ENERGY
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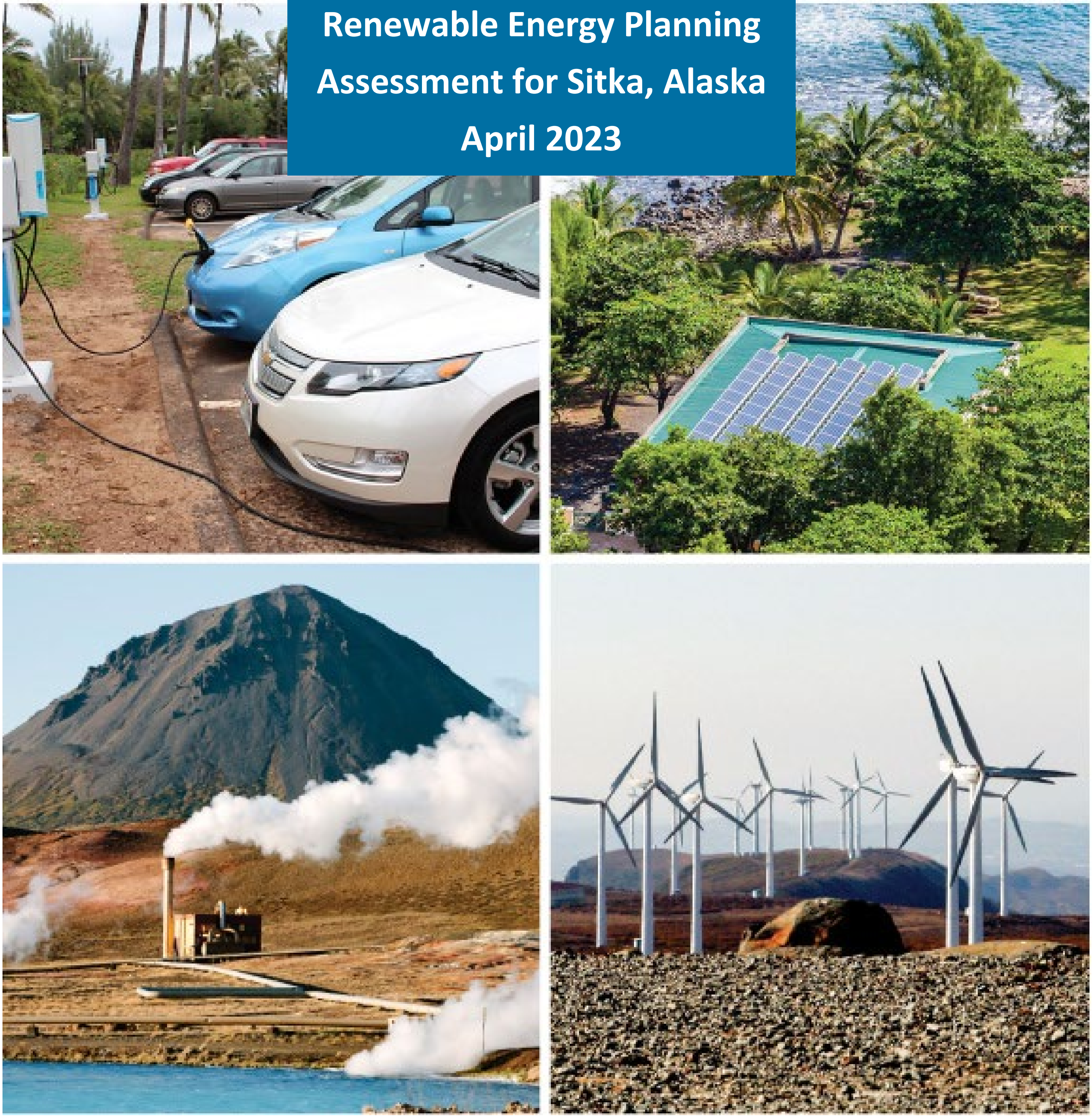
Technical Assistance for
CBS Utility Planning

Renewable Energy Planning Assessment for Sitka, Alaska

April 2023



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Disclaimer

Introduction

The City and Borough of Sitka, Alaska (CBS) Electric Department applied for technical assistance from the Department of Energy (DOE) through the Energy Transitions Initiative Partnership Project (ETIPP) program in February 2021. ETIPP selected CBS as one of the communities in Cohort 1 and partnered them with Pacific Northwest National Laboratory (PNNL), the National Renewable Energy Laboratory (NREL), and the Renewable Energy Alaska Project. The team worked together to develop a project scope that will assist CBS with meeting their climate and resilience goals. This report documents the assessment of renewable energy options for CBS, per Task 3 of the scope, and addresses several CBS goals as outlined below.

ETIPP Overview

DOE's ETIPP program works alongside remote, island, and islanded communities seeking to transform their energy systems and increase energy resilience through strategic energy planning and the implementation of solutions that address their specific challenges.

ETIPP defines remote, island, or islanded communities as follows:

- **Remote** communities are isolated from population centers and, as a result, have limited access to centralized energy systems.
- **Island** communities are isolated from the mainland by waterways.
- **Islanded** communities are not grid-tied to large, transmission-scale power systems and thus experience frequent issues with power quality or reliability. These communities may or may not be categorized as "remote" or "island."

This multi-year, cross-sector technical assistance effort applies a tailored, community-driven approach to clean and resilient energy transitions, leveraging the experience and expertise of the ETIPP partner network: a broad coalition of local stakeholders, tribal leaders, regional organizations, national laboratories, and DOE offices.

By understanding local energy and infrastructure challenges, goals, and opportunities, ETIPP's partner network empowers communities to proactively identify and implement strategic, holistic solutions tailored to their needs.

Sitka ETIPP Project Scope

The project scope developed for Sitka by the ETIPP team includes the following five tasks:

1. Steady-state grid model development
2. Dynamic grid model development
3. Renewable energy assessment to meet future loads
4. Electric grid controls assessment
5. Evaluation of green fuels production potential

These tasks provide CBS with tools and information necessary to plan for future investment in the energy generation equipment and infrastructure required to meet the long-term needs of the community. They are complementary to ongoing and previous CBS efforts and assessments, such as improving management and operation of current generation assets and the investigation of an additional hydropower plant.

CBS Electric Department Clean Energy Goals

The CBS Electric Department is a community-owned electric utility with a seasonal hydro and diesel microgrid located in southeastern Alaska. CBS is striving to reduce its carbon footprint and optimize energy use by modernizing its microgrid, increasing renewable penetration, and maximizing its utilization of hydropower (by reducing hydro spillage or exploring other uses for surplus power), specifically in the face of growing electric demand.

As documented in its ETIPP application, Sitka's energy resilience depends on a wide range of goals. These include several related to renewable energy:

- Identify, develop, and implement new renewable energy systems
- Optimize water usage [in the hydroelectric dams]
- Develop a project-by-project [power generation] expansion plan
- Stabilize electric rates
- Become a more self-reliant community in the face of natural disasters that are not uncommon in the region: tsunamis, severe weather, landslides, etc.
- Reduce greenhouse gas emissions
- Develop sustainable community investments and technical assistance that transition away from fossil fuel usage towards decarbonized fuels.

This report addresses these goals through evaluation of local wind, solar, geothermal, and ocean energy resources. These resources were chosen through discussions with the CBS Electric Department as well as National Lab input on available renewable energy options in the region. The analyses presented here consider resource availability, siting, capacity expansion needs given expected loads in Sitka, and coordination with existing generation assets to identify options for meeting these goals.

CBS Load Characterization

Understanding the current and expected future load that will be served by CBS is critical for planning investment in additional generation capacity. This assessment characterized the current, short-term future, and long-term future loads through an understanding of annual variations in weather, energy use sectors, and growth plans and trends.

The CBS electric system that serves Sitka is electrically isolated and is the sole provider of power to the city and surrounding area. The typical load demand is seasonal and varies between 20–24 MW (winter: electric heating loads) and 18–19 MW (summer: fishing economy) with a high Energy Use Intensity hospital as a critical load. The U.S. Coast Guard and Federal Aviation Administration are also present in the vicinity of Sitka and require resilient power supply and energy infrastructure. The electric load at any point in time across all sectors must be met with the available resources. Therefore, an understanding of the current and future loads on at least an hourly timescale is critical to determining appropriate generation assets. The three load scenarios considered are graphed in Figure 1 and described below. In 2021, CBS generated 122 GWh of electricity to serve the Sitka community. This load is expected to grow to 147 GWh in 5–10 years, and to 206 GWh with high levels of load electrification.

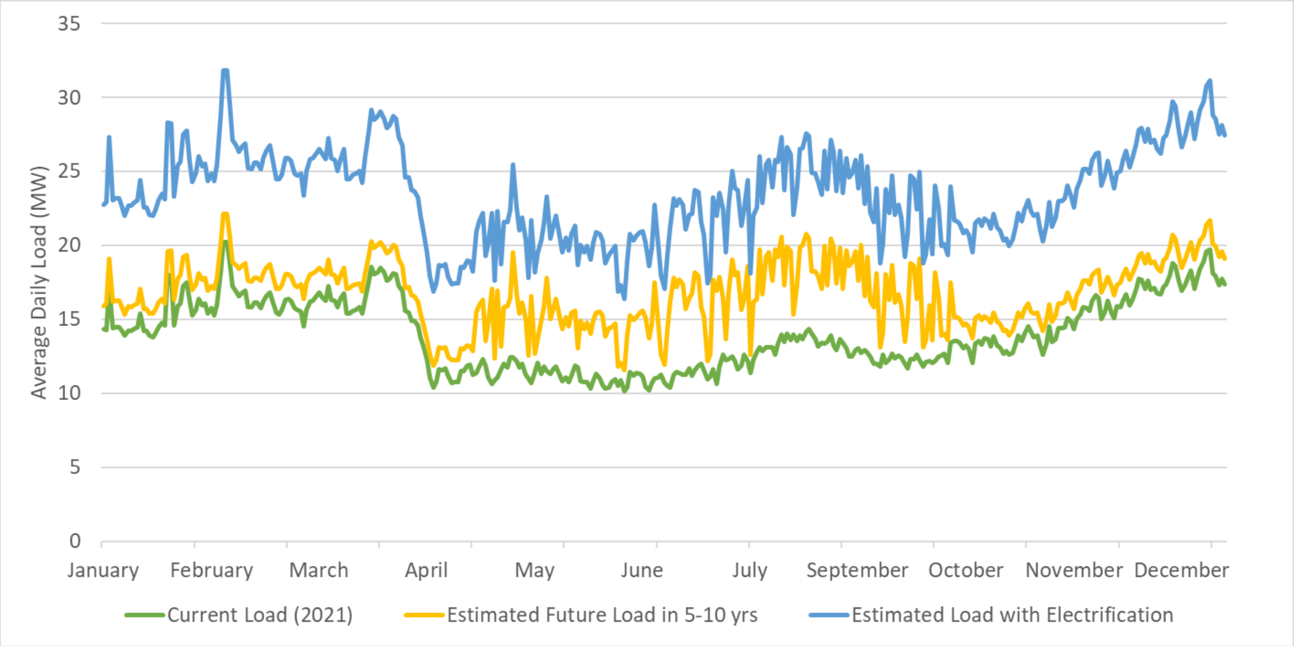

Figure 1. Sitka current and estimated future loads.

Current Load Profile

In 2018, D. Hittle & Associates, Inc. (DHA) performed an electric load analysis and development plan (DHA 2018). DHA found the main demands of Sitka's load are closely tied to the main components of Sitka's economy: seafood processing, health care, tourism, federal government, and education. Seafood processing and tourism are seasonal components, experiencing higher activity in the summer months, although electric demand peaks in winter with heating requirements. In 2017, residential and commercial customer classes made up a majority of CBS's energy sales, with boats, municipal facilities, and Sawmill Cove Industrial Park (GPIP) making up the rest (DHA 2018). Figure 1 above depicts the seasonal variation in the 2021 electric load in Sitka, which was a relatively high-load year.

Figure 2 demonstrates the relationship between Sitka's annual historical heating degree days (HDDs) and electricity requirements (developed by CBS), showing that colder years (with higher HDDs) require more electricity for heating.

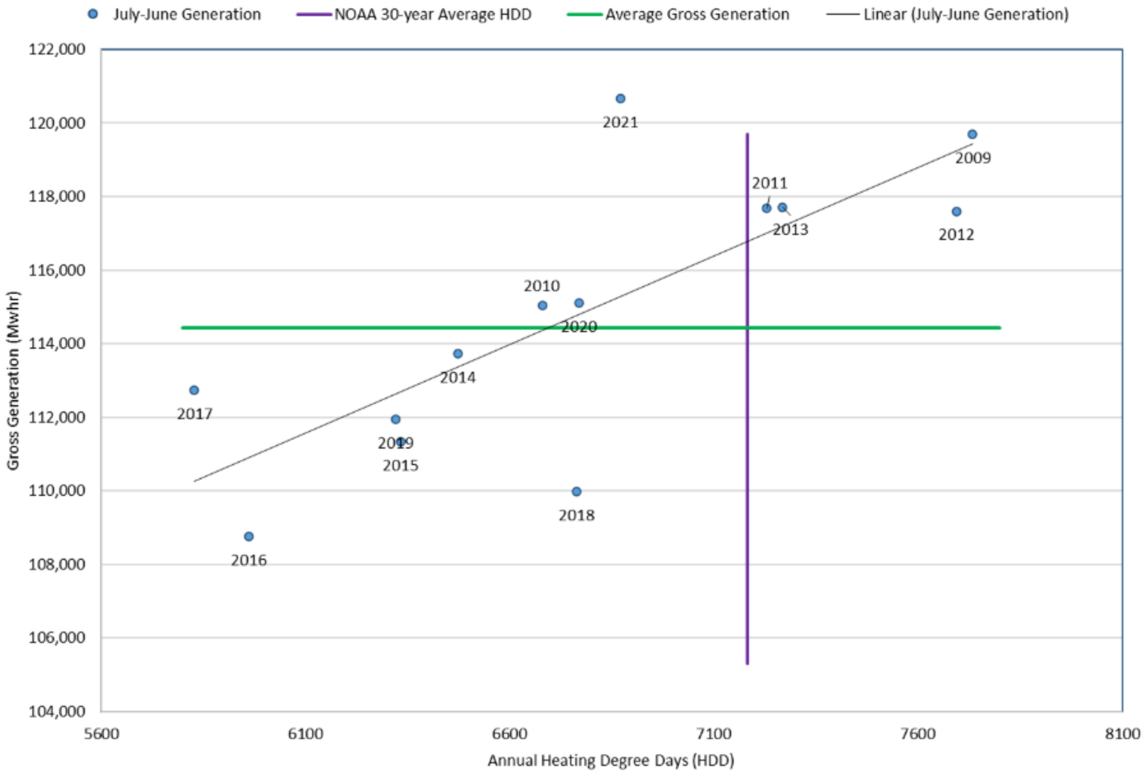

Figure 2. Sitka annual generation by HDD.

Anticipated Load in 5–10 Years

CBS estimates the annual electric load will grow by 20% in the next 5–10 years primarily due to construction of the new SouthEast Alaska Regional Health Consortium (SEARHC) hospital and electrification of cruise ship docks and tourist buses. An understanding of this load increase is required to plan for future generation requirements.

HDD data was used to identify years with low, medium, and high loads. For planning purposes, high loads need to be the target to ensure sufficient power will always be available. The high-load base case used for this assessment was based on 2021 electricity consumption data.

To estimate the future 20% load increase on an hourly basis, hourly load profiles were developed for the known contributors to the increase: the new SEARHC facility, electric cruise ships, and electric tour buses. These estimated loads equal 17% of the 2021 load; the remaining 3% of the expected increase was allocated evenly across the hours. Annual load estimates for the three known future loads are:

- SEARHC: 8.6 GWh/year
- Cruise ships: 10.4 GWh/year
- Tour buses: 0.4 GWh/year

More details about the forecast assumptions can be found in Appendix B.

Potential Load with Electrification

Sitka is following the trend of electrification that the rest of the country is experiencing. Building heating is already being converted from fuel-fired boilers to electric heat pumps to save costs as well as reduce emissions. Electric vehicles are not yet common in Sitka, but it is expected that diesel-fueled buses and eventually personal vehicles will be replaced with electric vehicles. To consider this future with widespread electric vehicle and heat pump adoption across the residential and commercial sectors, it is assumed that every household (3,703) and general service account (652) in Sitka installs a residential heat pump, each of which consumes on average 6,000 kWh/year (DHA 2018). This also assumes that all currently registered vehicles, including light-duty vehicles, pickups, motorcycles, commercial trailers, trailers, commercial trucks, buses, and snowmobiles (8,967 as of 2021, per the Alaska DMV [DMV 2022]) are replaced with electric vehicles, each of which consumes on average 3,600 kWh/year (DHA 2018). These additional electric loads, when added to the anticipated 20% load increase in 5–10 years, result in a 68% increase in annual electricity demand compared to 2021.

This estimate was used as an approximate future electric load target and should be re-assessed as electrification occurs and loads change in the next 5–10 years. A refined estimate will be beneficial for CBS to plan investment in future generation capacity to meet these growing needs. In addition, the location of these added electric loads, specifically charging stations, will need to be considered and modeled for their impact on the Sitka grid.

CBS Existing Generation Assets

CBS electricity is generated from hydropower and supplemented with diesel as needed, as described in this section. These resources are sufficient to meet current needs but have limitations for meeting Sitka's expected load growth. Specifically, hydropower is dependent on precipitation, which varies each year: in the past ten years, a low of 127 GWh to a high of 190 GWh of electricity generation potential were available given different precipitation levels. In addition, Sitka would like to reduce the emissions produced from diesel engines.

Hydropower: Blue Lake and Green Lake

CBS currently produces almost 100 percent of its electricity at two hydroelectric power plants, Blue Lake and Green Lake. The Blue Lake Project (FERC P-2230), first authorized in 1958, consists of Blue Lake Dam on Sawmill Creek, a 7,000-foot long penstock, and a powerhouse with three generators, resulting in a combined nameplate capacity of 15.9 MW. These new generators have flywheels that can be used in the future to help stabilize power fluctuations. Sitka expanded the Blue Lake Project between 2012 and 2014, raising the dam by 83 feet to its present 425 feet and construction of a complete new powerhouse with new generators. At full capacity, the reservoir has a storage capacity of 266,000 acre-feet (120,900 of which are usable for power generation) and a surface area of 1,646 acres.

The Green Lake Project (FERC P-2828) began operation in 1979 and consists of Green Lake Dam on the Vodopod River and a powerhouse at the dam containing two generators with a combined nameplate capacity of 18.6 MW.

Blue Lake and Green Lake are located in watersheds with large topographic gradients. Blue Lake's 37 square mile watershed ranges from approximately 400 feet (average water surface elevation) to above 4,000 feet. Green Lake's 28 square mile watershed ranges from approximately 350 feet (average water surface elevation) to above 4,000 feet. Each watershed contains small glaciers, and inflow is driven by a combination of snowpack melt during the summer and rainfall during the fall and winter. Early spring has the lowest production.

A constraint on power production at Blue Lake is the minimum streamflow requirement for Sawmill Creek that ranges between 50 and 70 cfs depending on time of year. However, there is a 1.5 MW generator there that can leverage the energy from this flow before it enters the creek.

Both the Blue Lake and Green Lake reservoirs are operated using monthly rule curves specifying reservoir elevations by month. These curves were developed using derived historical inflows and attempt to maximize stored water and minimize spill of water. CBS is currently exploring the value of inflow forecasts in operating the reservoirs. These forecasts offer the potential ability to deviate from the existing rule curves, expanding flexibility in generating power while also ensuring that enough water is stored to provide a stable power supply year-round.

Diesel Generators and Interruptible Loads

CBS also owns 15 MW of diesel generators at the Jarvis Street Substation. The generators are used to supplement hydro generation when the Blue Lake and Green Lake hydroelectric plants are down for maintenance or when reservoir levels are low. CBS uses rule curves and weekly lake-level forecasts to determine when to use the diesel generators to prevent further drawdown of the lakes. The cost of diesel fuel is about 35–40¢/kWh; these costs as well as generator operations and maintenance (O&M) are expected to increase over time.

CBS leverages an interruptible energy sales program to reduce load when needed to avoid using diesel generation and to otherwise sell power to customers at a reduced rate while decreasing the amount of greenhouse gas emissions and fuel oil used for heating in the community. Interruptible loads are mostly CBS-owned electric boilers that are shut down when the generation capacity is close to or below power demand at a given time. Currently, two municipal buildings, four school buildings, and the post office have been upgraded to utilize interruptible electric boilers for building heat.

Potential Renewable Energy Generation

Several promising renewable energy resources are available to Sitka. The resource potential and development considerations for wind, solar, geothermal, wave, and tidal energy are discussed in this section. Additional hydropower generation at Takatz Lake has been considered by CBS and was not analyzed as part of this scope.

Wind

Wind is the most promising renewable energy resource for CBS to develop in the near term (next 5–10 years). Both wind observations and models were considered when analyzing options, as outlined in the sections below.

Turbine Options

Analysis of the wind resource at Sitka and discussions with the City of Sitka yielded the following desired wind turbine criteria:

- International Electrotechnical Commission (IEC) 1A wind class
- Direct drive technology
- 3–6 MW turbine size.

