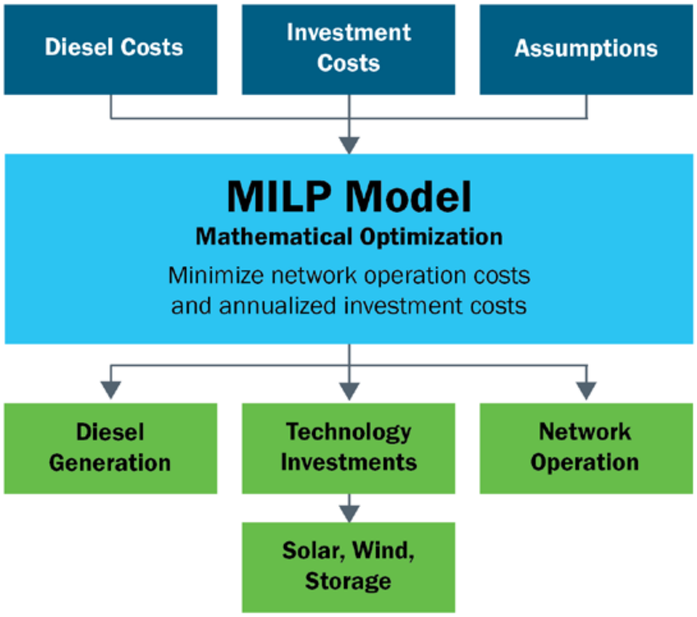


Figure 22. Optimization model inputs and outputs.

## 4.2 Objectives and Scenarios

### 4.2.1 Objectives

In this analysis, the TA team considered three alternative objectives for the optimal resource planning, which the TA team analyzed as three separate cases in the modeling:

- **No Investment:** This is the base case investment scenario, which assumes that no additional energy resource technology investment is considered and the system keeps the existing portfolio of generation.
- **Least Cost:** In this case, it is assumed that the investments are made to minimize the annual cost of the community electricity system, considering the annualized investment in new technologies, as well as operational costs and the energy savings. Under this objective, the model will choose the best combination of technology investments that leads to the lowest system costs.

**Spinning Reserve (Enhanced Reliability):** In this case, the least-cost economic objectives are kept as an objective, but an additional constraint is imposed so that the new investments ensure a non-diesel spinning reserve of 2 hours, in order to enhance the reliability of the system. This security criterion guarantees that, at any point in time, the system has enough energy stored capacity to supply the electricity loads for at least 2 hours. An amount of 2 hours was selected as the base case based on discussions the Northwest Arctic Borough energy manager. The TA team found that a 2 hours of battery storage spinning reserve is a common practice for systems with similar size and resilience needs in Alaska.

### 4.2.2 Planning Scenarios

As reported in the hydropower section above, at the time this analysis was conducted, there were ongoing efforts from the community to upgrade the control system of the hydro turbine, which could significantly increase the hydropower system efficiency without the need for additional capital cost investments. For each objective, two planning scenarios were analyzed, considering two different hydro generation profiles:

- **Existing hydro:** existing hydropower generation system
- **Enhanced hydro**: hydropower generation system with enhanced controls.

### 4.2.3 Operational Scenarios

In addition to the objectives and planning scenarios, the system operation was evaluated under different conditions of availability of primary renewable energy resources, with the objective of evaluating different impacts on wind and hydropower generation. A scenario of high, low and average generation was considered for each location with wind turbines and for the hydropower generation. The average scenarios were considered for the purpose of economic system design. The high and low scenarios of wind and hydropower generation were combined to create two extreme operation conditions:

- Low Renewables: low wind energy generation year combined with a dry year.
- High Renewables: high wind energy generation year combined with a wet year.

A combination of objectives and hydro planning scenarios resulted in six different runs of the planning problem. For each planning instance, the team evaluated two additional variations of wind operational conditional (high and low), which resulted in 12 supplementary operational runs, shown in Table 18.

**Table 18. Power System Scenarios Analyzed**

| Analysis Objective | Planning Scenario | Operational Scenario |
|---|---|---|
| No Investment | Existing Hydro | Average Renewables |
| | | High Renewables |
| | | Low Renewables |
| | Enhanced Hydro | Average Renewables |
| | | High Renewables |
| | | Low Renewables |
| Least Cost | Existing Hydro | Average Renewables |
| | | High Renewables |
| | | Low Renewables |
| | Enhanced Hydro | Average Renewables |
| | | High Renewables |
| | | Low Renewables |
| Spinning Reserve (Enhanced Reliability) | Existing Hydro | Average Renewables |
| | | High Renewables |
| | | Low Renewables |
| | Enhanced Hydro | Average Renewables |
| | | High Renewables |
| | | Low Renewables |

## 4.3 Results

### 4.3.1 Planning Scenarios

This section presents the results of the three planning objectives mentioned above. The No Investment case considers the Ouzinkie power system as it is today, while the Least Cost case minimizes the total annual costs of the Ouzinkie electricity system, considering a combination of investments and operational costs. Finally, the Spinning Reserve (Enhanced Reliability) case extends these objectives by adding a reliability criterion to the design.

As shown in Table 19, for the No Investment case, the total annual system costs (i.e., annual operating costs plus annualized investments) are about $94,000 if the existing hydropower infrastructure is maintained, and $92,000 if the hydropower control system is upgraded according to the community plans. From these results, the team can conclude that the control system upgrades would immediately benefit the community and produce approximately $8,500 per year in system cost savings.

The renewable investments that lead to the Least-Cost-system are a combination of 25 kW of wind and approximately 13 kW of solar PV, assuming the current hydro system. If the hydropower control system is upgraded, the optimal PV required is lower, approximately 5 kW total. In general, these investments would lead to a 11% reduction in the overall annualized system costs.

When a reliability criterion is added to the objective, a storage investment capacity of 124 kWh is installed to accomplish the 2 hours spinning reserve requirement. It is interesting to note that in the case with existing hydro, the optimal wind capacity increases when compared to the Least Cost. In fact, since there is more storage in the system for reliability purposes, such storage can also be used to help integrate more wind generation, which makes a higher wind capacity economically viable.

