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Assessment Framework of Marine Hydrokinetic Technologies for Microgrid Applications

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ACRONYMS

BESS	battery electric storage systems
CAPEX	capital expenditures
LCOE	levelized cost of energy
PV	photovoltaic

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Assessment Framework of Marine Hydrokinetic Technologies for Microgrid Applications

MICROGRID NEEDS IN ALASKA

Microgrids are a Necessity for Rural Alaskan Communities

Communities in Alaska that are not connected to a regional grid rely heavily on stand-alone generators with imported diesel fuel as the primary source of energy.[a] The reliance on diesel fuel ties the cost of generating power to the price of oil, which is on average higher in Alaska than the rest of the United States.[b] Given Alaska's long winters and adverse weather conditions, the diesel supply chain can be impaired and delayed with little warning. These delays put reliant communities at risk of experiencing power failures. Current system configurations provide limited opportunities for generation backups.

Integrating renewable-based microgrids into these grid-islanded communities could have several positive impacts that address the gaps left by traditional diesel generation configurations. The first of these impacts is the increased community resilience through generation diversification. Renewable-based microgrids also reduce carbon outputs generated through the diesel supply chain. Construction, operation, and maintenance activities associated with these new microgrid configurations can facilitate the economic growth of remote communities.

Many Alaskan Communities could Integrate Marine Hydrokinetic Generation Resources

The United States has 2,3000 terawatt hours a year of marine energy resource potential; 48% of this potential is in Alaska.[c] The majority of this potential is located in the wave category. Currently, there is only one active project site utilizing marine energy in the state.[d] Indicating Alaska has significant marine energy potential that is currently being underutilized. A major limiting factor in the deployment of marine hydrokinetic projects is a low technology maturity.

MICROGRID RESOURCE ASSESSMENT FRAMEWORK

Evaluating Alaskan Microgrids' Renewable Energy Options

The goal of this assessment was to establish a framework that could determine the feasibility and potential of planning renewable-based microgrids in grid-islanded Alaskan communities—ideally making the planning and construction of these microgrids approachable and more cost effective for community members and other stakeholders. Over the course of this study, three main stakeholder groups were identified: the population of the grid-islanded communities, microgrid operators, and marine hydrokinetic vendors. The assessment was conducted from the viewpoint of microgrid operators with consideration towards community impacts.

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[a] University of Alaska Fairbanks. 2017. "Diesel Generator Technology Briefing." Alaska Center for Energy and Power. Last accessed on October 29, 2021. http://acep.uaf.edu/projects-(collection)/diesel-generator-technology-briefing.aspx.

[b] U.S. Energy Information Administration. n.d. "Alaska State Profile and Energy Estimates." U.S. State. Last accessed on October 29, 2021. https://www.eia.gov/state/?sid=AK#tabs-4.

[c] Kilcher, L., M. Fogarty, and M. Lawson. 2021. "Marine Energy in the United States: An Overview of Opportunities." NREL/TP-5700-78773, National Renewable Energy Laboratory. https://www.energy.gov/sites/default/files/2021/02/f82/78773_3.pdf.

[d] Pacific Northwest National Laboratory. n.d. "Tethys Knowledge Base." Content. Last accessed on October 29, 2021. https://tethys.pnnl.gov/knowledge-base-marine-energy?f%5B0%5D=content%3A550&f%5B1%5D=technology%3A423.

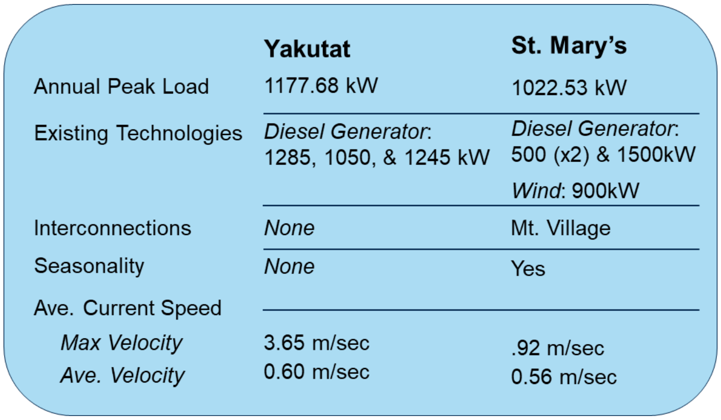
Assessment partners included the Alaska Center for Energy and Power, XENDEE, and Idaho National Laboratory. The assessment framework includes first establishing the existing grid configuration for a community and then establishing what a renewable-based microgrid configuration would contain.