The IEC wind class of 1A is desired so that the selected turbine will be able to withstand the extreme winds and turbulence in the complex terrain of the Sitka area. The City of Sitka indicated an interest in using turbines designed for offshore environments due to their ability to withstand extreme conditions. Direct drive technology is desired to reduce maintenance and repair events in an area challenging to access. Large-capacity wind turbines are desired due to the future growth of Sitka's energy needs. Deployment of wind turbines in the 3–6 MW range would be unprecedented, because no similar turbines are currently online in Alaska. PNNL investigated wind turbines currently available for purchase and deployment in the United States (Table 1) and selected the Siemens Gamesa SWT-6.0-154 as the turbine model for simulating generation because it meets the desired criteria.

Table 1. Wind Turbine Models Considered for Sitka Deployment.

Manufacturer	Model	Design	IEC Wind Class	Technology	Rated Capacity
Vestas	V112-3.45	Onshore	1A	Gearbox	3.45 MW
Vestas	V150-6.0	Onshore	S	Gearbox	6.00 MW
Siemens Gamesa	SG 5.0-132	Onshore	1A	Gearbox	5.00 MW
Siemens Gamesa	SWT-6.0-154	Offshore	1A, S	Direct Drive	6.00 MW
GE	4.2-117	Onshore	1A	Gearbox	4.20 MW
GE	Haliade 150-6	Offshore	1B	Direct Drive	6.00 MW
GE	Sierra-154	Onshore	S	Gearbox	3.60 MW
Goldwind	GW165-5.6	Onshore	S	Direct Drive	5.60 MW
Goldwind	GW165-5.2	Onshore	S	Direct Drive	5.20 MW
Goldwind	GW136-4.8	Onshore	IIB	Direct Drive	4.80 MW
Goldwind	GW155-4.5	Onshore	IIIB	Direct Drive	4.50 MW
Goldwind	GW140-3.4	Onshore	IIIA,B	Direct Drive	3.40 MW
Goldwind	GW140-3.57	Onshore	IIIB	Direct Drive	3.57 MW
Nordex	N163/6	Onshore	TBD	Gearbox	6.00 MW
Nordex	N155/4.5	Onshore	S	Gearbox	4.50 MW
Nordex	N133/4.8	Onshore	S	Gearbox	4.80 MW

The SWT-154-6.0 is equipped with a High Wind Ride Through system that allows slow ramp down at wind speeds exceeding 25 m/s instead of the typical complete shutdown that occurs during extreme winds. We simulate the High Wind Ride Through feature by mirroring the steep portion of the SWT-6.0-154 power curve (The Wind Power 2022) for wind speeds above 25 m/s (Figure 3).

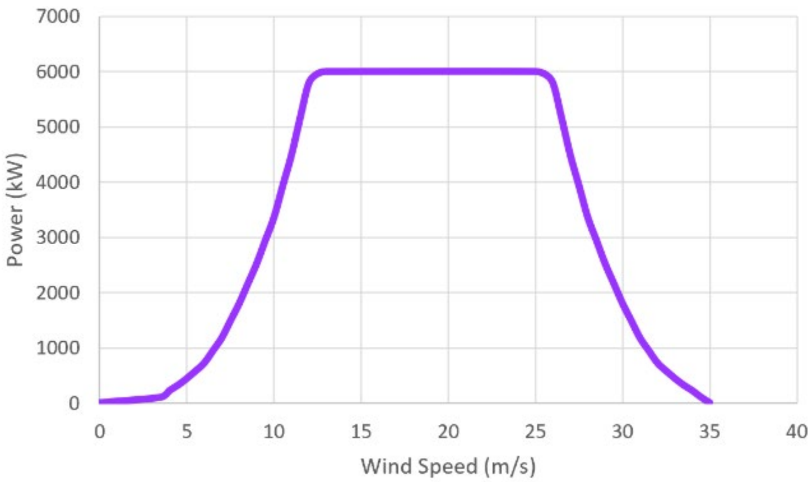

Figure 3. Siemens Gamesa SWT-6.0-154 power curve (The Wind Power 2022) with simulated High Wind Ride Through.

Observations

Wind observations in the Sitka area are present but are located far from areas of wind deployment interest and at heights much lower than typical turbine hub heights (> 80 m), as shown in Table 2. Therefore, these observations are used to characterize average, high, and low wind resource years, evaluate the predominant wind directions, and assess the local wind resource according to time of year and time of day. Additionally, temperature and pressure measurements at the low-elevation airport station and high-elevation Harbor Mountain station are used to establish temporally varying air density profiles that are applied to the wind speed timeseries discussed in the following Models section before conversion to power estimates.

Table 2. List of observations near Sitka.

Observation	Location	Height	Elevation
Airport	57.0471°, -135.3616°	10 m	2 m
Station STXA	57.116°, -135.391°	10 m	9 m
Station SHXA	57.055°, -135.349°	10 m	0 m
Harbor Mountain	57.089050°, -135.34399°	2 m	667 m

Models

Since the wind observations in the Sitka area are far from the locations of wind development interest and not close to typical turbine hub heights, models are employed to estimate the on-site hub height wind resource. The models that provide coverage in the Sitka area fall into one of two categories: (1) high spatial resolution but low temporal resolution or (2) high temporal resolution but low spatial resolution. High spatial resolution is needed to represent the wind resource as it follows the local terrain, which is especially complex in the Sitka region. High temporal resolution is needed to understand the wind resource as it changes seasonal, diurnally, and on much shorter timescales to facilitate assessment of events important to load management, such as ramp events.

The wind resource estimates for Sitka begin with the European Centre for Medium-Range Weather Forecasts (ECMWF) Reanalysis v5 (ERA5) (ECMWF 2022) to provide long-term hourly trends in wind speed and direction (Table 3). ERA5 is geographically one of the coarsest models of our analysis suite but provides the decades of simulated wind speeds that are essential for setting seasonal and diurnal expectations for average, high, and low wind resource years (Table 3).

Early release wind resource data from NREL's upcoming WIND Toolkit LED (WTK-LED) product were used as preliminary data for the 5-minute data required in Sitka grid simulations. Data for the last 6 months of 2018 in Alaska were available for high temporal frequency assessment at the writing of this report (Table 3).

Global Wind Atlas 3 (GWA3) (DTU 2022) offers the highest spatial detail of our analysis suite (0.25 km resolution), enabling improved representation of local wind variation and influences, like terrain features (Table 3). GWA3 is less comprehensive temporally, however, outputting wind information annually for a range of 10 years and seasonally and diurnally for the average of all years. Similarly, Wind Report, a wind resource assessment tool developed by Bergey WindPower Co. and 3Tier, provides annual average wind resource estimates (Table 3) (Bergey WindPower Co. 2022).

The Modern-Era Retrospective analysis for Research and Applications version 2 (MERRA-2) (NASA 2022) is a geographically coarse model that we consulted for supplemental information on the seasonal, diurnal, direction-dependent, and interannual wind resource in the Sitka area (Table 3).

To maximize both spatial and temporal resolution for the wind resource assessment and generation simulations, three models (ERA5, WTK-LED, and GWA3) were employed in the following manner. Using the grid cell that overlaps with the site of interest from the high-spatial-resolution GWA3, the high-temporal-resolution wind speeds from ERA5 and WTK-LED were scaled to each site of interest via Eq. 1:

$$v_{site} = v_{ERA5/WTK} \cdot \frac{\overline{v_{GWA3}}}{\overline{v_{ERA5/WTK}}} \tag{1}$$

where $\overline{v_{GWA3}}$ is the mean wind speed from GWA3 at the location of interest and $\overline{v_{ERA5/WTK}}$ is the mean wind speed from ERA5 or WTK-LED. Eq. 1 was applied for the ERA5-based runs using the annual GWA3 estimates. Because only half a year of WTK-LED data were available, Eq. 1 was applied monthly for the WTK-based analysis for the grid simulation. Because only one ERA5 grid point is near the proposed Sitka wind project locations, wind speeds from that single point were utilized in Eq. 1. The higher-spatial-resolution WTK-LED wind speeds were extracted by applying inverse distance weighted interpolation from the four surrounding grid points to each project location.

The output height nearest to current industry average turbine hub heights and common to all three models, 100 m, was selected for evaluation to avoid potential additional errors resulting from vertical extrapolation techniques. Because power curves are typically developed at an air density of 1.225 kg/m^3 before converting wind speeds to power, the 100 m wind speeds were adjusted for the local and temporally varying density using the following calculation:

$$v_{adjusted} = v_{site} \cdot \left(\frac{density}{1.225\ kg/m^3}\right)^{1/3} \tag{2}$$

Table 3. Characteristics of the models that provided wind resource data for this assessment.

Model	ERA5	GWA3	WTK-LED	MERRA-2	Wind Report
Developer	European Centre for Medium-Range Weather Forecasts	Technical University of Denmark Wind Energy, World Bank Group	National Renewable Energy Laboratory	National Aeronautics and Space Administration	Bergey WindPower Co./3Tier
Temporal Coverage	1950–present	2008–2017	July–December 2018*	1979–present	Unknown
Temporal Output Frequency	1-hour	1-year	5-minute	1-hour	Annual average
Horizontal Spatial Coverage	Global	Global	CONUS, Alaska	Global	Global
Horizontal Grid Spacing	0.25°	0.25 km	2 km	0.5°	5 km
Wind Speed Output Heights	10 m, 100 m	10 m, 50 m, 100 m, 150 m, 200 m	10 m, 20 m, 40 m, 60 m, 80 m, 100 m, 120 m, 140 m, 160 m, 180 m, 200 m	10 m, 50 m	User supplied
Nearest Grid Point to Proposed Wind Sites	57.00°, -135.25° (near Leesoffskaia Bay)	Within 0.25 km of each of the seven proposed turbine locations	Within 2 km of each of the three proposed wind site locations	57.00°, -135.25° (near Green Lake)	Within 5 km of analysis location

** At the time of this report, July–December 2018 is available for WTK-LED at Alaska. Eventually, the temporal coverage period will be 2000–2020.*

It is useful to note that both high-temporal-resolution products, ERA5 and WTK-LED, generally perform consistently, with a correlation of 0.89 during the overlapping data coverage period of July–December 2018 (Figure 4). WTK-LED shows more variability in the wind resource, but both products capture the same overall trends. The dropoff in wind speeds at a height of 100 m during late November and early December, an event that would be highly significant to wind plant operators, is particularly well-represented by both ERA5 and WTK-LED.

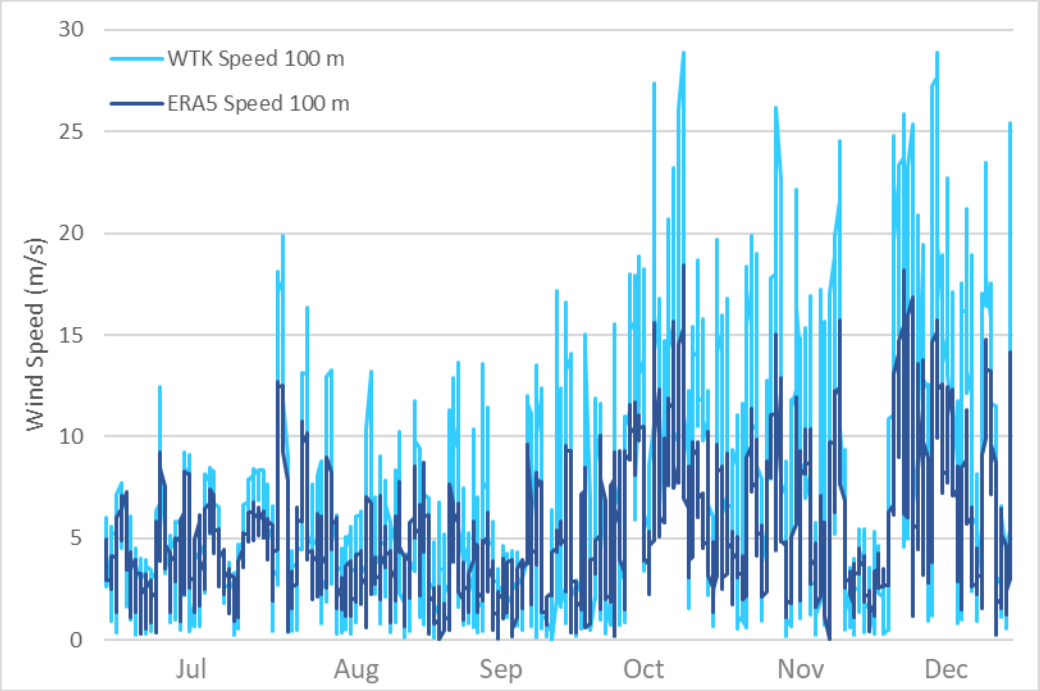

Figure 4. Timeseries of ERA5 and WTK 100 m wind speeds during the overlapping period of July–December 2018 at the location of the nearest ERA5 grid point to Sitka (57.00°, -135.25°).

As with any model, biases exist. The analysis shared with the Sitka team on 17 February 2022 revealed discrepancies between observations and four wind models from 2–3 m/s in the vicinity of Sitka (Table 4).

Table 4. Discrepancy in annual average wind resource across observations and models near Sitka.

Site	Location	Height	# of Observations	# of Models	Discrepancy in Annual Average Wind Speed
Sitka Airport	57.0481°, -135.3647°	10 m	1	2	2.1 m/s
STXA2 Station	57.116°, -135.391°	10 m	1	2	3.1 m/s
SHXA2 Station	57.055°, -135.349°	10 m	1	2	3.4 m/s
Harbor Mountain	57.08905°, -135.344°	2 m	1	1	2.2 m/s
Nearest ERA5	57.0°, -135.25°	10 m	0	3	3.4 m/s
Nearest ERA5	57.0°, -135.25°	100 m	0	3	2.9 m/s
Nearest MERRA-2	57.0°, -135.0°	10 m	0	3	3.1 m/s
Nearest MERRA-2	57.0°, -135.0°	50 m	0	3	3.1 m/s

Loss Recommendations

Wind energy sites are subject to generation loss for a variety of reasons, ranging from availability to turbine array waking and environmental loss. The loss recommendations for the proposed Sitka wind sites (see below) are detailed in Table 5. Loss due to turbine performance is presumed to be small, assuming that current advanced technology wind turbines are selected for deployment. Environmental loss is assumed to be high, given the challenging weather experienced in the mountainous and coastal environment of Sitka and based on our conversations with the operator of the Kodiak Island Pillar Mountain Wind Farm, who relayed that wind-driven heavy precipitation events negatively affected turbine generation.

Table 5. Categorized loss assumptions for Sitka wind projects. The single turbine assumptions are recommended for the proposed Beaver Lake deployment site, and the multiple turbine assumptions are recommended for Lucky Chance and Starrigavan Ridge.

Loss Category	Typical Range	Notes	Sitka Assumption (Single Turbine)	Sitka Assumption (Multiple Turbines)
Availability	4–6%	Downtime for maintenance	4%	4%
Wake (Array)	0–15%	Dependent on quantity of turbines and arrangement	0%	5%
Turbine Performance	1–3%	Assume high performance	1%	1%
Electrical	2–3%	Standard electrical losses	2%	2%
Environmental	1–10%	Assume weather may disrupt production, like the experience with wind-driven heavy precipitation reported by the Pillar Mountain project on Kodiak Island	10%	10%
Curtailment	0–3%	Excess production desired	0%	0%
Total	12–25%		17%	22%

Wind Speed and Generation Assessment

The cut-in wind speed, typically around 3 m/s, is the lowest wind speed at which a wind turbine can generate power. Considering this constraint and wind energy investment costs, project developers typically advise that average annual wind speed minimums of 4 m/s at 30 m (DOE 2012) and 6.5 m/s at 80 m (DOE 2011) are required for feasible wind energy project deployment. Extrapolating these rules of thumb to 100 m means that a 7.5 m/s minimum annual average wind speed at 100 m is required to facilitate a feasible wind project using wind turbines at that hub height.

Five locations of interest for potential wind deployment were initially assessed for their resource suitability (Figure 5). GWA3 analysis suggests that all five locations exceed this minimum wind speed threshold—therefore, no sites were removed from the assessment due to wind resource quality.

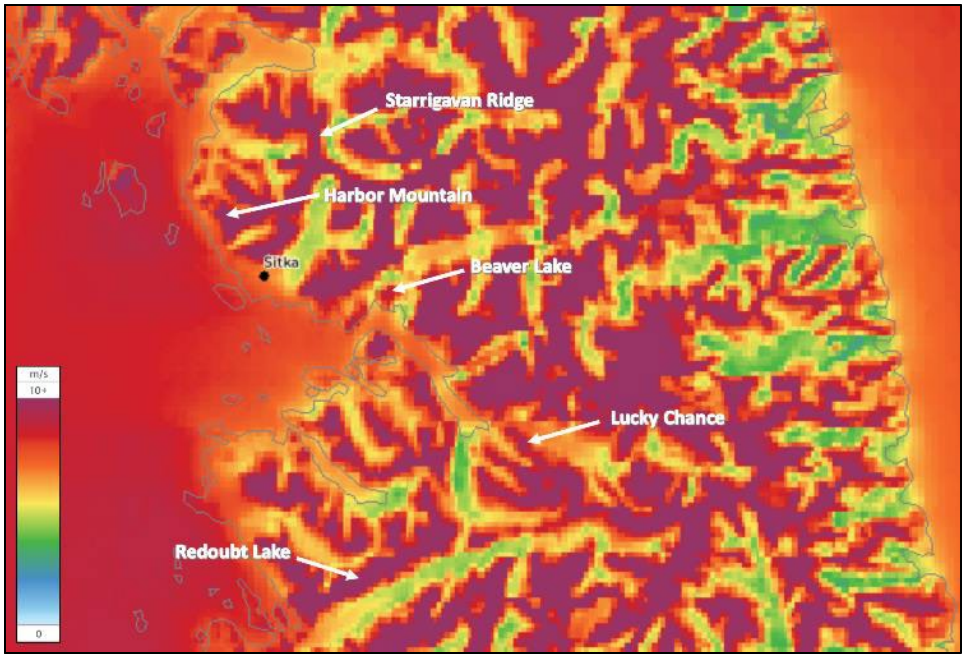

Figure 5. Original areas of interest for wind energy deployment with Global Wind Atlas 100 m annual average wind speeds.

Further investigation from the City of Sitka narrowed the selection down to three potential locations for wind deployment: Beaver Lake (single turbine), Lucky Chance (three turbines), and Starrigavan Ridge (three turbines) (Figure 6). The simulated wind speeds and gross and net energy generation expectations (assuming the 6 MW Siemens Gamesa SWT-6.0-154 turbine model) are provided in Table 6. Starrigavan Ridge produces the highest wind speeds (and thus the highest wind generation expectations), followed by Lucky Chance and then Beaver Lake with the lowest wind speeds of the proposed deployment locations.

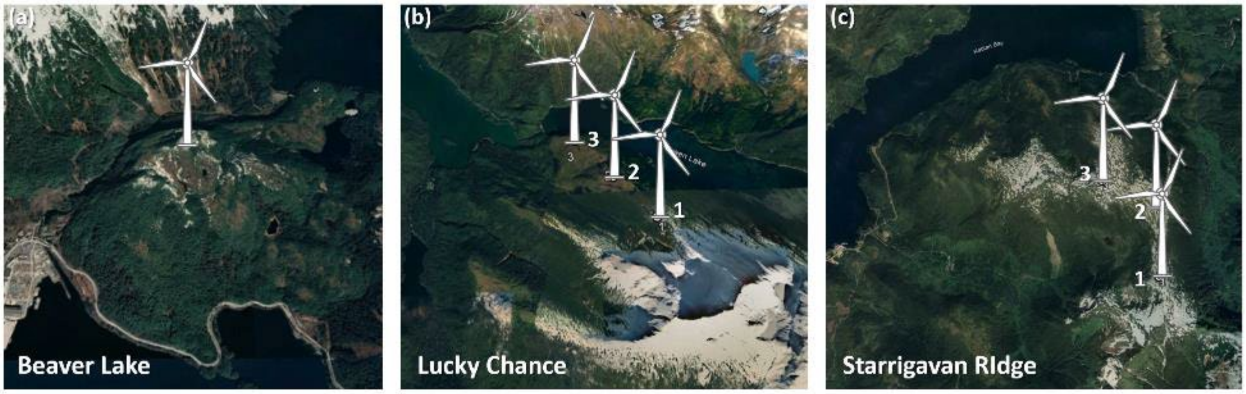

Figure 6. Locations of proposed wind deployment at (a) Beaver Lake, (b) Lucky Chance, and (c) Starrigavan Ridge.

Table 6. Annual average wind speed and gross and net wind energy generation estimates for an average wind resource year at each proposed wind site based on ERA5 and WTK-LED wind resource data, assuming the 6 MW Siemens Gamesa SWT-6.0-154 turbine model.

