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Enabling the electrification of offshore activities – co-demonstration of next-generation autonomous offshore power system and resident, uncrewed mobile and static assets at PacWave wave energy test site

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Introduction

Oceans cover two-thirds of the earth's surface and form the world's biggest and best – yet largely untapped – battery. Ocean waves have more energy density than other renewables, including wind, solar, and biomass, and have the potential to supply 4x the world's annual energy consumption (Masterson, 2022; Zic, 2020). In addition to the impact wave energy can have on decarbonizing and diversifying the electric grid, it offers a significant value proposition in the emerging blue economy sector (LiVecchi et al, 2019). The blue economy consists of industries operating offshore, including shipping, oil and gas, defense and security, aquaculture, and research. These industries require bringing people and energy on site to perform daily work, but current energy costs in the blue economy are extremely high. The prevailing processes are complex, including shore dependencies and fuel transportation logistics. Few alternatives for reliable power generation exist, with the most prominent being high cost and high carbon emissions diesel generation. Because of this lack of affordable, reliable power, the trends of electrification, digitization, and automation that have led to substantial innovation and improvements in the terrestrial economy over the last two decades are slow to come to the blue economy.

An Autonomous Offshore Power System (AOPS) provides a cost-effective power solution for the blue economy. An integrated system consisting of power generation, energy storage, asset management, and data communications, an AOPS can transform how industries operate in the ocean today. They can enable autonomous, digital, longer-residency assets and drive lower cost, complexity, and carbon-intensity.

The U.S. Department of Energy-sponsored PacWave South test site, slated to open off the Oregon coast in 2024, provides a critical test facility for AOPS technologies. The focus of this paper is the process of designing and building a third-generation AOPS for testing at PacWave South, incorporating lessons learned from three previous design, build, and test cycles.

Market Overview

The blue economy has an estimated value of $2.5 trillion annually and is expected to double in size over the next decade (PNNL, 2024). Yet there are mounting macro and competitive pressures in the offshore commercial, aquaculture, defense, security, and research sectors to move away from the current people-, carbon- and capital-intensive operational environment to one that is less expensive, safer, cleaner, and more connected. Successfully completing this transition requires innovation in how the energy used by offshore operations is generated, stored, and delivered, as carbon-based fuels have been the primary solution. The only practical alternatives to carbon-based fuels for offshore operations are renewables, with wave energy positioned as an optimal resource for loads below 10 MW. To be successful, marine renewable systems in the offshore market need to deliver a multi-faceted value proposition that drive cost, complexity, and carbon reductions.

One primary opportunity for wave energy serving the offshore market is replacement of legacy power solutions, such as diesel gensets, subsea umbilicals, and crewed vessels. However, offshore markets also require the provision of data communications capabilities, which systems converting wave energy to power can provide. Generally speaking, data communications is equally important to power generation and has a profound impact on marine renewable system designs within the offshore market. Without power, there is no data, and without data, there is a strict limit to the value afforded to the customer.

AOPS Overview

An AOPS is a new class of renewable energy system. It creates an unattended, offshore power and data mini-grid for support of mobile and static marine assets on the surface, in the water column, or on the seafloor. An AOPS consists of power generation at the ocean's surface connected by a mooring, power, and data communications line(s) to an energy storage system (ESS) on the seafloor. An ESS is critically important to an AOPS configuration for time shifting of energy supply to meet demand and to provide operational reliability for offshore customers.

An AOPS typically generates electricity through a wave power system (WPS). A WPS harnesses the energy from the heave and surge of ocean waves, converting mechanical energy to useable and storable forms of energy. While wave energy is the primary power resource, an AOPS can utilize other energy technologies, such as fixed solar, and can co-generate alongside offshore wind and floating solar for larger offshore loads.

C-Power's SeaRAY™ AOPS is the first commercially available instance of an AOPS, providing power, energy storage, and real-time communications support to enable autonomous, connected, and resident technologies. It is designed to support uncrewed offshore activities and equipment, including subsea vehicles, sensor packages, and operating equipment. Designed to deliver the core benefits of AOPS technology, a deployed SeaRAY lowers costs and carbon emissions, reduces operational complexity, and increases safety for the offshore operations of blue economy industries. The SeaRAY AOPS is transportable anywhere in the world and deployable with smaller, lightly crewed vessels (C-Power, 2024).

