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# A Comprehensive Review of Promising Hybrid Sea Waves Energy Powered Desalination Techniques

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**ABSTRACT**

*Freshwater scarcity is a critical problem faced by many communities worldwide and utilizing renewable energy sources to power water treatment processes is becoming increasingly important. Also, our oceans is a potential source of power using the oscillations waves hitting our costal lines every second. So, this review paper examines the feasibility and potential of hybrid systems that use wave energy converters to generate power for freshwater water production. Various wave energy converter technologies, such as oscillating water columns, overtopping devices, and wave-activated bodies, are discussed to be integrated with desalination methods. The paper presents an overview of various hybrid systems, highlighting their design, operation, cost, environmental impacts, and performance. By comparing various hybrid systems, this review paper aims to provide valuable insights for researchers, engineers, and policymakers seeking to develop sustainable solutions to freshwater scarcity by clarifying the benefits and challenges and suggested considerations that needs to be taken in future studies.*

## 1. Introduction:

Based on the World Water Development Report of the United Nations, 3.7 billion people are directly impacted by water shortages. In 2050, this figure could grow by 5.7 billion. (Amin et al., 2021), hybrid desalination systems that are integrated with wave energy converter systems are becoming an increasingly important topic in the field of sustainable water production. These systems aim to utilize renewable energy sources to power water treatment processes to address the pressing issue of freshwater scarcity.

Wave energy converters represent one of the most promising forms of renewable energy sources that can be harnessed to power desalination systems. Various types of wave energy converters have been developed, including oscillating water columns, overtopping devices, and wave-activated bodies,(Drew et al., 2009) which can be integrated with desalination methods such as reverse osmosis, electrodialysis, and HDH(H. Mahmoudi et al., 2008).

However, the integration of wave energy converter systems with desalination processes presents several challenges. For example, the cost of producing freshwater, the intermittency of power production, and the potential environmental impacts of wave energy converters and desalination methods need to be carefully considered.(Hacene Mahmoudi et al., 2010)