Site	Turbine	Coordinates	100 m Annual Average Wind Speed (m/s)	Gross Annual Generation (kWh)	Net Annual Generation (kWh)
Beaver Lake	1	57.055686°, -135.213558°	8.54	20,974,000	17,408,400
Lucky Chance	1	56.968528°, -135.079717°	9.43	23,671,000	18,463,400
Lucky Chance	2	56.975692°, -135.091780°	9.66	24,398,700	19,031,000
Lucky Chance	3	56.982909°, -135.103089°	9.11	22,821,600	17,800,900
Starrigavan Ridge	1	57.122373°, -135.282411°	11.11	27,991,400	21,833,300
Starrigavan Ridge	2	57.134065°, -135.282606°	11.18	28,121,300	21,934,600
Starrigavan Ridge	3	57.137731°, -135.298656°	11.60	29,021,000	22,636,400

Wind Speed Expectations at Meteorological Towers

The City of Sitka is deploying two 10 m meteorological towers at the proposed locations of Beaver Lake and Lucky Chance in order to perform wind resource assessments and to validate the 10 m GWA3 wind estimates. For future comparison purposes, the 10 m wind speed estimates for average, high, and low wind resource years from GWA3 at the meteorological tower locations are provided in Table 7.

Table 7. 10 m wind speed expectations at the meteorological tower deployment locations at Beaver Lake and Lucky Chance.

Wind Resource Year	Beaver Lake Average (m/s)	Beaver Lake High (m/s)	Beaver Lake Low (m/s)	Lucky Chance Average (m/s)	Lucky Chance High (m/s)	Lucky Chance Low (m/s)
Annual	*7.50*	*7.95*	*6.75*	*7.94*	*8.42*	*7.07*
January	11.63	12.32	10.46	12.15	12.88	10.81
February	9.68	10.26	8.71	10.08	10.69	8.97
March	8.48	8.98	7.63	8.97	9.51	7.99
April	6.30	6.68	5.67	6.67	7.07	5.94
May	5.55	5.88	5.00	6.19	6.56	5.51
June	4.50	4.77	4.05	5.16	5.47	4.59

Wind Resource Year	Beaver Lake Average (m/s)	Beaver Lake High (m/s)	Beaver Lake Low (m/s)	Lucky Chance Average (m/s)	Lucky Chance High (m/s)	Lucky Chance Low (m/s)
July	3.75	3.98	3.38	4.29	4.54	3.82
August	4.05	4.29	3.65	4.53	4.80	4.03
September	7.05	7.47	6.35	7.07	7.49	6.29
October	9.08	9.62	8.17	9.37	9.93	8.34
November	9.98	10.57	8.98	10.00	10.60	8.90
December	10.13	10.73	9.11	10.88	11.53	9.68

Comparing the 100 m estimates in Table 6 with the 10 m estimates in Table 7, the 100 m/10 m GWA3 scaling factors are 1.14 for Beaver Lake and 1.24 for Lucky Chance. However, because model bias is generally not consistent across the wind profile, it should not be assumed that the model error seen at 10 m is indicative of model error at 100 m.

Wind Direction Assessment

Wind direction is an important consideration for wind energy deployment, especially for appropriate turbine siting. Multiple sources of observed and modeled wind direction were consulted to produce the geographically mapped wind roses in Figure 7. For coastal locations, the wind tends to follow the coastline, sourcing mainly from the southeast. Inland, in the highly complex terrain, wind directions are less consistent, with representation across much of the wind rose.

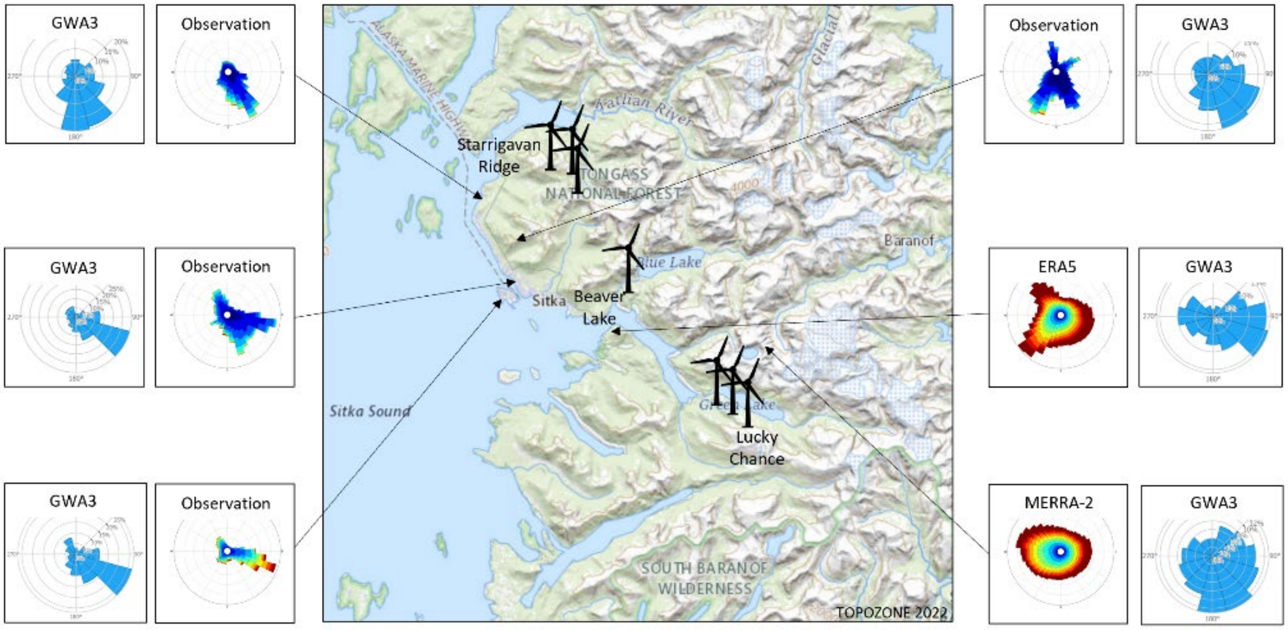

Figure 7. Observed and modeled wind directions near Sitka.

Interannual Wind Resource and Generation

In addition to an average wind resource year, it is imperative to set generation expectations for high and low wind resource years. Based on long-term analysis of wind speed observations and model estimates in the Sitka area, 2008 was determined to be a high wind resource year and 2013 was identified as a particularly low wind resource year for the region. Like the average wind resource year, analysis of ERA5 and WTK-LED wind speeds during these extreme years was performed, with the generation expectations provided in Table 8.

Table 8. Annual average wind speed and gross and net wind energy generation estimates for high and low wind resource years at each proposed wind site based on ERA5 and WTK, assuming the 6 MW Siemens Gamesa SWT-6.0-154 turbine model.

Site	Turbine	Wind Resource Year	Annual 100 m Wind Speed (m/s)	Gross Annual Generation (kWh)	Net Annual Generation (kWh)
Beaver Lake	1	High	9.05	23,232,100	19,282,700
		Low	7.69	18,024,600	14,960,400
Lucky Chance	1	High	10.00	25,725,000	20,065,500
		Low	8.39	20,405,900	15,916,600
Lucky Chance	2	High	10.24	26,378,600	20,575,300
		Low	8.60	21,149,200	16,496,400
Lucky Chance	3	High	9.66	24,952,800	19,463,200
		Low	8.11	19,541,300	15,242,200
Starrigavan Ridge	1	High	11.78	29,499,800	23,009,900
		Low	10.00	25,287,300	19,724,100
Starrigavan Ridge	2	High	11.85	29,614,400	23,099,200
		Low	10.06	25,435,100	19,839,400
Starrigavan Ridge	3	High	12.30	30,402,300	23,713,800
		Low	10.44	26,494,100	20,665,400

Seasonal and Diurnal Wind Resource and Generation

At many locations, wind speed follows trends according to time of year and time of day. Using wind speed observations and the models described previously, the seasonal and diurnal trends in the wind resource near Sitka were depicted (Figure 8). While winds tend to be steady throughout the day, a noticeable pattern according to season is identified, with the fastest winds in the winter and the slowest winds in the summer.

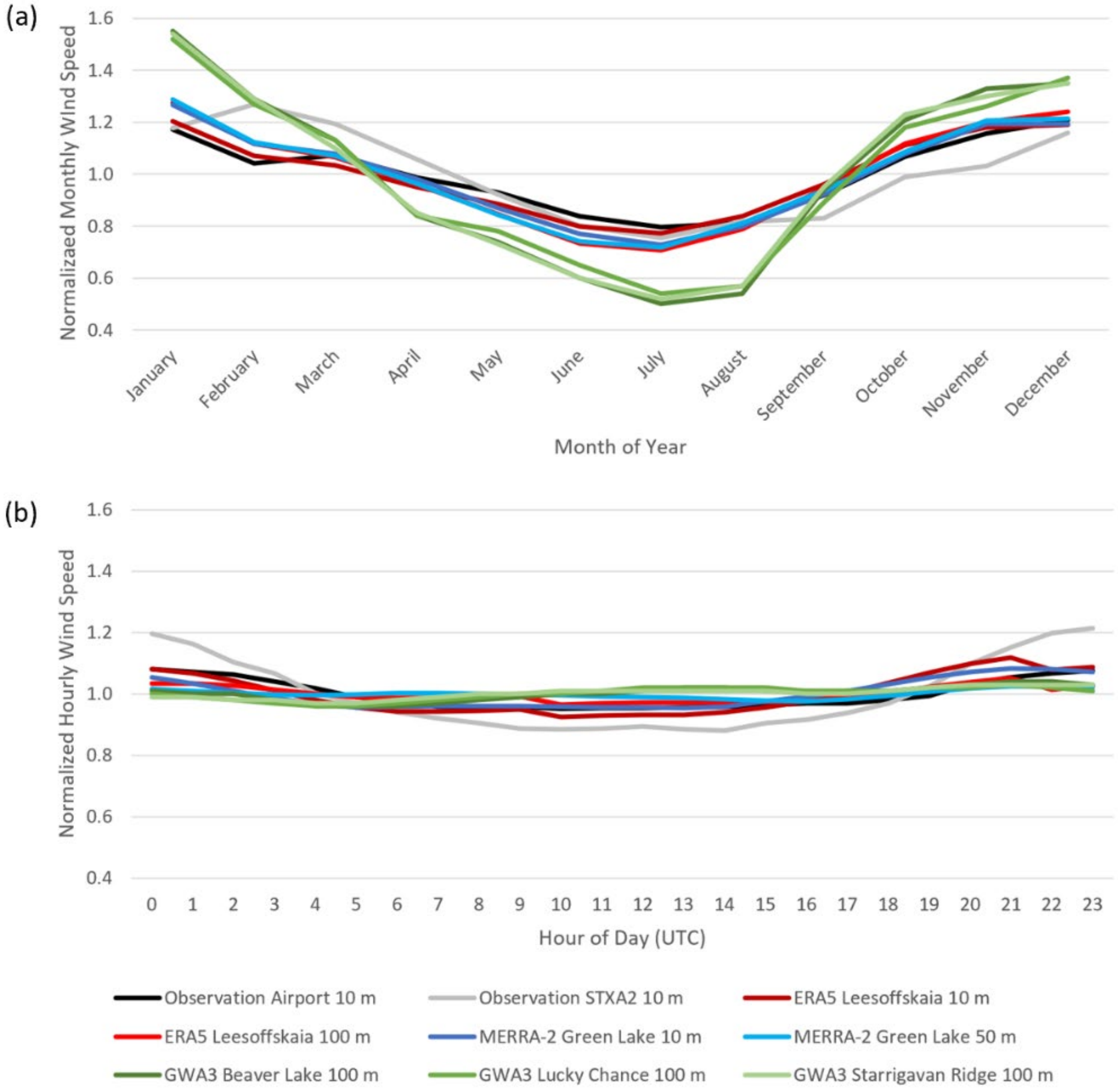

Figure 8. (a) Seasonal and (b) diurnal trends in the wind resource near Sitka from nearby observations and models.

To examine the impact of the seasonal cycle on wind generation, the gross and net wind generation expectations according to month for an average wind resource year are provided in Table 9 and Table 10, respectively, for each selected location.

Table 9. Gross simulated wind generation by month for an average wind resource year, assuming the 6 MW Siemens Gamesa SWT-6.0-154 turbine model.

Site→ Month↓	Beaver Lake	Lucky Chance 1	Lucky Chance 2	Lucky Chance 3	Starrigavan Ridge 1	Starrigavan Ridge 2	Starrigavan Ridge 3
January	2,538,500	2,705,000	2,741,100	2,655,800	2,807,300	2,806,000	2,786,100
February	1,756,800	1,884,500	1,915,100	1,846,900	2,024,400	2,027,900	2,055,200
March	2,275,700	2,598,700	2,683,700	2,498,500	3,070,100	3,082,000	3,162,600
April	1,293,400	1,522,300	1,587,800	1,447,900	1,949,400	1,963,200	2,060,400
May	1,510,200	1,735,500	1,798,700	1,663,800	2,155,800	2,170,400	2,270,400
June	1,414,000	1,666,100	1,734,300	1,586,300	2,086,000	2,100,100	2,199,900
July	706,800	883,500	935,300	826,000	1,226,400	1,238,800	1,331,400
August	1,586,900	1,882,200	1,967,300	1,786,900	2,431,300	2,449,800	2,582,400
September	1,355,300	1,575,800	1,643,100	1,501,400	2,014,000	2,028,500	2,135,300
October	1,996,000	2,202,700	2,261,700	2,136,700	2,591,200	2,603,500	2,687,900
November	2,241,000	2,492,700	2,556,000	2,416,000	2,851,700	2,862,500	2,939,100
December	2,299,300	2,522,000	2,574,500	2,455,600	2,783,800	2,788,600	2,810,300

Table 10. Net simulated wind generation by month for an average wind resource year, assuming the 6 MW Siemens Gamesa SWT-6.0-154 turbine model.

Site→ Month↓	Beaver Lake	Lucky Chance 1	Lucky Chance 2	Lucky Chance 3	Starrigavan Ridge 1	Starrigavan Ridge 2	Starrigavan Ridge 3
January	2,107,000	2,109,900	2,138,060	2,071,500	2,189,700	2,188,700	2,173,100
February	1,458,200	1,469,900	1,493,800	1,440,600	1,579,000	1,581,700	1,603,100
March	1,888,800	2,027,000	2,093,300	1,948,800	2,394,700	2,404,000	2,466,800
April	1,073,500	1,187,400	1,238,500	1,129,300	1,520,500	1,531,300	1,607,100
May	1,253,500	1,353,700	1,403,000	1,297,800	1,681,500	1,692,900	1,770,900
June	1,173,600	1,299,500	1,352,800	1,237,400	1,627,100	1,638,100	1,715,900
July	586,700	689,100	729,500	644,200	956,600	966,300	1,038,500
August	1,317,200	1,468,100	1,534,500	1,393,700	1,896,400	1,910,900	2,014,300
September	1,124,900	1,229,100	1,281,600	1,171,100	1,570,900	1,582,200	1,665,500
October	1,656,700	1,718,100	1,764,200	1,666,600	2,021,100	2,030,700	2,096,600
November	1,860,000	1,944,300	1,993,700	1,884,500	2,224,300	2,232,800	2,292,500
December	1,908,400	1,967,100	2,008,100	1,915,300	2,171,400	2,175,100	2,192,000

Wind Installation and Operations and Maintenance Costs

The sample size of wind energy projects in Alaska is small, with only 64 MW of land-based wind using turbines greater than 100 kW deployed as of 2021 (Wiser et al. 2022). For comparison, Texas has nearly 36,000 MW of wind deployed as of 2021. The small sample size of projects with variable cost data availability combined with the current uncertainty around supply chain availability and shipping costs in the wake of the global COVID-19 pandemic yield uncertainty in the cost expectations for deploying wind energy at Sitka.

The following analysis presents ranges of recent national wind cost reports from the Land-Based Wind Market Report: 2022 Edition (Wiser et al. 2022) (Table 11). Because no large-scale wind projects were deployed in Alaska during the last couple of years, the current continental United States ranges of cost expectations are adjusted to Alaska using historical ratios of Alaskan wind project costs, including in remote locations similar to Sitka, to continental costs. For example, the three-turbine second phase of the Pillar Mountain wind project on Kodiak Island was deployed in 2012 with an estimated installed cost of $23,150,000, or $5,144/kW, which is 2.24 times the continental average installed cost in 2012, $2,285/kW (Wiser et al. 2022). The 2021 continental installed cost range, which includes turbine purchase and installation, balance of plant, and substation and/or interconnection expenses (Wiser et al., 2022), is scaled with the 2.24 ratio to estimate current installation costs for remote Alaska, yielding a range of approximately $2,250–4,500/kW (Table 11). It is important to note that the installation costs could be even higher than the projected range due to the large size of the desired turbines, which is unprecedented in Alaska, and the complex terrain of the Sitka region.

VanderMeer et al. (2017) present a wide range of wind energy O&M costs in Alaska, with an average of $0.036/kWh across their sample and an average of ~$0.02/kWh for projects with annual wind generation ≥ 10 GWh/year. Combining the ranges of estimated wind generation in Table 8 with the average of $0.02/kWh for high-producing projects compiled by VanderMeer et al. (2017) produces an expected O&M cost range of ~$45–80/kW/year (Table 11).

Table 11. Wind installation and O&M cost estimates.

Cost	Source	Cost Range for the Continental United States	Sitka Expectation	Comments
Turbine Cost	2021 Wind Turbine Prices, Land-Based Wind Market Report: 2022 Edition	~$800–950/kW	~$800–950/kW	Turbine model dependent
Total Installed Cost (including turbine cost)	2021 Installed Project Costs, Land-Based Wind Market Report: 2022 Edition	~$1,000–2,000/kW	~$2,250–4,500/kW	2021 installed costs adjusted up from continental range using the 2012 ratio of Pillar Mountain to continental average installed costs

Cost	Source	Cost Range for the Continental United States	Sitka Expectation	Comments
O&M Cost	2021 O&M Costs for Turbines Deployed in 2020, Land-Based Wind Market Report: 2022 Edition Wind power project size and component costs: An Alaska case study, VanderMeer et al., 2017	$8–38/kW/year	~$45–80/kW/year	O&M costs in Alaska can be more than double the costs in the lower 48

Given these cost ranges and a 25-year project life, it is estimated that wind serving Sitka will have a levelized energy cost of approximately 8.6–16.7¢/kWh.

Wind Deployment Recommendations and Next Steps

From a generation standpoint, PNNL identifies Lucky Chance as the most optimal of the three sites considered for wind energy deployment due to abundant wind resource and land availability for multiple turbines (Table 12). Although they provide the most plentiful wind resource, the three potential turbine locations evaluated atop Starrigavan Ridge are not recommended for wind deployment because the annual mean wind speed for an average wind resource year (> 11 m/s) is estimated to exceed the maximum annual mean wind speed for IEC class I turbines (10 m/s) (Pryor and Barthelmie 2021). Beaver Lake, while limited to single turbine deployment due to land availability, has adequate wind resource for wind energy deployment and is the most optimal location for transmission. The ETIPP team recommends advancing Lucky Chance and Beaver Lake to the next stages of deployment evaluation. The ETIPP team does not recommend consideration of the proposed locations atop Starrigavan Ridge for wind deployment.

Table 12. Recommendations for proposed Sitka wind deployment locations.

Proposed Wind Site	Number of Turbines	Wind Resource	Transmission	Recommendation
Beaver Lake	1	Abundant	Optimal	Proceed with deployment consideration
Lucky Chance	3	Optimal	Challenging	Proceed with deployment consideration
Starrigavan Ridge	3	Too high	Challenging	Discontinue deployment consideration

CBS is already collecting wind resource data at Beaver Lake and Lucky Chance at 10 m above ground level, which is beneficial for assessing model wind speed performance at this height but should not be considered representative of model performance at turbine hub height. Given the level of investment involved in deployment of utility-scale wind turbines and the limitations of wind models in the complex coastal terrain around Sitka, PNNL recommends, if at all possible, the gathering of on-site wind resource observations near turbine hub height (80 m – 120 m) through the means of taller meteorological towers or lidars to refine hub height wind speed estimates. Lidars in particular are beneficial for wind resource assessment as they allow for analysis at a variety of potential turbine hub heights and can be moved to multiple sites of turbine deployment interest. Lidar costs have dropped significantly in recent years and are found to be cost competitive alternatives to meteorological towers, with the additional benefit of avoiding tower construction. Dodd (2018) reported that purchasing and installing a 100-m meteorological tower in the U.S. cost between \$80,000 and \$130,000. For their wind farm study, Bakhshi and Sandborn (2020) utilized a lidar system that cost \$120,000. If CBS decides to proceed with wind energy deployment, the next recommended steps include assessment of wildlife risks, procurement of financing, and selection of equipment and construction providers.

Solar

Rooftop-mounted solar photovoltaic (PV) systems are a viable option for renewable energy generation in Sitka. However, installing PV is not a priority because PV potential represents a small percent of the city's total demand. PV potential is limited by available roof space and low solar resource potential at high latitudes.

Solar Resource

Sitka has an average annual global horizontal solar irradiance of approximately 2.5 kWh/m^2/day. This is one of the lowest annual averages in the U.S. due to both the city's high latitude (resulting in few daylight hours and low sun angles in winter) and its marine climate (which results in frequent cloudy skies). However, solar PV still generates electricity in this region and can be cost-competitive with local electric rates, especially diesel-fueled electricity. Figure 9 shows the average solar radiation and estimated electrical output per kW of PV capacity per month in Sitka using the system assumptions in Table 13. The solar resource and potential PV output in Sitka peaks in May and is lowest in December.