AOPS Market Service Goals

Using an AOPS in place of incumbent solutions carries a strong value proposition for the customer, including significant capital and operational cost and carbon-emissions reductions. Furthermore, an AOPS enables real-time and near-real-time data communications not possible today, allowing for more effective operations and easier maintenance of both mobile and static systems.

Incumbent approaches often use vessels to periodically recharge batteries for an offshore data-gathering system or to support a subsea vehicle, which is suboptimal from a cost, complexity, and carbon emissions perspective relative to an AOPS-enabled solution. Vessels can cost over $100,000 per day and, over a year, produce approximately 7,000 cars worth of CO_2 emissions (Iversen, 2020; Oceaneering, 2020).

Avoiding umbilicals is another market service goal for AOP systems — a significant benefit to customers compared to incumbent solutions. High-cost subsea electrical umbilical cables, even for watt- or kilowatt-scale loads, are currently used to supply power to electro-hydraulic gear in remote fields. Previously installed cables usually have little to no excess capacity available to provide the incremental power necessary to convert to all-electric. Additionally, umbilical cables often fail due to insulation degradation and accidental cuts, potentially stopping production. This failure risk represents a significant safety concern, substantial revenue loss, and large potential capital and operating expenses for replacement. The opportunity to avoid new umbilical runs and provide redundant or emergency power in the case of failure is significant and global. Average umbilical costs are roughly $1 million per kilometer. By avoiding long umbilical runs, an AOPS can reduce these costs up to 90% (Slorach et al., 2023).

The approach to meet these goals via AOPS design engineering is outlined in the Design section. The approach to meet goals via prototype demonstrations in operating environments is outlined in the Federally Funded Pilots and Oregon Pilot sections.

Design

Design History

The first six years of C-Power WPS development drove a number of significant techno-economic design improvements. C-Power's initial R&D efforts during these years were aimed at developing a WPS for utility-scale applications.

While direct-drive power take-offs (PTOs) have been a primary focus of C-Power from the start, the linear motion of the first WPS designs was replaced by rotary motion to enable heave and surge energy-capture and a more cost-effective use of the active generator materials. Following the change to a direct-drive-rotary (DDR) permanent-magnet generator (PMG) and further testing, a new shape was devised, reflecting a balance between hydrodynamic optimization and manufacturability. The design incorporated structural fiber-reinforced plastic for corrosion resistance.

Following sea trials in Washington's Puget Sound, C-Power developed several innovations that decreased structural costs and increased power production, including production through a wider range of sea states. These improvements were experimentally validated at 1/33 scale in 2012. By eliminating end-stop loads and associated mitigation costs — a significant issue impacting service life, capital expense, and operating expense — C-Power made a significant leap forward in the ability to integrate a WPS capable of heave and surge energy capture with a highly-efficient electric plant. Further cost and performance optimization led to material cost- and performance-improvement in WPS design. The innovation effort delivered a WPS that can meet the acceptability, availability and affordability needs of utility, industrial, and power producer customers.

By the mid-2010s, the fundamental elements of C-Power's current WPS design emerged with a central body (nacelle, spars, braces, pontoons, and ballast tank) and a float. The central body is coupled to the float through a drive shaft along the nacelle's central axis. The system captures wave energy by creating relative pitch between the central body and float and directly converts the captured energy to electric power with a large diameter, direct-drive permanent-magnet rotary generator contained inside the nacelle. The capture-to-conversion cycle is efficient and available over a wide range of operating conditions. In heavy seas, the float may be pushed over the top of the nacelle and take a mean position to the aft of the nacelle. The WPS will continue to operate, and end-stop loading and related structural fatigue have been avoided. After heavy seas calm sufficiently, the float will be driven under the nacelle and back to its forward position using ballasting and previously tested motoring-capabilities of the generator.