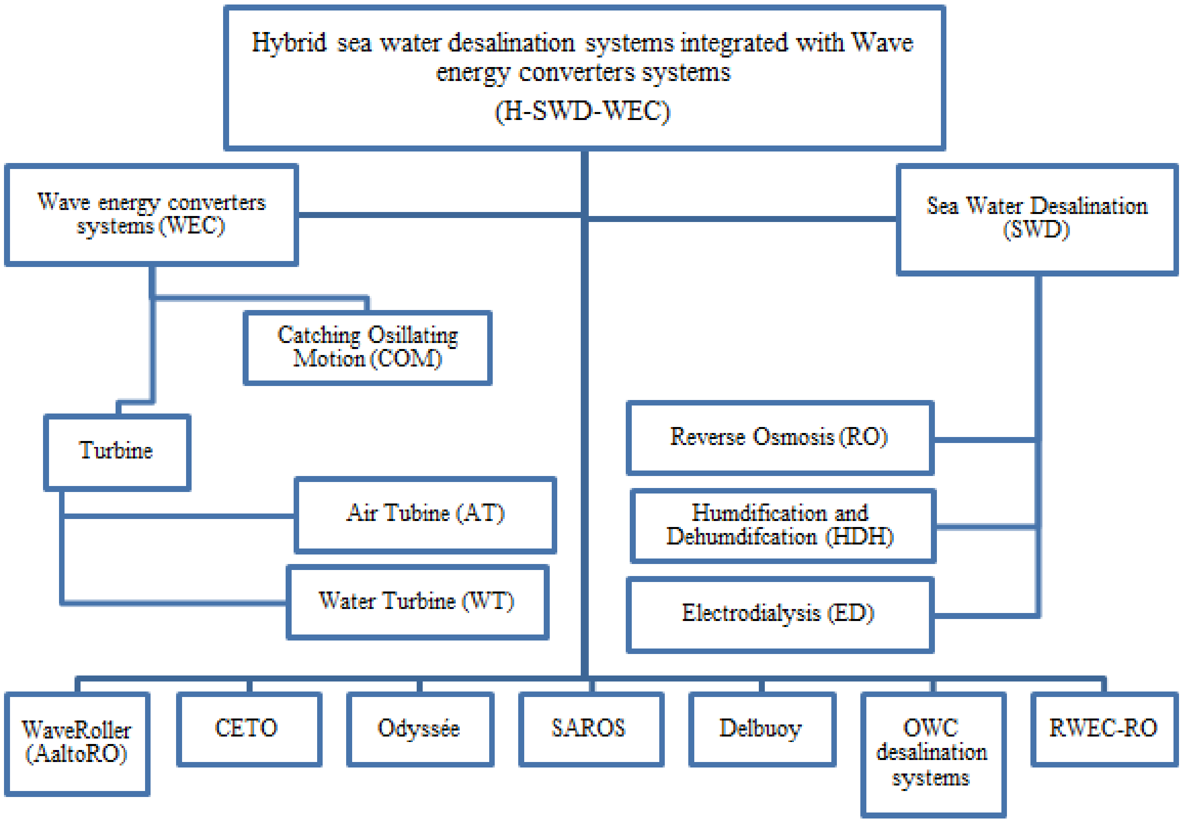


Figure 1: classification tree of hybrid systems reviewed

This area of research has been gaining attention in recent years, with various successful examples of hybrid systems being developed, such as CETO, Odyssée, and SAROS. The design, operation, and performance of these hybrid systems are key factors in determining their effectiveness in addressing freshwater scarcity.

Overall, the integration of wave energy converter systems with desalination processes has the potential to provide a sustainable and cost-effective solution to the challenge of freshwater scarcity. Further research and development in this area are needed to overcome the challenges and fully realize the potential of these hybrid systems.

Table 1: Type of system reviewed according to classification

| | Plant / Project / Paper | WEC Method | SWD Method |
|---|---|---|---|
| 1 | WaveRoller (AaltoRO) | COM | RO |
| 2 | CETO | COM | RO |
| 3 | Odyssée | COM | RO |
| 4 | SAROS | COM | HDH |
| 5 | Delbuoy | COM | RO |
| 6 | OWC desalination systems | AT | RO |
| 7 | RWEC-RO | WT | RO |

## 2. WaveRoller: (AaltoRO):

WaveRoller is a wave energy converter (WEC) that captures energy from ocean waves and converts it into electricity. The device consists of a submerged panel that is attached to a fixed structure on the seabed. As the waves pass over the panel, it moves back and forth, driving a hydraulic piston that pumps seawater through a turbine, generating electricity. The WaveRoller is designed to be deployed in near-shore areas with a significant wave height of at least 0.7

meters. Testing of the device has demonstrated its ability to generate reliable and consistent power, with an installed capacity of up to 350 kilowatts. (Ylänen & Lampinen, 2014) The WaveRoller has the potential to provide a reliable source of clean energy, with the added benefit of reducing carbon emissions and dependence on fossil fuels.

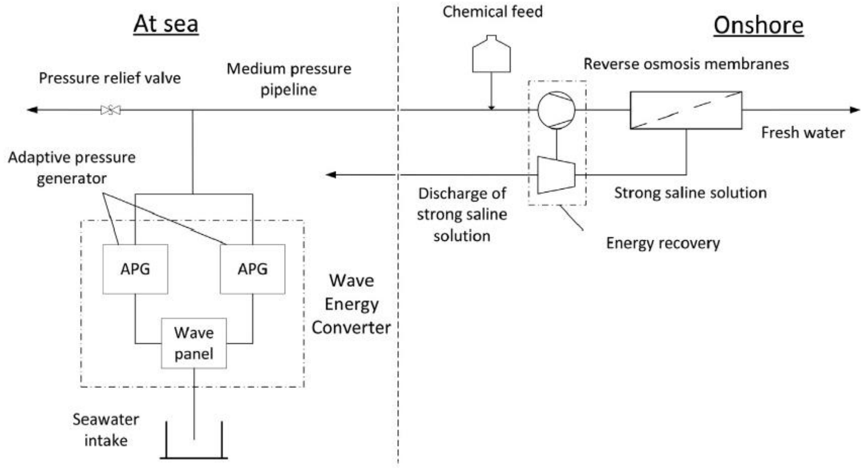


*Figure 2: schematic drawing of AaltoRO system* (Ylänen & Lampinen, 2014)