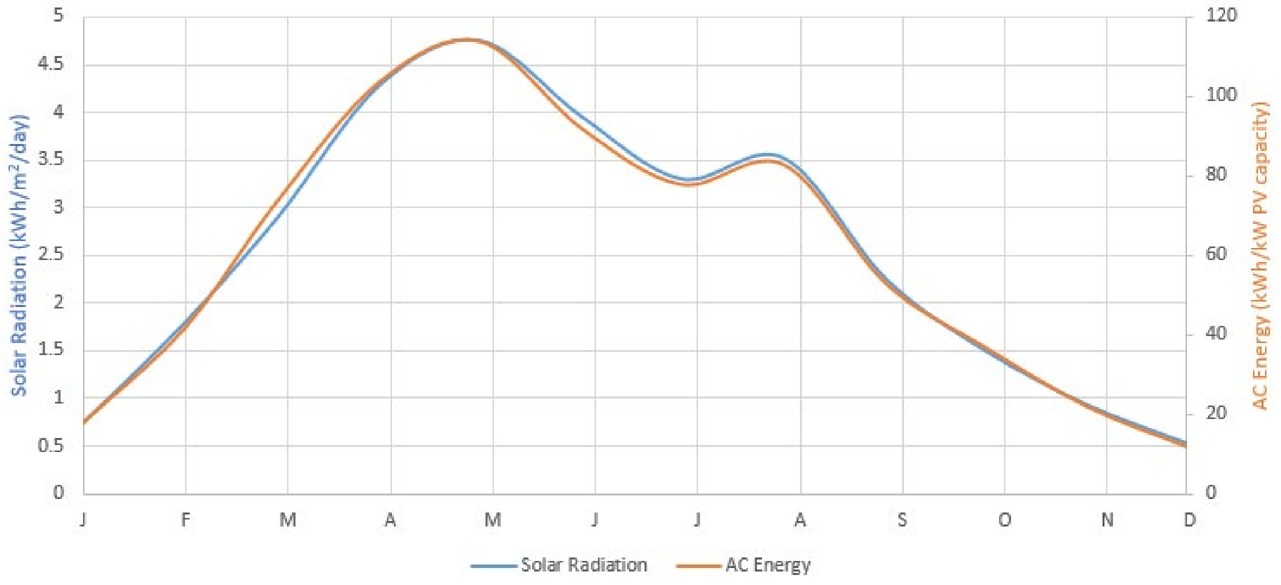

Figure 9. Sitka, AK, monthly estimated average solar radiation and AC energy output per kW PV capacity.

Potential Locations

Solar PV can be mounted on the ground, roofs, or parking structures. CBS directed the ETIPP team to consider fourteen publicly owned buildings in Sitka for rooftop PV, as publicly owned buildings fall within CBS purview. The focus of the study was kept on small-scale systems that can provide resilience to individual or small groups of buildings if paired with a battery. Large-scale solar PV that would produce enough power to sufficiently supplement hydropower to meet future loads would require hundreds of acres of unshaded land.

Large roofs, flat roofs, and roofs with minimal equipment are preferable locations for PV installation. If a roof is sloped, only the southern-facing portion of the roof was considered for PV. If a flat roof consists of multiple areas and/or levels, only the main, highest surface was considered for PV. Table 13 shows the 14 buildings considered for PV, approximate available roof area estimated from satellite images, and approximate capacity of PV that could fit on the roof. Panel space requirements were estimated using the NREL PVWatts® tool[1] assumption of 0.15 kW/m^2. Appendix A contains satellite images of each building considered.

Table 13. Buildings evaluated for rooftop PV potential

Building Number	Building Name	Approximate Available Roof Area (m^2)	Approximate PV Capacity (kW)*	Notes
600-B3	PSC Office & Warehouse	874	131	Sloped roof, only south side is suitable.
600-B4	PSC Pole Barn	428	64	Sloped roof, only south side is suitable.
600-B5	PSC Electric Warehouse, Shop	472	71	Sloped roof, only south side is suitable.
705	Blue Lake Powerhouse	0	0	Not shown on satellite map. From the image provided, the building does not appear to have great PV potential because the roof has multiple heights and the building is surrounded by trees, which causes shading.
510	City-State Building	1,338	201	Flat roof, minimal rooftop equipment.
550	Baranof Elementary School	2,560	384	Flat roof, minimal rooftop equipment.
450	City Hall	471	71	Flat roof, minimal rooftop equipment. Recommend top tier only.
483	Harrigan Centennial Hall	820	123	Mixed roof type—both sloped and flat with tiers. Recommend top flat part only.
535-S1	Crescent Harbor Fisherman Shelter	0	0	Do not recommend due to north-south configuration of building.
415	Marine Services Center Building	1,740	261	Flat, square roof.
500	Sitka High School	5,685	853	Flat roof, minimal rooftop equipment.
460	Blatchley Middle School	5,000	750	Flat roof, minimal rooftop equipment.

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[1] https://pvwatts.nrel.gov/

Building Number	Building Name	Approximate Available Roof Area (m^2)	Approximate PV Capacity (kW)*	Notes
320	Keet Goshi Heen Elementary School	1,290	194	Sloped roof, only south side is suitable.
800	Airport Terminal Building	825	124	Flat roof, minimal rooftop equipment.
TOTAL		**21,503**	**3,225**	

*Assuming 0.15 kW/m^2

The Public Service Center (PSC) Office and Warehouse (Building #600-B3) was identified by CBS to be the most likely building to first receive rooftop PV. Using the assumptions in Table 14, the PSC Office and Warehouse building was determined to have the potential for a 131 kW PV system with an estimated annual energy output of 96 MWh/yr.

Table 14. PSC Office and Warehouse PV assumptions and analysis.

Parameter	Value	Notes
Approximate available roof area	874 m^2	From satellite imagery
Approximate PV capacity	131 kW	PVWatts® assumes 0.15 kW/m^2
Module type	Standard	
Array type	Fixed (roof mount)	
Snow losses	1.30%	From NREL (Ryberg and Freeman 2017). Nearest city is Annette, AK.
Tilt	26.6°	Assumed slope of roof
Azimuth	195°	Angle of south-facing portion of roof
Estimated annual energy output	96 MWh/yr	Estimated with PVWatts®
Capital costs	$1,360–2,720/kW	From BNEF 2020. Assumes residential array in Alaska installed in 2023, with potentially doubled cost for more remote location
O&M costs	$12.4–20/kW/yr	From BNEF 2020 and NREL 2018
Levelized cost of energy	18.4–36.1¢/kWh	Assuming 25-year lifetime

Solar PV Recommendation and Next Steps

Barring supply chain issues, a rooftop PV system could be operational within a year of contracting the project. Solar PV technology is proven, even in Alaska, and many contractors are experienced with solar PV installation. Following successful installation and initial operation of PV on the PSC Office and Warehouse, and pending plans for other energy infrastructure investments,[2] additional buildings could be considered for PV to reduce local

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[2] If there is not a need for additional electricity capacity in the summer (e.g., if development of wind resources eliminates use of fossil fuels), there will be no financial benefit to solar PV. If resilience is desired, additional assessment of the economics of adding energy storage will be needed.

demand. Priority should be given to buildings with large available roof area and southern orientations. Additionally, pairing PV with battery storage and microgrid controls at a building can provide energy resilience for that facility in the event of a grid outage.

Geothermal

One option for power generation for Sitka, AK, is to develop a geothermal power plant. Geothermal energy is produced from the heat of the Earth and can be used in multiple ways depending on the temperature and geologic characteristics of the resource. Higher temperatures, such as those found at several kilometers depth or in locations with particularly high heat flow, can be used to generate electricity. Geothermal energy from lower temperature resources may only be suitable for thermal applications, such as space and water heating. This includes use of hot water from geothermal wells or hot springs for space heating as well as the relatively constant temperature at depths of a few feet to a few hundred feet, which can be used to provide heating and cooling to buildings using a geothermal heat pump system.

Here, we focus on geothermal as a power generation technology for the CBS Electric Department. Geothermal power plants use steam produced from heat reservoirs found below the Earth's surface to generate electricity. The process of generating electricity from steam, whether from boiling water using fossil fuels or using natural geothermal sources, involves a process referred to as a Rankine cycle. The steam rotates a turbine connected to a generator that produces electricity.

Geothermal energy has many benefits that can complement those of other power sources. First, geothermal energy is a renewable energy so long as the resource is properly managed and can generate zero emissions for certain configurations (e.g., binary geothermal power plants; DOE-GTO 2019). Additionally, geothermal energy can produce a baseload power supply, providing a consistent power source that does not rely on the weather or vary by season. While geothermal power production is a proven technology, it is important to consider the potential resource available near Sitka to determine whether it warrants further investigation.

Geology and Tectonic Setting

Southeast Alaska is considered one of the most promising regions of Alaska in terms of potential for producing geothermal resources of sufficient quality for power production (Decker et al. 2012). This inferred potential is largely driven by the presence of nearby hot springs that occur within a tectonically active plate boundary that accommodates relative motion between the Pacific Plate and North American Plate. West of Baranof Island, this motion is accommodated along the Queen Charlotte Fault zone, which exhibits right lateral transform motion, as shown by geodetic measurements and the patterns of seismicity along the fault (Elliott et al. 2010; Figure 10). Bounding the island to the east is the Chatham Strait fault (Reifenstuhl 1986). While most of the motion on these faults is transform (i.e., horizontal motion), there is also some convergent motion along this plate boundary, suggesting a transpressional stress state. Such zones of active deformation are often associated with high heat flow, indicating a potential for promising geothermal resources.

In contrast to the current, somewhat uniform plate boundary motion, the Baranof Island region has a complex geologic history with periods of plate subduction and extension leading up to a transition to the current strike-slip regime, which initiated about 40 million years ago (Hyndman 2015). The ancient geologic features that provide clues to this complex geologic history can be observed in the Goddard Hot Springs area, where the geothermal resource of interest for Sitka is located. This resource is in an area that has experienced many phases of deformation, including both faulting and folding. The primary type of bedrock exposed at the surface near Goddard Hot Springs is a granodioritic pluton that is crosscut by basalt dikes (Motyaka and Moorman 1987). In general, granodioritic plutons are relatively massive and extend to great depths; however, the complex deformation history of the region makes it very difficult to extrapolate the specific rock type(s) and potential fracture networks that are critical for assessing the potential reservoir capacity at the anticipated depth of the thermal resource.

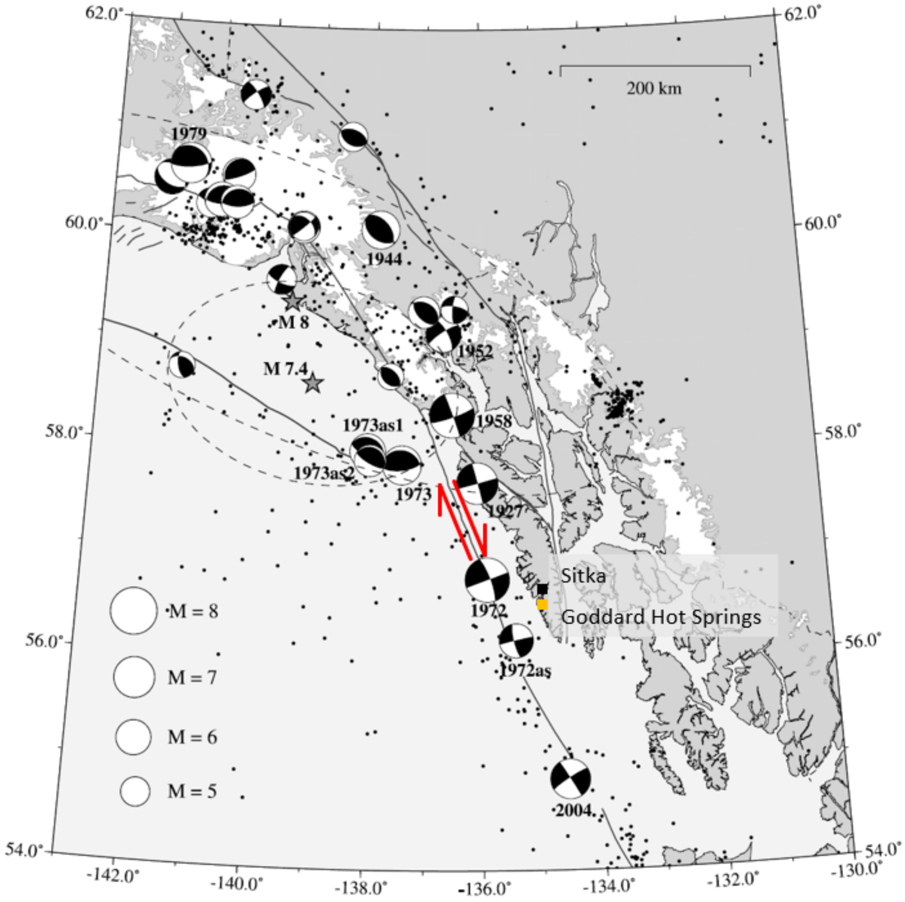


Figure 10. Map of southeast Alaska showing earthquakes of M ≥ 3. Earthquakes with M ≥ 4.5 are shown with their focal mechanisms (the “beachball” circles shown on the map). Focal mechanisms represent the type of motion accommodated during earthquakes. These focal mechanisms indicate a consistent right lateral sense of motion along the Queen Charlotte Fault zone (shown with red arrows). Map modified from Elliott et al. 2010.

Geothermal Potential at Goddard Hot Springs

The Goddard Hot Springs are located about 15 miles south of Sitka (Figure 11) and consist of four surface hot springs that lie within 70 m of each other. The springs are on land owned by the City of Sitka and have a combined discharge rate of almost 100 liters per minute (Motyaka and Moorman 1987) and surface water temperatures of 50.1–65.6 °C (Reifenstuhl 1986).

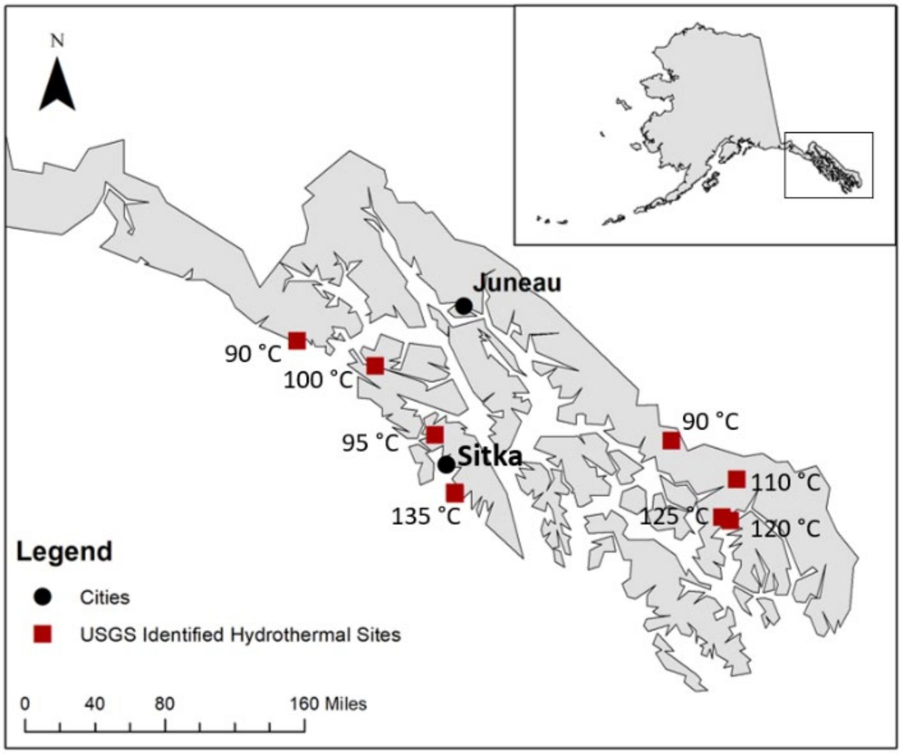


Figure 11. Map showing the locations of hot springs identified by the United States Geological Survey in Southeast Alaska, with estimated resource temperatures (red squares). Data from Williams et al. 2008.

Geochemical analyses have been conducted with water samples collected from Goddard Hot Springs to investigate the potential resource temperature at depth and to identify the source of the water flowing into the springs. Temperature at depth has been estimated using four geothermometers (Table 15) and results suggest a potential geothermal resource with temperatures of 130–160 °C (Reifenstuhl 1986). Additionally, geochemical measurements indicate that the water in the hot springs is predominantly sourced from fresh water, although there is a saline component. This observation, along with oxygen isotope data, suggests that the freshwater component is likely to come from either Redoubt Lake or from nearby cold water streams. The saline component could be sourced from deeper in Redoubt Lake (the lake contains saline water below 100 m depth) or from the ocean (Reifenstuhl 1986). This water is then heated through deep circulation in the subsurface, although the source of the heat is not clear. The primary heat source could be an igneous intrusion at depth, perhaps related to nearby volcanism. Alternatively, subsurface heating could be related to a higher than average (potentially up to 42 °C/km) geothermal gradient (Reifenstuhl 1986), likely resulting from a deep fracture network associated with active tectonics, which could provide a pathway for more efficient conductive heat flow into the shallow subsurface. Geothermometry results suggest a relatively low-temperature heat source (Table 15), which is consistent with an above-average geothermal gradient.

Table 15. Reservoir temperature estimates for Goddard Hot Springs based on several geothermometer techniques. Data from Reifenstuhl 1986.

Geothermometer	Reservoir Temperature Estimate
Silica	130 °C
Quartz, assuming no steam loss	141 °C
Quartz vs. pH	148 °C
Sodium/potassium	160 °C

Based on the temperature estimates discussed above, the resource temperature at Goddard Hot Springs has the potential to support a binary geothermal power plant (Figure 12). In fact, it has been demonstrated that binary geothermal power plants can be supported by even lower temperatures in cases where very cold water is available to cool the system. This was demonstrated by the 400-kW geothermal plant built at the Chena Hot Springs. This plant uses a 77 °C resource to heat the geothermal working fluid and uses the Chena River to provide ~5 °C water for cooling (Chena Power Company 2007).

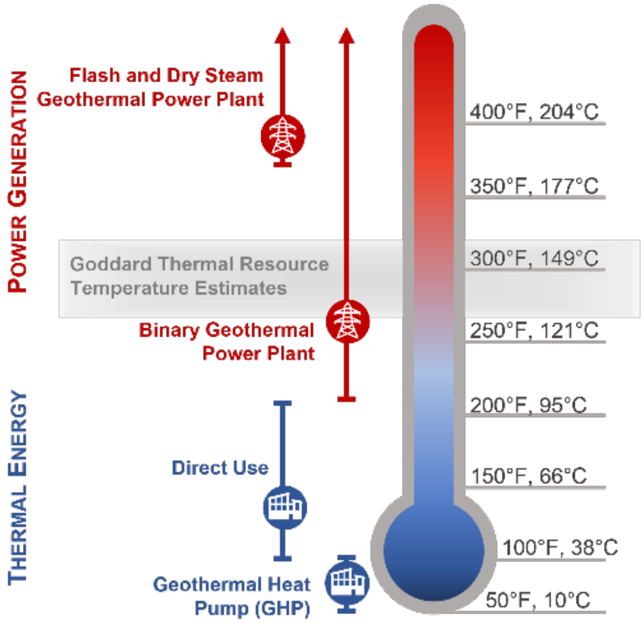


Figure 12. Schematic showing the types of geothermal technologies that can be deployed by resource temperature. The temperature range estimated for the thermal resource at depth for Goddard Hot Springs is shaded in grey. Figure modified from DOE-GTO 2019.

Despite the potential for a relatively shallow heat source, there are some important factors for understanding the potential for energy generation at Goddard Hot Springs that are not well established. For example, as mentioned above, the complex geology of the area means that the permeability of the rocks at depths where the thermal resource can be accessed is largely unknown. The magnitude of permeability, as well as whether the permeability structure is dominated by faults or fractures, can have a strong impact on the longevity of the resource for power generation (Bauer et al. 2019). Additionally, the flow rate that can be achieved through drilling into the resource has not been measured. These factors are critical for estimating the capacity of the geothermal resource to produce energy over an extended lifetime.

Next Steps

Although Goddard Hot Springs appears to have a sufficient heat source to support power generation through a binary geothermal power plant, the availability of sufficient reservoir quality at depth to support the high fluid production rates required for geothermal power production are largely unknown. Additional characterization and field validation via drilling a test well would be required to determine:

- Constraints on resource flow rates
- Verification of resource temperature
- Understanding of the permeability structure.

Initial steps that should be considered before investing in additional characterization include reaching out to geothermal developers. Because the hot springs in southeast Alaska are well known and have been documented since the early 1900s and because resource characterization efforts were initiated in the 1980s, it would be helpful to understand if developers have shown interest and formed a basis for not moving forward with development at Goddard Hot Springs. For example, if the key barrier to investment has been the lack of transmission infrastructure, it is possible that now is a good time to revisit the resource given the upcoming build-out of transmission lines. However, if developers have a more resource-related reason that they have not pursued development here in the past, this would be an important consideration before investing in a test well. Additionally, this survey could be a good way to identify whether there are industry partners that are willing to be involved in the characterization and potential development at Goddard Hot Springs. Finally, the project team could reach out to the Geothermal Technologies Office at DOE to identify any potential upcoming funding opportunities that could help support a characterization or development effort in partnership with the City of Sitka.

