



Microgrid Technology Screening Memorandum

Ketron Island Microgrid Study

Ketron Island, WA

March 30, 2026



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Acronyms and Abbreviations

BESS	battery energy storage system
DGE	diesel gallon equivalent
GGE	gasoline gallon equivalent
HDR	HDR Engineering, Inc.
kW	kilowatts
kWh	kilowatt hours
MMSL	Municipal Maximum Sound Level
NG	natural gas
O&M	operations and maintenance
PV	photovoltaic

Introduction

Ketron Island is a small island community located in the Puget Sound. The island is currently connected to the power grid on the mainland by an underwater cable. This cable is past the end of its usable life, and a new solution is needed to provide reliable power to the island. HDR Engineering, Inc. (HDR), was tasked with a four-phase plan resulting in a 10 percent microgrid design for the island. The detailed development history of the island along with the energy and power demand forecast can be found in Task 1 of the Ketron Island Microgrid Study - Real Estate Potential Assessment and Peak Electrical Energy Load Forecast. The current and forecasted electrical loads are summarized in the next paragraph, which provides framework requirements of the potential microgrid and sizes of technologies under assessment herein.

The future projected daily electrical load with high growth rate is 1,811 kilowatt hours (kWh) with peak power of 200 kilowatts (kW) in normal weather conditions per the peak electrical energy load forecasted in Task 1. The electrical load with no-growth projection (i.e., current electrical load) is 1,763 kWh with peak power of 85 kW. The electrical load prediction is also considered in the selection of microgrid configurations.

This Microgrid Technology Screening Memorandum (memo) addresses Task 2 of the plan and is the second deliverable of the Ketron Island Microgrid study.

Scope

Several different resource technology types are assessed for the potential to be used as part of a permanently islanded microgrid on Ketron Island in this technology screening memo. This memo defines the screening criteria as indicative performance, area requirements, compatibility with existing infrastructure, technology readiness level, capital cost, and operating expense for the technology types. A technology analysis was completed (see Appendix A) that discusses centralized vs isolated decentralized systems, wind turbine axis configurations, and generator fuel types. The centralized and decentralized versions of technologies, including wind turbines; fixed, mounted solar photovoltaic (PV), fossil-fuel generators; hydrogen fuel cells; and lithium-ion battery energy storage systems (BESSs), are described and compared based on the screening criteria (see Appendix B). Finally, technologies will be selected to create several microgrid configurations to be analyzed in Task 3 of the Ketron Island Microgrid Study, titled Analysis of Alternatives Memo. The selected technology configurations are described in Section 1.3.

Technology Evaluation

Appendix A documents the full set of technologies initially considered for Ketron Island. These technologies were screened using the criteria summarized in Appendix B (indicative performance, area requirements, infrastructure compatibility, technology readiness, capital cost, and operating expense). Based on this preliminary screen, technologies that were not viable for Ketron Island were removed from further consideration, and the remaining technologies were used to assemble the candidate microgrid configurations presented in Section 1.3.

Technologies Not Considered Further

The following technologies were excluded from the microgrid configurations:

Natural Gas. Natural gas generation is not favorable in the Ketron island microgrid because there is no natural gas pipeline to the island and the amount of space needed to store natural gas on the island would be very large.

Compressed Natural Gas. Compressed natural gas requires an additional auxiliary system to regulate pressure for fueling power generation. A 14-day supply of compressed natural gas requires about two 8-foot-wide, 36-foot-long, and 9-foot-high tube trailers, which is a significantly more complex system than other fuel types. The added complexity of the system will increase auxiliary equipment and therefore price, making this fuel source less desirable than other options.

Ocean Power. Ocean power source technology is removed from further consideration due to the immaturity of the technology, the lack of significant and supportive commercial partners, and the high capital investment. Additionally, ocean power development could face complex permitting requirements and lengthy environmental review. The remaining viable technologies are selected to establish a few microgrid configurations evaluated in the section below. A detailed description of each technology and a table summarizing the rating of screened technologies are included in Appendix A.

In addition, any ocean-based generation would require a new submarine cable (or equivalent marine interconnection) to deliver power to the island—similar to the existing asset that this project aims to replace.

Centralized vs Isolated Decentralized Systems

For all technology types explored in this memo, both centralized and decentralized versions of the technology are considered. Centralized power for each technology type would consist of a single large generation site that produces power utilizing the existing Tacoma Power electric grid that would distribute this power from the central power generation source. The isolated decentralized solutions consist of individual properties having their own power generation, fuel storage, and a BESS on their premises that are islanded from the existing Ketron Island distribution system. For example, small residential-scale generators with fuel supplies and batteries could be connected to each premises' electrical service panel (residential and non-residential loads such as pumps or dock facilities) for premises-level power only.

In this memo, isolated decentralized generation refers to premises-level systems that are not electrically networked together (i.e., not a microgrid).

Power distribution systems are complex and expensive because they require control and operation equipment to be precisely connected and coordinated to maintain power quality (voltage and frequency) even as loads and generation are starting up and turning off. Each individual site will balance generation and BESS, and net power inflow or outflow to the distribution system must coordinate with all other sites to balance the power generation and load demand in a dynamic way. Connecting and coordinating more than 20 individual residential-scale loads and generation, intermittent solar generation, and BESS sources will be complex and expensive.

A resistive load bank is required to balance power generation, which adds expense and will reduce the overall efficiency of the microgrid system. An isolated decentralized system that doesn't use the

Ketron Island distribution system can avoid sophisticated load balancing requirements and reduce utility coordination.

The overall operations and maintenance (O&M) cost for an isolated decentralized microgrid power system would likely be less than a connected and coordinated microgrid utilizing the distribution system, as there are more electrical components contained in the system and would require higher O&M expenditures and system maintenance – a problem for an island due to limited access to professional mechanics and electricians.

The centralized system could be more cost effective due to the economy of scale from the development, design, procurement, installation, and O&M perspectives. The advantage of the decentralized system is that permitting residential power generators and a BESS is less complex than creating a centralized facility. An additional comparison of centralized and isolated decentralized systems can be seen in Table 1.