The WaveRoller is a 25-30 m wide and 10 m high panel, which oscillates back and forth with the movement of the waves. The standard operation for the WaveRoller would not produce electricity, but AaltoRO works as a pump, traditional systems use high-pressure pumps powered by the grid, but wave power presents new challenges. The article suggests that maintaining the high-pressure level and good pretreatment may be too expensive and explores the effect of lowering the operational pressure on the system. The study aims to challenge old design principles and investigate the potential benefits and drawbacks of lowering the pressure in a wave power and RO system.

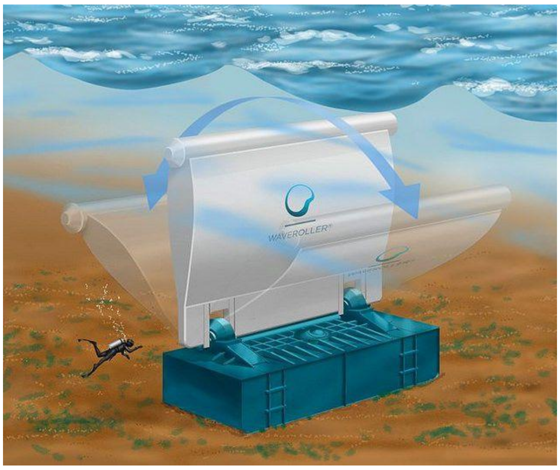

*Figure 3: WaveRoller osillating teqnique* (CONSULTINGJMJ, 2016)

The study found that for a wave-powered desalination system, a pressure level of 45 bar (Ylänen & Lampinen, 2014) provided the best balance between low cost and optimal performance, with a minimum water price of around 0.8 euro/m3 and a recovery rate of 30%. The study recommends careful consideration of the effect of different pressure levels on the system's operation, maintenance, and economics, and suggests that overlooking this factor could lead to inaccurate or false results and hinder the advancement of renewable-powered desalination.

This paper was involved in calculating the cost of the fresh water developed and the total volume produced per day not the effect of weather on the production and the effect of location on the project, also the paper did not study several designs as cases and the effect of the volume of the plant of the production and cost.

**3. CETO:**

A WEC system that uses the power of ocean waves to drive a submerged pump, which pressurizes seawater and forces it through a reverse osmosis membrane.

The CETO wave energy converter (WEC) is a device that captures energy from ocean waves using a unique hydraulic power take-off system. This technology has been designed to operate in a wide range of wave conditions, with a focus on reliability, efficiency, and ease of maintenance. Successful trials have demonstrated the CETO WEC's ability to generate consistent and predictable power, making it a potentially significant source of renewable energy, which could reduce carbon emissions and improve energy security.

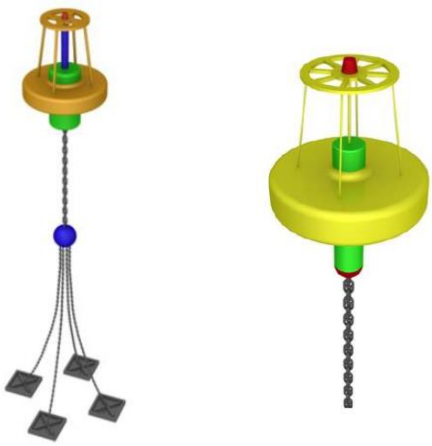

*Figure 4: point absorber WEC developed by DEIM* (Viola et al., 2016)

On Pantelleria Island, Italy, the consumption of electricity increases during the summer, and the island burns over 10 million liters of diesel to generate electricity, costing more than 1 euro per liter. A hybrid system with a solar installation is expected to reduce fuel consumption by more than 7 million liters a year, leading to cost savings of 10.5 million euros annually and reducing $CO_2$ emissions by 20,725 metric tons. (Viola et al., 2016) The island's drinking water network is supplied by two desalination plants that purify seawater and brackish water from a well. Additionally, small-scale solar-powered membrane distillation systems have been installed to produce 5 [m3/ day] of water using both solar energy and waste heat from the local diesel power plant. (Franzitta et al., 2016)

