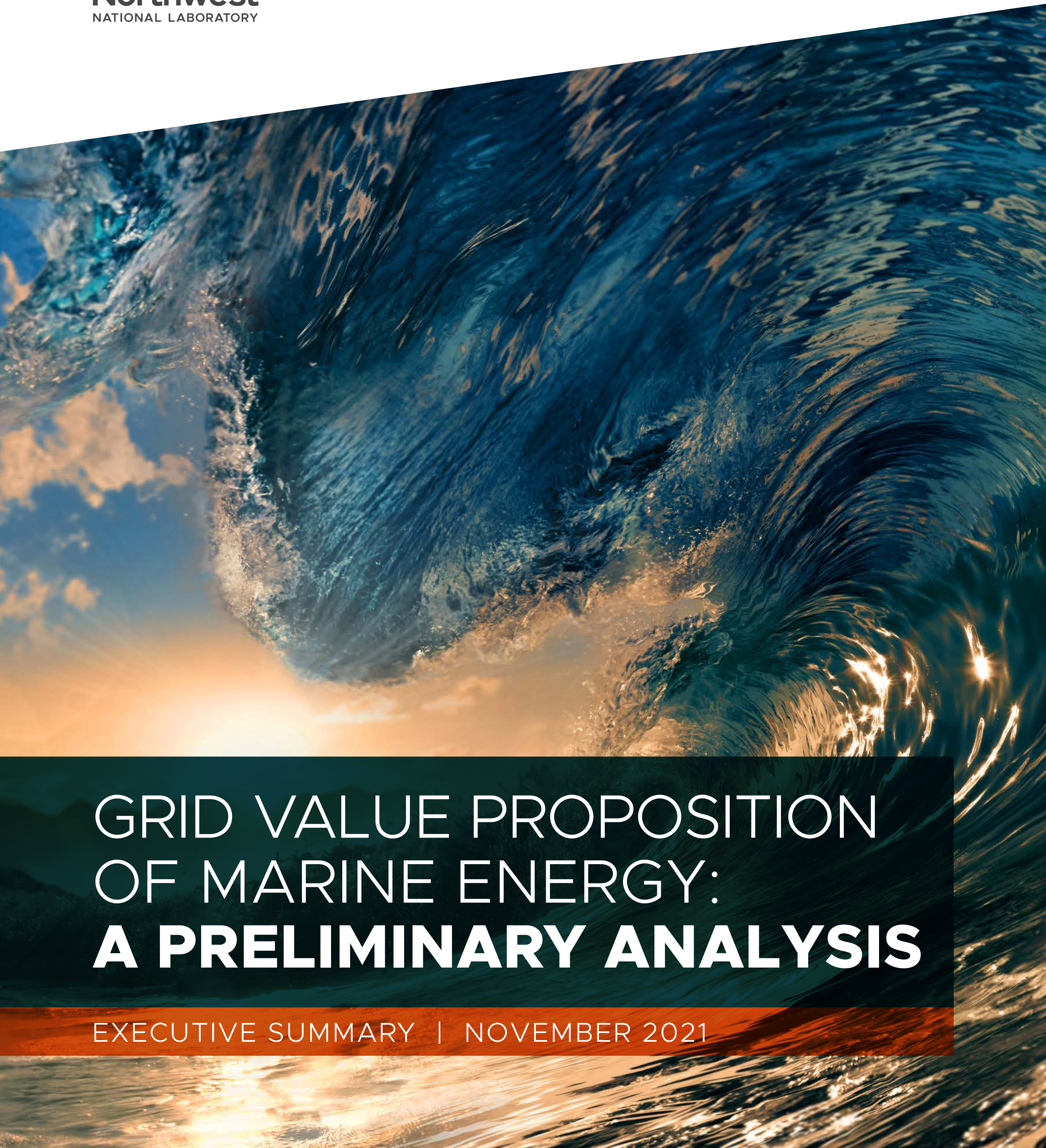
Pacific Northwest
NATIONAL LABORATORY



GRID VALUE PROPOSITION OF MARINE ENERGY: **A PRELIMINARY ANALYSIS**

EXECUTIVE SUMMARY | NOVEMBER 2021

The Azura point absorber wave energy converter being tested at the U.S. Navy's Wave Energy Test Site in Kaneohe Bay on Oahu.