Further optimization led to C-Power's current utility-scale product, the Sting RAY™. Parameterized cost and mass estimates were developed for over 700 unique WPS configurations, and model results were assessed for performance, leading to the identification of configurations that had favorable cost-to-performance ratios. The study indicated that a large WPS (~2800 mt displacement) minimized estimated levelized cost of energy (LCOE) and was optimally sized for long-term commercial development. However, concerns arose that a WPS of this size was not a rational next step in the technology development path. C-Power decided to design a smaller prototype WPS, while maintaining long-term focus on a larger commercial WPS, allowing for technology development goals to be met while reducing near-term technical and economic risk to manageable levels.

The previous StingRAY design iterations led to a breakthrough low-power Wave Energy Buoy that Self-deploys (WEBS) design. In 2016, the Company designed, built, and delivered a 100-watt, floating system for a U.S. Defense Advanced Research Projects Agency's (DARPA) program (Figure 1).

The WEBS prototype was a drifting system conceived, modeled, designed, built, and delivered in 14 months. It was a successful initial effort to apply the knowledge gained from C-Power's utility-scale R&D efforts to the design of lower-power, kW-scale systems. For C-Power, the project demonstrated a viable low-power device that garnered definitive interest in the marketplace.

Fig. 1—C-Power's WEBS wave power system prototype developed for a U.S. Defense Advanced Research Projects Agency program.

Present Design Prototypes

The WEBS prototype served as the technical baseline for a WPS optimized for the low-power needs of offshore operations in the blue economy, which was first incorporated as a WPS that was delivered to the University of Washington-Applied Physics Lab (UW-APL) in 2022. That unit, which is full-scale for its intended purpose, has been bench-tested and deployed in-water multiple times. This unit was upgraded in late 2023 and began additional in-water testing in January 2024.

A U.S. Department of Energy and U.S. Navy-sponsored demonstration of the SeaRAY AOPS is underway at the Navy's Wave Energy Test Site (WETS) in Hawaii. This second-generation WPS for the Hawaii demonstration was bench-tested at the National Renewable Energy Lab (NREL) Flatirons campus in Colorado prior to its open-ocean deployment. It was designed to accommodate deployment that could survive 100-year storm conditions at Oregon's PacWave North test site. During the 10 months of testing at NREL, the drivetrain, power electronics, supervisory control and data acquisition (SCADA), communications, ancillary, and other systems were fully tested for functionality using wave resource data from intended operational environments. Testing of the SeaRAY included use of a Regatron system to simulate energy storage and bi-directional flow to and from a seafloor energy storage system, using real seas inputs. As needed, various components were upgraded or improved during the testing period. Besides the real seas trials, testing included:

- Friction characterization
- Efficiency characterization
- Hotel load measurements
- Constant speed trials

A third WPS designed for a SeaRAY AOPS deployment at Oregon's PacWave South test site is in development, iterating on the previous Hawaii SeaRAY. A visual comparison of the Oregon and Hawaii WPS hulls is given in Figure 2.

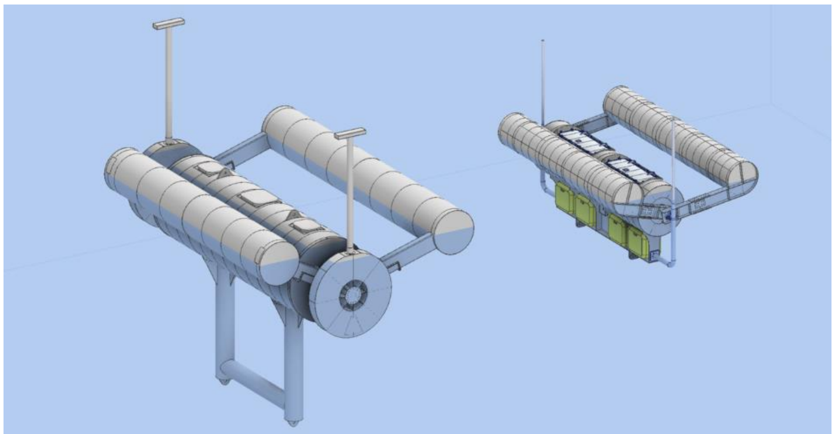

Fig. 2—C-Power's WPS design for a SeaRAY AOPS deployment at the PacWave South test site (Left) incorporates design enhancements to the WPS designed for the Hawaii SeaRAY AOPS deployment (Right).

