UMERC+OREC
2025 Conference

12-14 August | Corvallis, OR USA

Wave Energy Converters (WECs) for powering offshore aquaculture

Pablo Matamala[a], Martin Wosnik[a,b], David Fredriksson[a], Arezoo Hasankhani[a]

[a] *University of New Hampshire, 105 Main St, Durham, NH 03824, United States*
[b] *Atlantic Marine Energy Center (AMEC)*

Abstract

The Blue Economy promotes the sustainable use of ocean resources, with growing interest in Wave Energy Converters (WECs) to support Powering the Blue Economy (PBE) efforts. However, the co-location of these systems remains a key challenge. This work highlights key opportunities and challenges in offshore aquaculture, a promising co-location candidate, and identifies suitable WECs and Power Take-Off (PTO) systems to power it. The WECs considered include the Oscillating Water Column (OWC), Point Absorber (PA), and Oscillating Surge Wave Converter (OSWC), while the PTO systems include Air Turbines (AT), Direct Mechanical Drive (DMD), Direct Electrical Drive (DED), and Hydraulic Motor-Based (HMB) systems. Based on the specific requirements of offshore aquaculture, such as reliability, energy stability, environmental compatibility, and ease of maintenance, functional combinations of WEC and PTO systems are proposed to offer optimal performance and energy output. The selected configurations are designed to ensure efficiency, robustness, and compatibility with the energy demands of offshore aquaculture. An example of these functional candidates is the PA device combined with an HMB PTO system, considering the adaptability of the WEC to ocean conditions and the ease of maintenance of the PTO system and the scalability of the hydrodynamic coefficients related to its performance.

Keywords: Offshore aquaculture; WEC; PTO system; PBE applications.

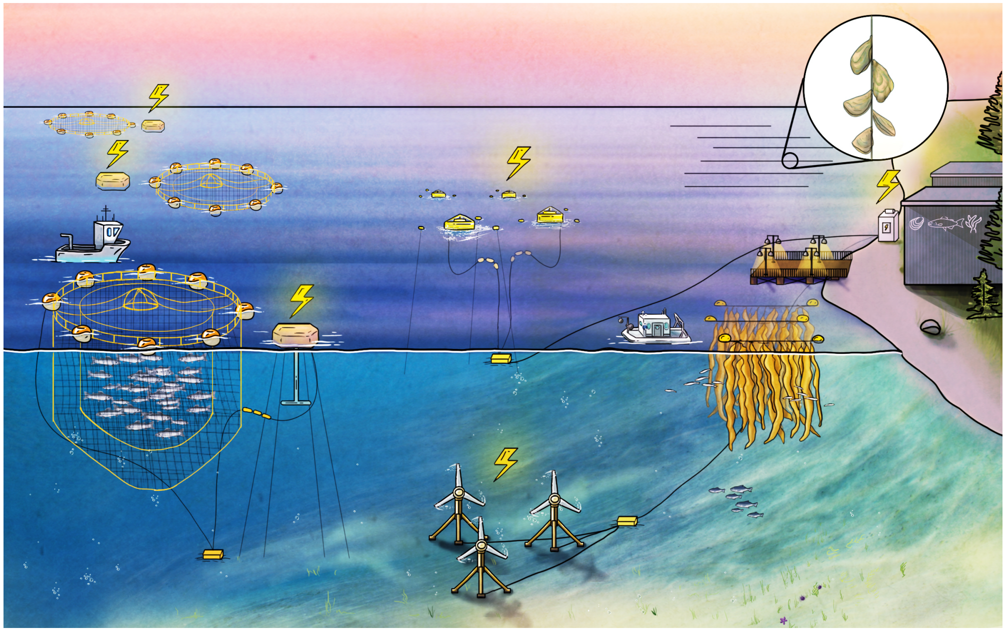

Figure 1: Marine energy technologies, co-located with offshore aquaculture operations. (Illustration by Stephanie King, Pacific Northwest National Laboratory) [3]