INTRODUCTION TO **MARINE ENERGY**

Marine energy resources have the potential to become a key clean energy resource of the future U.S. grid and our transition to a 100% renewable energy economy. Several U.S. states have established strong renewable or clean energy targets, and the U.S. Federal government has declared a policy goal of a 100% carbon free electricity sector by 2035. The promise of marine energy resources is significant: a recent study from the National Renewable Energy Laboratory finds that **marine energy resources have the potential to provide 57% of U.S. electricity needs**. For comparison, the currently installed wind and solar capacity across the country served 12% of U.S. electricity needs in 2020.

Wind and solar resources have achieved grid cost parity with traditional resources and energy storage technology costs are rapidly declining, but these resources will not be enough to ensure a reliable clean energy grid at reasonable cost. Marine energy resources have the potential to help overcome this challenge and are abundantly available along the country's coastlines, island regions, and in rivers or channels.

While technologies that convert marine energy resources to renewable power are advancing rapidly, the industry still faces hurdles to reach full commercialization. Without many real-world deployments, the value they represent to the electric grid is not well known and not captured by traditional energy comparison metrics like the levelized cost of energy. Accelerating the understanding of marine energy's grid value proposition will help enable system planners consider marine energy alongside alternatives in charting out future grid resources. This acceleration will also help research institutions, manufacturers, and developers target funding, designs, and deployments to optimize the capture of value in delivering electricity.

Pacific Northwest National Laboratory, working with colleagues from the National Renewable Energy Laboratory, Oregon State University, and the Pacific Ocean Energy Trust, have together conducted several types of analyses to identify an illustrated value proposition for marine energy resources. This effort provides a fresh framework for evaluating electric system benefits based on marine energy's attributes and provides **a preliminary analysis to** illustrate and quantify those benefits beyond what can be achieved from a specific project, **and considering the early stage of technology development**.

Overall, we find that marine energy provides value to the grid in the following ways, especially as the U.S. works to a 100% carbon free electricity system:

- Marine energy resources provide important **complementarity and diversity** within a portfolio of renewable resources.
- Marine energy resources help **serve coastal loads** across U.S. coastlines where more than 40% of our population resides.
- Marine energy resources help reduce the reliance on imported fuels for **small, island and remote grids**, while supporting local energy system reliability.

APPROACH

The goal of this work is to identify, evaluate, and measure characteristics of marine energy that offer unique benefits to the electric grid by building a crosswalk between resources, technologies and electric grid value.

For purposes of this investigation, the term *grid value* is meant to include, but not be limited to, provision of a defined grid service, measurable benefit to grid performance, avoided costs to system investments or operations, revenue capture, and contribution to desired grid qualities (e.g., low carbon intensity).

Certain aspects of marine energy—location, relative predictability, generation profiles, and persistence—should be beneficial, but there has been limited research to quantify these benefits. Just as solar is not the cheapest energy resource at scale, it is still successful because it offers unique value like modularity and scaling that make it a competitive solution. Marine energy likely has a value proposition under certain circumstances where other generating resources are not feasible; for example, transmission investments to remote coastal locations could be deferred or avoided. And marine energy as a predictable resource with periodicity linked to electric system needs would require a fraction of associated integration costs of other variable resources. Our analyses provide clear indicators of marine energy's potential to provide value to a clean electric grid.

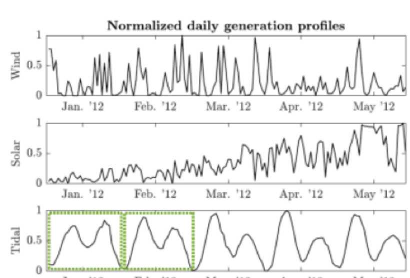
We outline the landscape of marine energy attributes and their potential value streams, or benefits, into three bins: (a) spatial or locational aspects; (b) temporal or timing aspects; and (c) special applications. This structure ensures most potential benefits are captured, and finding the intersection between these benefits, available resource data, generation technology models, and grid data is a key component for enabling research.

LOCATION

The benefits associated with marine energy resources being a coastal resource.

TIMING

The benefits associated with the forecastability, predictability, seasonality and load and resource correlation of marine generation.



SPECIAL APPLICATIONS

The benefits associated with the ability of marine energy resources to provide services in unique contexts.