The Oregon SeaRAY AOPS consists of a surface expression comprising three cylindrical bodies for power generation (the WPS), a mid-column "heave plate" providing a stable platform for the WPS to react against, and a seafloor base unit serving as gravity anchor and energy storage. The Oregon SeaRAY is intended to be moored, to generate and store electrical energy, and to provide the stored energy to various interfacing payloads.

Power generation is accomplished by the floating, cylindrical bodies. The central body of the three is called the nacelle, and houses the PTO, controls, and power electronics. The other two bodies are attached to the nacelle via hinged articulations and are called the forward and aft floats. Each float is directly connected to a PTO unit housed within the nacelle. The nacelle is held relatively still in the water due to the connected heave plate, while the highly buoyant floats tend to follow the wave surface, resulting in the floats partially rotating about the nacelle as the waves propagate by. The relative motion between float and nacelle actuates its PTO, driving its generator, and producing electricity.

The floats and nacelle are steel fabrications. Bearing support structures are rigidly fixed just outboard and on either end of the primary nacelle cylinder. A rigid yoke extends downward from the nacelle for mooring line connections. The floats are filled with closed cell foam to mitigate the risk of water intrusion and have sufficient excess buoyancy to hold up the nacelle in the event of flooding (to be confirmed in design). The two floats are positioned such that they will not collide with one another (i.e., the forward float has shorter arms and can nest between nacelle and aft float). The excess buoyancy of the floats, combined with the low freeboard of the nacelle and the downward pull of the mooring, make it highly unlikely for the floats to ever go under the nacelle (where they collide with the mooring spars). If the forward float moves to the aft side (e.g., carried over by a large wave), it will be automatically returned: the nacelle will begin to sink, causing the floating forward float to rise and return to the front, and once again lift the nacelle.

The heave plate is a shallow square prism, fabricated from steel, and ballasted with lead and sea water in operation. It is suspended from the nacelle's mooring yoke via four polyester lines and provides resistance to nacelle heave motion. This restraint provides a reactive force for the floats to move against whilst actuating the PTOs. The heave plate also supports a mid-column junction connecting the upper and middle sections of umbilical cable.

The umbilical cable serves as the mooring line, as well as electrical and data connectivity, between the nacelle and the seafloor energy storage system (ESS). There are three distinct sections of umbilical. The upper section is non-load bearing and runs from the nacelle to the heave plate. The load bearing connection between nacelle and heave plate comprises four polyester lines, running from the nacelle mooring yoke to mooring lugs at the four corners of the heave plate. The middle section of umbilical is load-bearing and provides the necessary compliance. This EOM offshore stretch hose is specifically designed for open ocean, single point mooring applications. The lower section is an armored umbilical cable and connects the middle section to the seafloor ESS. A large buoyancy module (1 ton) sits at the interface between middle and lower sections and ensures that the lower section remains taut. All umbilical sections have copper conductors and fiber optic lines. The mooring system is designed to maintain positive tension and eliminate any slack in the lines. The expected watch circle is 120 m.

The seafloor ESS serves as a gravity anchor, primary energy storage, and provides interfaces for the various payloads. The ESS unit comprises a seafloor rated, commercial energy storage product (e.g., Verlume, SubCTech, or similar). These seafloor units are used extensively to support offshore energy needs. Energy storage is provided by lithium-ion battery cells.

Standards Approach

The following standards will be followed to the degree determined to be practical:

- *IEC 62600-2 Marine Energy Systems – Design Requirements*
- *IEC 62600-3 Measurement of Mechanical Loads*
- *IEC 62600-10 Assessment of Mooring System for Marine Energy Converters*

The above-listed standards normatively reference many other standards, generally IEC and ISO. Alternates may be considered for these 'secondary standards,' provided the alternates are fit-for-purpose and provide similar confidence to the design.

The SeaRAY is being designed to a normal safety level, in accordance with *IEC 62600-2* and *IEC 62600-10*. A normal safety level corresponds to an annual failure rate of less than 1e4. If risk assessment identifies components with intolerable levels of risk, a higher safety level (e.g., high safety level, corresponding to an annual failure rate of less than 1e-5) will be considered for affected subsystems or components.

A comprehensive set of Design Load Cases (DLCs) will be specified in accordance with *IEC 62600-2* and *IEC 62600-10*.