Table 1. Centralized vs Decentralized System Comparison

Parameter	Centralized	Decentralized
Efficiency	Higher	Lower
Economy of Scale	Higher	Lower
Permitting Complexity	Higher	Lower
O&M Requirement	Lower	Higher
Capital Cost	Lower	Higher
Area Requirement	Utility-Owned Space	Customer Premises

Horizontal vs Vertical Wind Turbines

Wind feasibility depends on site-specific resource (persistent wind speeds) and siting (land use) constraints. Wind resource screening and siting will be confirmed in Task 3 prior to advancing a wind-inclusive alternative.

Wind turbines are available in horizontal and vertical axis configurations. Efficiency is one of the most significant differences between the two types. Vertical-axis turbines have reduced efficiency because of “drag.” When one side of the turbine is propelled by the wind, the other side is then pushed into the oncoming wind, costing valuable power. The turbine is effective only because the turbine blade is shaped to scoop or capture wind on one side while it deflects the wind on the opposite side. This means that vertical turbines lose efficiency throughout half of their rotation. This issue of drag is less of a concern for horizontal-axis configurations.

Horizontal and vertical turbines also differ in regard to where the mechanical parts are placed on the turbine. The working parts of a horizontal-axis turbine are located at the top of the tower. This makes maintenance more difficult and expensive, as workers have to scale the tower to address mechanical issues. The working parts of a vertical-axis turbine are stored at the base, close to the ground, making repairs easier, less expensive, and less hazardous.

Wind turbine development will be evaluated for community impacts regarding safety setbacks, noise, and shadow flicker. For safety, 1.5 times the total turbine height is recommended for the setback from the closest point of property line, public or private roadways, and occupied buildings. The noise of the wind turbine will be modeled to compare against the allowable increase of Municipal Maximum Sound Levels (MMSLs) during daytime and nighttime.

The difference between the sound level produced by rotating wind turbines and the pre-turbine ambient sound level should be less than the allowable MMSL increase over ambient required by the zone code.

Shadow flicker will also be considered during detailed wind turbine design. Shadow flicker occurs when rotating wind turbine blades pass between the sun and an individual's home, casting a periodic shadow that may result in a flickering phenomenon. It cumulatively occurs for only a few hours per year. The recommended industry standard is less than 30 hours of shadow per year at occupied structures, which represents less than 0.3 percent of annual daylight hours. This is based on an expected or realistic scenario that incorporates cloud cover and operational statistics.

Additional comparison criteria can be seen in Table 2.

Table 2. Horizontal vs Vertical Winds

Parameter	Horizontal	Vertical
Efficiency	Higher	Lower
Wind Speed and Type	High-Quality Winds	Gusty Wind
Ease of Maintenance Access	Top of Tower	Base of Tower
Capital Cost	Comparable	Comparable
Area Requirement	0.74 acre/MW	0.74 acre/MW

Note: MW = megawatt

Fuel Evaluation

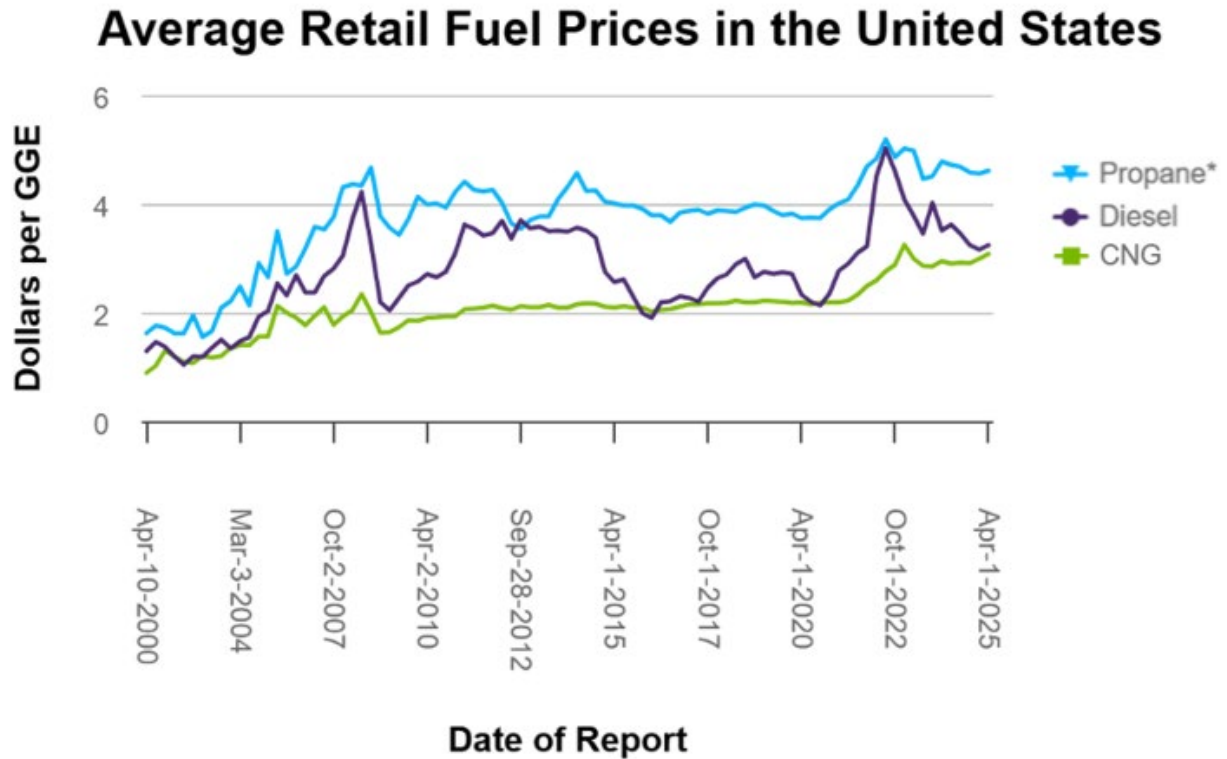
Several different types of fuel can be used for power generation. Common fuel types include diesel, biodiesel, natural gas, and propane. Some generator units can run on multiple types of fuels. Diesel and biodiesel are largely equivalent and can be blended. Diesel fuels are transported and stored in liquid form and have a relatively high energy density. Natural gas has a relatively lower energy density. Propane has an energy density between those of diesel and natural gas and is stored and transported as a compressed liquid.