MARINE ENERGY DEVICES

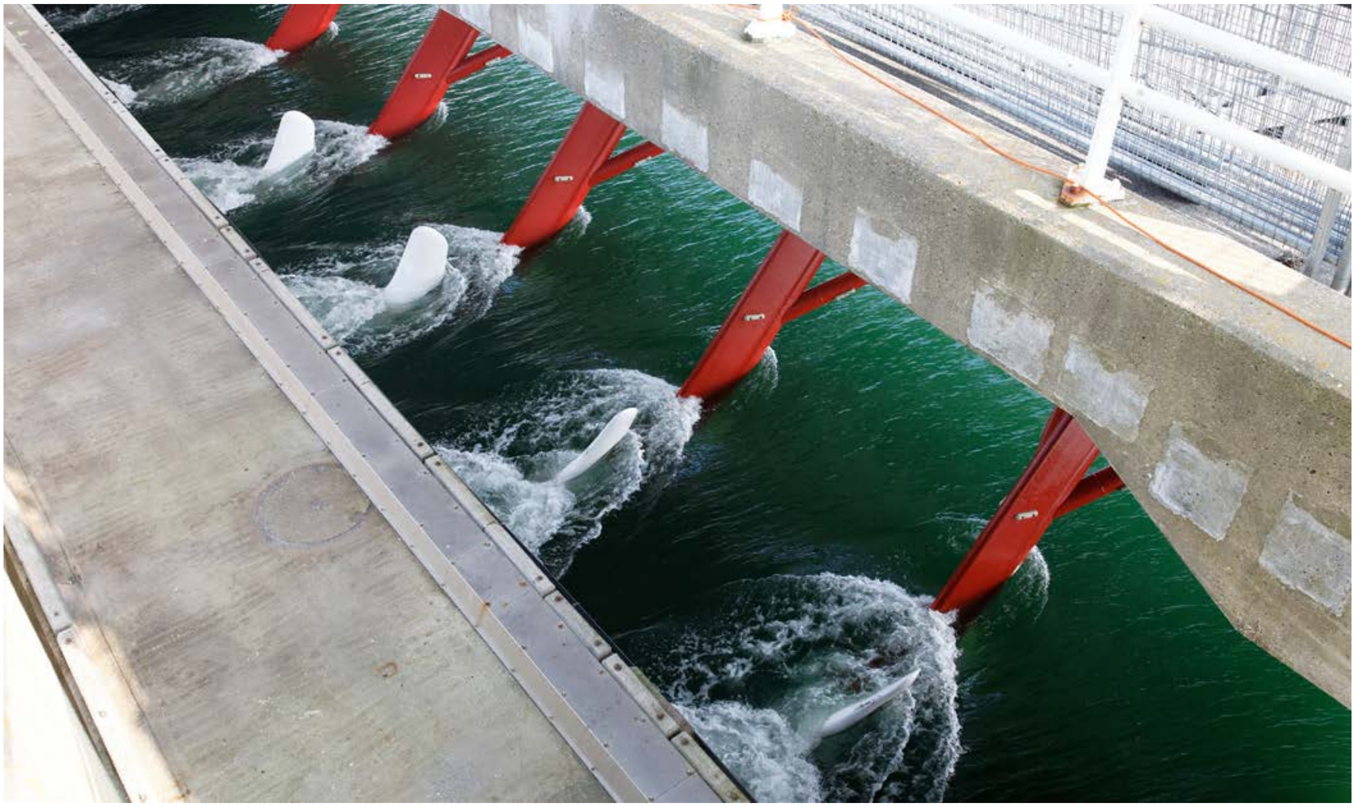
A broad range of energy conversion device designs exist but this project is limited to wave, tidal, and ocean current technologies.

Wave energy converters harvest the kinetic and potential energy from ocean waves. A wide variety of systems have been proposed and developed over the past decades, but they generally generate electricity by either harnessing the motion of waves or the displacement of air caused by the wave motion.

Tidal current devices harness energy from the flow of tidal currents. These devices most often resemble a three-blade, horizontal-axis wind turbine, but other types also exist.

Ocean current energy devices harness the horizontal flow of ocean currents. These devices are often similar to tidal current devices. However, unlike tidal currents, which frequently change direction due to the rise and fall of tides, ocean currents are generally stable and maintain their direction over time.