1 Introduction

The Blue Economy is defined as the sustainable use of available ocean resources for economic growth [1]. Within this context, the concept of PBE applications refers to energy solutions and technological innovations that enable the development and operation of key economic activities in the ocean [1]. The US Department of Energy (DOE) categorized the PBE applications into different areas, such as strategic industries—desalination, mining seawater minerals, or offshore aquaculture—or for research and geographical monitoring—underwater vehicle charging or ocean observation and navigation. In the case of offshore aquaculture applications, farms can benefit from reliable and autonomous energy sources, as many fish farms operate in remote environments far from the traditional power grid. These systems often rely on diesel generators, which pose challenges for energy security, fuel transport, and the associated costs. Integrating ocean energy at the farm location can improve energy autonomy and security while reducing or eliminating dependence on diesel [2]. In this paper, a summary of the main opportunities and challenges associated with this co-location is provided, and the functional candidates of the WEC and PTO systems are introduced.

2 Offshore aquaculture

Aquaculture refers to the cultivation of marine species such as fish, crustaceans, mollusks, algae, and others, either in freshwater or saltwater environments [1]. To enhance production while ensuring the conservation and maintenance of coastal areas, the aquaculture industry is increasingly shifting toward offshore locations [1] [2]. Offshore aquaculture operations require energy to support feeding systems, instrumentation, and sensors associated with safety, navigation, and maintenance [2]. These energy demands can be met partially or fully using WECs [2]. Table 1 presents a summary of the main opportunities and challenges associated with the implementation of WECs in the offshore aquaculture industry, farm energy requirements based on fish production volumes, and some real-world examples. Figure 1 illustrates the concept of co-locating WEC devices with offshore aquaculture farms.

3 Wave Energy Converters (WECs)

There are different types of WECs, each based on the various ways in which wave energy can be captured and converted. In 2010, Falcão et al. categorized these technologies according to their operating principles [4]. A general

Table 1: Key opportunities and challenges in co-locating WECs with offshore aquaculture farms, along with power demand ranges for Offshore Aquaculture as a PBE application and real-world examples.

OPPORTUNITIES [2]	**CHALLENGES** [2]	**RANGE OF POWER DEMAND**	**REAL-WORLD EXAMPLES** [2]
- Cost savings on energy use and shared operations with multi-use platforms. - Potential for reduced environmental effects. - WECs may provide shelter to the fish farms for the waves.	- High costs and investment barriers. - Safety risks must be studied considering the co-location in fish farms areas. - Low commercialization of WEC devices.	**Small-Scale Farms:** 10 kW – 50 kW Power demand: Basic feeding, instrumentation and sensors, aeration. **Medium-Scale Farms:** 50 kW – 500 kW Power demand: Automated feeding, lighting, instrumentation and sensors. **Large-Scale Farms:** 500 kW – 5 MW+ Power demand: Automated feeding, lighting, instrumentation and sensors.	**Chilean Farms:** 100-250 kW generators, 370 kWh/day. **Scottish Farms:** 1,000 tonnes production, 730 kWh/day. **Norwegian Farms:** 3,120 tonnes production, 700 kWh/day. Feeding systems consume over half of total energy.

overview of each type of device can be found in [5], focusing on the fundamental operating principles and key characteristics. The main devices described in this study are the Oscillating Water Column (OWC), Point Absorber (PA), Attenuator Devices (AD), Oscillating Surge Wave Converter (OSWC), and Overtopping Device (OD). Another study [6] classified WECs not only by their working principle but also by their location, listing onshore, nearshore (10 to 25 meters depth), and offshore devices (over 40 meters depth).

The Sandia National Laboratories (SNL) Reference Model Project (RMP) was created to provide publicly available, standardized designs for various Marine Hydrokinetic (MHK) energy devices [7]. The project developed a set of detailed conceptual designs defined as Reference Models (RMs). These models cover six MHK device types, including tidal turbines, current turbines, and WECs. Among them, RM3, RM5, and RM6 focus on wave energy conversion.

- **Reference Model 3 (RM3)**: RM3 describes a two-body PA system, where a floating buoy moves relative to a submerged structure under the action of ocean waves. The resulting relative motion is used to drive a PTO system [8]. The concept design was inspired by Ocean Power Technologies's PowerBuoy [9].