### Table 19. Annualized Costs and Capacity of New Renewable and Storage Assets, by Planning Scenario

| Analysis Objective | Planning Scenario | Annualized Cost (k$/year) | Wind Inv (kW) | PV Inv (kW) | Storage Inv (kWh) |
|---|---|---|---|---|---|
| No Investment | Existing Hydro | 98.2 | 0 | 0 | 0 |
| | Enhanced Hydro | 92.7 | 0 | 0 | 0 |
| Least Cost | Existing Hydro | 87.7 | 25 | 13 | 0 |
| | Enhanced Hydro | 82.9 | 25 | 5 | 0 |
| Spinning Reserve (Enhanced Reliability) | Existing Hydro | 104.5 | 50 | 0 | 124 |
| | Enhanced Hydro | 91.2 | 25 | 5 | 67 |

The optimal sites within the distribution system for these investments are shown in Figure 23 below. For both Least Cost and Spinning Reserve cases, the optimal location selected for the installation of the wind turbine (Eocycle EOX-S16 25 kW) was close to the diesel power house, while the optimal location for the installation of the PV panels was the full runway. These locations were chosen automatically by the model, considering the specific renewable productivity profiles in each location as well as the characteristics of the network. Given the proximity of trees around the selected location for the wind turbine, a detailed analysis is crucial to assess the potential turbulence and sheltering effects, which could significantly impact the turbine's efficiency and overall energy production. The preferred location for each resource was the same in all the scenarios, and the only thing that differed was the amount of capacity selected (except for wind, which has large discrete steps in capacity). As shown in Figure 23, the two selected locations are relatively close to the main consumption points of the Ouzinkie system, which makes distribution grid losses smaller.

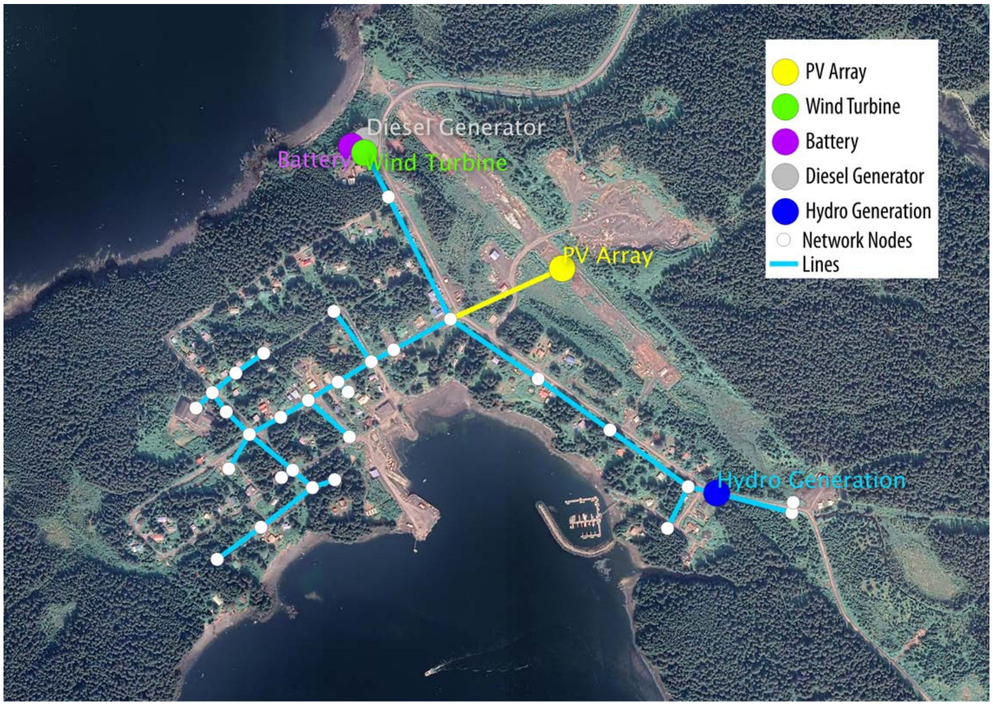


Figure 23. Optimal location of new renewable generating sources within the Ouzinkie power grid. Image source: Google Maps.

### 4.3.2 Operation Results

Besides selecting the optimal mix of generating resources, the model also estimates annual energy produced by each generating resource, assuming optimal operation. These annual energy generation shares are presented here for the two hydropower planning scenarios: existing and enhanced hydro, and for the three investment cases: No Investment, Least Cost, and Spinning Reserve (Enhanced Reliability).

As shown in Figure 24, the presence of renewables in the system, both in the Least Cost and Spinning Reserve, significantly decreases the need for diesel generation, which is expected to represent between 20% and 30% of the annual system generation when renewables are included (reduced from nearly half of the annual energy in the current system). It is interesting to note that the Spinning Reserve cases allow for additional renewable penetration when compared to the Least Cost objective. In fact, as discussed above, this increase in renewable penetration is due to the presence of storage that, although primarily selected to meet the reliability criterion, also helps make better use of the renewables in the system.