The potential for these technologies to provide electricity and grid services is substantial but grid quality data are not readily available to evaluate value propositions for potential deployment. To address this gap, this project spends considerable effort in modeling electric output in a device-agnostic way to establish a representation of device value.



Tidal turbines at the 1.25 MW Oosterschelde Tidal Power Plant in the Netherlands.

Value Propositions

Our work indicates that marine energy provides important benefits to the grid. These benefits include energy, capacity, and reserves, as well as predictable generation patterns that integrate well with energy storage systems and complement more variable and less predictable renewable energy resources. Device and project developers can target these benefits, enhancing revenue opportunities, reducing system costs, and helping advance the nation's broader energy transition.

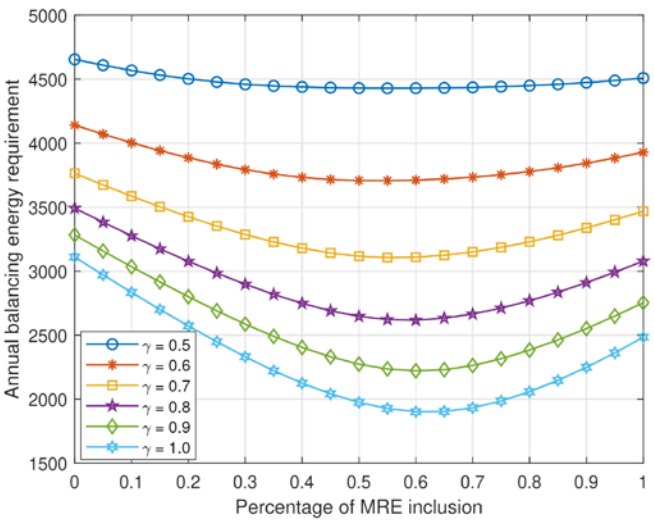
Timing Value: Complementarity and Diversity

Research indicates that increasing resource diversity helps to meet electricity needs while minimizing the overbuild of wind, solar, and storage resources. Marine energy provides improved predictability over wind and solar and can be shown to complement their output: waves and currents keep going when the sun goes down or the wind stops blowing.

We find the annual hourly maximum balancing requirement, that is the hourly mismatch between generation and load, to be reduced by 19.5% with wave energy in place of equal amounts of wind and solar.

Reduce Grid Operating Costs

A capacity value analysis across the U.S. Pacific Northwest indicates that local wave energy has a higher load carrying capacity, a measure of a resource's ability to generate electricity when the grid is likely to experience energy shortfalls, relative to local solar and wind generation. This is particularly valid in winter during night hours when the wave resource is robust. This can be attributed to the relatively stable nature of the wave resource, which is typically winter peaking in the Pacific Northwest. We find similar results on Nantucket Island in Massachusetts, where a deployment of tidal energy helps to alleviate energy storage capacity requirements under high renewable deployment scenarios, complementing the output of solar generation. The nature and extent of that benefit, however, is sensitive to several factors, including location, the characteristics of other energy resources, load characteristics, and the characteristics of the marine resource. In this example, **a generation portfolio with a 30% proportion of tidal energy minimizes the storage capacity required to balance the system at an hourly level by up to 10% relative to the deployment of solar energy.**



This chart shows that when generation resources are compared at a specific site, the Pacific Northwest in this case, marine energy production adds resource diversity to the generation mix, bringing down balancing needs. The y-axis is balancing requirements in megawatts and the x-axis represents added levels of marine energy to an equal portfolio of wind and solar. γ represents the proportion of renewable energy, with the balance assumed to be fossil.

More Reliable Generation

An analysis of hourly ramp rates, which is the change in output of the resource, indicates benefits in the coupling of wave and offshore wind off the Oregon coast and solar and wave resources on the Northern Puerto Rican coast. These benefits manifest as reductions in hourly ramp rates, which translate to **lower integration and balancing costs as fewer other resources are needed to address the gap between resource output and electricity demand**. The coupling of resources may also enable mutual benefits for infrastructure investment, including ports and ships for offshore wind, and transmission and distribution facilities for both wind and solar.

In these situations, adding marine energy to the portfolio adds a diverse resource with different generation characteristics, complementing—or filling in the gaps—of wind and solar generation.