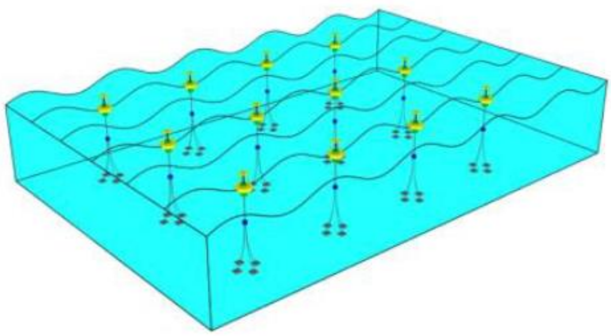

*Figure 5: Suggested design of WEC field (Viola et al., 2016)*

Although the RO systems provide high energy savings, the use of renewable energy sources such as wave energy could be a more sustainable choice for meeting the island's electricity needs.(Corsini et al., 2015) Studies have indicated significant wave energy potential along Pantelleria's coastline, with a medium annual extractable power of about 7 kW/m and a theoretical annual extractable energy of about 60 MWh/m.

The significant wave height is less than 4 meters,(Mørk et al., 2010) and the main direction of the wavefront is North-West, indicating that Pantelleria could be a suitable location for a wave farm in the Mediterranean Sea.

This paper did not give a detailed information about the result of desalinated water production per day or per year and focus in the conclusion about the amount of energy produced from waves and the availability of building the plant in Pantelleria, also the paper did not mention the effect of the plant size on the cost and production and suggested the design as a "real system or small-scale pilot".

**4. Odyssée:**

A hybrid Odyssée wave energy converter (WEC) with a reverse osmosis (RO) desalination system. The hybrid system consists of a WEC that converts the kinetic energy of ocean waves into electrical energy, which is used to power the RO desalination system. The performance of the hybrid system is analyzed based on its energy efficiency and its ability to produce fresh water.

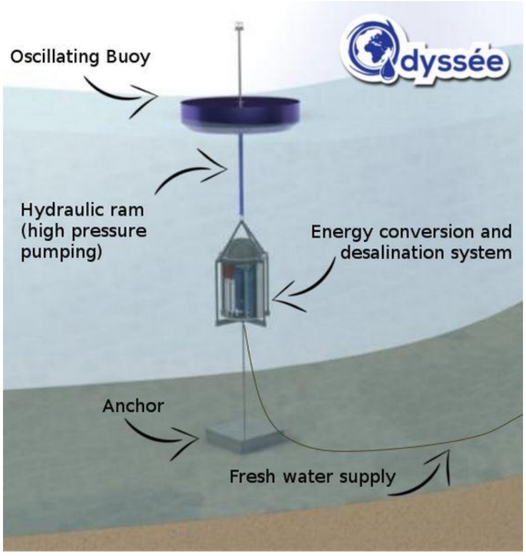


*Figure 6: Point Absorber Odyssée WEC* (Nick Lavars, 2014)

A detailed mathematical model of the hybrid system has been made, which considers the dynamics of the WEC, the electrical generator, and the RO desalination system. The model is used to simulate the performance of the hybrid system under different operating conditions, such as varying wave heights and seawater temperatures.

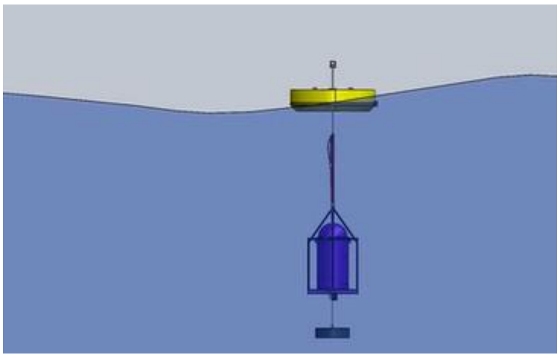

*Figure 7: Odyssée suggested design* (Nick Lavars, 2014)

The results of the simulation show that the hybrid system can produce a significant amount of freshwater (Golbaz et al., 2021) while also generating electrical energy. The energy efficiency of the system is found to be around 50%, which is a good performance for a WEC-RO hybrid system.