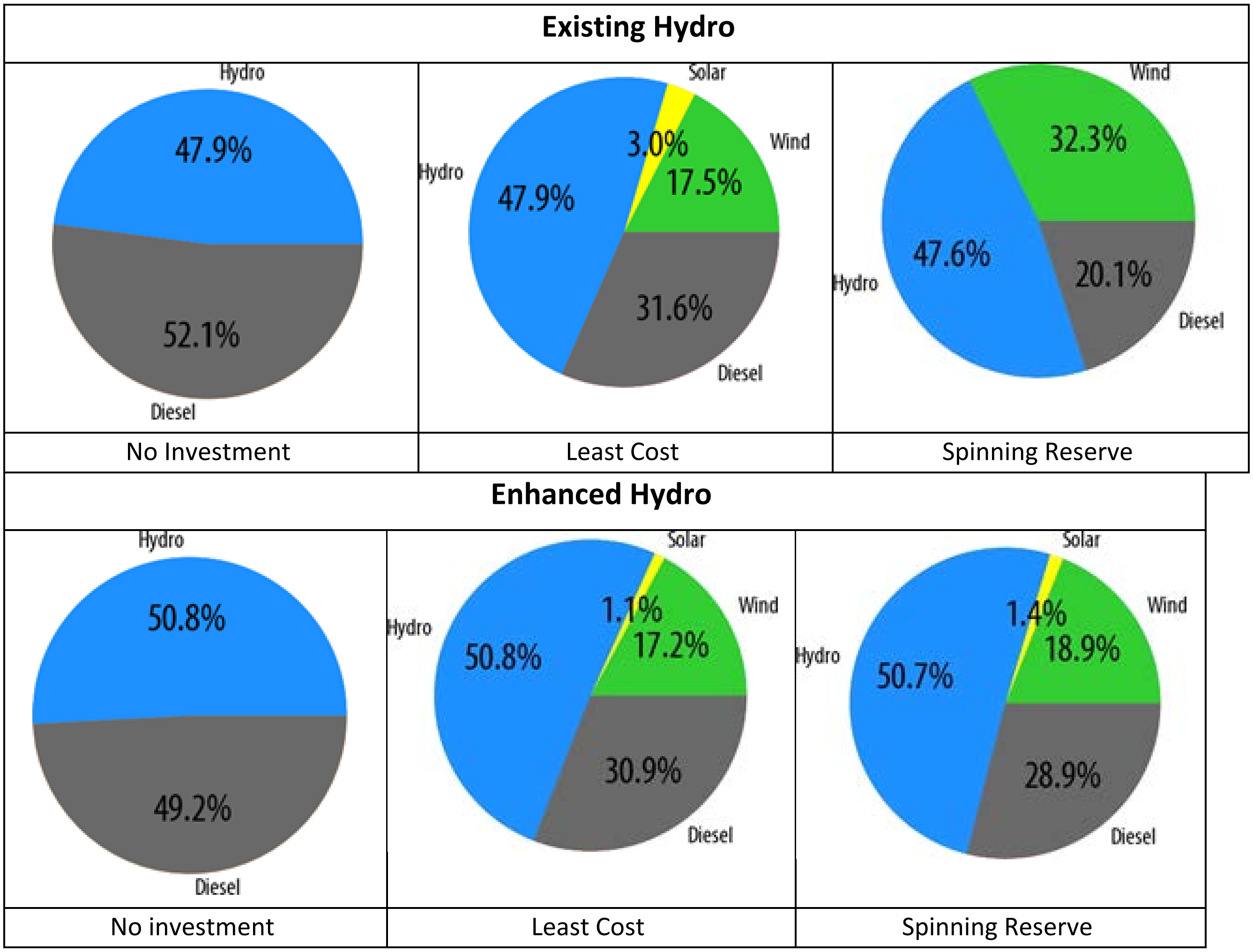


**Figure 24. Annual energy share by generating resource under different planning scenarios.**

Using the hourly load data and renewable production data, the analysis models also estimate the share of generating resources that best serve the load in each hour. Figure 25 shows the weekly dispatch in four different seasons for the Least Cost scenario, considering the existing hydropower generation system. Under these assumptions, the hydropower generation capacity is sufficient to supply the base load throughout the year, which provides the system with a solid baseline for the dispatch of other renewable generation.

On the other hand, the availability of wind and solar generation varies significantly across seasons and throughout the day. As expected, the solar generation comprises a significant seasonal variation, with a low production in the fall/winter periods and a high productivity in the summer. In contrast, the availability of the wind resources is more intermittent, with some high and low wind production days even in the same week. Under this configuration of the system, the function of the diesel generation is to supply flexible generation to meet the daily load fluctuations when wind and solar resources are not sufficient.

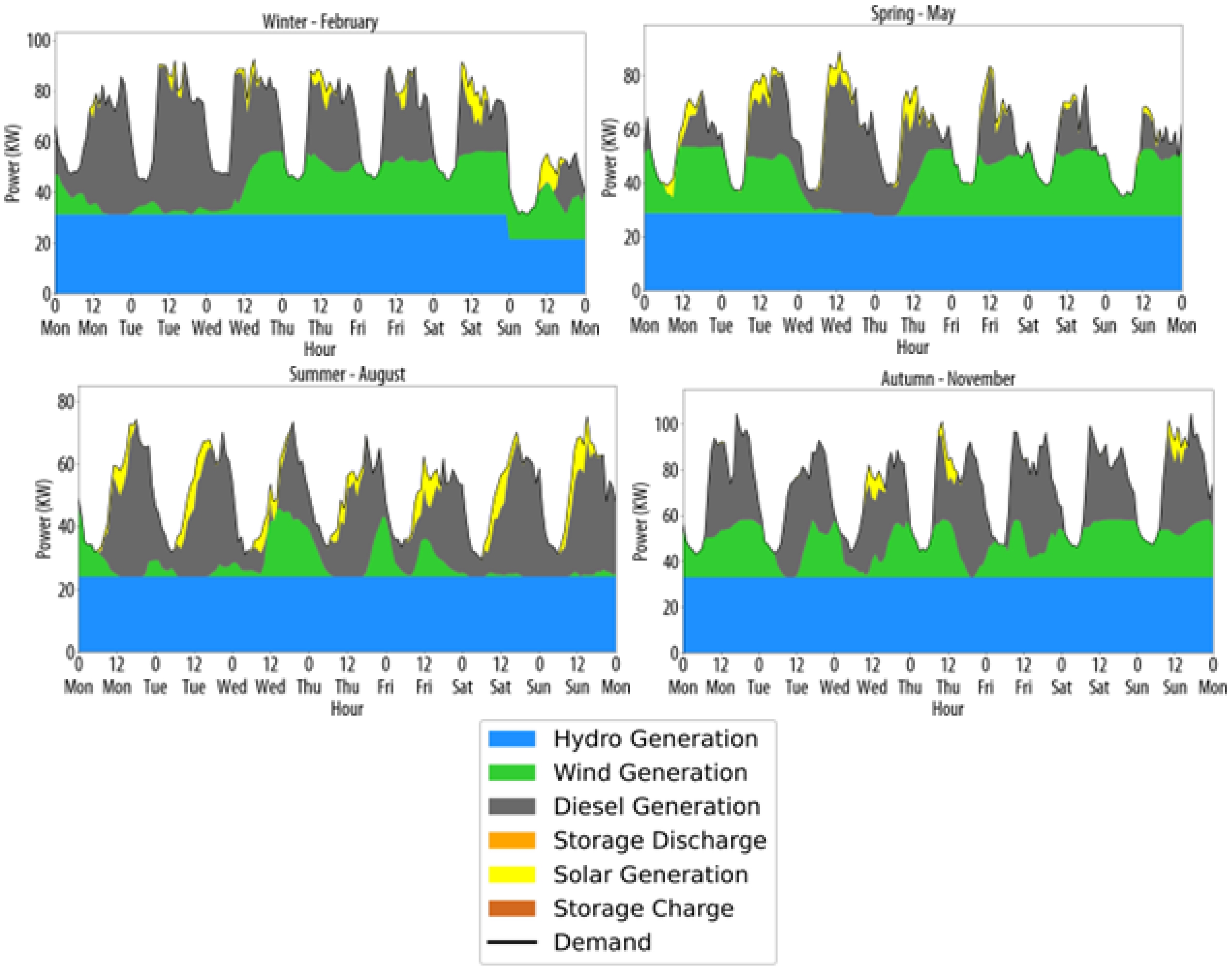


**Figure 25. Optimal dispatch of generating resources in a typical week for each of four seasons – Least Cost, Existing Hydro Scenario.**

In the Spinning Reserve case, a battery is added to the system, which significantly affects the system operation, as shown Figure 26 below. It is possible to see that the presence of 125 kWh of storage can compensate for intermittency of renewable generation, allowing to duplicate the capacity of the wind capacity and decrease the need for diesel, when compared to the Least Cost case. For example, in every season it is possible to observe the storage unit charging (shown in the graphs as orange areas with negative power values) during the periods with high wind availability and discharging later in the day, when the wind production cannot cover the peak.