Locational Value: Serving Coastal Loads

Delivering the amount of renewable energy needed to meet the goal of a 100% carbon free electricity system will necessitate a significant buildout of renewable

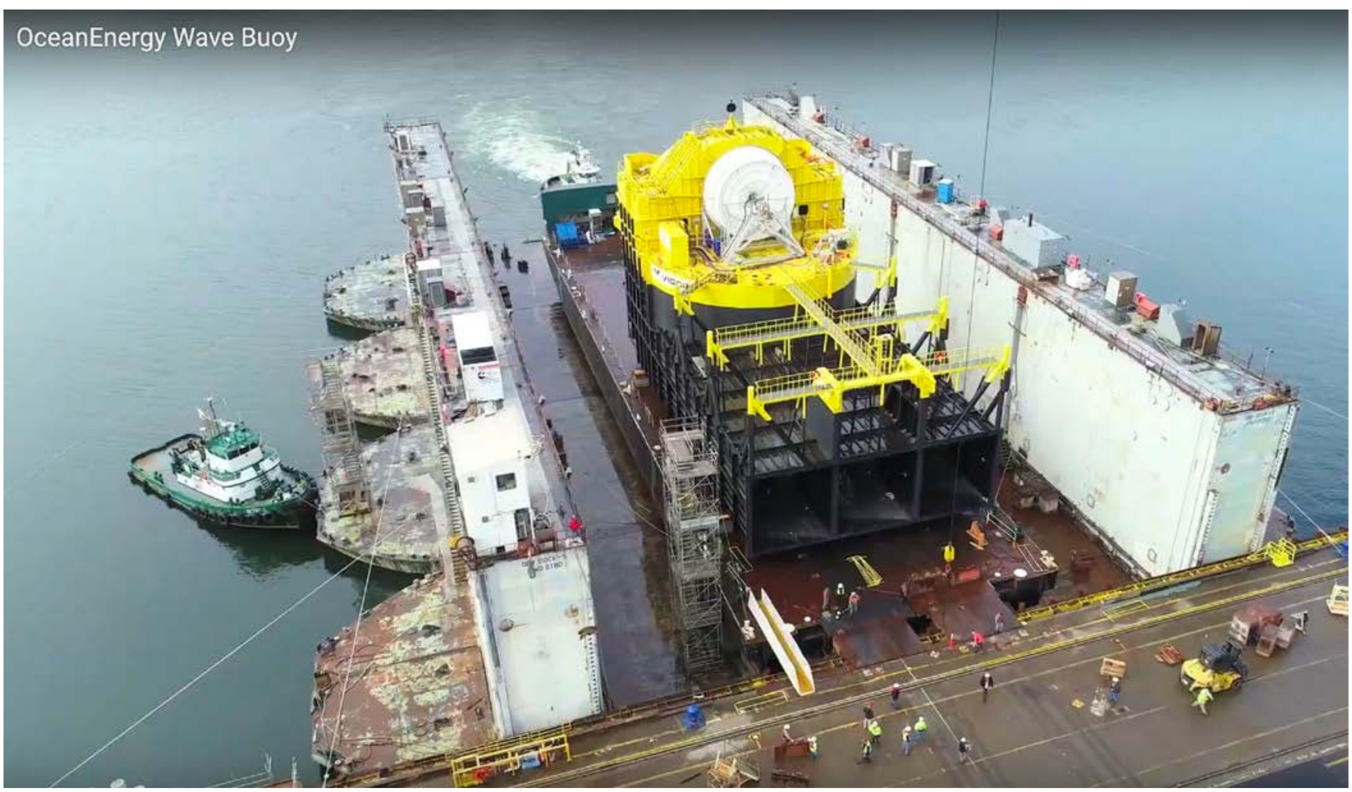
The deployment of wave technologies along the Oregon coast can be shown to open transmission capacity in the state and enable the deployment of new renewables with existing infrastructure.

resources. The deployment of marine energy can help reduce some of that buildout and the transmission needed by being an energy source near major loads along our coastlines. It can also provide increased reliability and resiliency to the electric system. With nearly 40% of the United States' population living in coastal counties and vast untapped resources available, there is a clear opportunity for marine energy technologies to play a role.