- **Reference Model 5 (RM5):** RM5 describes an OSWC device that captures energy from the horizontal motion of ocean waves near the surface. This model consists of a large submerged oscillating flap that is hinged on a moored submerged platform. As waves pass through the device, the surge motion of the water forces the flap to oscillate [10].

- **Reference Model 6 (RM6)**: RM6 describes an OWC device, where the wave motion induces the increase and fall of pressure inside the capture chamber, which conducts the air through an Air Turbine (AT), activating a Power Take-Off (PTO) system [11].

4 Power Take-Off (PTO) systems

The PTO system of a WEC is the mechanism responsible for converting the energy absorbed by the primary converter into usable electrical energy. The performance of the PTO system has a direct impact on the overall efficiency of the energy conversion of the device [12]. Accurate numerical modeling of the PTO in the early stages of development is a critical step in the successful design of any WEC project. A detailed analysis is presented in [13], which describes the most common PTO configurations and their operating principles, as well as a database of both commercial and experimental models, offering valuable insights into the current state of PTO technology. The most commonly used PTO systems in combination with WECs are described below:

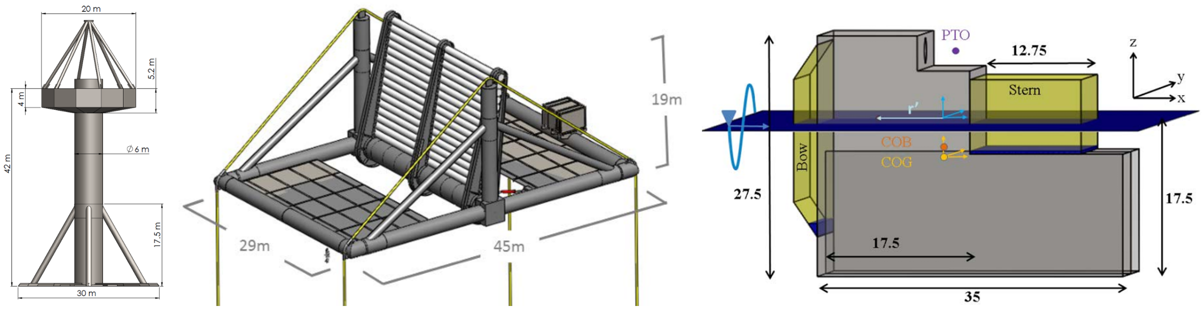

Figure 2: RMs main dimensions [7]. RM3 (left), RM5 (center) and RM6 (right).

- **Air Turbine-Based (AT):** In AT systems, air is alternately compressed and decompressed within a sealed chamber due to the vertical motion of the water column caused by incoming waves. The resulting pressure variations force the air to flow through a bidirectional air turbine, which in turn drives an electric generator. These turbines are designed to rotate in a single direction regardless of the airflow, making them ideal for OWC applications [13].

- **Direct Mechanical Drive-Based (DMD):** The DMD system generates energy by directly converting the motion induced by ocean waves into electrical power. This is typically achieved using a gearbox that transfers the oscillatory or rotational motion of the WEC to an electric generator [13].

- **Direct Electrical Drive-Based (DED):** The DED system relies on the interaction between a translator and a stator, acting like a linear generator, producing electricity through electromagnetic induction. This approach eliminates the need for intermediate mechanical or hydraulic conversion systems [13].

- **Hydraulic Motor-Based (HMB):** The HMB PTO system typically consists of key components such as a hydraulic cylinder or ram, a hydraulic motor, an accumulator, and an electric generator. In general, oscillatory motion acts on the hydraulic cylinder, which compresses a working fluid (usually hydraulic oil). This pressurized fluid is then directed through the hydraulic motor, converting the stored hydraulic energy into mechanical rotational energy. Finally, this mechanical energy is used to drive an electric generator, producing electrical power [13].