This plant or project do not rise to the level of a scientific research because of the lack of scientific information, the project mentioned in other papers as promising technique in this field but with no research paper references, the only reference found was the project website with no detailed data of different studied cases to validate the results.

**5. SAROS:**

A WEC system uses the power of ocean waves to compress air, which is then used to power a mechanical vapor compression desalination plant.

SAROS wave energy converter (WEC) system to power a mechanical vapor compression desalination plant. The SAROS WEC system works by using ocean waves to compress air, which is then used to power a generator to produce electricity. This electricity is then used to power the mechanical vapor compression desalination plant. (Shannon McGarry, 2015)


*Figure 8: SAROS commercial shape*

A detailed analysis has been done of the potential energy output of the SAROS WEC system, as well as the economics of the system. The analysis shows that the SAROS WEC system has the potential to produce a significant amount of energy and could be economically competitive with other renewable energy sources, such as wind and solar. (SAROS Desalination, n.d.)

A film was made by the company building this plant discusses the technical challenges associated with implementing the SAROS WEC system, such as the need for high-pressure air storage and the potential for corrosion and fouling in the compressed air system.

Overall, a paper concludes that the SAROS WEC system has the potential to be a viable technology for powering desalination plants without studying different cases or giving a real comparison with other projects or a detailed information about the cost of producing fresh desalinated water or total volume produced desalinated water per day, and further research and development could help to overcome the technical challenges and improve the economics of the system. (Leijon & Boström, 2018a)

**6. Delbuoy:**

A WEC system that uses the motion of ocean waves to power a pump, which pressurizes seawater and forces it through a reverse osmosis membrane.

Delbuoy is a wave energy converter (WEC) developed by the Swedish company Sea based AB, which utilizes a linear generator to convert the kinetic energy of waves into electrical power. Delbuoy consists of a buoyant module, a subsea mooring system, and a power cable that connects the WEC to the onshore electrical grid. The device has a unique feature that allows for passive rotation, which helps to optimize the energy capture from incoming waves. (Bayoumi S et al., 2010) Delbuoy has been successfully deployed in a pilot project in Sotenäs, Sweden, and has demonstrated promising results in terms of power output and reliability. (Cruz & Salter, 2006) The device has potential applications in remote locations and off-grid areas, where it can provide a reliable source of renewable energy from ocean waves .

The paper titled "Delbuoy Wave-Powered Seawater Desalination System" presents the design and performance analysis of a wave-powered seawater desalination system called Delbuoy. The Delbuoy system is a floating platform that uses the motion of ocean waves to drive reverse osmosis (RO) desalination plants to produce fresh water.

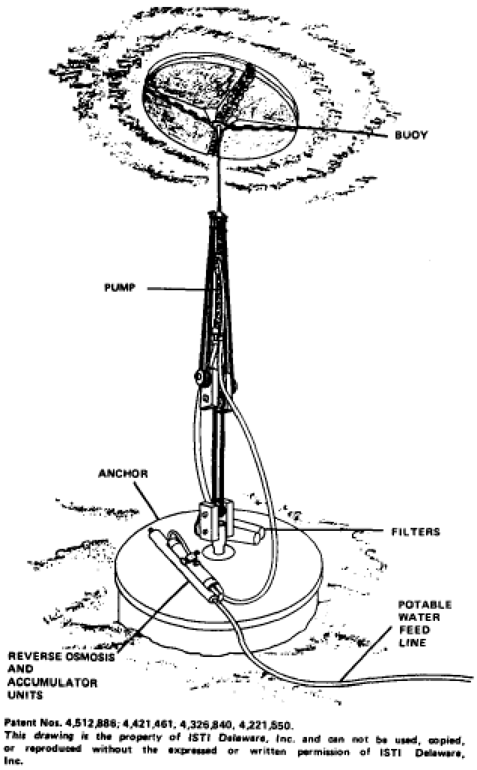


*Figure 9: Delbuoy WEC Design* (Hicks et al., 1988)