Note that in the case of the Chena geothermal power plant, the project cost was approximately $2 million (Chena Power Company 2007), but this cost did not include the resource characterization. The geologic characterization was supported by a DOE grant as well as a significant awardee contribution (Karl 2010, Chena Power Company 2007). These investments primarily covered drilling and analysis costs associated with the resource characterization.

Wave

Alaska is a hotspot for marine renewable energy, with abundant wave energy and powerful tidal energy particularly in channels and inlets (Kilcher et al. 2021). PNNL investigated the potential for CBS to pursue wave energy development. This section discusses wave energy device options, observed and modeled resource availability near Sitka, and next steps. Given that wave energy is not yet a commercially viable technology, the information on the wave conditions near Sitka would be relevant for (1) determining whether a future wave energy project could be feasible in Sitka, (2) early modeling of wave energy converters in Sitka seas, and (3) choosing a location and wave energy converter (WEC) type for a future wave energy project.

Wave Energy Converters

WECs have not converged to a common archetype, and many variants exist. The types of WECs are generally considered to be attenuators, point absorbers, pressure differentials, oscillating water columns, overtopping, and oscillating wave surge converters. The categories are not rigid, and slightly different categorizations may be used. Descriptions of different technology types are available at Pacific Northwest National Laboratory's TETHYS Engineering website, PRIMRE MRE Basics (https://openei.org/wiki/PRIMRE/MRE_Basics/Wave_Energy), and at The Liquid Grid (https://theliquidgrid.com/marine-clean-technology/wave-energy-converters).

There are no commercial wave energy farms in the United States, although there are some permitted in-ocean test facilities, numerous indoor tanks that have been used for in-water testing, and several facilities specifically for isolated power system testing. These facilities are listed on the *TEAMER Testing & Expertise for Marine Energy* website (https://teamer-us.org/). The U.S. Navy runs a Wave Energy Test Site (WETS) in Kaneohe Bay, O'ahu, Hawai'i. It has a 1 MW maximum capacity. This site has smaller seas than the U.S. West Coast and Alaska and has been used to test scaled prototypes of wave energy devices that are designed for larger seas. PacWave, a wave energy test site off the central Oregon Coast, is currently under construction and is planned to be ready to take testing clients in late 2024. The site will have a maximum capacity of 20 MW and will require about 2 square nautical miles of ocean space. The sea conditions at both WETS and PacWave have been well characterized and are commonly used in modeling of wave energy devices. There are three companies who were recently awarded funding to test at PacWave upon its completion—CalWave Power Technologies Inc., C-Power Technologies Inc., and Littoral Power Systems (EERE 2022).

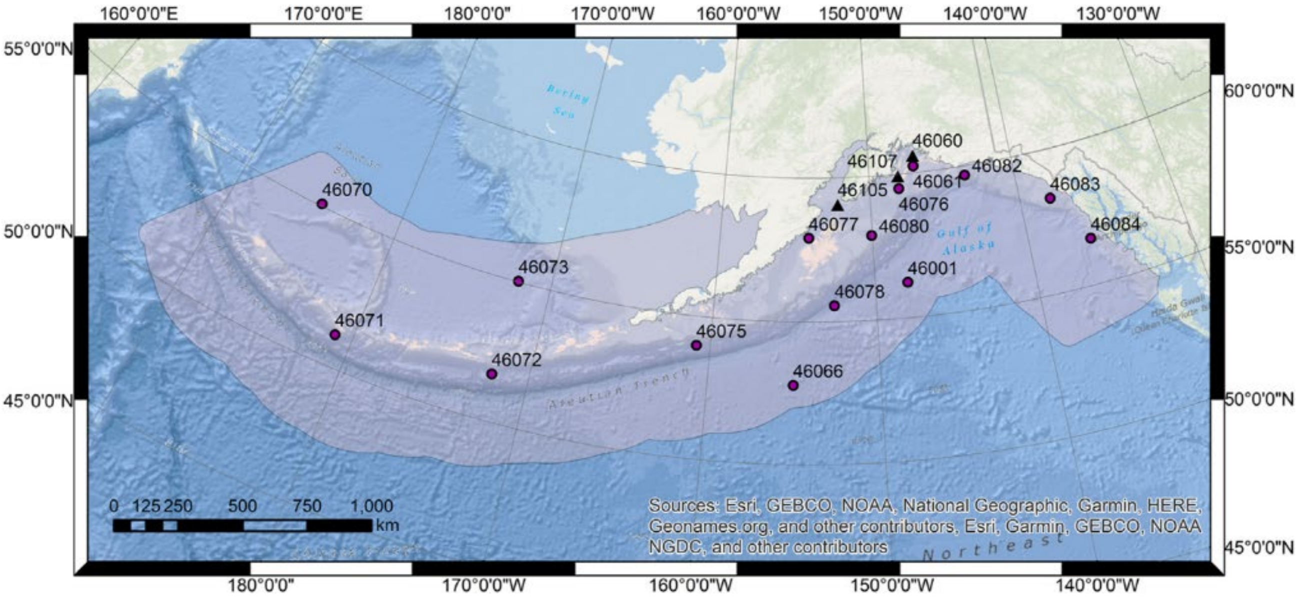
WEC CONSIDERATIONS

Few studies of wave energy device comparative performance have been undertaken. That, combined with the nascency of the industry, makes it difficult to recommend a specific WEC or WEC archetype to suit Sitka's needs. The following information might be helpful in the future, should Sitka continue to consider wave energy technology.

- Because cost estimation for wave energy devices is complex and uncertain, designers and developers often use representative metrics for cost. These metrics include mass, surface area, and power take off (PTO; defined further in Appendix C) force, none of which can totally represent cost, but each of which is related to a meaningful cost driver. It is common to take the annual energy generation over one of these representative metrics to assess WEC performance (Babarit et al. 2012).
- A study comparing eight different WECs in five different locations found no meaningful differences in annual absorbed energy per cost representative metric. The WECs had a common annual absorbed energy per characteristic mass on the order of 1 MWh/metric ton, annual absorbed energy per surface area on the order of 1 MWh/m^2, and annual absorbed energy per PTO force of 2 MWh/kN (Babarit et al. 2012).
- Attenuator, pressure differential, terminator, oscillating water column, and overtopping devices can all be sensitive to the direction of the incoming waves.
- Fish, marine mammals, and birds face minor collision risk with wave energy devices. The devices could attract marine species or cause them to avoid the area where a device is located. As with all electricity generation, there is some concern that electromagnetic fields generated by power cables and moving parts may affect animals that use Earth's natural magnetic field for orientation, navigation, and hunting. Large-scale changes in flow (from arrays) may disrupt natural physical systems to cause degradation in water quality or changes in sediment transport, potentially affecting ecosystem processes. Alternatively, devices absorbing wave energy may positively act as shoreline defense. Research on environmental impacts is ongoing, and such impacts are difficult to characterize without a specific site and project in mind (Copping and Hemery 2020).
- The capacity factor for a wave energy device should be at least 20% (Babarit et al. 2012), but could be as high as 80% (Coe et al. 2021).
- Depending on the type and size of a device, its annual absorbed energy can range from 1 to 1,000 kW (Babarit et al. 2012).

Observations

Approximately 27 miles Southwest of Biorka Island (Lat/Long: 56.600, -136.101), there is a National Oceanic and Atmospheric Administration (NOAA) National Data Buoy Center (NDBC) buoy, number 46084. The device is located at approximately 1,400 m depth and collects weather and wave data for the NDBC, where it is published online for public use. Buoy 46084 is the closest buoy to Sitka that collects wave data, but it is too far away and in too deep of water for its location to be considered as a wave energy site. Potential wave energy sites near Sitka are in much shallower water, meaning sea conditions are expected to be significantly different and the buoy data should not be directly used to assess the feasibility of those sites. However, models (described in the next section) created by researchers with the Water Power Technologies Office have used buoy 46084 data along with data from 18 other buoys to model the wave resource in Alaska. Figure 13 shows the location of the buoys from which data was used to characterize Alaska's wave resource.



Sources: Esri, GEBCO, NOAA, National Geographic, Garmin, HERE, Geonames.org, and other contributors, Esri, Garmin, GEBCO, NOAA NGDC, and other contributors

Figure 13. Map of NDBC Buoys used to model wave energy resource data.

Models

The DOE Water Power Technologies Office's U.S. Wave dataset includes 32-Year Wave Hindcast data for the U.S. Atlantic Coast, West Coast, Hawaii, and Alaska, and in the future will also include the Gulf of Mexico and Pacific Islands regions. The dataset includes historical wave statistics for 1979 to 2010 in 3-hour temporal resolution and 200 m to 10 km spatial resolution depending on depth (deeper waters have lower resolution).

The Hindcast wave resource characterization (hereon referred to as "Hindcast") uses several models[3] to generate wave statistics shown in Table 16. The Hindcast was validated using real buoy data and meets almost all IEC-TS Class 2 (feasibility) resource assessment requirements; the locations of the buoys used for this analysis are shown in Figure 13. Water-level variations and wave–current interactions are not modeled in the Hindcast but are only expected to be important in the Inside Passage, Cook Inlet, and Prince William Sound (García-Medina et al. 2021).

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[3] Hindcast uses the Simulating Waves Nearshore (SWAN) and NOAA's Wavewatch III models generated by the Pacific Islands Ocean Observing System (PacIOOS) at the University of Hawaii. Bathymetry inputs are from the Southern Alaska Coastal Relief Model, and NOAA Fisheries digital elevation models and wind forcing and sea ice inputs are from Climate Forecast System Reanalysis (CFSR) data.

Table 16. Hindcast output wave resource parameters.

Statistic	Common Variable	Units	Description
Omnidirectional wave power	J	Watts/meter [W/m]	Measure of wave energy flux from all directions, describing the density of wave power
Significant wave height	H_{m0}	Meters [m]	Average height of the highest one-third of waves
Energy period	T_e	Seconds [s]	Period of waves containing the most energy
Spectral width	ε_0	Unitless	Parameter between 0 and 1 (small is good) characterizing the spread of energy in the frequency space
Directionally resolved wave power	J_θ	Watts/meter [W/m]	Wave power from a specified direction
Directionality coefficient	d	Unitless	Ratio of wave power from the direction of maximum wave power $[J_{\theta max}]$ to omnidirectional wave power $[J]$

Hindcast data is stored on Amazon Web Services' Registry of Open Data and managed by NREL. Currently, the Alaska dataset does not have a public domain name (and is therefore more difficult to access) because some years of data are not yet available. Those years were removed from this analysis (1979, 1991, and 2010).

An additional model of the wave resource for all of Alaska has been completed and is available at the Marine Energy Atlas (https://maps.nrel.gov/marine-energy-atlas/), which allows for comparative evaluation of sites, shown in Figure 14.

INTERANNUAL WAVE RESOURCE AND 30-YEAR AVERAGES

A more specific wave resource assessment was performed for two locations near Sitka by in-depth analysis of the Hindcast data; these two locations are west of Biorka Island and at the end of the causeway off Japonski Island. CBS indicated interest in the Biorka site because a transmission line to connect Biorka to the CBS grid is being considered. This site is outside the Sitka Sound and represents one of the largest wave resources available to Sitka. The Japonski site was selected as one of the nearest sites to the existing electric grid for which data was available. (A wave energy deployment at Biorka Island will require about 7–10 kilometers more underwater transmission cabling than a deployment at Japonski Island, costing $7–30 million; this is in addition to on-land transmission lines from the Redoubt Lake area.) These two sites represent feasible extremes in terms of available wave power, and potential sites between those follow similar trends, where the wave power is generally larger closer to the open Pacific Ocean and outside the Sound, as shown in Figure 14.

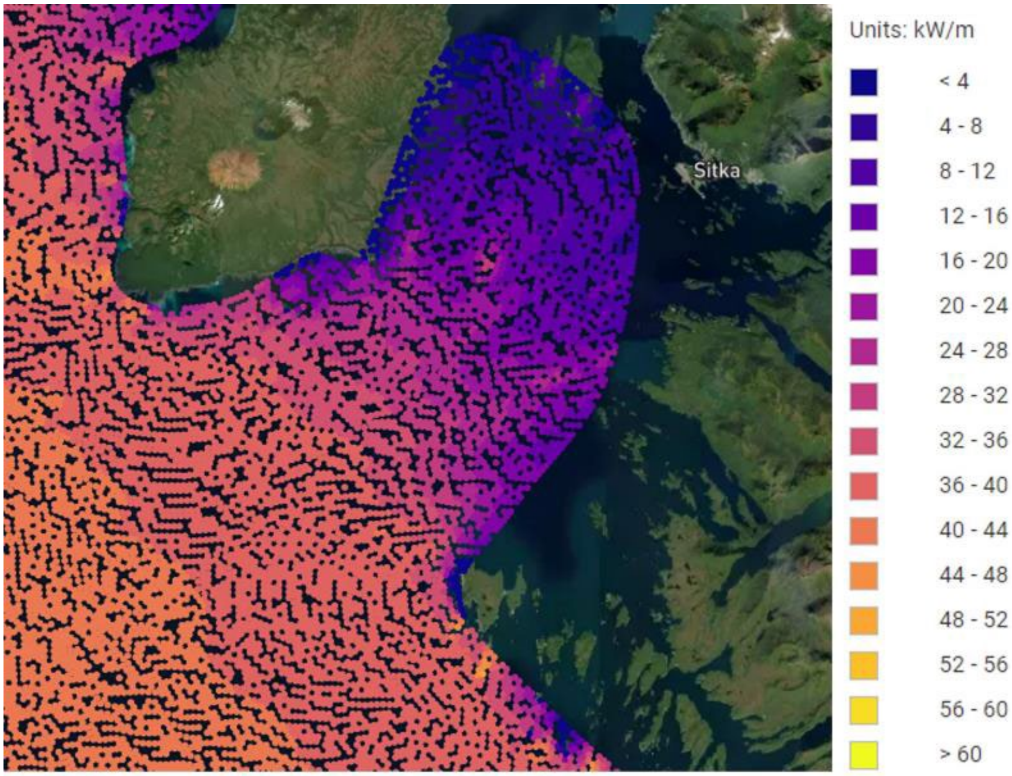

Figure 14. Screen capture from the Marine Energy Atlas Tool (https://maps.nrel.gov/marine-energy-atlas/) showing data of omnidirectional wave power from the 2021 Alaska Wave Model.

TEMPORAL VARIABILITY AND CORRELATION WITH ELECTRICITY DEMAND

At both the Biorka and Japonski locations, wave power follows trends according to the time of year (larger and more variable in winter and smaller and less variable in summer). Figure 15 and Figure 16 show seasonal differences in significant wave height, energy period, omnidirectional wave power, and directionally resolved wave power averaged over each month for the Biorka and Japonski sites, respectively. Biorka has a much stronger wave resource than Japonski, with average significant wave heights approximately double that of Japonski's and a single standard deviation range from approximately 1.5 to 4 m, vs Japonski's approximately 0.75 – 2 m. This leads to a greater range of power availability (represented by standard deviation) at Biorka, particularly during the stormy winter months. The mean wave power thus peaks around 50 kW/m for Biorka and 10 kW/m for Japonski in winter, and at 20 kW/m for Biorka and 4 kW/m for Japonski in the height of summer.

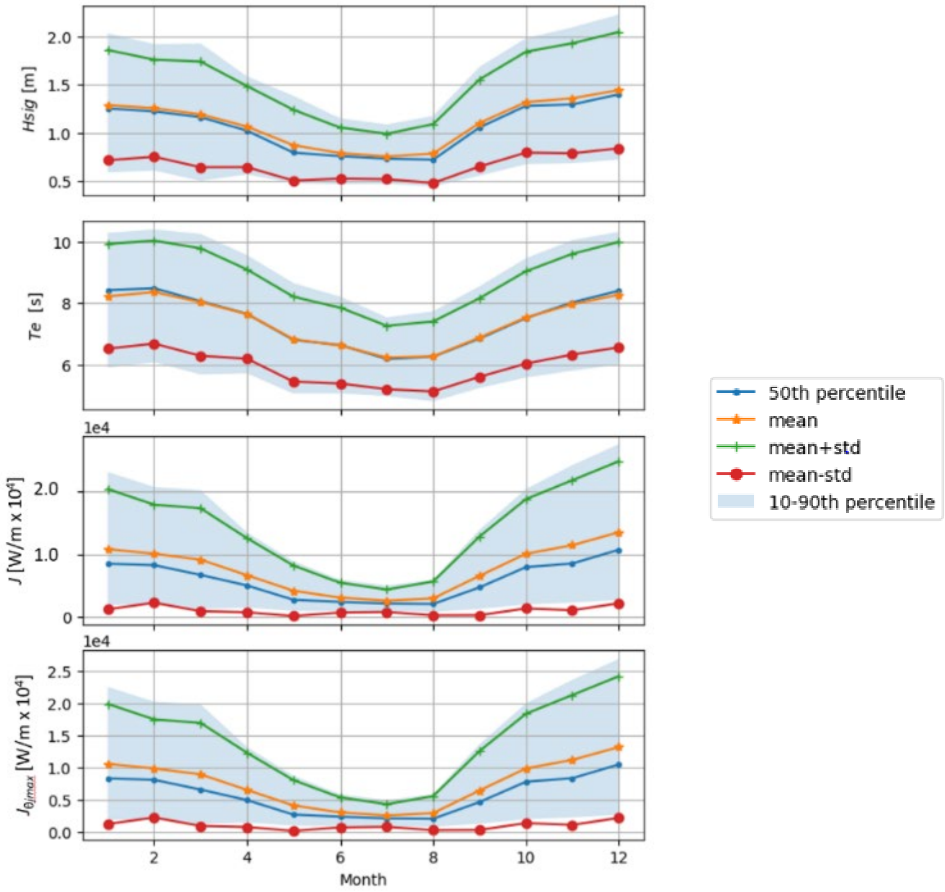

Figure 15. Monthly averaged wave energy statistics for Japonski Island.

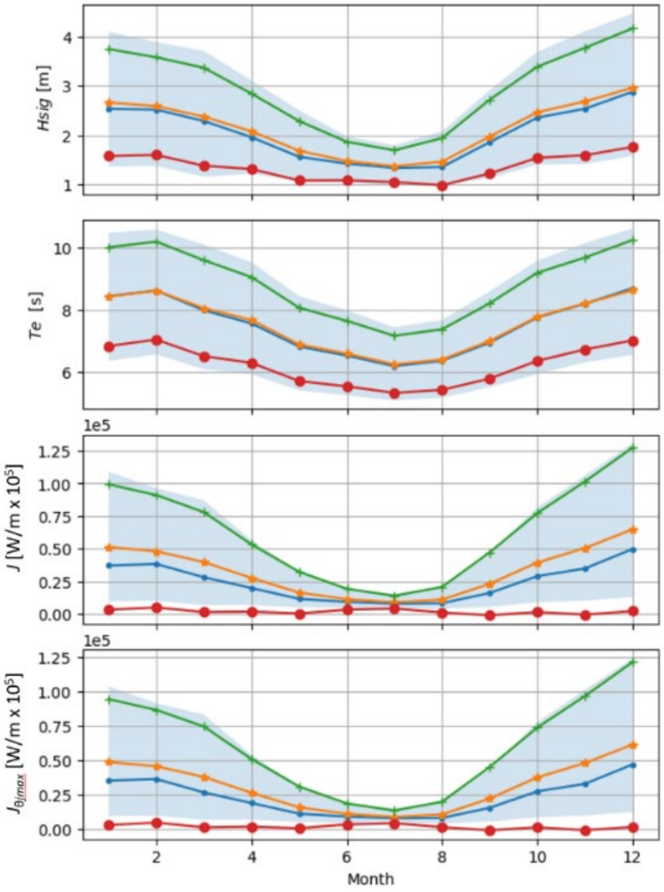

Figure 16. Monthly averaged wave energy statistics for Biorka Island.

Along with lower (about 4×) omnidirectional wave power (kW/m), the Japonski Island site has smaller wave heights (H_m, which is expected because wave height strongly influences wave power), a similar energy period (T_e) although with a smaller range, a smaller spectral width (ε_0), and a larger directionality coefficient (d) (Table 17). The spectral width is typical or slightly low compared to most U.S. West Coast locations, and both sites have a high directionality coefficient, typical of areas close to land (Yang et al. 2018). A directionality coefficient close to 1 means that much of the wave power is coming from a single direction. In general, a high directionality coefficient is considered good because it allows for directionally dependent WECs to be considered and it eases array optimization and estimation of loads. Both sites have waves coming from the West-Southwest, with the Biorka site exhibiting a larger spread.

Table 17. Wave resource parameters for a high- and low-wave year for each site.

Site	Lat/Long, Depth	Wave Resource Year	Omnidirectional Wave Power J [kW/m]	Significant Wave Height H_{m0} [m]	Energy Period T_e [s]	Spectral Width ε_0	Directionality Coefficient d
Biorka Island	56.8447, -135.5664	High (1988)	45.67	2.25	7.79	0.35	0.94
	35m	Low (1996)	24.92	1.89	7.23	0.35	0.93
Japonski Island	57.034708, -135.39356	High (1987)	10.34	1.28	7.61	0.30	0.97
	59m	Low (1996)	5.82	0.96	7.44	0.29	0.97

In summary, Sitka has a large and moderately to highly variable wave resource at Biorka Island and a substantially smaller wave resource with a similar variability to the Biorka site at Japonski Island. At both the Biorka and Japonski locations, most wave energy occurs at wave periods between 6 seconds and 10 seconds, meaning a WEC designed for Sitka should resonate at frequencies of 1/10 to 1/6 Hz. More detailed analysis of the wave energy resource at these two sites is provided in Appendix C.