During the high wind week in the spring, the storage allows the system to rely almost exclusively on hydro and wind generation for 5 days. As shown in the corresponding chart, in some hours of the week, the wind generation is even higher than the remaining load in the system. This excess of wind is not being curtailed, but instead stored in the battery to be used later in the day when the wind productivity decreases.

However, it is important to observe that, on most days, the storage unit does not aggressively discharge during the peak hours, even when it could be used to offset the diesel generation. This conservative dispatch behavior is justified by the main function of the storage in the system, which is to provide the 2 hours spinning reserve. In other words, although there is enough capacity to utilize storage for improving the economic performance of the system and integrate more renewables, the spinning reserve criterion forces some energy capacity to be kept in the storage to account for the possibility of outages.

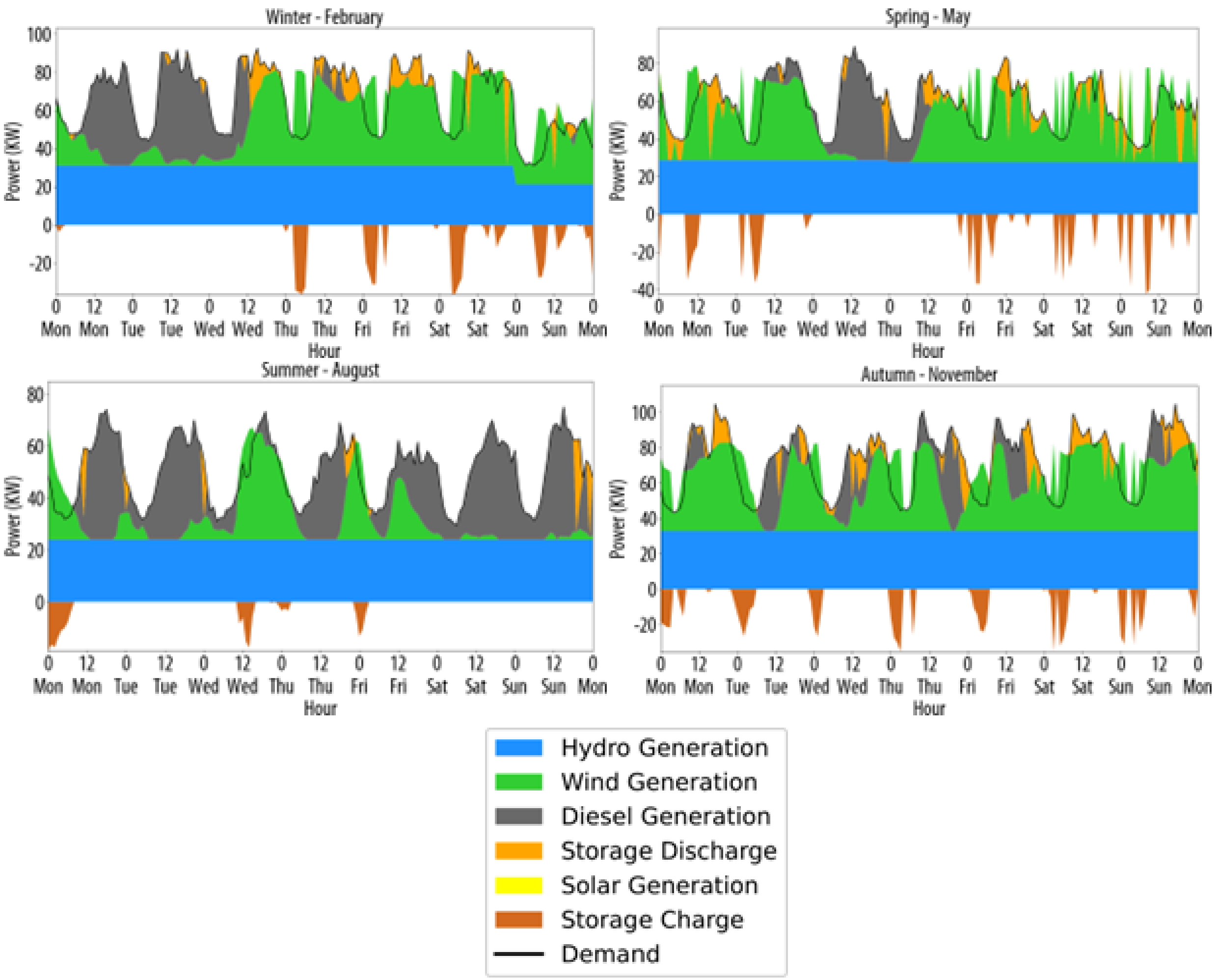


Figure 26. Optimal dispatch of generating resources in a typical week for each of four seasons – Spinning Reserve (Enhanced Reliability), Existing Hydro Scenario.

### 4.3.3 Low and High Renewable Availability Scenarios

Table 20 shows the generation share per technology for low and high renewable availability years, considering the Least Cost and Spinning Reserve investments for the two hydro planning scenarios. With the new investments in renewable resources described above, the diesel generation plays a less determinant role in the system for all the scenarios considered. Even for dry years with low wind resources, the diesel electricity production would always represent less than 42% of the system annual generation.

The hydropower dominates the system generation, supplying between 41% and 52 % of the annual load, depending on the availability of the resources. The wind generation can represent between 14% and 28% of the total generation and the PV would be responsible for supplying up to 3% of the annual load.

In summary, what these results show is that with the solutions proposed, there is enough renewable capacity in the system to supply at least 60% of the annual energy needed to run the power system in any scenario of renewable availability.

**Table 20. Annual Share of Energy Provided by Generating Resources, High and Low Renewables Scenarios**

| Analysis Objective | Planning Scenario | Operational Scenario | Generation Share (%) | | | |
|---|---|---|---|---|---|---|
| | | | Diesel | Hydro | Wind | Solar |
| Least Cost | Existing Hydro | High Renewables | 32.4 | 50.1 | 14.5 | 3.0 |
| | | Low Renewables | 41.4 | 41.5 | 14.1 | 3.0 |
| | Enhanced Hydro | High Renewables | 33.1 | 51.6 | 14.2 | 1.1 |
| | | Low Renewables | 36.5 | 48.7 | 13.6 | 1.1 |
| Spinning Reserve (Enhanced Reliability) | Existing Hydro | High Renewables | 23.6 | 49.7 | 26.7 | 0 |
| | | Low Renewables | 31.9 | 41.3 | 26.8 | 0 |
| | Enhanced Hydro | High Renewables | 31.3 | 51.4 | 15.9 | 1.4 |
| | | Low Renewables | 35.2 | 48.7 | 14.7 | 1.4 |
| **Total Variation (%)** | | | 23.6–41.4 | 41.3–51.6 | 13.6–26.8 | 0–3.0 |

# 5. Summary of Findings

The analysis presented here is intended to help the Ouzinkie community develop a plan for their power system that best meets the community's needs. As illustrated by the results of the different scenarios, the "optimal" mix of energy resources depends on the goals and values of the community, as well as access to funding to invest in new generating resources. To bound these possibilities, the study team analyzed three possible scenarios that serve different goals for the community. These three cases are summarized in Table 21.