An analysis of wave energy deployment on the Oregon coast shows that marine energy resources fulfill local coastal energy demand and provide energy to other loads in the region, reducing existing transmission utilization and reliance on imports from other regions. Resource deployment on the coast provides a resilience benefit in serving local loads. Beyond offshore resources, Oregon geography prevents the development of other coastal renewables. Increasing transmission capacity enables existing infrastructure to provide additional renewable generation from the Columbia Gorge and points north and east, such as wind from resource-rich Wyoming, to West Coast loads. **On average, a 500 MW deployment of wave on the coast opens 200 MW of east to west transmission capacity at peak hours**. Marine energy can enable similar value in California and the East Coast, especially as traditional resources retire. This is particularly valuable given that many coastal states have stringent renewable or clean energy generation targets and building new transmission is an expensive and logistically challenged proposition. The benefit may be enhanced through co-deployment with offshore wind resources, which can provide similar benefits. Co-deployment may also provide value in sharing infrastructure and associated costs between technologies.

Special Applications: Small, Island, and Remote Grids

There are many island and remote communities across the entire United States and its territories. Many of these regions have limited renewable resource potential, land availability for renewable resource development, or transmission connections to other regions to import generation. Marine resources provide an energy source and other benefits that reduce the reliance on expensive imported fossil resources whose supplies are subject to disruption in these regions.



The Ocean Energy Buoy, a floating oscillating water column type wave converter.

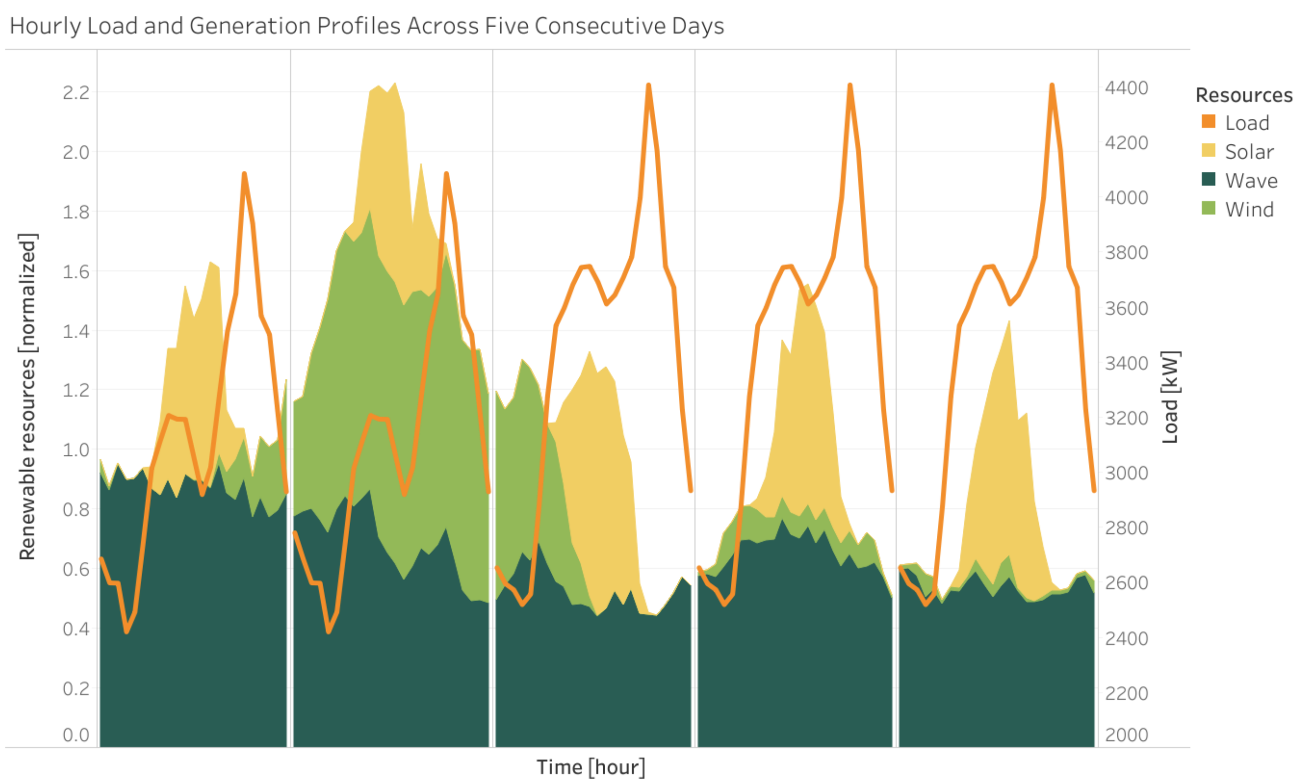
On **Nantucket Island**, the availability of tidal energy during hours when other resources such as solar are not available helps to stabilize the local power quality on smaller, distribution grids. In particular, the deployment of tidal energy was shown to help meet voltage quality requirements, resulting in grid equipment staying within limits and extending equipment lifespan and assuring reliable function. Further, the coupling of tidal with energy storage helps to reduce potential voltage swings associated with strong tidal currents and provide relief in peak loading of the distribution system. Similarly, **replacing combustion turbine capacity with tidal generation minimizes operational risk levels relative to turbine replacement by solar or wave resources in both normal operating and grid disruption conditions**. We used the risk of grid disruption as a way to measure resilience. This was used in both regular day-to-day operations as well as major event, or contingency, situations. While wind resources provide similar results, in island environments, marine energy has significant advantages in avoiding use of scarce high-value land and its low visual impacts.