The paper describes the design and construction of the Delbuoy system, which consists of a buoyant platform with a central mast that houses the RO desalination plant and the power take-off (PTO) system. The PTO system uses a hydraulic accumulator and a hydraulic motor to convert the motion of the waves into rotational motion, which drives a generator to produce electricity to power the desalination plant (Hicks et al., 1988)

The authors present the results of numerical simulations and experimental tests to evaluate the performance of the Delbuoy system under various wave conditions. The simulation results show that the Delbuoy system can produce fresh water with high energy efficiency, and the experimental tests confirm the feasibility of the design and the performance of the PTO system. (Leijon & Boström, 2018a)

Overall, the paper concludes that the Delbuoy wave-powered seawater desalination system has the potential to provide a sustainable solution for producing fresh water in coastal areas, and further research and development could help to improve the efficiency and reliability of the system. (Folley et al., 2008)

There is no detailed comparison between this design and other designs with same main technique, also the paper mentioned that this project has the potential but in science the paper is not professional as the is no numbers of graph as a comparison between different cases to study the efficiency, cost and production of desalinated water by this plant.

**7. Oscillating Water Column (OWC) desalination systems:**

OWCs use the motion of waves to drive a turbine, which generates electricity to power a desalination plant.

An oscillating water column (OWC) is a type of wave energy converter (WEC) that harnesses the power of ocean waves to generate electricity. (Falcão & Henriques, 2016) In addition to electricity generation, OWCs can also be used in desalination systems to produce fresh water from seawater. OWC desalination systems work by pressurizing seawater using the air column inside the device as waves pass over it. This pressurized seawater is then fed into a reverse osmosis membrane, which separates the salt from the water, producing fresh water. OWC desalination systems have the potential to provide a sustainable source of fresh water in coastal areas, particularly in regions where both wave energy and fresh water are in high demand. However, further research is needed to optimize the design and operation of OWC desalination systems to maximize their efficiency and minimize their environmental impact. (Sharmila et al., 2004)

OWC-RO system, which includes the OWC device, air turbine, generator, power electronics, and the RO system. The analysis shows that the OWC-RO system has the potential to produce a significant amount of fresh water with high energy efficiency and that the system could be economically competitive with other renewable energy sources, such as wind and solar.(Davide Magagna & Muller, 2009)

The technical challenges associated with implementing the OWC-RO system, such as the need for efficient energy storage and the requirement for a reliable control system to manage the power output of the OWC device.

Overall, the OWC-RO system has the potential to be a viable technology for powering desalination plants, and further research and development could help to overcome the technical challenges and improve the economics of the system. (Amin et al., 2020)

**Example 1:** The Vizhinjam WEC-RO in India

The Vizhinjam OWCRO in India is a large infrastructure project that includes an oscillating water column (OWC) wave energy converter coupled with a desalination plant to provide fresh water to the seaport. The OWC device is designed to capture the energy of ocean waves, which is then converted into mechanical energy to drive an electrical generator, which in turn powers the desalination plant. (Leijon & Boström, 2018a)

*Figure 10: The Vizhinjam WEC-RO in India* (Leijon & Boström, 2018b)

The desalination plant uses reverse osmosis (RO) technology to produce fresh water from seawater and is designed to produce up to 10 million liters of fresh water per day to meet the needs of the seaport. The OWC-RO system is designed to be highly efficient, with a capacity factor of up to 50%, which makes it a viable and sustainable source of fresh water for the seaport.

The Vizhinjam OWC-RO project is a significant step forward in the development of wave energy technology for desalination and could serve as a model for other coastal communities seeking sustainable sources of freshwater.