- **No (or Minimal) Investment Cost**: If the community is not able to obtain grants or other funding to invest in new generating assets, the lowest-cost approach would be to make the planned improvements to the hydro system described in Section 2.9, as well as the hydro controls enhancement. The modeling shows that this could save approximately $5,500/year in system operating costs (compared to today's hydro system when it is operating) and avoid significantly higher diesel fuel expenses by getting the hydro system working again.
- **Lowest Overall Cost**: If the community is able to obtain funding for new generating resources and wants to minimize electric utility bills for the residents, the best approach would be to enhance the hydro controls, install a 25-kW wind turbine and 5 kW of solar PV. This would reduce the community's diesel

running the power system by about one-third compared to when the current hydropower system is operating (and much more savings compared to when the hydropower system is offline).

- **Enhanced Reliability**: This goal would be pursued if the community wants to reduce the diesel costs *and* improve power reliability such that the system can still serve the residents even with up to a 2-hour outage from the diesel generators. To achieve that, there are two main solutions: 1) the first, based on 50 kW of wind and 124 kWh battery; 2) the second, based on a 25-kW wind turbine, 5 kW of solar, 67 kWh battery, and an upgrade of the hydropower controls. The cost of enhancing reliability is still an economically viable solution because it would not increase the system costs.

**Table 21. Summary of Preferred System Resources to Meet Different Community Goals**

| Goal | New Resources | | | Cost ($) | | |
|---|---|---|---|---|---|---|
| | Wind (kW) | Solar (kW) | Battery (kWh) | Capital Investment | Total Annualized** | Annual Diesel |
| **No Investment*** | 0 | 0 | 0 | $0 | $92,660 | $92,660 |
| **Lowest Overall Cost** | 25 | 5 | 0 | $321,526 | $82,900 | $58,240 |
| **Enhanced Reliability** | 25 | 5 | 67 | $395,014 | $91,200 | $54,660 |

*All cases include upgrading the hydropower controls, which is not included in the capital costs for any of the scenarios.

**Including annualized investment and annual operating costs.

# 6. Future Analysis Opportunities

## 6.1 Hydropower

As noted in Section 2, a number of assumptions were made during the hydropower electricity calculations. Understanding the true values will not only improve the confidence with electricity generations estimated above, but could also serve as the basis for evaluating the potential for increasing reservoir volumes. In particular, if another assessment is required in the future, the team recommends that key assumptions be revisited, specifically those related to local rainfall patterns and the storage capacity of current reservoir. Additional details about future work needed are captured below.

All of the calculations developed in the course of this analysis use monthly rainfall information based on historical estimates from 1981–2010. However, these values do not provide a lot of information about the daily or hourly patterns observed. Understanding this level of detail would enable a better assessment of the ability of the reservoir to buffer against this variability or the lost potential associated with overflow of the reservoir. The community is currently evaluating options for installing a local meteorological station, which would help support gathering these critical numbers. Local monitoring at the reservoir system itself (e.g., by installing water level sensors) would also be helpful to support real-time monitoring of water available within the reservoir. Information about reservoir levels can also be used to assess if there's any lags or travel times associated with water traveling to the reservoir (something assumed to be negligible in the calculations for Equation 1 in Section 2).

As noted above, the TA team used a back-of-the-envelope calculation to evaluate the volume of the reservoir. However, it is likely that the depth is not even across the entire reservoir. So, the community might consider doing a follow-on engineering assessment to specifically assess the shape/capacity of the current reservoir, as well as potential for volume increases. Information about these capacities could be used to help evaluate whether the storage size of the reservoir is a limiting factor for generation of hydropower (i.e., is there a lot of water being spilled because the reservoir is too small, especially when considering finer resolutions of daily or hourly rates?).

The capacity of the reservoir can be measured in a couple of ways. One is to use a boat to traverse the length of the reservoir and take manual point measurements of the depth in various locations to gauge the general depth. Another approach is to equip a boat with measurement tools that can be used to conduct a more formal bathymetry study to evaluate the depth across the entire profile of the reservoir; two tools that can be used to support these measurements are acoustic doppler (USGS, 2016) or echo sounders (Budi et al., 2017). The engineering study could also assess different opportunities for increasing the functional volume of the reservoir, from further raising the spillway to potentially lowering the outfall. The latter would enable more of the existing water in the reservoir to be used. Such assessments would be able to help the community identify whether the size of the reservoir itself is a limiting factor for their hydropower generation.

## 6.2 Wind

The wind resource time series for the different potential turbine locations were derived as explained in Section 2.3. After the Ouzinkie community completes its anticipated met tower data collection campaign, it will have observational wind resource data with which to make site-specific wind resource time series. These new time series can then be applied to the desired turbine model power curves to create new generation profiles. The Ouzinkie community can contact the TA team to request that these new generation profiles be added to the model so Ouzinkie can conduct updated evaluations with its observational wind data.

## 6.3 Web Planning Tool

To allow the Ouzinkie community to explore more scenarios and assumptions beyond the ones presented in this report, the project team prepared a custom web application to be used exclusively by the community. The application allows the community to change the assumptions of the analysis presented in this report and obtain additional results. For example, it is possible to update diesel costs; change the economic parameters of candidate technologies (wind, solar and storage), namely technology costs and lifetime; model potential load growth; and modify spinning reserve criteria.

For each combination of assumptions, the web application runs a new instance of the model and provides a new optimal solution for the system plan. The main outputs include the optimal portfolio of energy technology investments, the new operation costs, and energy mix as well as the optimal location of the new investments.

Modify energy parameters in Ouzinkie.

Made by *Grid Integration Group*.

Parameters

● Map
○ General Parameters
○ Wind Technologies
○ Solar Technology
○ Storage Technology

Case

Ouzinkie Network

**Figure 27. Web application interface.**

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# Appendix A: Other Energy Sources Not Considered

As described in the main body of the report, the Ouzinkie community expressed interest in a number of other renewable energy resources and technologies, in particular tidal energy, biomass, rooftop solar PV, and residential wind, which were not considered in the TA team's detailed modeling and analysis. This appendix documents the details of the screening assessments for these resources and technologies.