The final step consists of comparing the tradeoffs between existing microgrid configuration and potential renewable microgrid configurations. Note, given the limited scope of this project, the reliability and stability testing was not conducted for the use cases detailed below.

Identifying Two Alaskan Communications for Assessment

St. Mary's and Yakutat were the two communities chosen for this initial effort (Figure 1). These communities were picked based on (1) knowledge of the existing systems, (2) their diversity from each other, and (3) marine and river hydrokinetic energy potential (Figure 2).

Figure 1. Map of St. Mary's and Yakutat, the two case study communities.



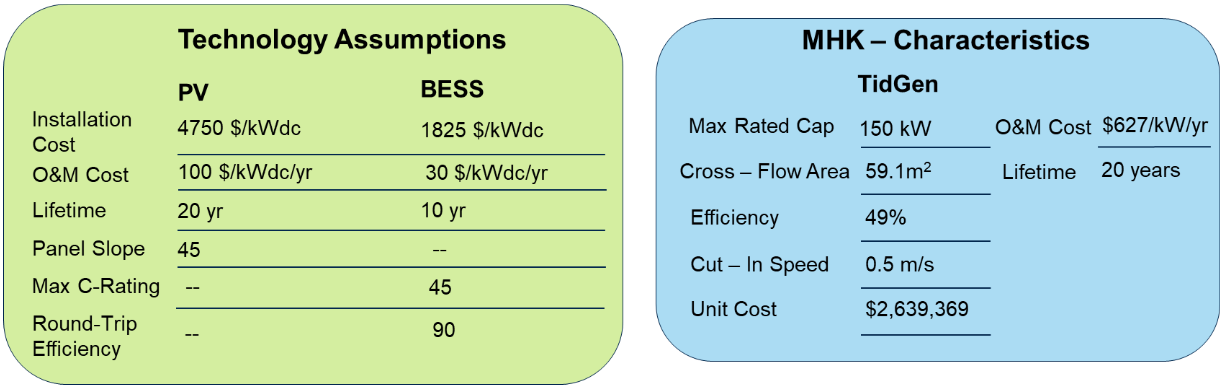
	Yakutat	**St. Mary's**
Annual Peak Load	1177.68 kW	1022.53 kW
Existing Technologies	*Diesel Generator*: 1285, 1050, & 1245 kW	*Diesel Generator*: 500 (x2) & 1500kW *Wind*: 900kW
Interconnections	*None*	Mt. Village
Seasonality	*None*	Yes
Ave. Current Speed		
Max Velocity	3.65 m/sec	.92 m/sec
Ave. Velocity	0.60 m/sec	0.56 m/sec

Figure 2. Electric load and marine hydrokinetic resource highlights for case study sites.

Evaluating Several Renewable Technologies

Wind, photovoltaic (PV), battery electric storage systems (BESS), diesel, and tidal current generation were considered for this assessment. The first two diesel generators and wind turbines are already in use in the selected communities. Ocean Renewable Power Company's TidGen Power System was used to model possible tidal generation integration at Yakutat. Additionally, PV and BESS were considered in the renewable microgrid configurations. It should be noted that PV and BESS technology cost are highly location dependent due to shipping, and there is significant uncertainty in installation cost and operations and maintenance cost due to the few numbers of examples of installations in rural Alaska (Figure 3).

The assessment considered two unique base scenarios "PV Considered" and "No PV Considered" in addition to modeling the community's current systems. "PV Considered" included the inclusion of PV generation in addition to associated battery storage. "No PV Considered" excluded PV generation, focusing on tidal and other renewable sources of generation. Including the "No PV Considered" scenario allowed for the consideration of tidal-based microgrids despite results indicating an increase in microgrid cost. Note, in St. Mary's the "No PV Considered" scenario was expanded to include variable capital expenditures (CAPEX) values for tidal generation. Additionally, both base scenarios were capped at a 50% increase in cost from the current system scenario.