## 8. RWEC-RO:

The RWEC is designed to capture the energy of the waves by resonating at the same frequency as the incoming waves, which maximizes the amount of energy that can be extracted from the waves. The RWEC is connected to a hydraulic system that drives a high-pressure pump, which in turn powers the RO desalination plant. (D. Magagna et al., 2009)

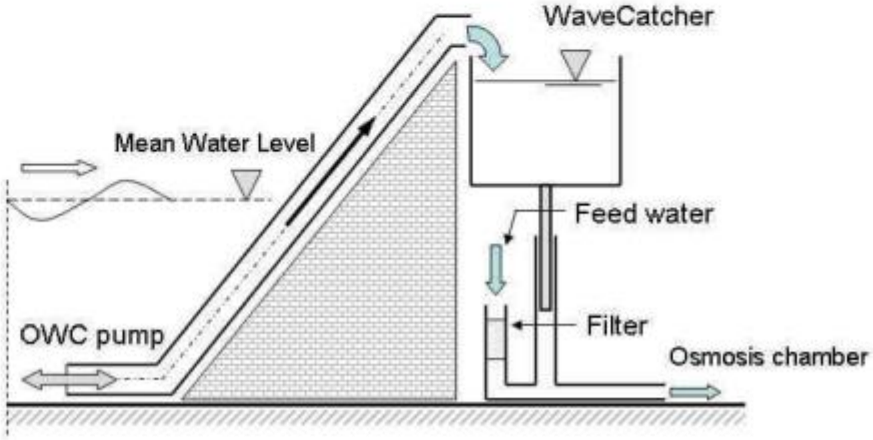


*Figure 11: RWEC-RO schematic design (D. Magagna et al., 2009)*

The proposed system is analyzed using simulation models and laboratory tests, which demonstrate the feasibility of the RWEC-RO system for both water and power production. The system is shown to be highly efficient and to have the potential to deliver significant amounts of fresh water and electricity from ocean waves.

The paper also discusses the challenges associated with the implementation of the RWEC-RO system, such as the need for efficient energy storage and the requirement for a reliable control system to manage the power output of the RWEC device.

Overall, the paper concludes that the RWEC-RO system is a promising technology for delivering fresh water and generating electricity from ocean waves with introducing numbers to compare with other projects about the cost and total production per day, further research and development could help to overcome the technical challenges and giving more solid study with different cases to improve the economics of the system.

## 9. Conclusion:

After reviewing various scientific papers on hybrid wave energy converters (WECs) and seawater desalination systems, WECs have a lot of potential to power desalination systems and produce fresh water. These systems have been designed and tested in various locations around the world, with a variety of different technologies and configurations being utilized. From the WaveRoller and CETO systems to Odyssée, SAROS, Delbuoy, and OWC desalination systems, many different approaches have been taken to combine wave energy conversion with desalination.

The benefits of these hybrid systems are clear: they provide a clean, renewable energy source for powering desalination plants, which can help address the growing global water scarcity issue. Additionally, they can be used in remote coastal areas where the grid connection is not possible, thus enabling access to freshwater in otherwise underserved areas.

Despite the benefits, challenges remain. The intermittency of wave energy, the high capital cost of installation and maintenance, and the impact of harsh marine environments on equipment all pose significant challenges to the viability of these systems. Therefore, additional research and development are necessary to determine and improve the performance and cost-effectiveness of hybrid WEC-desalination system as some of the introduced techniques are promising and had been described as having the potential to be a sustainable plant for producing desalinated water using sea waves extracted power.

The studies on hybrid WEC-desalination systems have shown that it is possible to generate freshwater from seawater by harnessing the power of ocean waves.

However, more research is needed to address the challenges that these systems present, and to continue improving their efficiency, reliability, and economic viability by comparing those systems after standardizing the factors that will be important in the future.

Nonetheless, these systems represent a promising approach to addressing the growing demand for freshwater and harnessing the renewable energy potential of our oceans but as the world is developing new techniques every day, a guide should be taken in consideration at introducing a new design or a new information about WEC-desalinated water plants.