The price of diesel fuel is generally higher than that of natural gas. Diesel and natural gas fuels have a lower price per gallon than propane. Figure 1 below shows the prices of these fuels using gallons of diesel equivalent to the unit of basis. This unit normalizes the price of these fuels to an equivalent power output. Diesel gallon equivalent (DGE) does not include transportation costs, as they are unavailable during the feasibility study.

Fuel usages are given as a comparison between fuel and generator types in Table 3. This metric takes into account the generator efficiency and the energy density of the fuel. For comparison purposes, it is assumed that the only generation source is the generator and the load case is a current development extreme weather load case. The fuel tank storage sizing is based on a 14-day winter peak. Tank area is based on tank size and local ordinances for setbacks. These values are intended to be a comparison between fuel types and are not indicative of the fuel demands of the various microgrid configurations.

Note that compressed natural gas (NG) and hydrogen require additional systems to resize pressure and temperature. The pressure of the NG will be regulated to ensure flow of the fuel to the generator. The temperature requirements for hydrogen power generation are critical for the efficient and safe operation of hydrogen and turbines. For the purposes of comparing fuel consumption, the

generators are assumed to provide 100 percent of the electrical demand over a full calendar year. Additional comparison data can be seen in Table 3.



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Figure 1. Average Retail Fuel Prices (U.S. Department of Energy 2025)

Note: GGE = gasoline gallon equivalent

Table 3. Generation Fuel Comparison

		Diesel	Bio Diesel	Gasoline	CNG	Propane	Hydrogen
Estimated Cost	\$/gal	\$4.77	\$4.86	\$4.70	\$3.84	\$3.65	\$/lbs \$4.09
Diesel Gallon Equivalent Cost	\$/gal	\$4.77	\$5.34	\$5.24	\$4.32	\$5.63	\$10.21
Technology Efficiency	%	40%	40%	35%	35%	25%	50%
Fuel Usage	gal/yr	40,433	44,438	51,534	52,030	99,711	lbs/yr 80,691
Peak 14 Day Fuel Usage	gal	1,605	1,764	2,045	2,065	3,957	lbs/mo 3,202

Tank Sizing		2 - 3.5x15 ft long, Cylindrical Tanks	2 - 3.5x15 ft long, Cylindrical Tanks	2 - 3.5x15 ft long, Cylindrical Tanks	2 - 8x9x36 ft long, Tube Trailer	4 - 3.5x15 ft long, Cylindrical Tanks		4 - 8x9x36 ft long, Tube Trailers
Tank Area Zone - ARL	sq ft	5,040	5,040	5,040	7,553	6,230		10,142
Tank Area Zone - R10	sq ft	2,240	2,240	2,240	3,913	3,430		6,195
Tank Area Zone - RNC	sq ft	990	990	990	2,178	1,755		3,882
Estimated Yearly Cost	\$/yr	\$192,863	\$215,968	\$242,211	\$199,796	\$363,945		\$330,100
Additional Infrastructure Complexity (Pressurization /temperature regulation)		Low	Low	Low	High	Low		High
Hazards		Flammable	Flammable	Flammable	Flammable	Flammable		Flammable
(1) Hydrogen is bought and sold on a per kg basis								
(2) Diesel Gallon Equivalent (DGE) is the normalized cost of a particular fuel relative to diesel fuel, this metric allows for relative price comparison of fuels								
(3) Assuming typical year load, generator only configuration, fuel volumes are intended to be comparative								
(4) Fuel tank is sized to hold 14 days of fuel								
(5) Assume 5 ft spacing between tanks and 10 ft set back in all directions								

Microgrid Configurations

Five potential microgrid configurations will be analyzed in the next phase: Task 3 - Analysis of Alternatives. These microgrids are comprised of various technologies that were evaluated in the aforementioned sections. These potential configurations include:

Centralized:

1. Solar + BESS + Diesel Generation (Primary Objective: Minimize fuel consumption while ensuring high reliability.)
2. Solar + Wind + BESS + Diesel Generation (Primary Objective: Maximize renewable penetration where land area allows.)
3. Solar (Higher Capacity) + BESS + Diesel Generation (Primary Objective: Reduce diesel reliance and deliveries via greater solar/BESS, recognizing added land use.)
4. Solar + Hydrogen + BESS (Primary Objective: Explore long-duration storage pathways and low-carbon alternatives.)

Isolated Decentralized:

5. Residential Diesel Generation + BESS (Primary Objective: Provide a simple, property-level, off-grid power solution with minimal infrastructure requirements. Use an isolated premises-level backup, not a networked microgrid.)

In addition to these supply-side configurations, energy efficiency and peak load reduction will be considered as complementary strategies for each microgrid configuration. These measures may help fine-tune system sizing—such as reducing battery or generator capacity—and lower overall costs, but they are not expected to affect the overall selection of generation technologies.

Centralized System: A centralized system refers to a single, shared microgrid that serves multiple loads through a common distribution system and centralized generation and storage resources. Requires a persistent and flexible generation system using BESS equipment to maintain power quality (frequency, voltage).

Stand-Alone System: A stand-alone system refers to a self-contained power system serving a single property with no electrical interconnection to other customers or the utility grid. This would require a source of power that was either on any time power was required or would include a BESS to maintain a source of power for the location even if the generator was off.

Note on Critical-Load Resilience: Regardless of the selected system-level configuration, optional premises-level backup (e.g., a small generator or equivalent) may be considered by customers with critical end uses (e.g., heating, refrigeration, life safety) to provide an additional layer of resilience during extended resource constraints. This backup is supplemental and does not replace the centralized microgrid supply.

Configuration #1: Solar + BESS + Diesel Generation

Proposed configuration #1 is made up of a centralized facility consisting of a solar array, a BESS, and a prime diesel generator. A prime diesel generator is designed to provide a reliable and continuous power source for various applications, especially in off-grid or remote locations. The prime power rating signifies that the unit can deliver power reliably and continuously over extended periods when the utility grid is not available or is unreliable. This configuration allows for a smaller solar array and BESS because the generator will be able to supplement the power when the sun is not shining. A prime diesel generator will be sized to cover the entirety of the load, but the generator can be run at partial load to minimize fuel use and extend generator service life. The sizing of the solar array can be based on land availability, and the BESS can be sized to maximize the cost benefit to the solar array size to store excess solar power generation.