To help achieve the **Hawaiian island of Molokai's** 100% clean energy goals, we considered deployment of wave energy to the existing system. Wave energy has a strong resource potential on Molokai's northern shore, which also exists on the northern shores of the other Hawaiian Islands.

We found that incorporating new wave resources to the current system to a meet 95% or 100% emissions free target, provides the following value:

- Added resource **diversity means less wave capacity than solar capacity is required to meet the same energy need** (about 15-47% less).
- Increased **predictability reduces the amount of energy storage needed by 17%** (reducing system costs and land use).
- Reduced variability **cuts down the balancing energy needed to deliver reliable electricity** and the use of fossil fuels to do so by over 50%.

These results point to the complementarity value of the wave resource to existing solar and wind, and may represent a pathway to meet the local utility's 100% clean energy target.

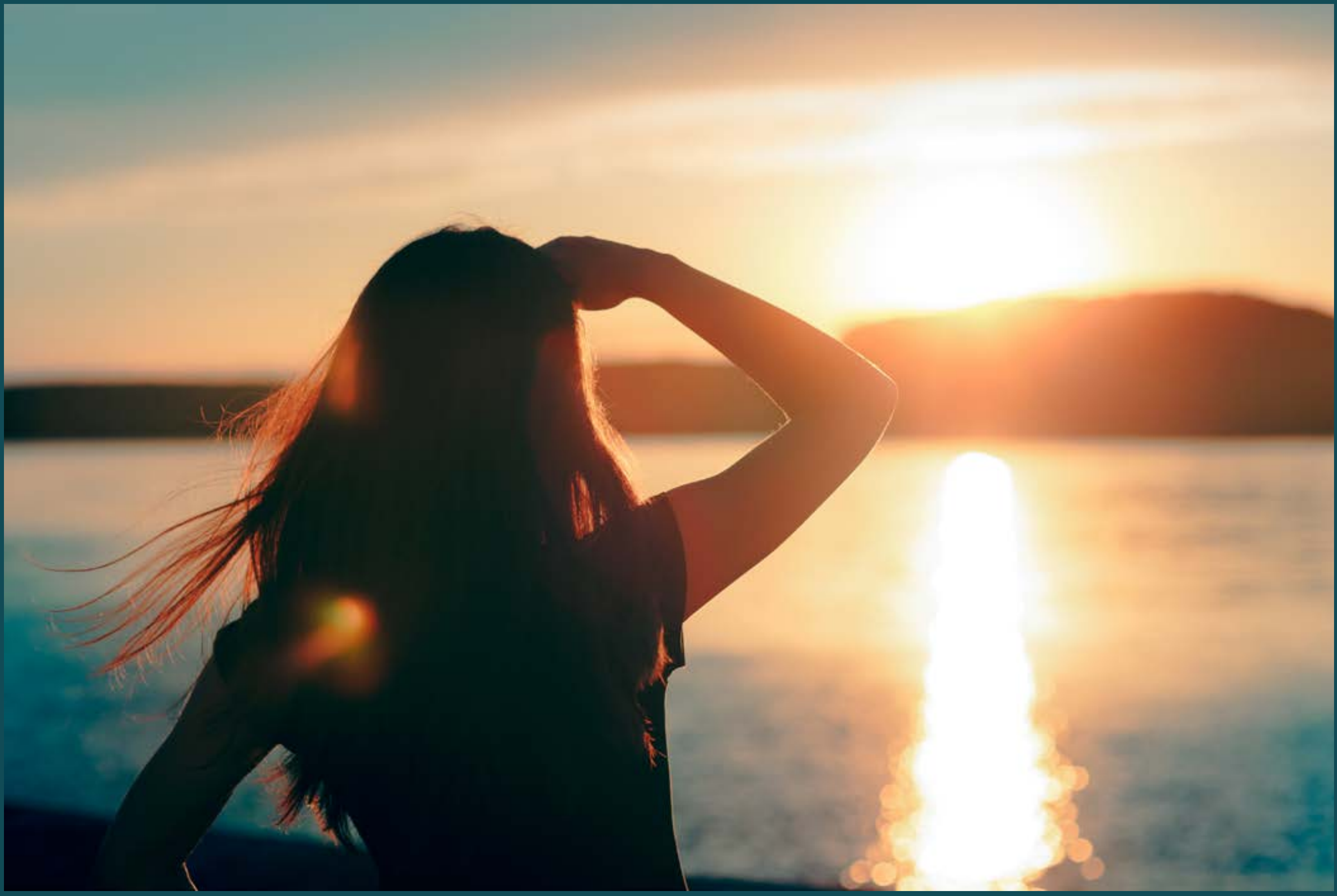


This graph highlights the complementary value associated with deploying wave alongside other renewables on an island system: when other resources are not available, the wave resource is present. This is for 5 days in December on the island of Molokai. Load is indicated by the orange line and the generation resources are normalized and stacked: solar generation in yellow, wind production in light green and wave generation in dark teal.

NEXT STEPS

Overall, we find several attributes of marine energy that point to a value proposition for deployment both in the near term and within typical utility planning timeframes (up to 20 years). From a resource and technology perspective, marine energy delivers distinct and valuable benefits to different configurations of the grid, whether bulk, isolated distribution systems, or remote communities, islands, and microgrids. In particular, marine energy can be valuable by providing resource complementarity and technology diversity in a portfolio of renewable resources, serving U.S. coastal loads, and helping reduce the reliance on imported fuels for small, island, and remote grids. The situation is ripe for marine energy stakeholders to further understanding of the technology in the grid planning community and enable deployment to help us move to a 100% carbon free grid.