A limit state design methodology will be followed, in accordance with *IEC 62600-2* and *IEC 62600-10*. Partial safety factors are defined for loads, for ultimate limit state design categories, by *IEC 62600-2* (see Table 1). Partial safety factors for mooring system elements will be taken from *IEC 62600-10*. Partial safety factors for materials will be taken from appropriate standards and documented during design.

Load category	Unfavourable loads				Favourable loads[c]
	Design category				All design categories
	Normal (N)	Extreme (E)	Abnormal (A)	Transport/erection (T)	
Environmental	1,35	1,35	1,1	1,5	0,9
Operational	1,35/1,5[b]	1,35	1,1	1,5	0,9
Gravity	1,1/1,35[a]	1,1/1,35[a]	1,1	1,35	0,9
Other inertial forces	1,35	1,35	1,1	1,35	0,9

[a] For masses not being determined by weighing.

[b] For MECs working within ±5 % of whole-body or component structural resonance (see Annex B).

[c] Pre-tension and gravity loads that significantly relieve the total load response are considered favourable loads.

Table 1— Partial safety factors for ultimate limit state design categories, from IEC 62600-2.

Lessons Learned

Developing the WEBS prototype for the DARPA project provided the key lesson that led to the genesis of the AOPS as a system. Prior to that project, development of ocean energy systems primarily focused on generating utility-scale power for terrestrial electric grids. DARPA's need for a WEBS system illuminated a broader market of low-power needs in sectors across the blue economy, including defense, security, aquaculture, research, and offshore oil and gas. Given the high cost, high carbon, and high complexity of incumbent solutions — most often diesel-generated power delivered by umbilicals or crewed vessels collecting and recharging battery-powered systems — a clear lesson was that an AOPS approach could provide a superior technical solution for a significant portion of a $15 billion annual market for ocean energy.

A key element of this understanding is the need for the creation of a power and data mini-grid. Given the type of infrastructure that it is intended to replace (e.g., an ROV support vessel or umbilical) an AOPS must provide sufficient energy and bi-directional communications with the data cloud, as required by each asset that it supports, to fully replace the power delivery and data communications capabilities of the legacy infrastructure. For a developer of wave power technology, the delivery of a 'whole' system capable of creating a power and data mini-grid is a substantial change, moving from a primary energy-related concern of producing as much electricity as possible at any one time to the necessity to autonomously generate, store, manage, and deliver a sufficient amount of electricity over the short and long-term to power the assets.

Through the iterative AOPS design, development, and prototyping process, additional lessons have been driven by partner and customer feedback. An AOPS must:

- enable autonomous or remote operation, longer residency, and digitalization of offshore equipment.
- be vendor and technology agnostic, enabling the full suite of desired capabilities for offshore equipment from any technology supplier.
- be easily transported and deployed at low cost and with low complexity, anywhere in the world.
- be able to meet customers' energy needs in any ocean environment, whether the wave energy resource is high or low, requiring scaled WPS designs and energy storage systems to ensure adequate energy generation and availability.

Moving forward, C-Power expects to learn a variety of lessons from the prototype demonstration process and use those lessons learned to enhance future designs. For example, lessons from the UW-APL WPS deployments and Hawaii SeaRAY AOPS deployment are currently being examined to yield design enhancements for the upcoming Oregon SeaRAY system.

Federally Supported Pilots — A Demonstration-Based Approach to Achieve Goals

Technical development of C-Power's WPS for low-power applications and SeaRAY AOPS has been accelerated by pilot demonstrations supported by U.S. federal government funding (see Table 2).

SeaRAY Product	Location	Customer	Status/Goal
Gen 1	Washington State	Navy & University of Washington–Applied Physics Lab (UW-APL)	Third successful deployment of TigerRAY by UW-APL/Navy in January 2024.
Gen 2	Hawaii	DOE; Navy; commercial participants Saab, Verlume, and BioSonics	Phase 1 deployment complete. Phase 2 deployment planned for 2024.
Gen 3	Oregon	$5M DOE-sponsored project with commercial participants Saab, Sonardyne, Wavefront, and Subsea7	Deep-water-ready system with live customer simulation capabilities. 4 companies committed to co-demonstratie with us.
Gen 4 Enhancements	Oregon	DOE- and Navy-sponsored project	Project goal is to enhance installation, operation, and maintenance of the SeaRAY.