Configuration #2: Solar + Wind + BESS + Backup Diesel Generation

Configuration #2 is similar to configuration #1, but a wind turbine array is included to offset the reliance on sunlight. This configuration has a solar array, a BESS, a vertical-axis wind array, and a diesel backup standby generator. A wind turbine array can help diversify the potential sources of power. The ideal turbine siting locations will need to be evaluated based on the wind speed and prevailing direction data collected on Ketron Island. Solar and wind power are often used together in stand-alone renewable power systems due to the synergistic effect they often exhibit. Each form of renewable generation makes up for the shortcomings of the other during their peaks due to varying natural resource availability.

A solar PV ground-mounted system will provide the primary source of power generation during the daytime in summer. Wind turbines are installed in an open area to be complemented with solar PV generation. Wind turbines are at peak production at dawn and dusk, when it is generally windiest. A BESS can be installed adjacent to the solar PV and wind turbine system on land and integrated into the existing electrical distribution system. The BESS can be charged by the excess energy generated by wind turbines and solar PV system and discharged when the electrical demand exceeds the renewable power supply.

The advantage of this microgrid configuration is that both renewable energy sources (i.e., solar PV and wind turbines) are utilized for power generation. The BESS will be sufficiently sized to meet the power and energy demands of the island. Centralized generation can simplify the land acquisition and system installation process and can minimize cost of monitoring, control, and O&M. Wind turbines are sometimes criticized for being unsightly, noisy, and present shadow flicker issues for the resident. Consultation with island residents and further evaluation for siting and setback requirements should be discussed during a public comment period. Additionally, this type of system could also benefit from a backup standby fossil-fuel generator for times when sun or wind generation is insufficient and the battery is depleted. Generators designed for standby or intermittent use are typically limited in annual operational hours, often capped at 200 to 500 hours per year, depending on manufacturer and local policy. Backup standby generator usage is temporary and minimized to allow non-commercial fuel delivery by the local residence.

Configuration #3: Solar (Higher Capacity) + BESS + Diesel Generation

Proposed configuration #3 is similar to configuration #2, but with a larger solar array and without wind generation. The solar PV array will be ground-mounted, fixed tilt, and will be maximally sized to cover the load of the island and to charge the batteries. The batteries will be sized to cover the load during periods when the sun is not available so that when the sun resource is insufficient, the BESS will supply power to the island. A smaller standby fossil-fuel generator could be used as a backup, as in configuration #2.

A notable benefit of this system is that commercial fuel deliveries to the island would be reduced or avoided. The microgrid design, installation, and operation are simplified due to established technologies. Potential challenges to this configuration include insufficient solar energy production. Initial assessments of this system estimate that a solar field would need to be overbuilt significantly, which presents a challenge in a space-constrained location such as an island.

Configuration #4: Hydrogen + BESS

Proposed configuration #4 is a centralized hydrogen-fed fuel cell with a BESS to provide efficiency and to help with power quality. This configuration with site controller can be one of the simplest forms of microgrid. It should be noted that only hydrogen fuel cells as a form of power generation will be considered, and power generation through hydrogen combustion, using a much larger and more sophisticated system is not being considered in any form.

Hydrogen can be produced from renewable sources through electrolysis or traditional fossil sources through steam methane reforming, which can also factor into sourcing hydrogen fuel, but only electrolytical (green) hydrogen will be considered for this analysis. Off-site hydrogen fuel

transportation is required due to lack of on-island renewable energy sources that generate electricity for hydrogen fuel production. Sizable on-site hydrogen storage is expected to be needed to meet the island's demand of electricity. A site controller (BESS) can be paired with the hydrogen generator to cover energy demand during outages and to regulate power output for voltage and frequency modulation.

A few local sources of electrolytic (green) hydrogen sources in the Puget Sound region have opened in the last few years. Transportation logistics of hydrogen fuel deliveries will be considered carefully in Phase 3 due to challenges with availability, cost, and delivery to Ketron Island from the mainland.

Configuration #5: Residential Diesel Generation + BESS

Configuration #5 is an isolated, decentralized option where each residence will own and operate a small diesel or gasoline generator paired to a BESS to meet their individual load. The BESS would be necessary to smooth the peaks and valleys of the load and allow the generator to run at a base load for less hours and with higher generator efficiency.

Each residential electrical system will be islanded and not interconnected with the utility grid to avoid the necessary integration equipment, and significant ongoing maintenance and operating costs of a complicated grid control system. This system has the same fuel challenges as the centralized generator options, where residences will need to supply fuel and storage for their own needs. This may be advantageous for residents who make Ketron Island their home for only part of the year. The decentralized configuration lacks the economies of scale for generator and BESS installation and would require residents to maintain and operate their own equipment. The benefit of the decentralized system is that land will not be required for equipment installation and that the siting and permitting process could be relatively simple.

Appendix A:

Technologies Evaluation

Technologies Evaluation

Wind

The first wind turbine used for electricity generation was installed in Scotland in 1887. Today, wind turbines are common on both the utility and the residential scale. Kinetic energy of the wind is used to spin the blades of a turbine, spinning the shaft of a generator to create electric energy. Utility-scale wind generation typically uses three-blade horizontal-axis turbines in the 1- to 6-megawatt (MW) size range, but wind technology is common on a variety of scales.

A centralized horizontal wind generation facility would be similar to a utility-scale wind generation site but on a smaller scale to match the load requirements of the area. Utility-scale wind turbines exist that could meet the load of Ketron Island single-handedly, but an array of smaller three-blade horizontal-axis turbines would be needed to provide redundancy and increase grid reliability. Vertical-axis wind turbines are not commonly used at utility scale but are common at the smaller scale considered in this application. The Darrieus turbine is one of the most established types of vertical axis turbines. This turbine is less efficient than the traditional three-blade horizontal-axis turbine and thus is less commonly used. A decentralized wind-generation solution would involve small residential-scale turbines located near individual loads. Figure 1 shows a Freen 20-kilowatt (kW) vertical axis turbine (Freen OÜ 2025). A more detailed discussion of horizontal vs vertical wind turbines is provided in Section 1.2.2 of the Microgrid Technology Screening Memorandum (the memo).