To date, there has been little work like this. This effort and similar value-focused efforts for other marine energy applications such as Powering the Blue Economy can help target technology design and deployment to where value is greatest.



KEY DEFINITIONS

- For purposes of this investigation, the term **grid value** is meant to include, but not be limited to, provision of a defined grid service, measurable benefit to grid performance, avoided costs to system investments or operations, revenue capture, and contribution to desired grid qualities (e.g., low carbon intensity).
- **Capacity and specifically, capacity value,** is a measure of a resource's ability to generate electricity relative to its installed capacity during periods of grid strain, for example, highest energy demand hours, or peak hours.
- **Load-carrying capacity** or effective load-carrying capacity (ELCC) is a statistical measure of capacity value. It represents the amount of additional load a resource can serve (relative to its installed capacity) when added to a system while maintaining system reliability.
- A **distribution grid** is the set of lower voltage infrastructure including wires, substations, feeders and other equipment that delivers electricity from the transmission system to customers. Smaller generators may be directly connected to the distribution system. The transmission system is higher voltage infrastructure that delivers electricity to the distribution system from large generators.
- Delivering reliable electricity to customers requires ensuring generation matches electricity demand at every instant. **Balancing resources, or reserves**, are those resources that ensure this match and can consist of fast moving natural gas generation, energy storage, or to an extent, inverter connected renewable resources.
- **Power quality** is a metric that defines how well the voltage and frequency of electricity complies with specifications. Poor power quality can mean connected devices do not operate properly. A system operator must ensure the system remains within acceptable power quality limits.

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https://www.pnnl.gov/projects/marine-energy-grid-value

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