## Rooftop Solar PV

In early discussions, Ouzinkie community stakeholders expressed their desire to deploy one centralized, ground-mounted solar PV array rather than multiple rooftop arrays. To objectively rule out the rooftop option, the analysis team qualitatively compared a centralized PV array to distributed rooftop arrays and found that the centralized array is preferred because it would:

- Cost less than rooftop arrays due to economies of scale
- Allow optimal sizing for the city's distribution system
- Give the city control over the PV system's operations and maintenance
- Avoid variable power output from multiple rooftop arrays that would likely be disruptive to the operation of Ouzinkie's small distribution grid
- Allow optimal orientation of the centralized PV array rather than being limited to the orientation of each building
- Avoid costly repairs to roofs and structural upgrades that may be required for rooftop.

## Residential Wind

The area around any wind turbine needs to be clear of obstacles, such as trees and houses, that would cause the wind turbine to experience undesirable turbulent wind flow. Turbulent wind does not allow for consistent wind energy production and can damage a wind turbine. Figure A-1 provides a graphic of the recommended distances a wind turbine should be from a tree or house, or similar obstacles.

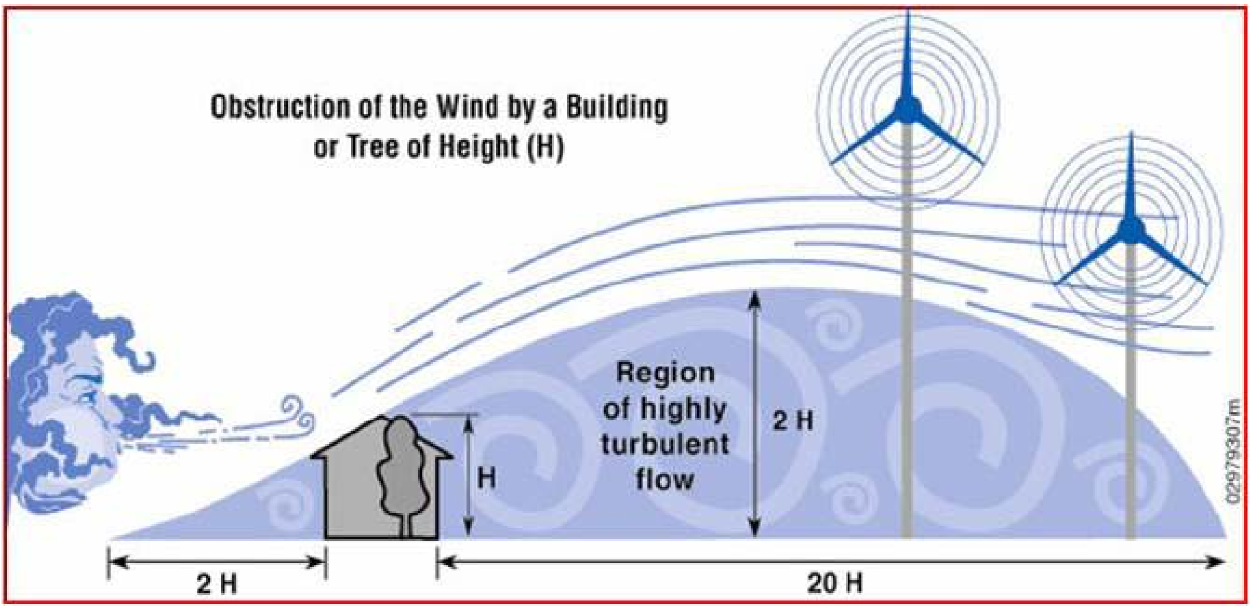

Figure A-1. Wind siting rules of thumb to avoid obstructions (DOE 2022).

Because most, if not all, homes in Ouzinkie are surrounded by trees, wind turbines sited at individual homes would suffer from the turbulent flows shown in Figure 18, and are thus not recommended. Several other issues also make residential wind a less desirable option, including:

- Sound or visual impact concerns for neighbors

- A lack of commercially available wind turbines in the 1-kW to 5-kW size range (the size range most appropriate for typical household loads)
- Variable generation from multiple small wind turbines, which could be disruptive to the operation of Ouzinkie's distribution grid (similar to rooftop PV)
- The need for a net-metering financial arrangement (similar to rooftop PV).

## Tidal

Southwest Alaska is a hotspot for marine renewable energy, with abundant wave energy and powerful tidal energy in particular channels and inlets (Kilcher, 2021). Wave energy conversion is an emerging technology still in the prototyping stage, so it was not explored as an option for Ouzinkie. Tidal energy was not considered in the TA team's modeling and analysis efforts, but its potential in the region is documented here for the city's reference.

### Summary

One location, Whale Passage, was determined to be a feasible location for tidal energy, but is located roughly 11 miles from Ouzinkie and is without existing transmission infrastructure that could transfer the energy to Ouzinkie.

### Results

Tidal water flow speed is the critical factor in determining tidal energy potential feasibility. A "cut-in" speed is the minimum water speed required to start turning a tidal generator and varies with the rated generator power output. Tidal energy devices typically require a minimum flow cut-in speed of 1.0 to 1.5 m/s.

A turbine's rated power is a function of generator size and water flow speed, with larger turbines and faster flow speeds generating more power. Because the size of the device matters, after flow speed, water depth is the next important factor in determining tidal energy potential. A water depth of 15 m is considered to be a minimum acceptable depth.

The TA team evaluated four potential tidal energy locations in the vicinity of Ouzinkie: Whale Passage, Narrow Strait, Balika Cove, and Anton Larsen Bay. The water current speeds, water depth, and distance to the Ouzinkie Power Plant (as a point of reference) are provided in Table A-1. The locations are identified in Figure A-2.

## Table A-1. Site Location and Current Speeds

| Location | Latitude | Longitude | Mean Speed[14] (m/s) | Max Speed (m/s) | Water depth at location (m) | Distance to Ouzinkie Power Plant | Data Source |
|---|---|---|---|---|---|---|---|
| Whale Passage | 57.9188 | -152.7953 | 1.34 | 3.00 | 20 | 11 | XTide |
| Narrow Strait | 57.9121 | -152.5241 | 0.38 | 0.87 | 30 | 1.3 | XTide |
| Balika Cove | 57.9345 | -152.4264 | - | 0.8 | 3.5 | 2.8 | Keulegan's method |
| Anton Larsen Bay | 57.889 | -152.6337 | - | 1.5 | 8.5 | 5.6 | Keulegan's method |