Figure 1. Freen 20 Vertical-Axis Wind Turbine

The most notable challenge of wind generation is the unpredictability of weather. The wind may not be blowing when power is needed. This can be addressed by overbuilding the capacity of the wind farm and adding battery storage to the system, which addresses the issue because excess power can be used to charge a battery bank when the wind turbines are producing more power than is needed. Energy stored in the battery can be discharged to the grid when the wind is not blowing and power is needed. Wind turbine reliability is highly dependent on the size of the turbine and the frequency of maintenance. A notable benefit of wind generation is its low

operating cost, with the potential to substantially reduce the frequency of fuel deliveries to the island, though some deliveries may still be required for diesel generation. Additionally, wind generation is one of the oldest forms of power generation and is well established.

Solar

A solar photovoltaic (PV) module is an established technology that is used widely in both utility- and residential-scale generation to capture solar energy. Solar PV modules rely on access to sunlight and are used mostly in areas with long days and ample solar irradiance.

Centralized solar power would require a solar field for production. The size of this type of field is proportional to the required load and quality of the sunlight. Like centralized wind power, some degree of overbuilding would be required to provide redundancy and increase reliability. There are many different mounting strategies for solar PV modules. The most common solar PV modules use ground-mounting systems that are fixed-tilt racking, single-axis tracking, and dual-axis tracking.

Decentralized solar PV module power would require solar arrays in dispersed locations near loads. This is typically accomplished by installing solar PV modules on the roofs of buildings or on racks in high-sun areas that lack significant shading from surrounding buildings and trees. For a centralized solution, fixed-tilt panels would most likely be used. Fixed-tilt racking systems are less expensive and less prone to repair and maintenance needs because they have fewer moving parts. They could have a higher power density if they are placed closer together than tracking systems.

A major limiting factor for the use of solar PV modules on Ketron Island is the cloudy climate of the island and lack of open space. Solar PV modules have a substantial reduction in production in winter due to shorter days, which limit the amount of exposure to the sun. This problem is compounded by the winter load peak of the island. Solar PV modules also have a relatively large land area requirement (i.e., 2.5 acres per MW) compared to other technology types, and shading from surrounding trees can substantially reduce energy production. Like wind, a notable benefit of solar generation is its low operating cost, with the potential to substantially reduce the frequency of fuel deliveries to the island, though some deliveries may still be required for backup generation.

Fossil Generation

Fossil generation is a widely established form of power generation at both the utility and the residential scale. Fossil generation can be broadly grouped into reciprocating engines and combustion turbines. Reciprocating engines are similar to car engines and use a stroking engine to spin a shaft. They are common as backup generators for homes and other small loads. Reciprocating engines offer very consistent power production across a large range of temperatures. Additionally, they are generally less expensive than combustion turbines. Combustion turbines are similar to airplane jet engines and rely on a spinning turbine to spin a generator shaft. Combustion turbines are generally more efficient and require less maintenance

than reciprocating engines. Both forms of power generation are largely impervious to external weather factors and able to produce consistent power under a wide range of conditions.

Advantages of fossil generation include the ability to produce power when called upon, regardless of weather conditions. A major drawback of fossil generation is the need to provide fuel for the equipment. There is no pipeline to the island, so it would be necessary to bring in fuel. Currently, fuel deliveries to the island are not accommodated by ferry. There is an existing ferry service that makes fuel deliveries to neighboring Anderson Island, but the logistical question of whether the ferry would also be able to support fuel delivery to Ketron Island would need to be considered.

Hydrogen Fuel Cells

Hydrogen fuel cells release stored energy within the constituents of a chemical reaction. Hydrogen is combined with oxygen to create water in a fuel cell. Electrons move over an electrolyte, carrying current and producing power.

Compressed gas hydrogen fuel cells use gaseous hydrogen under pressure at normal atmospheric temperatures in pressurized tanks. Liquid hydrogen fuel cells use hydrogen in liquid form as fuel. In this form, hydrogen must be kept at an extremely cold temperature to stay in liquid form, which requires significant refrigeration equipment, requiring additional energy and therefore significantly greater expense. The main benefit of liquid hydrogen is higher power density because hydrogen fuel is denser in its liquid state.

Hydrogen fuel cells have been used in a limited capacity at utility scale but have become increasingly common at smaller scales. Like fossil generation, one of the main drawbacks of this generation source is that fuel deliveries would be required. There are many different sources of power inputs to produce hydrogen, and the type of power used plays a substantial role in the carbon footprint of the fuel cell. The most widely produced and affordable hydrogen is “gray” hydrogen, which is produced from natural gas through steam-methane reforming. Green hydrogen can be produced from renewable resources but is roughly 50 percent more expensive than gray hydrogen; actual cost differences vary widely depending on production scale, renewable energy pricing, location, and delivery logistics.

Battery Energy Storage System

Battery energy storage systems (BESS) are used widely at consumer, industrial, and utility scales, with the most common type of battery storage technology being lithium-ion. Lithium-ion batteries utilize the exchange of lithium ions between electrodes to charge and discharge the battery, thus making them a secondary form of energy storage. Lithium-ion batteries have a round-trip efficiency of up to 86 percent and are the most power dense of the common BESS chemistries. Lithium-ion batteries come in sizes ranging from very small, like a cell phone battery, to large racks of batteries used for storing many megawatt hours of power. Utility batteries typically have a charge/discharge period of 2–4 hours, but the modularity of this technology means it is easily scalable. Degradation of the battery capacity due to usage and time might require future replacement or augmentation of the BESS. A large BESS can be

discharged at a lower C-rate, meaning that the battery is discharged more slowly for longer power duration or several batteries can be discharged in 4-hour blocks to increase the duration of the service. Lithium-ion batteries require charging to be able to supply power when called upon.

Lithium-ion batteries can also store renewable energy for future use. Energy storage is a key aspect of building a microgrid with intermittent resources such as wind, solar, or waves. When renewable resources are plentiful, power is produced at a higher rate than demand, and the power can be stored in a battery for future use.