5 Consideration of WECs and PTOs for offshore aquaculture

In this section, three WECs—OWC, OSWC, and PA—are paired with the studied PTO systems—AT, MDD, EDD, and HMB—with the aim of selecting the best match for offshore aquaculture applications. The functional combinations of WECs and PTO systems are selected based on the previously outlined requirements, ensuring optimal performance, efficiency, and compatibility with the energy demands of fish farms. Table 3 presents a comparative evaluation of different types of WECs and PTO systems, considering criteria such as energy efficiency, ease of maintenance, cost of implementation, technological maturity, and adaptability to site conditions.

6 Conclusions

This study reviewed the challenges and opportunities of co-locating WECs with offshore aquaculture farms and identified promising WEC and PTO system candidates to power them. Three different WEC technologies were describe: -two-body PA, OSWC, and OWC-, while, for energy conversion, four PTO systems were analyzed -AT, DMD, DED, and HMB-. According to the review, the most suitable WEC device is the PA, considering its adaptability to different offshore conditions. The main challenge lies in the selection of the PTO system, where the HMB system offers considerable advantages, such as ease of maintenance and the scalability of the hydrodynamic coefficients related to its performance.

Table 2: Main features for PTO systems

PTO SYSTEM	MAIN FEATURE
AT	- For OWC, the most common PTO system is the one based in ATs. - Does not have environmental impact since the fluid work is air. - High axial thrust and high noise. - It can be located in an easily accessible area, facilitating maintenance. - Lower mechanical efficiency (60% to 65%).
DMD	- Short lifetime and high maintenance cost. - The size of the gearbox is a parameter to consider into the design, and it is difficult to scale it to experimental model in wave tanks. - More efficient than the hydraulic motor based, due to the reduced friction. High performance, over the 95% of mechanical efficiency.
DED	- Without having a mechanical intermediate, avoid the losses related to this. - Continuous force control. - Low linear velocities, and low power-weight ratio. - Unequal generated voltage. - No mechanical losses.
HMB	- Suitable for low frequency operations and large power density. - The hydraulic motor can be used to control the WEC device, to maximize and regulate energy output. - Highly scalable to experimental models since the hydrodynamical response induced for the PTO can be modeled as linear loads. - The fluid work (generally hydraulic oil) can generate leakage due to the compression and decompression work, polluting the water and affecting the fish production. - Need regular maintenance due to the number of parts of the system. - Lower mechanical efficiency, that can be translated in a loss of power electricity. The overall claimed efficiency of the system varied from 69% to 80%, but in the real world could be lower.

Table 3: WEC and PTO Selection for offshore aquaculture applications.

WEC	PTO	CONSIDERATIONS	REAL-WORLD EXAMPLE
OWC	AT	- As the water depth increases, the efficiency of the OWC decreases, limiting its expansion to nearshore areas. - The AT is the most suitable option for this device and has no environmental impact since it operates with air, preventing pollution of the surrounding waters near fish farms. It can be placed in strategic locations for easy maintenance. However, its high axial thrust, and noise levels could negatively affect fish health.	
PA	DMD, DED, HMB	- The adaptability of PAs to offshore conditions, based on their design and the parametrization of physical and mass properties, makes them a promising technology for this PBE application. - For the PTO system, MDD, EDD, and HMB can be implemented on PAs, with MDD and HMB being the most common choices. - For MDD, the gearbox size is a key design parameter for PAs. - For EDD, the main challenges are the low power-weight ratio and the unequal voltage generation. - For HMB, the working fluid (typically hydraulic oil) may leak due to compression and decompression cycles, potentially polluting the water and affecting fish production.	- SINN Power. Shrimp and prawn aquaculture and wave energy – Cabo Verde [2]. - Aqua Power Technologies Nearshore finfish aquaculture and wave energy – Scotland [2]. - Carnegie Clean Energy Offshore aquaculture and wave energy – Australia [2].
OSWC	None	- Since OSWECs are designed for nearshore use in water depths of less than 20 m, they are not a suitable choice for offshore aquaculture applications.	.

Acknowledgments

This work was supported by the Atlantic Marine Energy Center (AMEC) - in partnership with the ECOLab research group at University of New Hampshire. Funding for undergraduate students on the project was provided by the AMEC Bipartisan Infrastructure Law BIL EE-0011379. The authors thank Usman Masood for his time and valuable input in reviewing the document. His support and feedback are greatly appreciated.