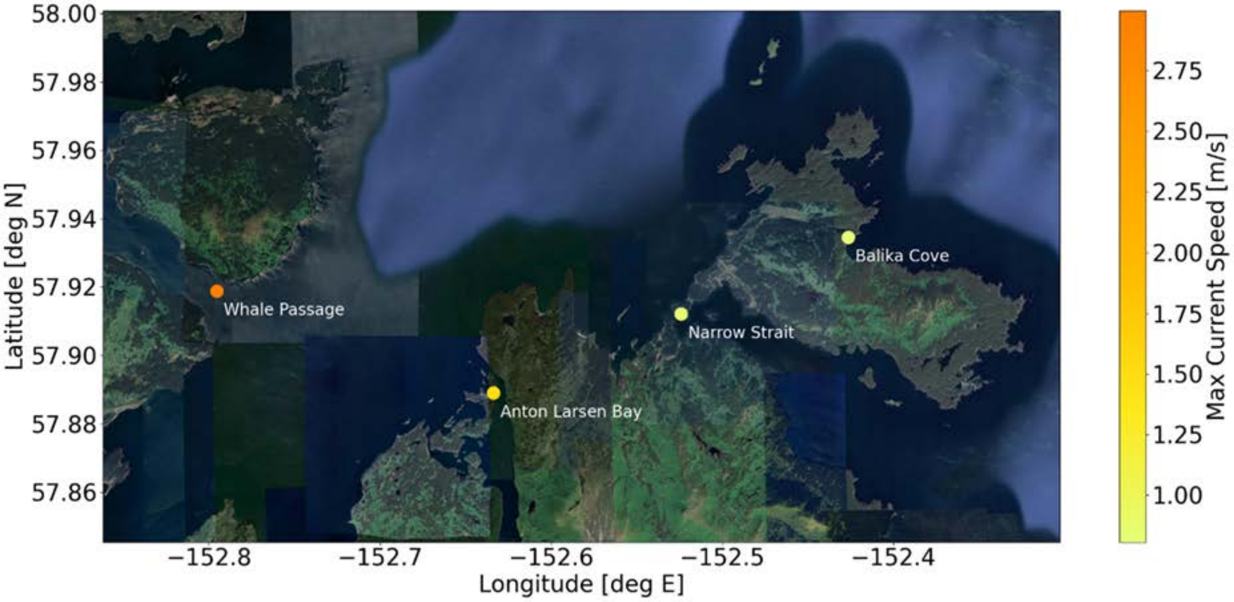

**Figure A-2. Maximum water current speeds around Spruce Island, Alaska (Flater 2020).**

With a maximum flow speed of 3 m/s, an average flow speed of 1.34 m/s, and a water depth of 20 m, Whale Passage is a feasible location for a tidal energy project, but it is 11 miles from the community, so building the infrastructure to transfer the energy would be costly.

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[14] Keulegan's Method does not calculate mean speeds.

The flows expected at the other three locations (Narrow Strait, Anton Larsen Bay, and Balika Cove) are too slow for present technology to create power, but if a smaller device is commercialized in the future, Anton Larsen Bay could be a possibility if power lines exist or could be built to route electricity back to the community.

The lack of power transmission infrastructure tends to be the limiting factor for most tidal sites in North America, but in addition, more work would need to be done to fully scope the resource at Whale Passage or Anton Larsen Bay to determine the feasibility of deploying a device in these locations. Unfortunately, the locations closest to Ouzinkie, Narrow Strait and Balika Cove, have flow speeds that are likely too slow for tidal energy based on present technology development.

## Analysis

Part of the reason Alaska has so many tidal energy resource sites compared to the rest of North America is the high tidal range, a requirement to drive water currents. Figure A-3 shows the tide, or water level, forecast for Ouzinkie based on a nearby tide gauge station (NOAA 2022).

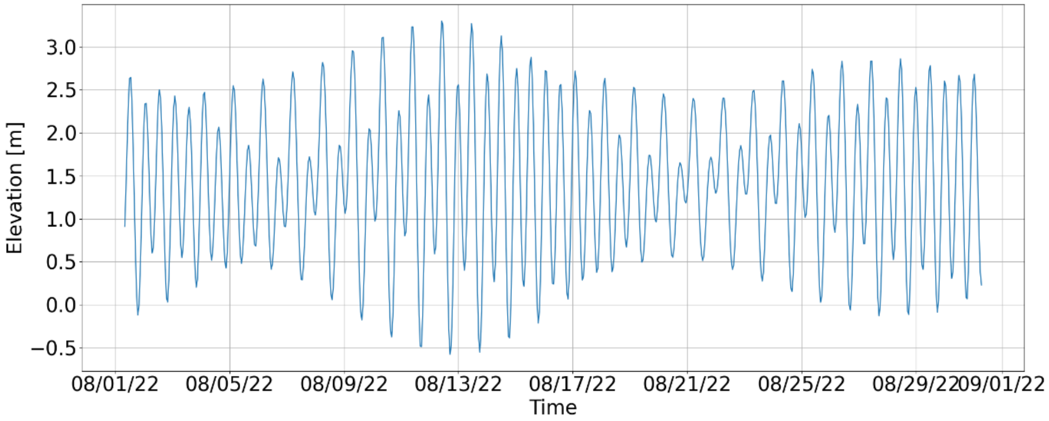

Figure A-3. Tidal forecast for Spruce Island, AK (NOAA 2022).

In Figure A-3, an elevation of 0 m corresponds to Earth's "mean low low water" (MLLW), or the average low tide water level. The local MLLW at any specific location might differ from the planetary average, and Ouzinkie's MLLW is around 0.5 m in elevation. The max tidal range around Ouzinkie is about 4 m, which is the difference between the highest and lowest slack tide elevations. A 30-day forecast is shown because that is longer than the length of a full "tidal" or lunar cycle. Tides are fundamentally driven by the moon's orbit, which takes a little longer than 29 days to circle the Earth.

The feasibility of harnessing tidal energy at four possible locations around the community was assessed in two ways. The first method was to use "XTide," an open-source software commonly used by government and industry to predict tides and currents at various locations around the maritime United States. Predictions and forecasts are based on tidal harmonics calculated from data collected from tide gauge and water current meter deployments, typically conducted by the National Oceanic and Atmospheric Administration (NOAA).

Where there are no water current meter stations, a second method (called Keulegan's Method) was used to calculate water velocity through an inlet into a bay. Keulegan's Method is a basic model to calculate the movement of water into and out of a bay (O'Brien, 1972). The model calculates the maximum flow through an inlet based on tide height, inlet geometry, and the size of the bay the inlet feeds into. Otherwise, in-depth models or in situ measurements (which is what the NOAA forecasts use) are needed to quantify water velocities at any specific location.

For the first method, NOAA forecast data[15] were collected from water current forecast stations in the nearby Whale Passage and Narrow Strait for August 1–31, 2022 (NOAA 2022). Since tidal cycles repeat every 30 days with little variability, data from a single month is adequate for tidal energy estimates.