A BESS that involves charging batteries on the mainland and transporting them to the island was also evaluated. This mode of power delivery to the island would face the same challenges as transporting fuel to the island and would have high costs due to the infrastructure required on both the mainland and island. Additionally, the BESS capacity would need to be doubled so that while one battery is being charged, there is another battery in use on the island. Flywheel technology was also considered as a form of energy storage. This technology was determined to be not well suited for this application due to short discharge times that would be unable to provide power over the necessary duration.

Ocean Power

Ocean power encompasses a wide range of technology types to harness the power of the ocean. The two types that are discussed in this memo are tidal power and wave power. Both technology types have many different device designs in development. Ocean power is still considered to be early in its development as a utility-scale resource. Even in locations rich in resource, it is not widely used. There are no significant firms that commercially supply this equipment and support it with parts, service, or warranties. Therefore, as a viable option, it is not a viable cost-effective technology type.

Tidal power generation is typically produced by a submerged turbine. The turbine spins at low speeds as a continuous tidal current comes in or goes out, producing power. Wave generation is typically produced by a floating point-absorber wave energy converter. This device has a base plate attached to a buoy that are connected but move independently, creating power via the relative motion. Figure 2 shows a tidal power turbine installed for the Roosevelt Island Tidal Energy (RITE) pilot project in 2019 (Tehtys 2019).



Figure 2. Tidal Power Turbine

Figure 3 shows a Point-Absorber Wever energy converter designed by CorPower in 2025 (CorPower 2025).

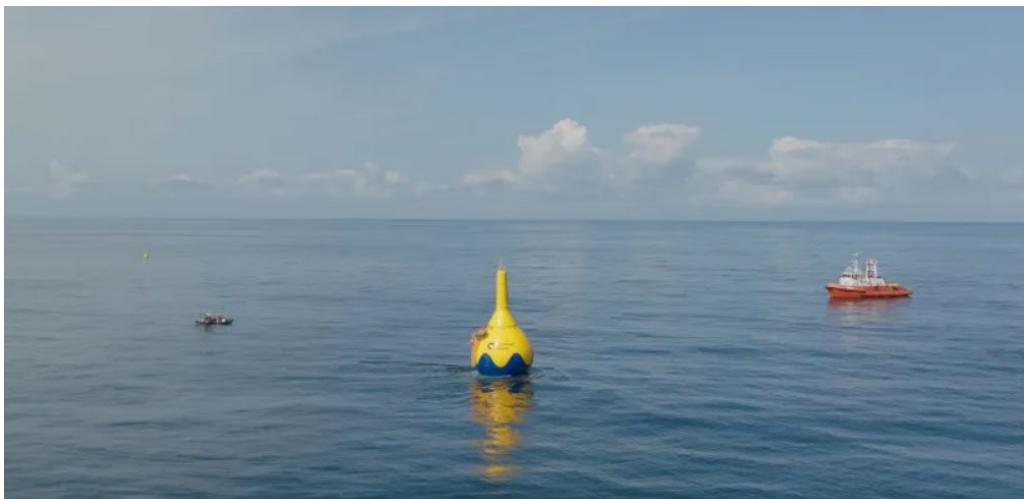


Figure 3. Point-Absorber Wave Energy Converter

Ketron Island is surrounded by an expanse of shallow water, not far from a narrow channel with high tidal current, making it well suited geographically for ocean energy production. Additionally, ocean power generation is a steadier and more reliable resource than wind or solar. The major drawbacks of ocean power generation are the potential permitting concerns; the challenges of interaction with marine life, the challenge of getting the power back to the island from the water (necessitating an undersea marine cable); and the limited commercial options for sourcing equipment, parts, and installers to ocean limitations due to ocean energy being an immature technology.

The Technologies Evaluation Table below provides a consolidated view of how each generation and storage option performs against the screening criteria defined for this study. The purpose of this table is to systematically compare the full suite of technologies initially considered and

documented in Appendix A using a set of parameters that reflect Ketron Island's physical, operational, and logistical constraints.

Technologies Evaluation Table

Technology	Indicative Performance*	Area Requirements	Compatibility to Existing Infrastructure	Technology Maturity	Technology Reliability	Capital Cost	Operating Expense
Wind - Centralized Horizontal	2	1	1	1	1	2	1
Wind - De-Centralized Horizontal	2	2	3	1	1	2	1
Wind - Centralized Vertical	2	1	1	1	1	2	1
Wind - De-Centralized Vertical	2	2	3	1	1	2	1
Solar - Centralized Fixed	2	4	1	1	1	2	1
Solar - De-Centralized Fixed	2	5	4	1	1	2	1
Generator - Centralized Diesel	1	1	3	1	1	1	3
Generator - De-Centralized Diesel	1	2	5	1	1	1	3
Generator - Centralized Biodiesel	1	1	3	1	1	1	4
Generator - De-Centralized Biodiesel	1	2	5	1	1	1	4
Generator - Centralized Natural Gas	1	1	3	1	1	5	5
Generator - De-Centralized Natural Gas	1	2	5	1	1	5	5
Generator - Centralized Liquid Propane	1	1	3	1	1	1	4
Generator - De-Centralized Liquid Propane	1	2	5	1	1	1	4
Hydrogen - Centralized Compressed Gaseous Fuel Cells	1	1	3	3	1	5	5
Hydrogen - De-Centralized Compressed Gaseous Fuel Cells	1	2	5	3	1	5	5
Ocean - Centralized Tidal	2	2	5	5	4	5	1
Ocean - Centralized Wave Generation	2	2	5	5	4	5	1

*Intermittent resources are assumed to be used in conjunction with Battery Energy Storage for Indicative Performance Assessment
Ranking are from 1 to 5 with 1 being the most favorable and 5 being the least. Refer to criteria ranking notes on the following page.