Technology Assumptions

	PV	BESS
Installation Cost	4750 $/kWdc	1825 $/kWdc
O&M Cost	100 $/kWdc/yr	30 $/kWdc/yr
Lifetime	20 yr	10 yr
Panel Slope	45	--
Max C-Rating	--	45
Round-Trip Efficiency	--	90

MHK – Characteristics

	TidGen		
Max Rated Cap	150 kW	O&M Cost	$627/kW/yr
Cross – Flow Area	59.1m²	Lifetime	20 years
Efficiency	49%		
Cut – In Speed	0.5 m/s		
Unit Cost	$2,639,369		

Figure 3. Key technology technoeconomic modeling assumptions.[e,f,g,h,i]

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[e] ORPC Maine. 2013. Cobscook Bay Tidal Energy Project: 2012 Environmental Monitoring Report. Report by Ocean Renewable Power Company (ORPC).

[f] Ocean Renewable Power Company. 2016. "TidGen LCOE Workbooks [data set]." Marnie and Hydrokinetic Data Repository. Last modified March 21, 2016. https://dx.doi.org/10.15473/1418357.

[g] Ocean Renewable Power Company. 2018. "Advanced TidGen Power System - ORPC Public Technical Report, Device Design [data set]." Marnie and Hydrokinetic Data Repository. Last modified June 27, 2018. http://data.openei.org/submissions/4009.

[h] Modeling Parameters: Michele Chamberlin thesis & discussions with ACEP contacts.

[i] ORPC. n.d. "TidGen® Power System." Our Solutions. Last accessed on November 12, 2021. https://www.orpc.co/our-solutions/scalable-grid-integrated-systems/tidgen-power-system.

TECHNOECONOMIC OUTCOMES OF THE TWO CASE STUDIES

Full results and figures can be viewed in the companion PowerPoint associated with this document.

Yakutat

Two scenarios outside of Yakutat's existing system were modeled (Table 1). In both the "PV Considered" and "No PV Considered" scenarios, there is a significant increase in total annual cost of the system. There is also a significant decrease in emissions in the "PV Considered" scenario with a difference of 1,335 metric tons of carbon from the current system. There is also an increase in operations and maintenance costs with either a renewable-based microgrid scenario in addition to a levelized cost of energy (LCOE) increase of .211 and .193 dollars per kilowatt-hour for each renewable microgrid scenario. While the renewable scenarios do result in an increase in costs, they also demonstrate the possible benefits of configuration through emissions reduction and increased storage capacity.

Table 1. Results of the two scenarios outside of Yakutat's existing system.

	Current System	PV Considered	No PV Considered
Total Annual Cost (k$)	2493.1	3739.5 (+50%)	3620.5 (+45.2%)
Emissions (MT)	3972.9	2637.6 (-33.6%)	3680.6 (-7.4%_
PV Capacity (kW)	N/A	3085	0
Storage Capacity (kWh)	N/A	1451	114
Tidal Capacity (# units)	N/A	0	4
Annual Maintenance (k$)	813.4	900.8	1145.4
Fuel Cost ((k$)	1070.6	710.7	991.8
LCOE ($/kWh) (Generation-based)	0.4291	0.6401	0.6230

St. Mary's

Each scenario for St. Mary produced an annual cost increase of roughly 50%. The greatest emission reductions were projected to occur in the "PV Considered" scenario. The St. Mary's scenarios also indicated a reduction in fuel costs and an increase in storage capacity for the community. Cost increases were seen across all three scenarios in both the "Annual Maintenance" and "LCOE" (Table 2). The "No PV Considered" scenario tidal generation becomes a viable option (stays below the 50% increase in the price ceiling) when CAPEX costs are set to 5.6$ per watt.

Similar to Yakutat, St. Mary's scenarios indicate that renewable-based microgrids both with and without the integration of marine and river hydrokinetics will result in an increase in annual costs.

However, there was a reduction in emission across all renewable microgrid configurations for both communities. This coincides with increased energy storage across all scenarios. St. Mary's "No PV Considered" scenario indicates that if CAPEX costs for tidal generation can below lowered the technology could be a viable addition to renewable generation options in microgrid configurations.