Table 2— Previous and planned pilot demonstrations of C-Power's WPS for low-power applications and SeaRAY AOPS with federal funding or other forms of federal support.

The first-generation system, ordered by and demonstrated for the U.S. Navy, represents the first commercial sale and deployment of a SeaRAY product. For the third deployment of this system, which commenced in January 2024, C-Power delivered additional paid upgrades that benefit the development of all future commercial product lines.

The second-generation system, a SeaRAY AOPS sponsored by the DOE and Navy and deployed at the Navy's Wave Energy Test Site in Hawaii, achieved several technical milestones during its first phase of deployment. These included:

- Completed the goals of the DOE contract, confirming critical operational capabilities and areas for innovation
- Demonstrated novel SeaRAY hull design, novel power electronics package, integrated AOPS design tailored for low-power applications, and powering of an offshore asset
- Collected and communicated live data to the cloud
- Deployed rapidly (less than 60 minutes, an industry first) and showed low-complexity logistics, transportation, and surface system recovery
- Established a supply chain for SeaRAY AOPS components
- Gained design and operational experience and knowledge

Design of the third-generation system is ongoing, iterating on the first- and second-generation system designs with learnings from the prior pilot demonstrations of those systems. This SeaRAY AOPS is expected to be deployed in late 2024 at the PacWave South test site in a $5 million DOE-sponsored pilot demonstration project. The goal is to demonstrate advancements including deep-water mooring capabilities, satellite communications, and more advanced SCADA and power electronics systems. The next-gen SeaRAY will also feature improved survivability for harsh ocean environments, more generating capacity, increased transportability, improved maintenance and operations, and more efficient manufacturing. The SeaRAY AOPS will also demonstrate its ability to simultaneously support surface and subsurface mobile and static assets in partnership with key stakeholders that conduct offshore operations in the energy, defense, security, and research sectors.

Federal funding is a critical source of support for early stage technologies, particularly for technologies at the DOE-defined Technology Readiness Levels TRL 1 through TRL 5 (U.S. Dept. Of Energy, 2011). As C-Power's WPS for low-power applications and SeaRAY AOPS navigated the path through those TRLs, federal funding advanced basic technology research and research to prove feasibility, followed by system and component validation at laboratory and full scale. As the SeaRAY AOPS advances from TRL 6 and beyond, federal funding can still successfully support system demonstration and commercialization, but certain limitations become relevant. For example, the structure of federal contracts, off-again-on-again nature of federal grant opportunities and grant payment schedules, and other limitations act as an unintended barrier to the type of innovation and nimble decision-making required to cross the valley of death to a commercial product. As such, C-Power intends to couple federal support for pilot demonstrations with private investor funding and commercial sales of SeaRAY products to continue development through the final TRLs and achieve a market-leading product.

Oregon Pilot

PacWave Test Site

PacWave is an open ocean wave energy testing facility consisting of two sites (PacWave, 2024), each located just a few miles from the deep-water port of Newport, Oregon, in the Pacific Ocean (Figure 3).

The DOE-sponsored SeaRAY AOPS pilot demonstration planned to begin in 2024 will be held at the PacWave South test site. PacWave South is an in-development, state-of-the-art, pre-permitted, accredited, grid-connected wave energy test facility developed in partnership with the DOE, Oregon, and Oregon State University. The two-square-nautical-mile ocean test site will consist of four berths and include a 12-mile cable route to shore. Each test berth is approximately 6,080 feet by 3,040 feet and is located in up to 215 to 255 feet of water. As PacWave South is pre-permitted for the majority of wave energy device types, site users will not have to undertake a costly and time-consuming permitting process prior to testing, which will enable more rapid technology development.