Opportunities and Next Steps

In pursuing a wave energy project, three primary considerations are the location of the project, the type of wave energy device(s),[4] and the size of the project. The wave resource assessment provided here will be useful for choosing both the best location and the best device type based on the resource. In fact, these two aspects are likely interrelated,[5] and further investigation would be necessary to select the best location or device type. The size of the project will mostly be determined by the needs of the Sitka community, related to the end use (grid connection or dedicated application such as recharging electric fishing vessels or providing power to future mariculture operations) of a wave energy project and therefore the necessary capacity. Funding opportunities could influence the size, location, and device type(s) for the project as well.

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[4] One investigation in Yakutat, AK, determined that the optimal wave energy array could include multiple different device types. Although this is a new area of research, there is a possibility that a future wave energy project in Sitka could involve more than one type of device.

[5] Lavidas and Blok published a paper in 2021 that indicated different sea conditions (“zones”) may favor different WECs (Lavidas and Blok 2021).

The next steps in pursuing a wave energy project include:

- Collecting more accurate measures of wave resource in locations of interest using a wave measurement buoy that can measure actual wave measurements.
- Using the steady-state grid model (developed for CBS through a separate ETIPP task) and assessing other potential resources to establish the requirements and role of wave energy.
- Assessing community interest in small applications of wave energy for which Sitka might apply for grants. Future funding opportunities may arise for grid applications or niche, power-at-sea applications such as aquaculture or ocean monitoring. Sitka may find low-risk, community-engaged opportunities among niche applications.

Tidal

PNNL investigated the potential for tidal energy generation in the waters near Sitka, including an overview of the area, as well as a more specific site at No Thorofare Bay. Quantifying the potential for tidal energy requires understanding tidal energy device options, observed and modeled resource availability, and the next steps required to fill identified gaps in information, as documented in this section.

Tidal Energy Devices

Tidal energy is an emerging industry with few commercial and grid-scale devices currently operational. Tidal turbines are typically broken up into two different categories: axial-flow and cross-flow turbines (Figure 17). In an axial flow turbine, the turbine blades face the direction of the flow; axial flow turbines change direction in ebb and flood tides. Cross flow turbines are oriented where the blades are oriented perpendicularly to the flow and the water flows across the blades; the turbine moves in the same direction on both ebb and flood tides.

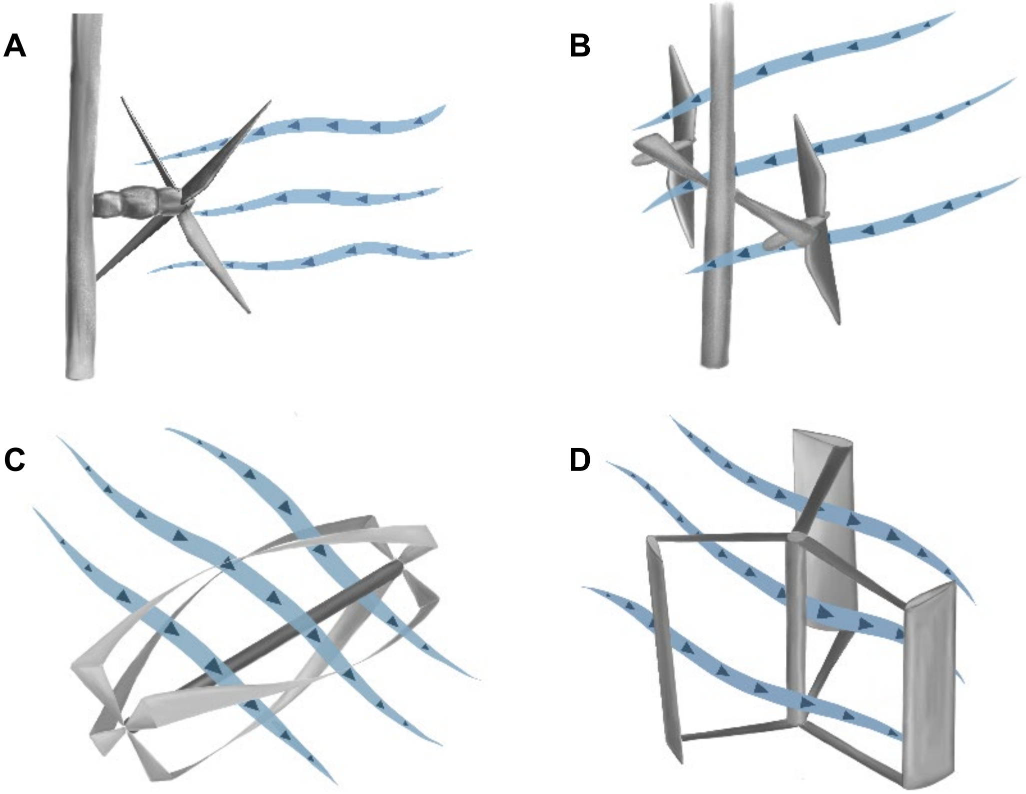

Figure 17. Examples of axial-flow (A and B) and cross-flow (C and D) turbines.

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 a minimum acceptable depth for commercial development of axial-flow devices. A deeper channel, especially for an axial-flow turbine, can allow for a greater swept area of the turbine rotor in combination with the turbine foundation. Cross-flow turbines may be more appropriate for shallower depths.

EXAMPLE PROJECTS

There are few deployed tidal energy turbine generators, including the following two examples built and deployed by Ocean Renewable Power Company (ORPC) and Verdant Power, respectively. 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.

ORPC’s RivGen turbine is deployed in the Kvichak River next to Igiugig, Alaska, in 2015, and the community of Igiugig has an ETIPP project in Cohort 2. Water flow in this river is highly turbulent, with a mean of around 2 m/s. A year after deployment, 2016, the turbine was producing an average of 12.5 kW (Forbush 2016). The ORPC RivGen is installed at a location with a depth of about 5 m. Verdant Power’s Gen5 turbine was deployed in the East River, which has smoother and steadier flow, in New York City from Oct 2020–May 2021. Its average power output was around 18 kW (Gunawan 2014).

Observations

Tidal current predictions based on observational data exist around Sitka from NOAA Tides and Currents.[6] These data are generated from temporary Acoustic Doppler Current Profiler (ADCP) deployments, which NOAA completes in different locations every year. The ADCPs can observe currents at various depths in the water column over the course of a few months. After the temporary deployment is complete, NOAA analyzes the data using a harmonic analysis. This separates the contribution of different constituents, such as the relative position of the moon and sun, on the tidal current. With these harmonics, the current speeds can then be predicted indefinitely at a single location.

Ten locations with this observed data nearest Sitka were downloaded from the NOAA website (Table 18, Figure 18, and Figure 19).

Table 18. Mean and max current speeds at 10 locations near Sitka, AK.

Location	Lat	Lon	Mean Current (m/s)	Max Current (m/s)
Allan Point, Nakwasina Passage	57.25	-135.433	0.59	1.47
Biorka Channel	56.8333	-135.5	0.12	0.37
Creek Point, Olga Strait	57.2101	-135.495	0.42	1.25
East Channel, Krestof Sound	57.1667	-135.55	0.46	1.30
Highwater Island, Neva Strait	57.2833	-135.6	0.40	1.29
West Channel, Krestof Sound	57.15	-135.583	0.38	0.94
Western Channel, Sitka Sound	57.0503	-135.396	0.11	0.31
Whitestone Narrows	57.245	-135.564	0.29	0.94
Wyvill Reef, Neva Strait	57.2667	-135.583	0.50	1.30
Zeal Point, Neva Strait	57.2869	-135.608	0.15	0.41

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[6] https://tidesandcurrents.noaa.gov/

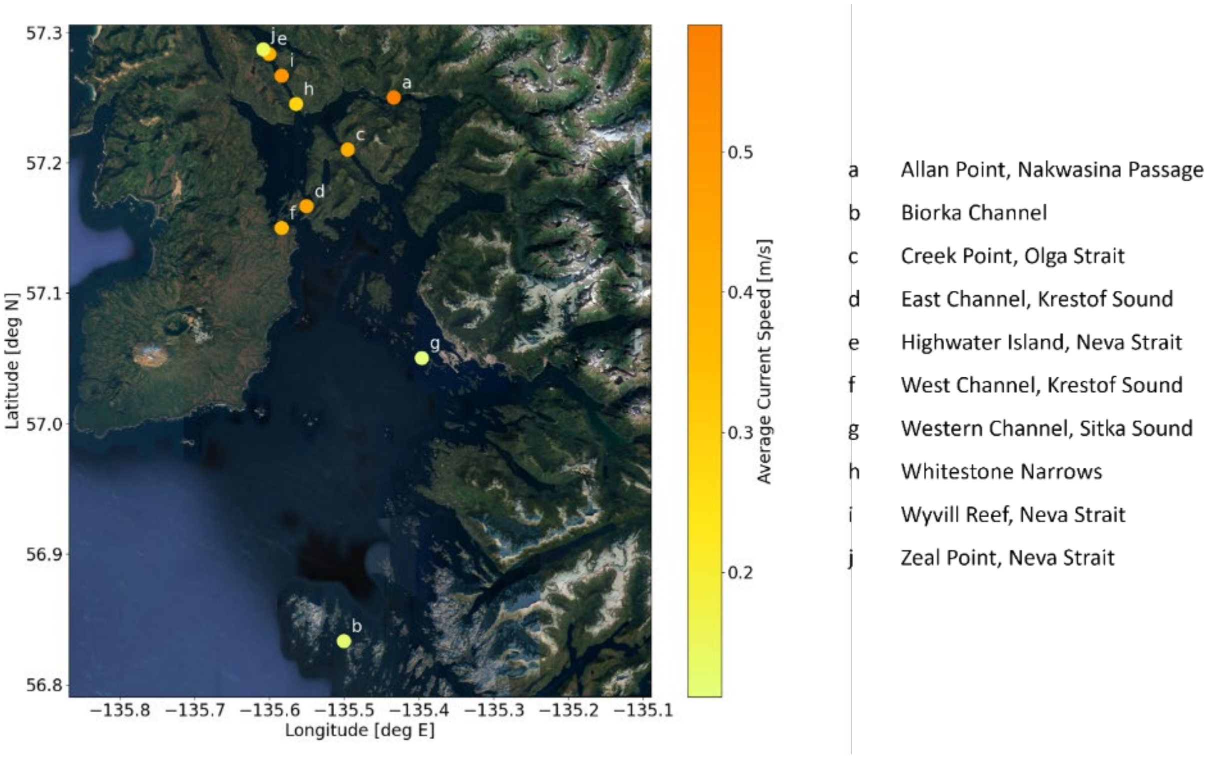

Figure 18. Average current speeds at 10 locations near Sitka, AK.

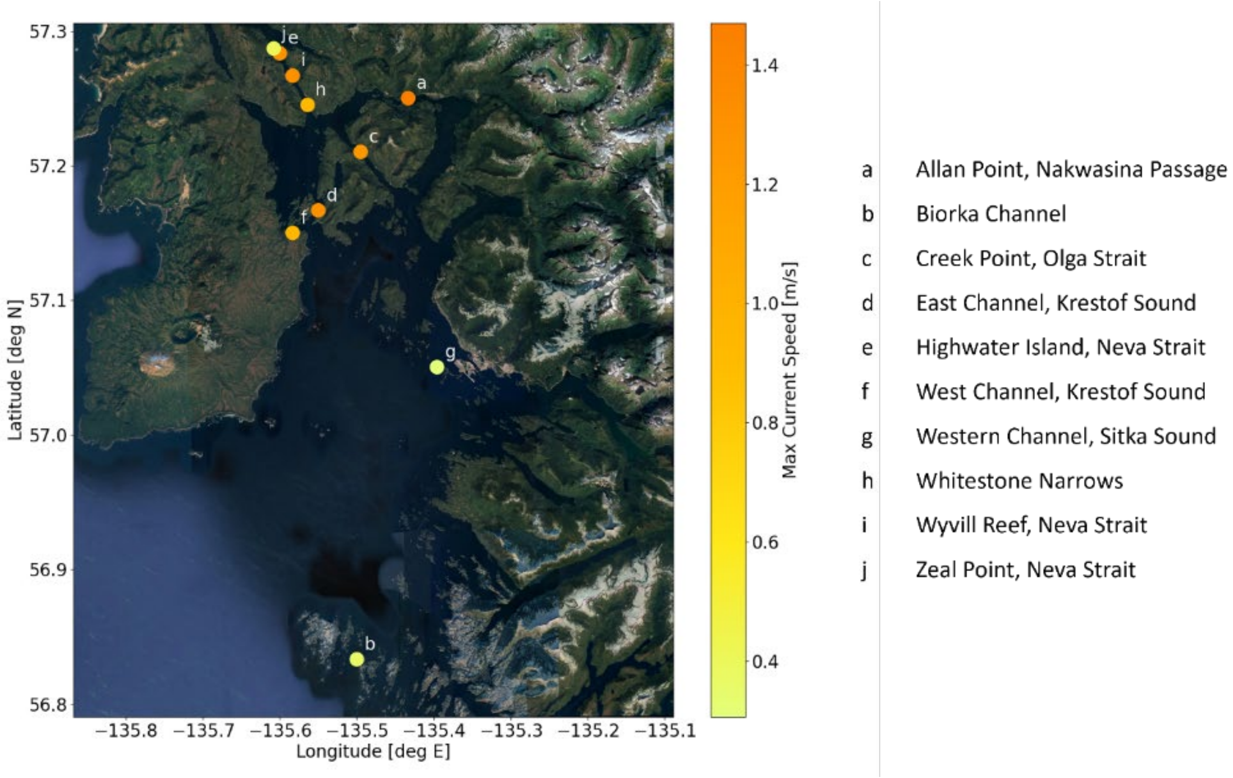

Figure 19. Max current speeds at 10 locations near Sitka, AK.

Preliminary Modeling

CBS was particularly interested in understanding the currents in No Thorofare Bay, where there were no existing tidal current models or observations. Estimates of maximum current velocity were developed based on Keulegan's Method (KM). KM is an approximation or 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:

$$U_{max} = \omega a_b \frac{A_B}{A_c} \tag{3}$$

Where ω is the tidal frequency, a_b is the tidal amplitude in the bay, A_B is the bay planform area, and A_C is the inlet cross-sectional area. The tidal amplitude a_b is estimated from the repletion coefficient K, which is calculated from

$$K = \omega a_0 \frac{A_C}{A_B} \frac{\sqrt{2ga_0}}{\sqrt{K_{en} + K_{ex} + \frac{fl}{4R_H}}} \tag{4}$$

Where g is acceleration due to gravity, a_0 is the tidal amplitude of the ocean, K_{en} is the contraction loss (as in flow through a pipe), K_{ex} similarly is the expansion loss, f is the friction factor, l is the inlet length, and R_H is the hydraulic radius of the inlet. The tidal ratio $\frac{a_b}{a_0}$ is equal to 1 for $K > 2$.

There are a couple of characteristics 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. The KM model takes these two waterway characteristics for a tidal inlet and approximates a maximum water velocity that the inlet can generate. 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 closest to the target locations (around 5 miles away).

There are some opportunities for tidal development in the region (Figure 20, Table 19). No Thorofare Bay has a fast maximum current but is a relatively small area for development. At mean sea level, PNNL estimates that the channel is 20 m wide and 5 m deep, which would only be appropriate for smaller-scale devices. By comparison, Deep Inlet has space for larger devices and is somewhat closer to existing electrical infrastructure than other options. However, the inlet has a lower maximum velocity, indicating that average velocity is likely closer to 0.5 m/s.

Table 19. Modeled max current speeds at seven locations near Sitka, AK.

Location	Lat	Lon	Max Current (m/s)
Deep Inlet	56.98575	-135.304	1.26
Silver Bay	57.03381	-135.236	0.37
Herring Cove	57.04032	-135.205	0.07
Camp Coogan Bay	57.01146	-135.239	0.49

Location	Lat	Lon	Max Current (m/s)
No Thorofare Bay	57.01903	-135.242	2.48
Nakwasina Sound	57.17743	-135.418	0.77
Katlian Bay	57.15461	-135.363	0.17

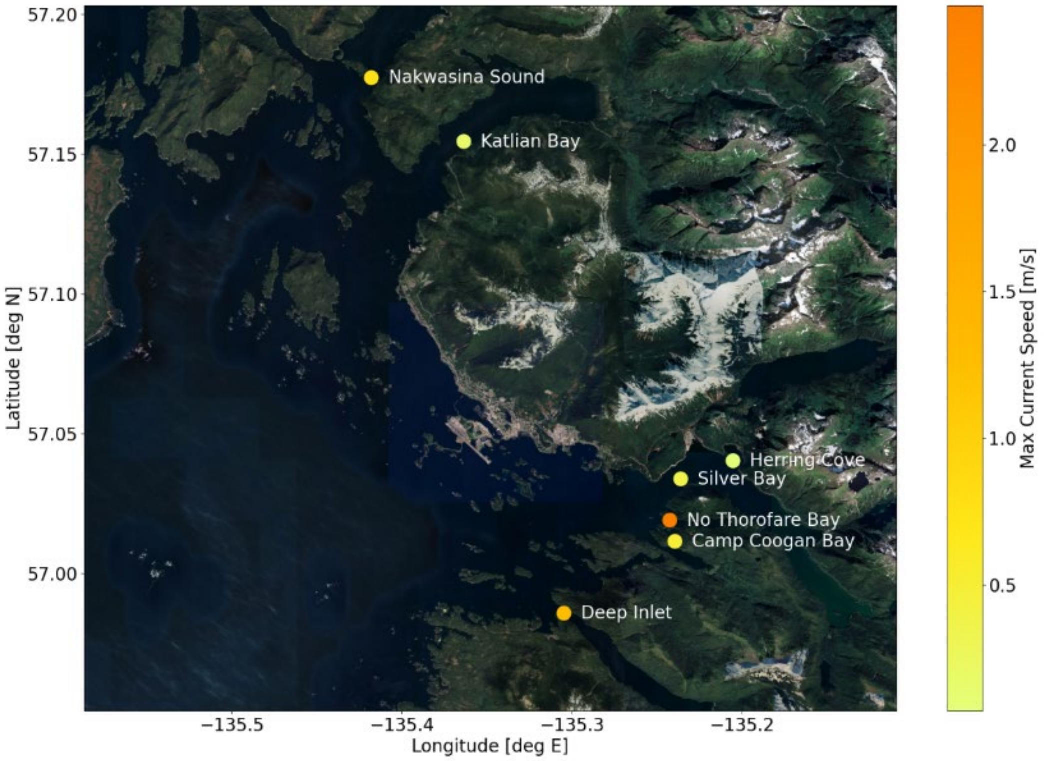

Figure 20. Modeled maximum current speeds at seven locations near Sitka, AK.

An additional model of tidal currents for the entire United States has been completed and is available at the Marine Energy Atlas (https://maps.nrel.gov/marine-energy-atlas/). This model is relatively low resolution and does not capture many of the inlets and bathymetry near Sitka. The Marine Energy Atlas does highlight the large tidal resource in Sergis Narrows, although this is currently far from any existing transmission lines.

Results

With max flow speeds expected below 2 m/s, tidal flows in all but one of the investigated locations are too slow for present technology to harvest power. No Thorofare Bay could be an option for smaller-scale tidal energy (on the order of W to kW), with two main difficulties: the shallow depth of the inlet and the distance from power infrastructure. The lack of power transmission infrastructure tends to be the limiting factor for most tidal sites in North America, and the inlet may not have the depth to support higher-capacity (kW) turbine technology. Water depth and water velocity measurements will need to be made in No Thorofare Bay to understand where strong flows and deep water align.

Opportunities and Next Steps

If CBS is interested in further pursing a tidal energy project, immediate next steps would include measuring the tidal resource in a location of interest, such as No Thorofare Bay. This would include measuring the tides using an ADCP, which can determine the actual current speeds throughout the tidal cycle. Additional necessary measurements include detailed water depth, seafloor composition, and width of the channel, which is typically measured by an echosounder. These measurements would allow a tidal energy developer to determine if their technology could perform at the chosen site.

Because tidal energy is an emerging technology, federal grants may be available to pursue development or demonstration of a tidal turbine operating on a remote and islanded grid. About $4 million of federal funding went into the Igiugig demonstration project, a 35 kW system. Some additional funding came from the tidal turbine developer (Alaska News 2014; KDLG 2019).

Summary and Recommendations

CBS has several options for renewable energy development to meet expected future loads. When considering options, CBS must weigh costs, development timeline, operation and maintenance requirements, and the potential for the option to provide the required electricity. These factors are compared in Table 20 for the five resources assessed here as well as new hydropower at Takatz Lake, based on information provided in DHA (2018). The levelized cost of energy for the other five resources does not include taxes, incentives, or discount rates—just the capital and O&M costs and annual expected generation are included over the life of each project. Capital cost estimates are preliminary and do not include site-specific considerations, although location-specific adders have been included. More detailed economic analysis will be needed once additional resource and project investigations are underway.