Notes:
Indicative performance ratings are based on how well each technology will be able to meet the required power peak, track the load profile, and produce the required amount of energy over the course of a year. Renewable resource-based generation sources are assumed to be used in conjunction with battery storage but are given a neutral rating because they are not guaranteed to overproduce frequently enough to be able to keep a battery bank charged to meet demand. The other technologies can provide power on demand and are given a favorable rating.
Area requirement ratings are based on the required area per kilowatt for each technology. Solar would take the most land area because it is a low-density power source and a large array of panels would be needed to overcome the low sun intensity and low number of daylight hours on the Island. Generators and fuel cells are power dense and are given a favorable rating. The remainder of technologies were given a neutral rating.
Compatibility with existing infrastructure ratings is based on how easily each technology type can be integrated into the current system on Ketron Island. Distributed generators are ranked less favorably because they would require fuel brought to the island and then distributed to different locations. Centralized generation is given a neutral rating because it would require fuel brought to the island. The renewable generation sources are given a favorable rating because they do not require fuel being brought to the island. The decentralized system will be connected to the service panel in the residential house. The service panel probably needs to be upgraded to accommodate the new equipment. The centralized generation can be integrated into the existing electrical distribution with utility duty electrical equipment. They shall be connected to the existing electrical distribution system.
Technology maturity ratings are assessed as 1 for commercialized and widely used, 3 for pilot projects, and 5 for experimental / development phase. Fuel cells are given a neutral rating because they have been used in power generation but are not widely available. Both ocean power solutions are given unfavorable ratings because this technology is more in a experimental phase of development.
Reliability of equipment is favorable because it increases the reliability of the power generated. Ocean power technologies have an unfavorable reliability rating because they face harsh conditions of the ocean. All other technologies are considered favorable.
Capital Cost ratings are based off the price of the technology and infrastructure updates to support it. Generators are given a favorable rating because they are well-established and affordable. Wind and solar are given a neutral rating because they are more expensive than generators but still generally affordable. Ocean power and fuel cells are given an unfavorable rating because they are novel and have very expensive components.
Operating expense ratings are determined based on the day-to-day cost to run and maintain the equipment. Favorable ratings are given to generation types that do not require fuel. Neutral ratings are given to generators that run on fossil fuel. Unfavorable ratings are given to technologies that run on hydrogen because it is more expensive to procure than fossil fuels. Ocean technologies have an unfavorable rating since it is more expensive to service the units in the ocean.
Redundancy and emissions will be evaluated in Task 3. Permitting is not part of technology investigation.

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U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy

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Appendix B:

Overview of Comparison Parameters

Overview of Comparison Parameters

Indicative Performance

The indicative performance variable evaluates how well each generation technology is suited to the conditions of a specific location, such as Ketron Island. Different locations favor different technologies based on site constraints, climate, and available resources. Given the island's small size, it is particularly important to assess which technologies can reliably meet peak power demand, follow the island's load profile, and generate sufficient energy over the course of a year.

Fuel-based generation technologies perform well under these conditions because power output can be adjusted as needed by supplying additional fuel, allowing them to consistently meet demand. As a result, these technologies receive favorable ratings. In contrast, renewable resource-based generation cannot meet these requirements as a stand-alone solution (e.g., wind-only) due to the variability of resource availability. To achieve acceptable performance, renewable generation must be paired with BESS and/or other supporting technologies.

For a microgrid configuration to be viable, it must reliably supply power at the time it is needed, not just when energy can be generated. This is a challenge for renewable resources, whose output depends on environmental conditions. Battery energy storage systems help address this limitation by storing excess renewable energy during periods of high production and discharging it when generation falls below demand. For example, batteries can be charged during periods of high solar output and discharged during nighttime or low-production periods. However, effective use of BESS depends on renewable resources being available frequently enough to consistently recharge the batteries and maintain reliable system performance.

Area Requirements

As part of this study, the land area requirements for each generation technology are evaluated. Different technologies have varying space needs, including land-based requirements (or water-based requirements for tidal and wave technologies). Ketron Island is heavily forested and has limited open space, which constrains where new infrastructure can be sited. This evaluation focuses on the physical footprint required by each technology, as options with smaller footprints generally result in lower land acquisition needs and are more favorable for implementation on the island.

Compatibility with Existing Infrastructure

Compatibility with existing infrastructure is also evaluated as part of this study. Due to its small size and remote location, Ketron Island presents unique challenges. The island has a relatively small population and limited access to fuel, as it is not connected to the mainland by a natural gas pipeline. Fuel is transported to the island via ferry service, as discussed in Section 3.2.4 of the Real Estate Potential Assessment and Peak Electrical Energy Load Forecast. Reliance on ferry-based fuel delivery is considered less favorable due to logistical constraints.

Compatibility with the existing electrical infrastructure is evaluated based on the complexity and difficulty of integrating each technology into the current Ketron Island electrical system. Technologies that require significant modifications or major retrofits to the existing infrastructure are considered less favorable. A description of the existing electrical infrastructure is provided below.

The existing electrical infrastructure on Ketron Island consists of a 12.47-kilovolt (kV) overhead power distribution system, 100-Amp (A) recloser with three single-phase Tripsaver-II 30k devices and three sentiment ZM1 current transformers, two 45-foot wood poles on the Ketron Island side, one 25-foot wood pole on the Steilacoom side, and a submarine medium-voltage (MV) cable connecting Ketron Island to the city of Steilacoom. A schematic of this system can be seen in Appendix D. The submarine MV cable is rated at 12.47kV with three 4/0 American Wire Gauge (AWG) copper conductors and one #2 AWG copper neutral conductor. Approximately 10 miles of submarine MV cable was direct-burial installed underwater in 1965 and is beyond the end of its usable age (see Appendix E). A 100A, three-phase recloser was installed on a utility pole. It is currently being utilized as an overcurrent protective device and as a disconnecting means for the power distribution system on the island, as shown in Appendix C. The 24 individual electrical meters on Ketron Island are located at 18 residential and 6 commercial premises. These meters are fed from 18 transformers installed on the utility poles that are owned and operated by Tacoma Power. Fifteen of 18 transformers are single-phase with 12.47kV primary voltage and 120/240-volt (V) secondary voltage suitable for residential usage. The rest of the transformers are three-phase with 12.47kV primary voltage and 277/480V or 120/240V secondary voltage suitable for commercial usage.

Technology Readiness Level

Technology readiness level reflects the maturity, reliability, and commercial availability of a given technology. Established, commercially deployed technologies tend to offer greater reliability and cost advantages and are generally easier to install and maintain than newer, less proven solutions. As a result, more mature technologies are considered favorable.