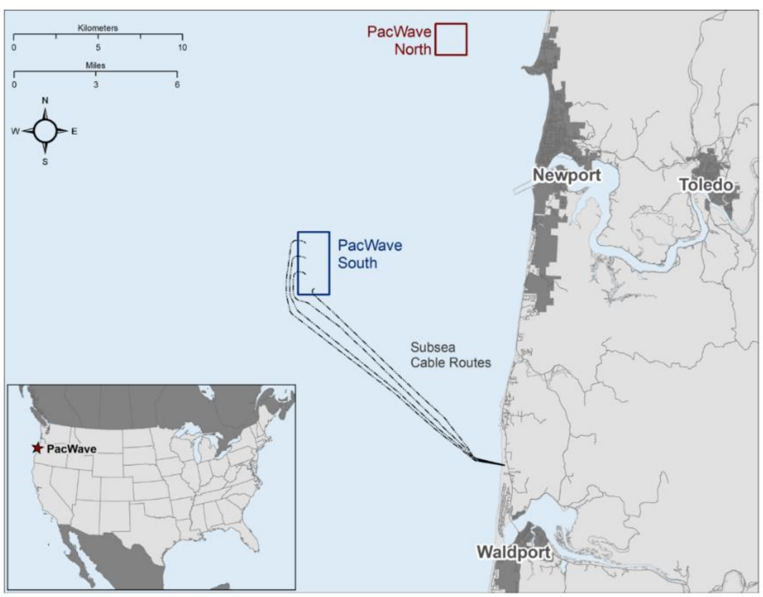

Fig. 3—PacWave consists of the PacWave North test site and the new PacWave South test site slated to open in 2024.

At PacWave South, the seafloor in the area is generally soft sand. The most commonly occurring seas feature a significant wave height of 1.75 m and an energy period of 8.5 s (~528 hours per year), while the highest annualized wave energy sea state is at a significant wave height of 2.75 m and at an energy period of 10.5 s (~231 hours per year). January and December are the only months that see a slight prevailing direction of current toward the shore. During the summer months, the slight negative mean velocity confirms coastal upwelling activities and associated flow away from the coast (PacWave, 2024).

Maximum high tide onshore of PacWave reaches just over 2 m while maximum low tide reaches just below -2 m. To provide a rough estimate of the impact of tidal water elevation on wave conditions at PacWave, the most frequency sea state is used as an example (1.75m and 8.5s). For the baseline PacWave water depth of 60m, and assuming linear wave theory, the shoaling related wave height changes would be less than 1% for the +2 m and –2 m tidal variation. As a result, the impact of tidal variation at PacWave can generally be deemed negligible (PacWave, 2024).

Asset Selection

In 2022, C-Power launched its Partner Engagement and Co-Development (PEC) program to formalize its business development efforts and accelerate commercial traction in the offshore market. PEC offers companies definitive opportunities to integrate systems and services with an AOPS and bring wave energy onto their innovation roadmaps.

There are four phases of the PEC program: Engage, Collaborate, Demonstrate, and Rollout. During the Engage and Collaborate stages, C-Power works with customers and partners to identify and target applications that solve their operational problems, centering around a lack of cost-effective, reliable power offshore. Moving to the Demonstrate stage, C-Power specifies use cases, integrates partner hardware, and co-demonstrates at pilot-scale. For Rollout, customers and partners move from pilot deployments to purchase or lease contracts.

C-Power has strategically leveraged federally funded projects, like the Hawaii and Oregon projects, to build its customer and partner ecosystem through a co-demonstration model. In the co-demonstration model, C-Power typically presents high-level project specs to customers and partners and highlights how a SeaRAY AOPS can transform their current operations and enable new capabilities. This co-demonstration model gives customers the opportunity to integrate their technology with C-Power's in a real-world scenario that produces field data, creates ample marketing material, and establishes a trusted relationship. For C-Power, these co-demonstrations are critical in proving customer-required features and capabilities, de-risking the technology, and providing opportunities to develop the next generation of offshore services with industry-leading companies.

The Oregon SeaRAY AOPS was designed to power multiple mobile and static assets – located on the surface, in the water column, and on the seafloor. These include providing power and data communications for subsea sensors, subsea and surface vehicles, and seafloor valve operations. C-Power has drawn from its PEC pipeline to recruit interested partners to participate as co-demonstrators in the Oregon deployment. One of the key enhancements between the Oregon SeaRAY AOPS and the Hawaii SeaRAY AOPS was broadening asset support capabilities. Thus, co-demonstration recruitment efforts have been aimed at bringing in partners with assets that can demonstrate critical marine applications, including met-ocean data collection and reporting and environmental monitoring. There are currently five co-demonstration partners confirmed for Oregon, representing a wide range of market sectors and use cases (Table 3).