Table 20. Summary of renewable energy resource options for Sitka.

Resource	Levelized Cost of Energy ($/kWh)	Capital Cost ($/kW)	Operation and Maintenance	Development Timeline (years)	Power Generation	Other Considerations
Hydropower (Takatz)*	29.6	13,000	$117/kW/yr: 24/7 operations + regular maintenance	~4–8	~76% of annual load; Baseload generation with storage capabilities, but dependent on precipitation	Long transmission line required
Wind	8.6–16.7	2,250–4,500	~$45–$80/kW/yr: monitoring, inspections	~4	Up to 63% of annual load; intermittent source	Vista alterations, access roads, wildlife impacts, LIDAR or investment-quality site-

Resource	Levelized Cost of Energy ($/kWh)	Capital Cost ($/kW)	Operation and Maintenance	Development Timeline (years)	Power Generation	Other Considerations
						specific hub-height wind data required
Solar	18.4–36.1	1,360–2,000	$12.4–20/kW/yr: Snow clearing, occasional cleaning	~1	~1% of annual load for CBS-owned rooftops; intermittent source	Structural integrity of roofs
Geothermal	TBD	2,850–5,000	$0.01–0.03/kWh/yr	~2 + initial exploration	Capacity unknown; baseload generation	Permeability of rocks and flow rate need investigation
Tidal	TBD	$$$	Yearly cleaning to remove biofouling	~10	< 5% of existing load, more predictable baseline power	More likely to have federal funding, requires underwater transmission
Wave	TBD	$$$$	TBD, based on technology type	~10	< 1% of existing load per device, intermittent and seasonal (higher in winter when hydro is lower)	More likely to have federal funding, potentially riskier technology

* Data based on information in DHA (2018), which may be outdated as more cost-effective concepts may be considered.

Because CBS is planning for a significant load increase in 5-10 years, additional generation development should align with this timeline. Therefore, geothermal, tidal, and wave resources should be considered as exploratory options rather than near-term solutions. Of the remaining resources, wind is the least expensive and is also very impactful with respect to providing the required amount of power, and should therefore be prioritized for development. Solar PV can be developed in the near-term as well, but as part of individual-building resilience plans rather than as part of CBS's long-term regional power supply plan.

Figure 21 demonstrates how wind development at Lucky Chance and Beaver Lake can contribute to the generation profile when future loads that include electrification of heating and vehicles need to be met. The contribution of hydropower is approximate and does not account for operational management of the resource; assumptions for calculating the hourly hydro generation are detailed in Appendix B.

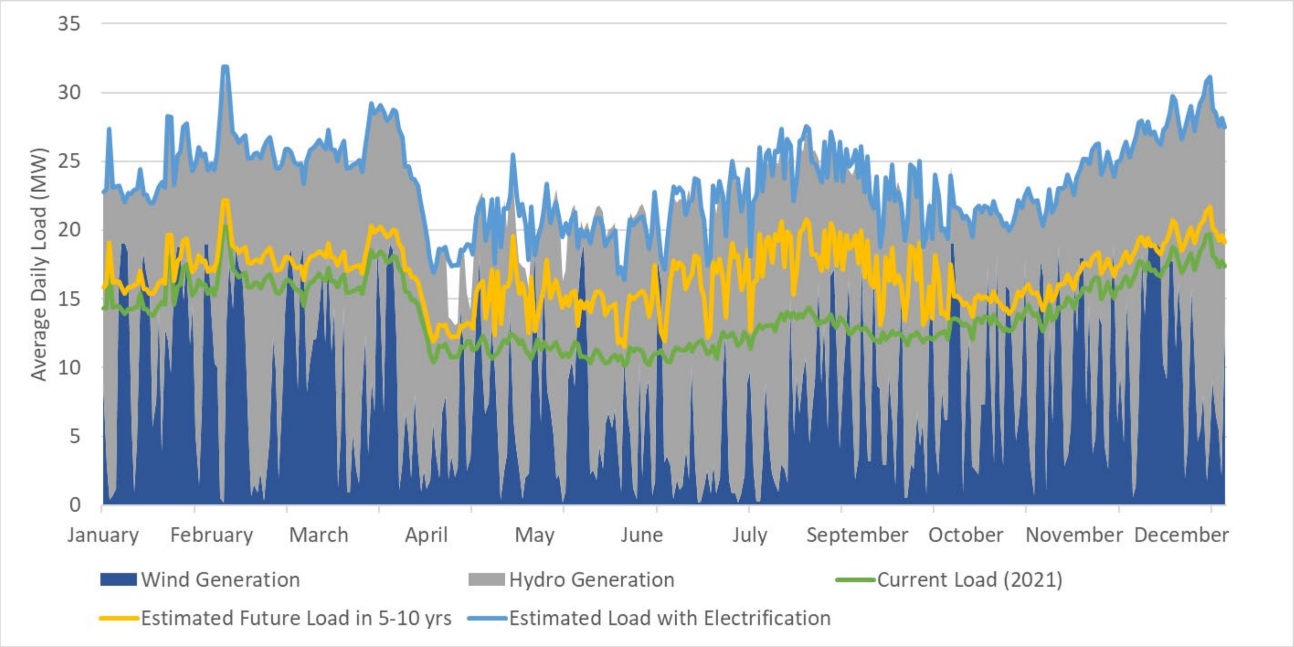

Figure 21. Future wind and existing hydro generation profiles for meeting estimated future loads.

Additional Considerations

This assessment does not consider any required upgrades to the distribution system to accommodate future load growth or generation additions. However, the GridAPPS-D steady-state model developed as part of this project can be used to determine required upgrades to the system. Additionally, the Opal-RT dynamic model also developed as part of this project can be used to understand impacts that additional generation, especially intermittent resources such as wind, will have on grid operations. Required upgrades may include expanded capacity for lines or substations, enhanced microgrid monitoring and controls, or energy storage (to include synchronous generation and flywheel capabilities).

CBS is currently working with HydroForecast to better predict and manage available hydro resources. This will enable them to optimize generation of power as well as utilize excess storage in the dams for economic opportunities such as green fuels production. A separate paper is provided that describes the options for hydrogen or ammonia production using existing hydropower resources.

With the head start in advanced planning provided by DOE’s technical assistance, CBS is well positioned to successfully and economically meet future electricity requirements with clean and diverse energy resources, enhancing energy resilience and reducing greenhouse gas emissions.

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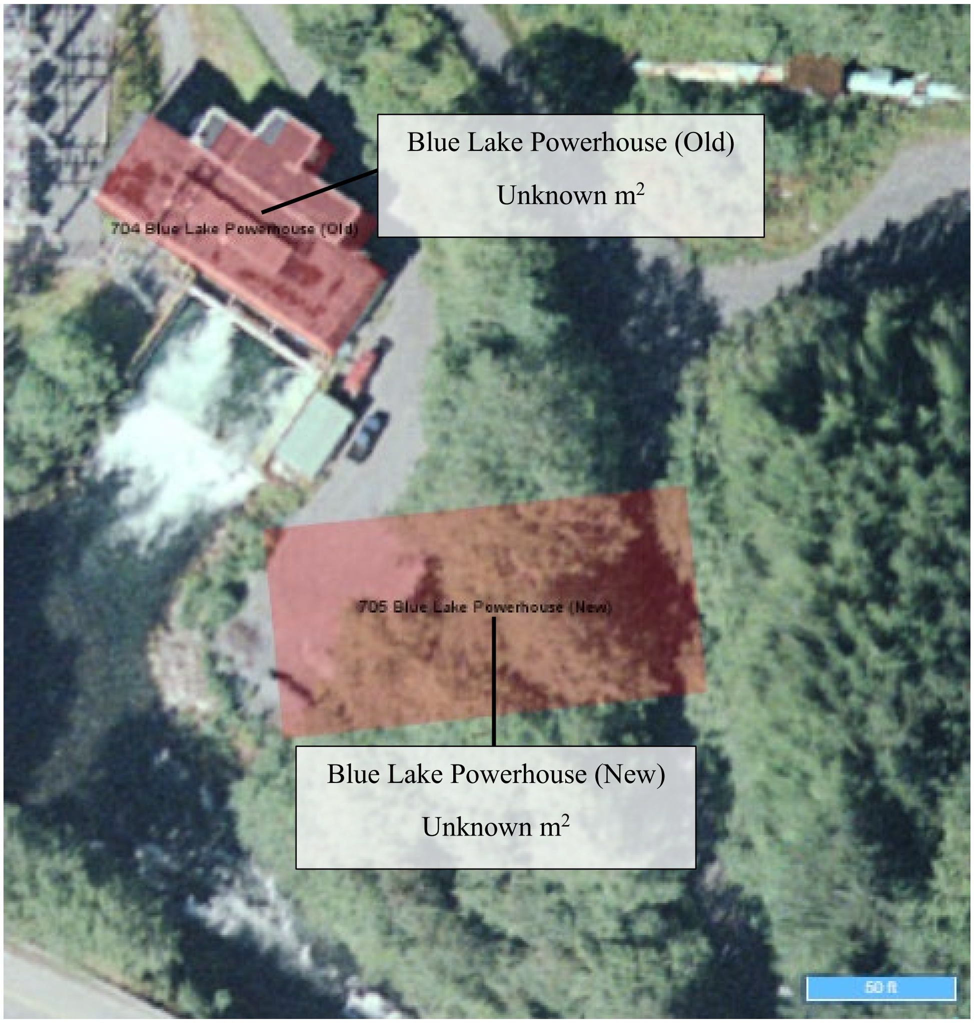
Appendix A. Satellite Images of Rooftops Considered for Solar Photovoltaics

The facilities suggested by CBS for rooftop solar photovoltaics (PV) are shown below, with the amount of available rooftop space assumed to be suitable for PV panels.

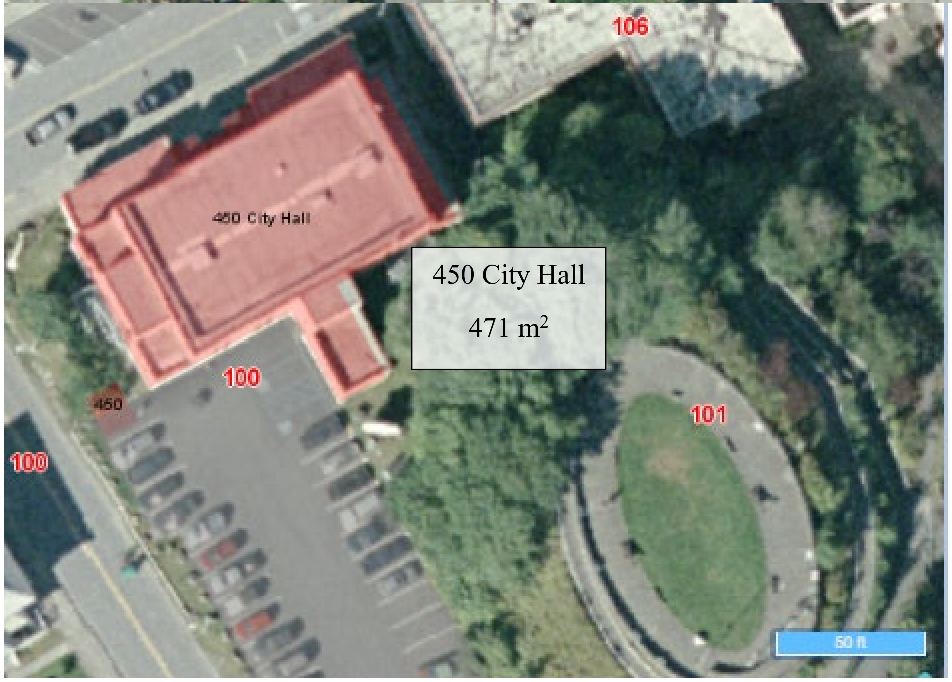

Blue Lake Powerhouse (Old)
Unknown m^2
704 Blue Lake Powerhouse (Old)
705 Blue Lake Powerhouse (New)
Blue Lake Powerhouse (New)
Unknown m^2
50 ft

550 Baranof Elementary School

2,560 m^2

510 City-State Building

1,338 m^2



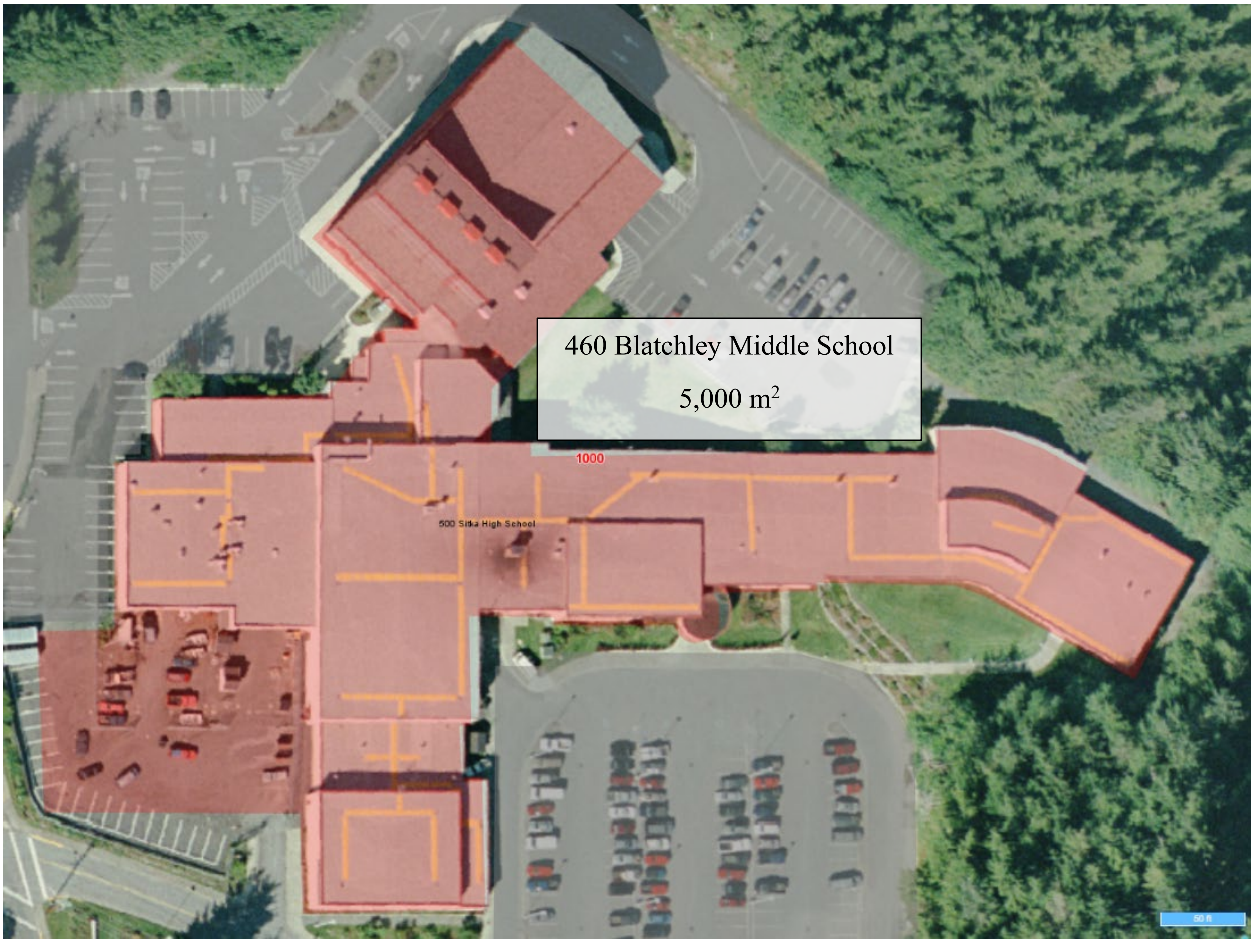
450 City Hall

471 m^2


535-S1 Crescent Harbor Fisherman Shelter
Not recommended due to orientation
500
330
483 Harrigan Centennial Hall
483 Harrigan Centennial Hall
820 m²
50 ft


603
600
601
415 Marine Services Center Building
1,740 m²
507
50 ft


239
604
500 Sitka High School
5,685 m^2
601
608
50 ft



460 Blatchley Middle School

5,000 m^2


1231
1233
401
307
Keet Goshi Heen Elementary School
320 Keet Goshi Heen Elementary School
1,290 m²
1208
1206
1204
1102
50 ft


800 Airport Terminal Building
825 m²
50 ft

Appendix B. Assumptions

Expected Future Loads

The forecasted load of the new SouthEast Alaska Regional Health Consortium (SEARHC) facility was generated using a reference EnergyPlus model of a similar facility, using the following high-level assumptions.

- 241,410 square feet
- Five floors
- Aspect ratio: 1.31
- Concrete construction
- Electric heat pump for conditioning; all electric loads.

The estimated monthly electricity consumption is shown in Table 21, and the estimated annual load profile is depicted in Figure 22.

Table 21. Estimated monthly electricity consumption for new SEARHC facility.

Month	Consumption (kWh)
January	785,711
February	729,084
March	772,950
April	732,975
May	712,142
June	647,967
July	654,701
August	667,244
September	647,877
October	718,046
November	743,090
December	801,251
Total	8,613,037

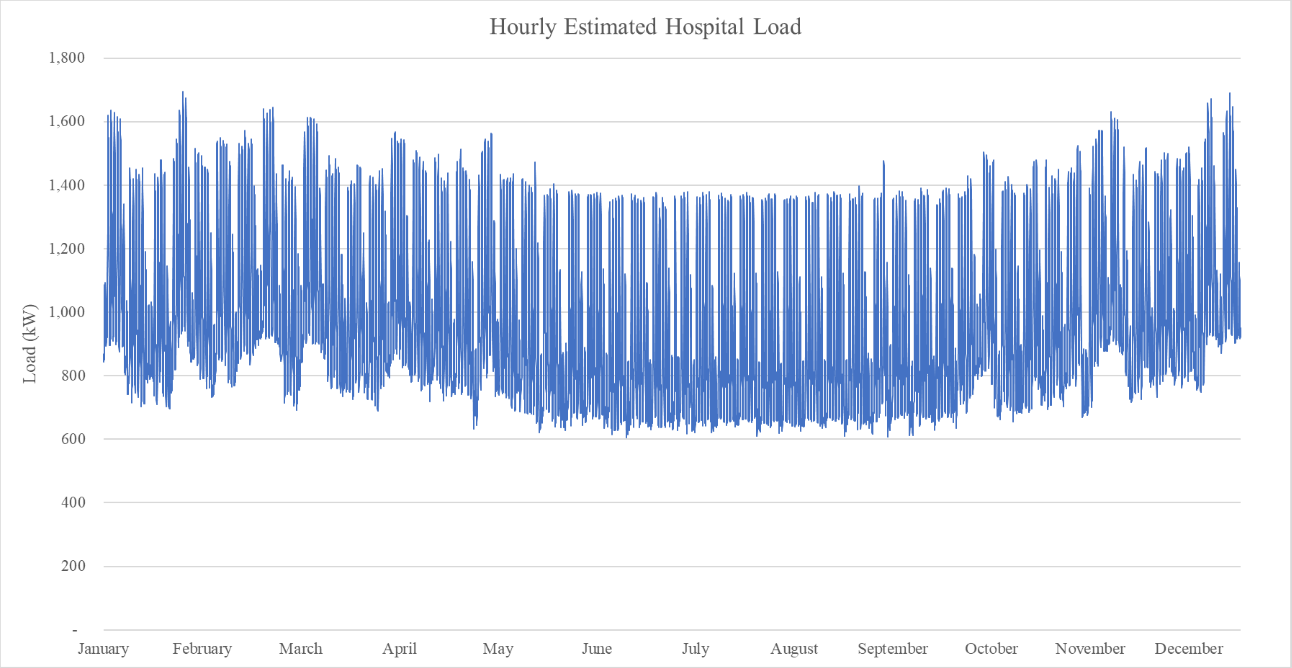


Figure 22. Estimated hourly load for new SEARHC facility.

The bus forecasted load was calculated using the following assumptions:

- Buses use a maximum total of 3.6 MWh per night (10 buses charging using 6 chargers, starting at 18:00).
- At 60% ship capacity they use 2.2 MWh per night (6 buses)
- At 40% ship capacity they use 1.4 MWh per night (4 buses)

The cruise ship forecasted load was calculated using the following assumptions:

- Cruise ships are plugged in approximately 8 hours per day
- If there is one cruise ship docked, the ship uses 6 MW
- If there are two cruise ships docked, the ships use a combined 12 MW.

The tourist season typical lasts from May through the end of September, as seen in Figure 23.