References

[1] A. LiVecchi et al. *Powering the Blue Economy: Exploring Opportunities for Marine Renewable Energy in Maritime Markets*. Report. Washington, D.C.: U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, 2019.

[2] M.C. Freeman et al. *Offshore Aquaculture: a Market for Ocean Renewable Energy*. Report. Report for Ocean Energy Systems (OES). Ocean Energy Systems (OES), Apr. 2022.

[3] Pacific Northwest National Laboratory. *Marine Energy for Aquaculture*. https://www.pnnl.gov/projects/marine-energy-aquaculture. Accedido el 4 de julio de 2025. 2025.

[4] António F. de O. Falcão. "Wave energy utilization: A review of the technologies". In: *Renewable and Sustainable Energy Reviews* 14.3 (Apr. 2010), pp. 899–918. ISSN: 1364-0321. DOI: 10.1016/j.rser.2009.11.003. URL: http://dx.doi.org/10.1016/j.rser.2009.11.003.

[5] M.A. Mustapa et al. "Wave energy device and breakwater integration: A review". In: *Renewable and Sustainable Energy Reviews* 77 (Sept. 2017), pp. 43–58. ISSN: 1364-0321. DOI: 10.1016/j.rser.2017.03.110. URL: http://dx.doi.org/10.1016/j.rser.2017.03.110.

[6] Iraide López et al. "Review of wave energy technologies and the necessary power-equipment". In: *Renewable and Sustainable Energy Reviews* 27 (Nov. 2013), pp. 413–434. ISSN: 1364-0321. DOI: 10.1016/j.rser.2013.07.009. URL: http://dx.doi.org/10.1016/j.rser.2013.07.009.

[7] Vince Neary et al. *Reference Model Project (RMP): Open-Source Reference Models for Marine Hydrokinetic Technologies*. Sandia National Laboratories/U.S. Department of Energy, Marine and Hydrokinetic Data Repository. Includes 6 open-source RM devices (tidal, river, ocean currents, wave OWC point absorber, surge flap); provides design methodology, CAD geometry, cost models, and LCOE tools for benchmarking MHK technologies. Sept. 2014. URL: https://energy.sandia.gov/programs/renewable-energy/water-power/projects/reference-model-project-rmp/.

[8] Vince Neary et al. *Reference Model 3 Scaled Geometry (RM3: Wave Point Absorber)*. Marine and Hydrokinetic Data Repository, Sandia National Laboratories. Sept. 2014. DOI: 10.15473/1818910. URL: https://doi.org/10.15473/1818910.

[9] Ocean Power Technologies. *Ocean Power Technologies*. Accessed: 2025-07-02. 2025. URL: http://www.oceanpowertechnologies.com.

[10] Vince Neary et al. *Reference Model 5 Full Scale Geometry (RM5: Oscillating Surge Flap)*. Open Energy Data Initiative / MHKDR, Sandia National Laboratories. Sept. 2014. DOI: 10.15473/1819897. URL: https://doi.org/10.15473/1819897.

[11] Vince Neary et al. *Reference Model 6 Full Scale Geometry (RM6: Oscillating Water Column)*. Dataset, Marine and Hydrokinetic Data Repository, Sandia National Laboratories. Sept. 2014. DOI: 10.15473/1819898. URL: https://www.osti.gov/biblio/1819898.

[12] Amélie Têtu. "Power Take-Off Systems for WECs". In: *Handbook of Ocean Wave Energy*. Springer International Publishing, Dec. 2016, pp. 203–220. ISBN: 9783319398891. DOI: 10.1007/978-3-319-39889-1_8. URL: http://dx.doi.org/10.1007/978-3-319-39889-1_8.

[13] Raju Ahamed, Kristoffer McKee, and Ian Howard. "Advancements of wave energy converters based on power take off (PTO) systems: A review". In: *Ocean Engineering* 204 (May 2020), p. 107248. ISSN: 0029-8018. DOI: 10.1016/j.oceaneng.2020.107248. URL: http://dx.doi.org/10.1016/j.oceaneng.2020.107248.