Project Partner	Asset	Location
Sonardyne	Origin 600 Acoustic Doppler Current Profiler (ADCP)	Seafloor
Wavefront	Sentinel 2 Intruder Detection System (IDS)	Seafloor
Subsea7	Subsea Chemical Storage and Injection (SCSI) pump	Seafloor
Fugro	D-FEL Lander with sensor package	Seafloor
Open Ocean Robotics	Unmanned surface vessel (USV)	Surface

Table 3— Oregon project partner asset list as of January 2024.

Asset Integration

In the design phase for the Oregon SeaRAY AOPS, C-Power met with potential project co-demonstration partners to identify assets of interest and confirm desire to participate. Subsequent technical discussions were scheduled with each project partner to discuss the asset(s) power needs, preferred communications protocol, deployment and recovery scope, and integration equipment (i.e., umbilicals, connectors, bulkheads). Asset integration discussions are still ongoing.

Build and Test Plan

Fabrication and Assembly

The SeaRAY hull structure will be fabricated from steel at a facility in the vicinity of Portland, Oregon. The hull structure will be leak checked at the completion of fabrication. Coatings will be applied, and the floats will be filled with marine foam.

The PTO shafts will be fabricated by the hull fabricator. All other PTO components will be sourced commercially off the shelf. The power electronics will be fabricated and tested by Vicor and the power conversion system by C-Power. The SCADA system will be fabricated by NREL in Colorado.

The mooring, power, and data cable will be fabricated by EOM in Massachusetts, and the other umbilical segments will be commercially sourced. The seafloor ESS (frame, batteries, and IEMS) will be fabricated and tested by Verlume.

Primary assembly will occur in stages and will take place across three locations: a hull fabrication facility, C-Power's Corvallis, Oregon, facility, and NREL's testing facility in Colorado. Final assembly at the deployment site will be limited.

The assembled SeaRAY will undergo extensive verification and validation testing at NREL prior to deployment. The PTOs will be actuated via dynamometer during testing, and the test program will encompass power generation, distribution to the seafloor ESS, and SCADA (instrumentation, safety, controls, and communication systems).

Installation, Operations, and Maintenance

The SeaRAY AOPS system is designed to be readily shippable to the deployment location through selective disassembly to fit within standard shipping containers and flat racks.

Upon arrival at the local deployment zone by a combination of truck, train, and ship, the unit is assembled in reverse order and prepared for deployment during an acceptable weather window.

The SeaRAY AOPS system, once deployed and brought online, is a completely autonomous system that will generate energy during periods of sufficient wave energy, using this energy to charge the seafloor ESS. The system will automatically go into low-power standby and be supplied by the seafloor ESS during calm seas.

Onboard sensors and computers monitor the health of all equipment and provide automatic notification in the event of setpoints being exceeded. This automated monitoring is supplemented with periodic checks from human operators.

No maintenance or repair is expected to be required during the prototype demonstration and testing. However, planning for such an eventuality is prudent. In the event of a component or system failure, the SeaRAY will be detached from the mooring system, then lifted or towed to return to shore for repair (or harbor without waves). A future goal, with units in production, will be to swap in-situ with a standby unit.

Conclusions

The Oregon SeaRAY represents the latest iteration of AOPS technology incorporating lessons learned through three channels:

1. Engineering design and testing processes
2. Qualitative customer and vendor feedback collected via business development efforts and the PEC program
3. Prototype demonstrations enabled by federally funded pilot projects

The result of those development efforts will be a full-scale, 18-month demonstration of an AOPS at the highly energetic PacWave South test site. The pilot will allow the system to demonstrate capabilities — including power, energy storage, and real-time communications support — that further prove its ability to meet the intended market service goals of an AOPS. Goals achieved will include:

- Reduction of capital and operational cost, operational complexity, and carbon emissions of offshore activities
- Improvement of safety of offshore operations
- Increased effectiveness of offshore operations and easier maintenance of both mobile and static systems
- Enablement of autonomous, connected, and resident offshore systems, including subsea vehicles, sensor packages, and operating equipment.

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