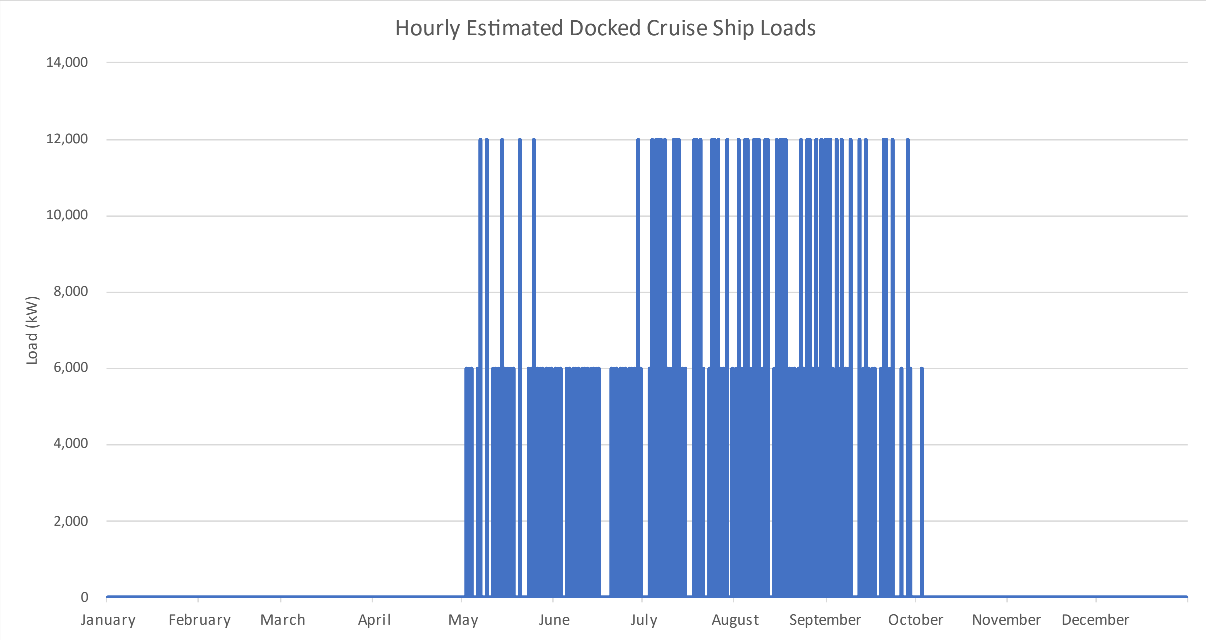


Figure 23. Estimated hourly load for electric cruise ships docking at Sitka.

Generation Forecast Assumptions

A rough model was developed to estimate the generation amount of the existing hydropower plants for various load scenarios. The following simplifying assumptions were made that affect the estimated ability of the existing plants to meet the load at certain times. However, the estimates are deemed sufficient for this preliminary analysis to show potential impacts of increased load and/or generation.

- Generation at Blue Lake (BL) and Green Lake (GL) is always determined by the ratio of their respective capacities, i.e.,
  - $BL\ generation = total\ generation \times \frac{BL\ capacity}{BL\ capacity + GL\ capacity}$
- The amount of water required to generate 1 kWh is based on the average of monthly 2017 BL outflows.
- Lake inflow is the same for every hour in a month, calculated by evenly distributing total monthly inflow for each lake across the hours in that month.
- Lake starting volumes on January 1 were 235,900 acre-feet for BL and 87,000 acre-feet for GL.
- Lake elevations correspond to lake storage volumes using historical lake elevation and volume data.
- If the lake level is too low (321 feet for Green Lake and 353 feet for Blue Lake) to generate the desired amount of power during any hour, no power is generated during that hour.

Generation for each lake was calculated using the following method:

- Checked if any hours in the forecasted load profile, minus the wind generation for each hour, exceed the combined nameplate capacity of both lakes. If so, generation was limited to the maximum capacity of the hydro plants times a 90% efficiency factor:
  - If $load > combined\ capacity,\ BL\ desired\ generation = (combined\ capacity) \times 90\% \times \frac{BL\ capacity}{BL\ capacity + GL\ capacity}$
- If generation was not limited by capacity, calculated desired generation (kW) for each lake for each hour:

  - If $load\ \leq combined\ capacity,\ BL\ desired\ generation\ = (load) \times \frac{BL\ capacity}{BL\ capacity+GL\ capacity}$
- Calculated the volume of water (acre-feet) needed to produce desired generation
  - $Water\ volume\ needed\ for\ desired\ generation\ = \frac{desired\ generation}{load\ per\ acre\ foot}$
- Calculated the hourly inflow using the corresponding historical monthly average inflows
  - $hourly\ inflow = \frac{monthly\ average\ inflow_{2017}}{24}$
- Calculated the hourly net flow
  - $hourly\ net\ flow = hourly\ inflow - volume\ needed\ for\ desired\ generation$
- Calculated the amount of stored water in each lake given the calculated net flow (called "tentative storage" here), which is based on the desired generation amount
  - $tentative\ storage = actual\ storage\ from\ previous\ hour + hourly\ netflow$
- Calculated hourly spilling by comparing the tentative storage amount to the maximum capacity of lakes:
  - If $tentative\ storage\ > max\ average\ volume\ ,\ hourly\ spilling = tentative\ storage - max\ average\ volume$
  - Else $hourly\ spilling = 0$ and $tentative\ storage = max\ average\ volume$
- Forecasted hourly lake elevation based on the tentative storage amount with a linear model
- Calculated actual hourly generation if the projected elevation was not below the minimum:
  - If $hourly\ elevation\ \leq minimum\ historic\ lake\ elevation, hourly\ generation = 0$
  - Else, $hourly\ generation = desired\ generation$
- Calculated actual storage based on actual hourly generation and actual storage from the previous hour.

Appendix C. Supplemental Wave Energy Information

Power Take-off

The power take-off (PTO) of a wave energy converter is the mechanism by which the energy absorbed by the primary converter is transformed into useable energy (i.e., electricity). In energy systems such as fossil fuel, nuclear, or wind, a generator converts unidirectional motion to electricity. The oscillatory (back-and-forth) motion of ocean waves makes the conversion of their energy a unique challenge compared to other sources. This challenge has led to the investigation of several types of PTO systems, visualized in Figure 24. Each wave energy converter (WEC) described in the linked websites in the Wave section of this report can use different PTOs. Oscillating water column devices are typically paired with an air chamber and air turbine PTO, while overtopping devices have hydro turbines. Rotating mass devices tend to have a rotational direct-drive PTO, and attenuators, point absorbers, pressure differential, and oscillating wave surge converters have each been paired with multiple PTO types.

Because the PTO system affects the mass and possibly the shape of the WEC, it also affects how the WEC responds to passing waves. This means that the PTO system can have a large impact on the efficiency of the WEC. The PTO system is likely to be responsible for a significant percentage of the capital cost as well.

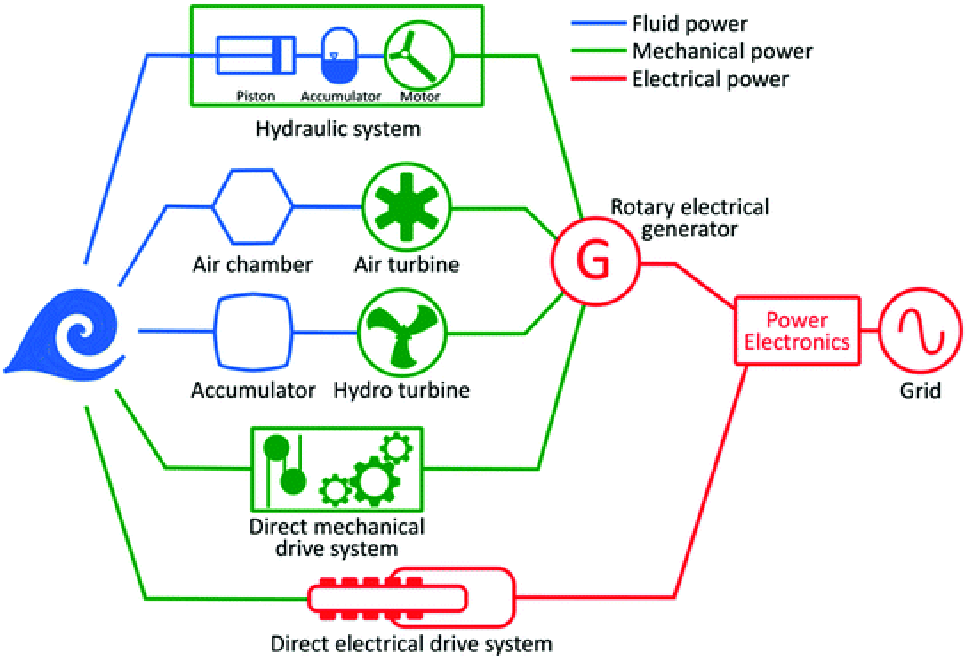


Figure 24. Types of PTO systems for wave energy conversion from Têtu (2017).

Detailed Wave Energy Assessment

Figures 25 and 26 show the average energy matrix for each site over the 29 years of data (1991 removed due to data errors). The average annual energy matrix shows the mean normalized annual energy—the portion of the totaled, averaged energy over the given timeframe—according to the wave height and wave period containing that energy. Figure 25 shows that most of the wave energy near Biorka Island is in 1–4-m high waves with 6–10-s periods. The Japonski location contains energy in the same range of wave periods, but smaller wave heights of 1–2 m.

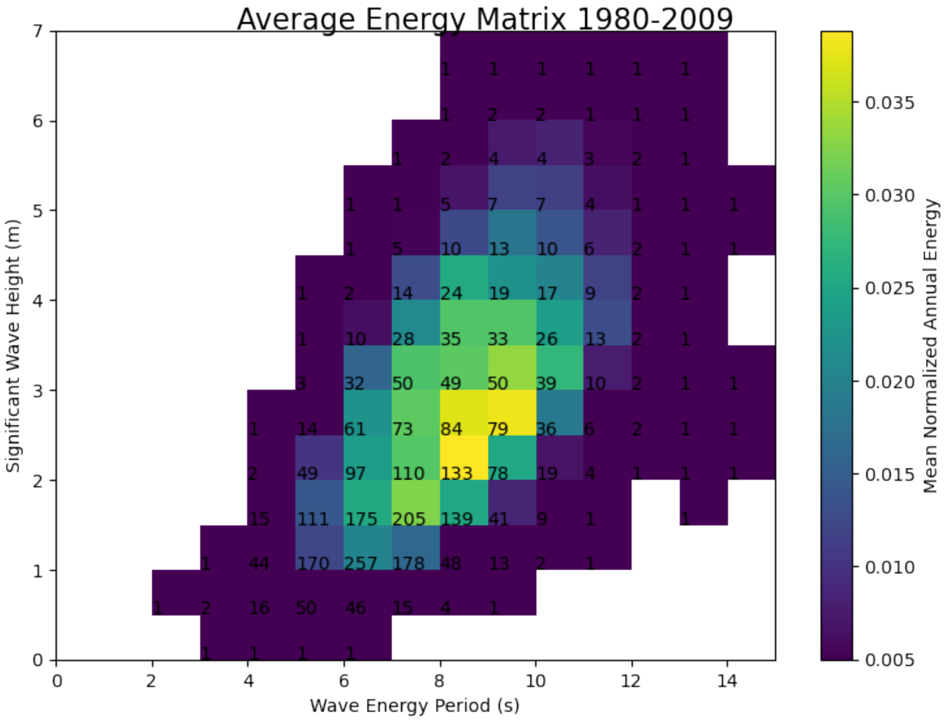


Figure 25. Average annual energy matrix for the Biorka Island site.

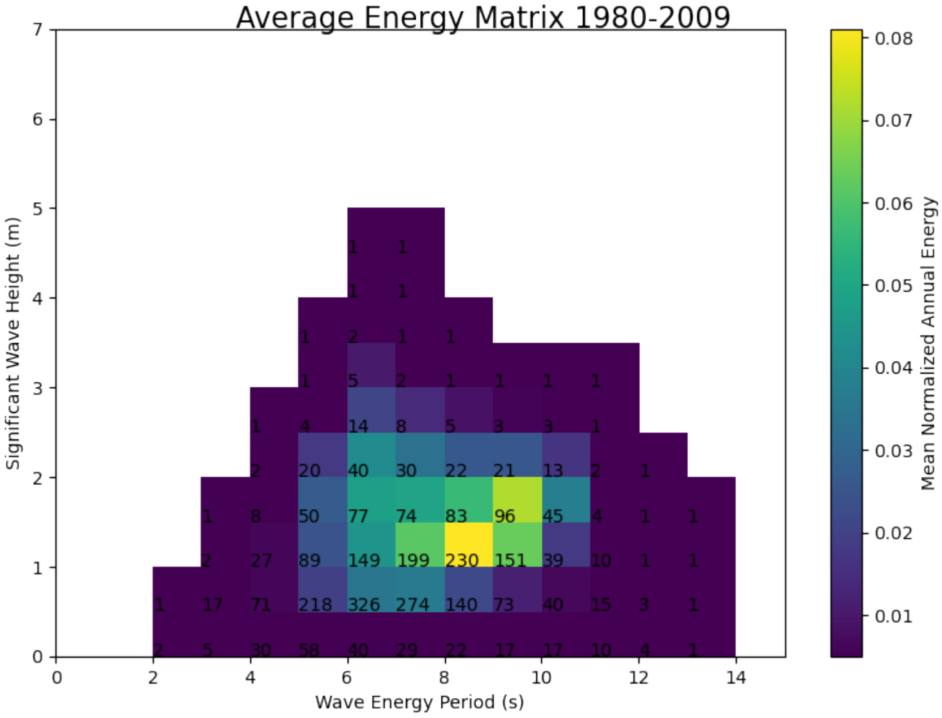


Figure 26. Average annual energy matrix for the Japonski site.

It had long been the standard assumption in wave energy research and development that the best place for wave energy farms would be in areas with the highest wave energy resource, and that the best way to extract that energy would be with the largest possible WEC. An evolving rule of thumb indicated that wave energy extraction is viable in seas with an average annual wave power of over 15 kW/m (Fairley et al. 2020) or even over 25 kW/m (Lavidas and Blok 2021). In recent years, researchers have challenged both of those assumptions in ways that are relevant for Sitka's consideration. The wave resource's variability, frequency bands, and correlation with electricity demand all influence the suitability of a site for wave energy development (Coe et al. 2021). Further, researchers recognize that the excess costs of ensuring survivability in high-energy seas might not be offset by greater energy production. And finally, the use of wave energy for off-grid applications such as aquaculture or ocean observation has brought more attention to moderate-to-low-energy sea states (Fairley et al. 2020). For these reasons, Sitka's wave resource must be characterized in terms of its frequency range, temporal variability, correlation with demand, extremes, and distance from grid connection.

Frequency Bands

Some WECs (especially point absorbers) have a single or small band of frequencies (frequency is the inverse of period) from which they best extract energy. Typically, at lower frequencies (higher periods) than the ideal, a WEC will also absorb energy, but not as much. At higher frequencies (lower periods), there is a steep drop-off in energy absorption. Although smaller WECs might absorb less energy at their ideal frequency, they also tend to have a higher ideal frequency, meaning that they are able to absorb energy from a larger range of frequencies. This is important to consider when choosing a wave energy site or sizing a WEC. Sites with a narrow band of high-energy wave periods are preferable (Coe et al. 2021).

There are several statistics that could be used to compare the frequency band of the potential sites. The standard deviation of the energy period and the percentage of time in which the energy period is higher than 6 s (which is approximately 1 standard deviation below the mean energy period) is used here. Specifically, the standard deviation from the monthly average of the energy period given as a range from the month with the lowest standard deviation to that with the highest is shown in Figure 15 and Figure 16. These statistics come from the 29-year dataset.

The summer months tend to have a lower standard deviation of energy period. At both sites, approximately one standard deviation below the mean (shown in Table 22 for a high- and low-energy year) is about 6 s. Both sites have a period of greater than 6 s about 80% of the time, meaning that a device that can capture waves at frequencies of 1/6 Hz and below will be able to capture energy about 80% of the time, not accounting for maintenance outages or weather interruptions. Figures 26 and 27 show that most of the wave power exists in that frequency range as well.

Table 22. Variability statistics show how often wave climate is within favorable ranges to produce electricity from a wave energy converter.

Site	Standard Deviation T_e for low-high years	Percentage time with mean T_e>6s	Percentage time with mean 60>J>40 kW/m	Percentage time with mean 40>J>20 kW/m	Percentage time with mean 20>J>10 kW/m
Biorka	0.97–1.60	83.8%	11.0%	22.4%	25.4%
Japonski	1.10–1.69	79.6%	0.8%	7.1%	18.4%

Extreme Loads and Electricity Transmission

Although the seas near Sitka contain the most wave energy in the winter months, the highest chance of storms and extreme loads also exists in those months. Many WEC developers deal with the possibility of extreme loading from storms and abnormally high seas with survival strategies, which may include submersion of WECs and/or pauses of operation. The primary objective is to ensure the WEC is not damaged or lost. Figure 27 shows the contours for the expected extreme conditions at Biorka Island. Comparing the extremes to Figure 26, the average energy matrix, it is apparent that even though extremely large waves contain a lot of energy, the energy available over the course of the year at these extreme wave heights and periods is small because they do not occur often. Because WECs typically only extract energy well from a limited range of wave heights and periods and the extreme waves lead to large forces on WECs, Sitka should aim to extract energy from the smaller waves, which occur most often.

The models used to estimate the contour in Figure 27 tend to be more accurate for lower-period waves due to nonlinearities that exist at higher-energy periods. That is why some Hindcast datapoints at high periods remain outside the contour. Any WEC deployed in Sitka should be built to withstand the forces of the waves within the 50- or 100-year contour plus a margin of error. How those wave forces translate to forces on a WEC depends on the WEC design. When considering WEC types or designing a wave energy project, Sitka should ask any developer about survival strategies and point loads (the places on a WEC that will bear the force of the waves).

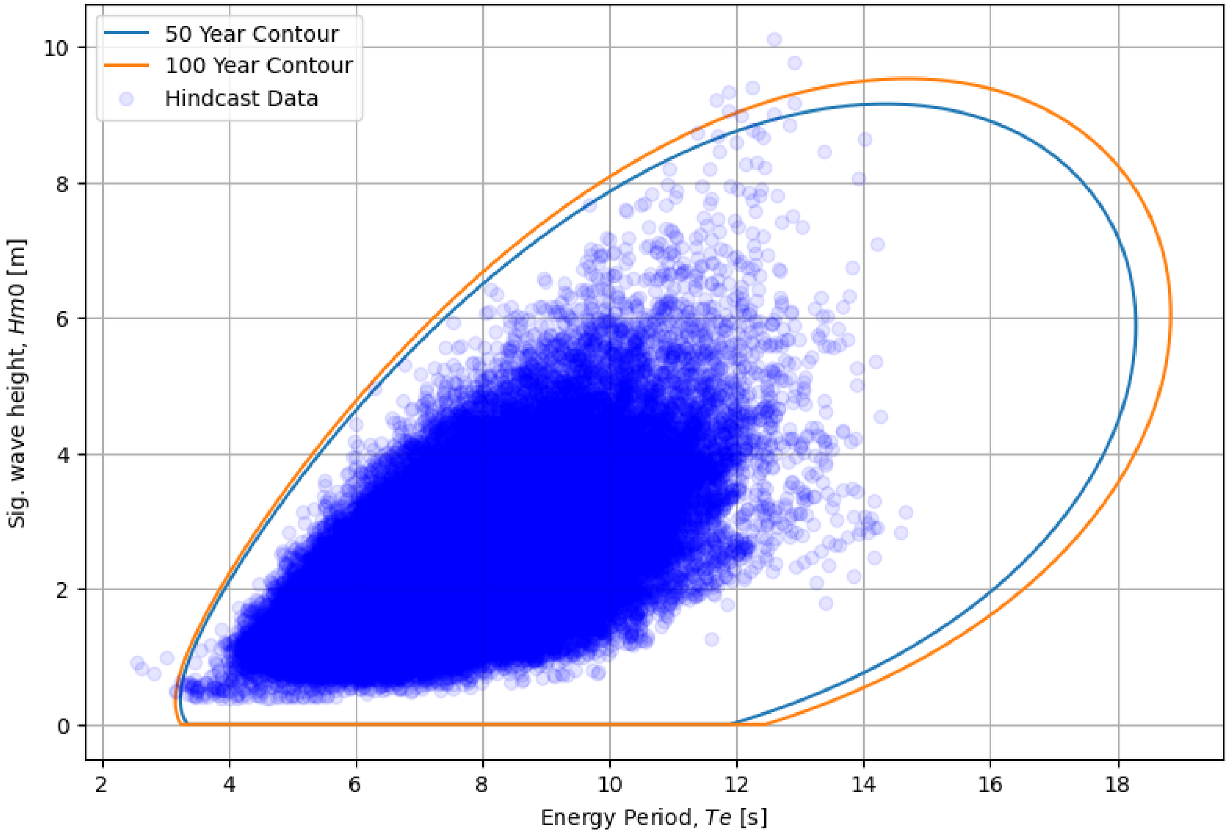


Figure 27. Extreme wave conditions contour for the Biorka Island location.

Along with extreme loads, the cost of energy transmission should be considered when siting a wave energy project in Sitka. The cost of underwater cable transmissions has been estimated between 1 and 3 million U.S. dollars per kilometer (Zhao et al. 2020; Purvins et al. 2018), depending on the difficulty of installation. An underwater cable that moves onto land near Redoubt Lake would be nearly 10 km long. A transmission line to Biorka would likely have to go under or on sand, gravel, and rock bottom substrate because different areas of the Sitka Sound have different bottom types. Rock bottoms tend to be the most difficult to work with for both transmission cables and device moorings.

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