Ketron Island is considering an islanded microgrid that operates independently of the larger electrical grid and therefore cannot rely on external power sources during generation interruptions. In contrast, interconnected power systems can rely on other generation units to maintain supply if one component experiences an outage. Because Ketron Island lacks this redundancy, the reliability of the selected equipment is especially important in minimizing the risk of power outages.

Some technologies are inherently more reliable and less susceptible to equipment failure than others, while certain options may also require more frequent or prolonged maintenance downtime. These factors are considered as part of the evaluation. It is also noted that the island's electrical load is classified as non-critical residential load, which has lower reliability requirements than critical services. Even so, technologies with higher reliability and proven performance are considered more favorable for this application.

Capital Cost

Capital cost represents the upfront investment required to implement a given technology. This includes costs associated with purchasing equipment, BESS and fuel cell replacement or augmentation, land acquisition, construction of new generation facilities, and upgrades to related infrastructure.

Capital costs can vary significantly between centralized and decentralized approaches. Centralized solutions typically require land acquisition and site development, while decentralized solutions may involve upgrades to individual homes, such as roof replacement to support rooftop solar installations and electrical panel upgrades to accommodate distributed generation. Technologies with lower overall capital costs are considered more favorable.

Operating Expense

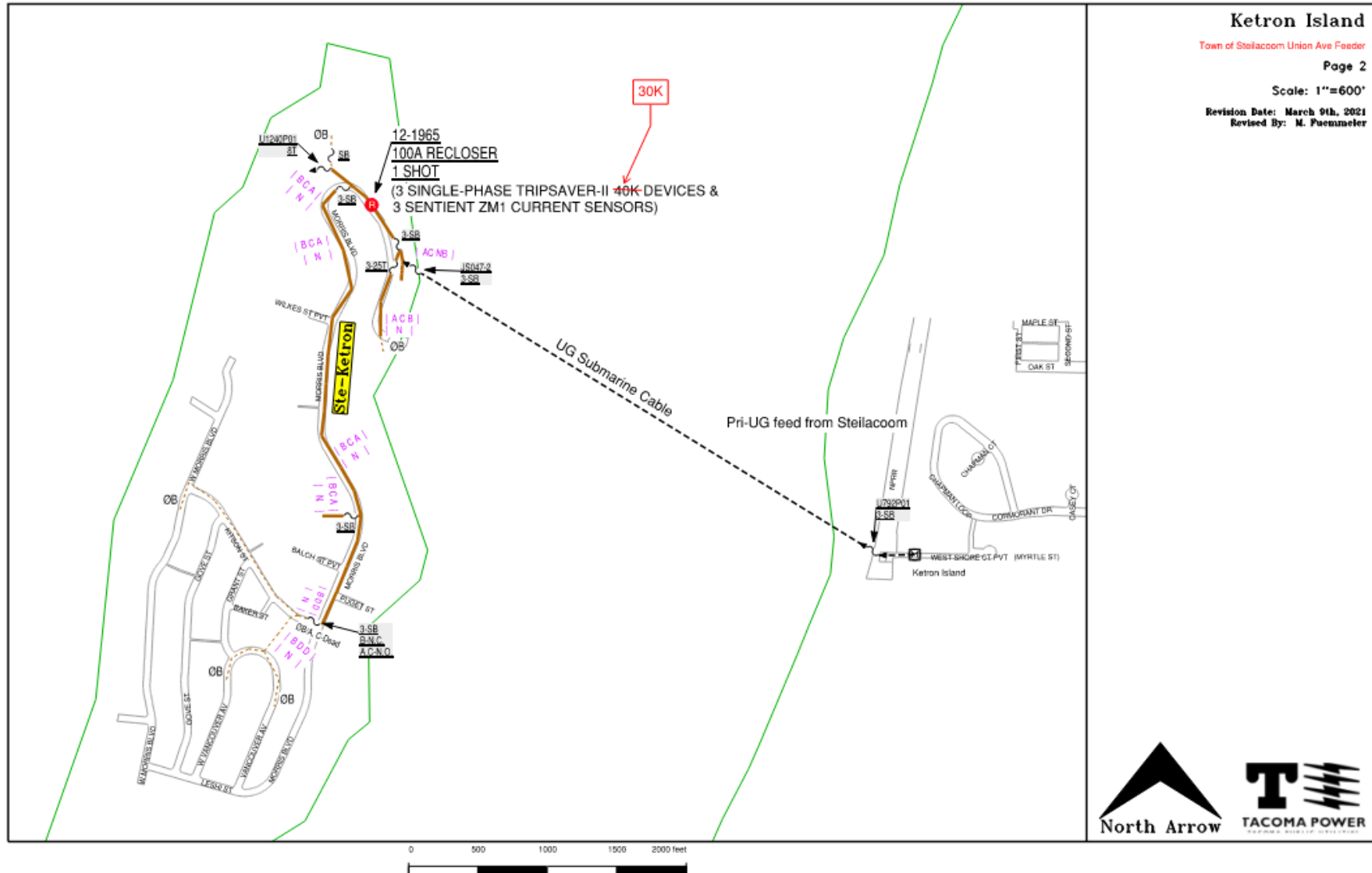
Operating expenses include the ongoing costs required to operate and maintain the equipment. These costs include fuel and other consumables, routine maintenance, and any additional support services needed to sustain operations. Operating expenses may also include the cost of additional ferry trips to the island. While a ferry service currently delivers fuel to a nearby larger island, several logistical considerations would need to be evaluated to determine whether this service could also support power generation needs on Ketron Island.

Operating costs generally increase with the amount of equipment deployed, as is often the case with decentralized solutions. Similarly, equipment located in less accessible or more challenging environments—such as ocean-based technologies—tends to have higher maintenance requirements. Technologies with lower operating expenses are considered more favorable.

Appendix C:

Ketron Island Electrical Distribution System Primary View

Ketron Island Electrical Distribution System Primary View



Appendix D:

Ketron Island Electrical Distribution System

Ketron Island Electrical Distribution System



Appendix E:

Ketron Island 12.5kV Submarine Cable Crossing Plan and Profile