Table 2. Results of three scenarios outside of the current system.

	Current System	PV Considered	No PV Considered (original CAPEX)	No PV Considered ($5.6/W Tidal CAPEX)
Total Annual Cost (k$)	1528.4	2292.6 (+50%)	2289.7 (+49.8%)	2292.6 (+50%)
Emissions (MT)	1839.13	1266.3 (-31.1%)	1738.5 (-5.5%)	1739.2 (-5.4%)
PV Capacity (kW)	N/A	1642	0	0
Storage Capacity (kWh)	N/A	1083	2990	1803
Tidal Capacity (# units)	N/A	0	0	2
Annual Maintenance (k$)	666.8	713.3	750.3	898.7
Fuel Cost ((k$)	526.4	362.5	497.6	497.8
LCOE ($/kWh) (Generation-based)	0.2617	0.391	0.3910	0.3918

RECOMENDATIONS FOR SCALING MICROGRID ANALYSIS

While PV and tidal were not cost effective in either community, the framework developed can be efficiently implemented to explore a range of other community and generation investment scenarios. Additionally, there are variations in PV installation costs and generator operational costs across locations in rural Alaska. Considering the uncertainty in cost inputs, the results presented in this case study do not negate the possibility for economically viable PV and tidal projects.

Further studies would greatly benefit from more detailed site-specific cost assessments for economic decision-making. There are numerous successful PV, wind, and BESS installations across rural Alaska including, such as Kokhanok (180 kW wind), Kotezbue (2.4 MW wind, 500 kW PV, and 1.25 MW/950 kWh BESS), and Kodiak (9 MW wind, 20.5 MW hydro).[j] These installations provide evidence that there is significant community interest and economic opportunity in additional renewable energy installments, including tidal, run-of-river, and wave especially as the technology matures. Kodiak is another example of where different storage technologies and renewable generation support the island's load requirements.[k]

The high costs associated with this assessment and renewable microgrids containing hydrokinetic technology can be largely attributed to technology readiness level. As the technology matures CAPEX would ideally decrease. Allowing for a lower barrier to entry for including hydrokinetic technologies into renewable microgrid configurations. The integration of hydropower at applicable sites may also contribute to the lowering of total microgrid configuration cost.

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[j] Holdmann, G. P., R. W. Wies, and J. B. Vandermeer. 2019. "Renewable Energy Integration in Alaska's Remote Islanded Microgrids: Economic Drivers, Technical Strategies, Technological Niche Development, and Policy Implications." Proceedings of the IEEE 107(9): 1820–1837. https://doi.org/10.1109/JPROC.2019.2932755.

[k] Clamp, A. 2020. "Microgrids with Energy Storage: Benefits, Challenges, of Two Microgrid Case Studies". Business and Technology Surveillance. https://kodiakelectric.com/wp-content/uploads/2020/10/Surveillance-CEATI-Rpt-Microgrids-and-ES-Pt2-September-2020-002.pdf.

Traditionally microgrid planning and deployment is expensive. To deploy a community microgrid costs on average $2.1 million per megawatt.[1] The initial planning before deploying a microgrid adds additional costs. These two factors compound into a heavy financial burden for communities. The framework and approach used here reduces planning costs by efficiently evaluating resource mixes that meet the community's energy objectives. It is flexible and can be efficiently applied to numerous grid-islanded Alaskan communities with marine and river hydrokinetic potential, as well as other resources such as hydropower. Ideally the framework will provide a stakeholder with the ability to (1) determine if their community is a candidate for a renewable-based microgrid, (2) work to establish which technology mix works for their location and community needs, and (3) test the reliability and stability of the new microgrid configuration before construction and deployment. Future development of the framework could directly involve stakeholders (e.g., community members and microgrid operators) to better inform the assumptions, including expected costs and weather conditions which could impact technology type. When paired with regional resource assessment maps, the framework could be implemented systematically to identify renewable energy microgrid roadmaps for Alaska.

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[1] Giraldez, J., F. Flores-Espino, S. MacAlpine, and P. Asmus. 2018. "Phase I Microgrid Cost Study: Data Collection and Analysis of Microgrid Costs in the United States." NREL/TP-5D00-67821, National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy19osti/67821.pdf.