There are a few other forecast stations in the area, but these report water speeds under 0.5 m/s which is insufficient to generate tidal energy. Average speed was calculated from the absolute value of current velocity, and maximum speed is the fastest speed seen at either ebb or flood tide.

The two other locations, Balika Cove and Anton Larsen Bay, were assessed with Keulegan's Method. The inlet to Balika Cove and the largest inlet to Anton Larsen Bay do not have NOAA water current station forecasts, but were determined to be promising locations based qualitatively on the size and shape of those inlets and bays.

There are a couple ingredients necessary to create strong current flow. The first is a narrow passage or constriction of the surrounding bathymetry or seafloor/landmass, typically provided by an inlet. The second is energy to drive water through this passage, sometimes provided by the tide. Keulegan's Method takes these two ingredients for a tidal inlet and approximates a maximum water velocity that the inlet can generate.

For Keulegan's method, water depths were determined using NOAA nautical charts, and geometry specs were measured using GIS software. Water level data was collected from 30-day NOAA tide forecasts at reference stations nearest to the target locations (around 5 miles away).

### Example Projects

There are few deployed tidal energy turbine generators, but the following are two examples built and deployed by Ocean Renewable Power Company and Verdant Power. Both companies' turbines have ratings of 35 kW at 2 m/s flow speeds, have a similar turbine size (17 and 19 m^2, respectively), and require a water depth of about 15 m.

Ocean Renewable Power Company's RivGen turbine was deployed in the Kvichak River next to Igiugig, Alaska, in 2015. Water flow in this river is highly turbulent, varies around 2 m/s, and at the time of publication the turbine was producing an average of 12.5 kW (Forbush, 2016). Verdant Power's Gen5 turbine was deployed in the East River, which has smoother and steadier flow, in New York City from October 2020 to May 2021, and its average power output was around 18 kW (Gunawan 2014).

## Biomass

Ouzinkie is located on Spruce Island, an island densely covered in spruce pines. Given this setting, the community was curious about the potential to generate energy from biomass on the island. Biomass energy was not considered in the TA team's modeling and analysis efforts, but its potential in the region is documented here for the city's reference.

### Summary

There is wood waste biomass available in the Kodiak region, but using biomass to generate thermal energy in Ouzinkie would first require converting the biomass to biofuel to use in the existing diesel fuel oil boilers or purchasing new boilers that could burn biomass. Alternatively, the steam from new biomass boilers could be used to generate electricity in a steam turbine generator, but those generators would have to be purchased as well.

### Analysis & Results

A biomass resource availability screening has not been conducted for Spruce Island specifically, but a biomass screening for the Kodiak region in general indicates that a total of 1,937 tons (3.87 million pounds) of wood waste biomass is available yearly (EIA 2022).

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[15] Forecast, rather than historical, data are used because it is costly to operate a tide gauge for long periods of time, and the forecasts are typically accurate within 1%–5%. All forecast data in this document are generated from Xtide and 2021 harmonics data (Flater 2020, harmonics-dwf-2021-01-10).

Household trash is also considered a biomass resource. The City of Ouzinkie does not currently weigh or sort its trash. It is unloaded at the city's dump and burned in barrels.[16] Therefore how much waste is regularly generated is unknown. However, given the small population of the community (between 100 and 200 people), the amount would be insufficient to sustain any consistent level of energy generation.

To utilize biomass, a solid fuel or biomass boiler is needed. A solid fuel boiler is designed to burn a fuel such as coal with co-firing of up to 15% biomass, such as wood waste, allowable. A biomass boiler is designed to burn 100% biomass.

The residential and city building boilers used in Ouzinkie are designed to use Diesel Fuel Oil No. 2. As such, Ouzinkie would have to buy new boilers capable of burning biomass. An alternative would be to co-fire biodiesel in the existing boilers, but that would require processing the biomass into biodiesel or purchasing from a biodiesel producer.[17] Another alternative would be to use the steam from new biomass boilers to generate electricity in steam turbine generators, but those generators would be new purchases as well.

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[16] Regional community partners, such as the Alaska Center for Energy and Power, could work with Ouzinkie on recycling and composting if there is interest.

[17] The only biodiesel producer in Alaska is Alaska Green Waste Solutions in Anchorage that makes biodiesel from used cooking oil.

# Appendix B: Community Workshop Feedback

## Summary

Members of the TA team visited Ouzinkie in June 2022. They hosted a community meeting to better understand community goals. This Appendix provides a summary of the feedback the team collected during that meeting.

## Community Responses on Wall Posters

*Currently, Ouzinkie gets energy from diesel & hydro (when working). What else would you like to see?*

- Wind: 24
- Solar: 8
- Tidal: 11
- Biomass: 0

*What is more important to you?*

- Lower energy costs: 13
- More energy from renewable sources: 10
- More reliable energy: 7
- Residential energy efficiency upgrades: 7

*If (when) energy becomes more affordable and reliable, what is your vision for Ouzinkie's future?*

- "Prices of fuel, electricity will be lower. People will be able to move back home or stay here. Jobs will be created."
- "With a reliable affordable energy grid we could help some young families move back to the village, possibly get a site for a local store, etc."
- "Growth in population."
- "When Ouzinkie has more reliable and affordable energy, I hope our community will grow and families will move back. I hope we will have good jobs for all of the people."
- "To see more reliable power source and more cost effective."
- "Love to see in the future… windmills and sawmills. Emergency power supply for all households, like mini-generators."
- "Population growth & sustainable energy."
- "Windmills & reliable energy."
- "My hope is with more affordable & reliable energy in Ouzinkie is that more people can afford to live here and also move back home. I'm afraid of such a decrease in our population. Also, maybe we can get a store back up and running here if we have affordable energy."
- "My vision for Ouzinkie is to lower utility cost & make it more affordable to live here so that families that are from here can afford to move back."

*Please share your thoughts on energy in Ouzinkie (needs, hopes, anything we all should know).*

- "I hope that we can become all energy efficient, of course we will need to keep oil generators for backup."
- "Tidal, windmill."
- "I think redundancy will be key – solar, wind, hydro, and maybe even tidal with batteries for storage of excess during lulls in hydro availability."
- "I appreciate the City of Ouzinkie & all they do to keep our electricity up & running. My hope is that they can get help to be more self-sufficient to be able to keep costs down for us & them."
- "Would like to see people be more responsible with their energy consumption."
- "Would like to have a B&B run off of renewable energy."
- "Energy production from the tides in the narrows."
- "Solar panels for homes."
- "Need hydro fixed right and more long term. Also have a good diesel backup system and wind power."
- "I hope there will be enough energy generated to allow our community to grow."
- "Multiple sources for energy."
- "Low-cost to free energy plan for all people in village."