## 10. References:

1. Amin, I., Ali, M. E. A., Bayoumi, S., Balah, A., Oterkus, S., Shawky, H., & Oterkus, E. (2021). Numerical hydrodynamics-based design of an offshore platform to support a desalination plant and a wind turbine in Egypt. *Ocean Engineering*, *229*(January). https://doi.org/10.1016/j.oceaneng.2021.108598
2. Amin, I., Ali, M. E. A., Bayoumi, S., Oterkus, S., Shawky, H., & Oterkus, E. (2020). Conceptual design and numerical analysis of a novel floating desalination plant powered by marine renewable energy for Egypt. *Journal of Marine Science and Engineering*, *8*(2), 1–23. https://doi.org/10.3390/jmse8020095
3. Bayoumi S, Incecik, A., Gamal, H. El, & Shalash, K. (2010). *Wave Powered Water Desalination in Egypt*. *14*.
4. CONSULTINGJMJ. (2016). *Waveroller, el invento que convierte las olas del mar en electricidad*. https://consultingjmj.wordpress.com/2016/08/16/waveroller-el-invento-que-convierte-las-olas-del-mar-en-electricidad/
5. Corsini, A., Tortora, E., & Cima, E. (2015). Preliminary assessment of wave energy use in an off-grid minor island desalination plant. *Energy Procedia*, *82*, 789–796. https://doi.org/10.1016/j.egypro.2015.11.813
6. Cruz, J., & Salter, S. (2006). *Update on the design of an offshore wave powered desalination device*. *1976*.
7. Drew, B., Plummer, A. R., & Sahinkaya, M. N. (2009). A review of wave energy converter technology. *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy*, *223*(8), 887–902. https://doi.org/10.1243/09576509JPE782

8. Falcão, A. F. O., & Henriques, J. C. C. (2016). Oscillating-water-column wave energy converters and air turbines: A review. *Renewable Energy*, *85*, 1391–1424. https://doi.org/10.1016/j.renene.2015.07.086
9. Folley, M., Peñate, B., & Whittaker, T. (2008). *An autonomous wave-powered desalination system*. *220*, 412–421. https://doi.org/10.1016/j.desal.0000.00.000
10. Franzitta, V., Curto, D., Milone, D., & Viola, A. (2016). The desalination process driven by wave energy: A challenge for the future. *Energies*, *9*(12), 1–16. https://doi.org/10.3390/en9121032
11. Golbaz, D., Asadi, R., Amini, E., Mehdipour, H., Nezhad, M. M., Nasiri, M., Taghi, S., Naeeni, O., Neshat, M., & Group, L. (2021). *OCEAN WAVE ENERGY CONVERTERS OPTIMIZATION: A COMPREHENSIVE REVIEW*.
12. Hicks, D. C., Pleass, C. M., & Mitcheson, G. R. (1988). *Delbuoy: Wave-powered seawater desalination system*. *3*, 1049–1054. https://doi.org/10.1109/oceans.1988.23660
13. Leijon, J., & Boström, C. (2018a). Freshwater production from the motion of ocean waves – A review. *Desalination*, *435*(November 2017), 161–171. https://doi.org/10.1016/j.desal.2017.10.049
14. Leijon, J., & Boström, C. (2018b). Freshwater production from the motion of ocean waves – A review. *Desalination*, *435*(October), 161–171. https://doi.org/10.1016/j.desal.2017.10.049
15. Magagna, D., Stagonas, D., Warbrick, D., & Müller, G. U. (2009). Resonating wave energy converter for delivery of water for desalination and energy generation. *8th European Wave and Tidal Energy Conference*, 393–399.
16. Magagna, Davide, & Muller, G. (2009). A wave energy driven ro stand-alone desalination system: Initial design and testing. *Desalination and Water Treatment*, *7*(1–3), 47–52. https://doi.org/10.5004/dwt.2009.699
17. Mahmoudi, H., Abdul-Wahab, S. A., Goosen, M. F. A., Sablani, S. S., Perret, J., Ouagued, A., & Spahis, N. (2008). Weather data and analysis of hybrid photovoltaic-wind power generation systems adapted to a seawater greenhouse desalination unit designed for arid coastal countries. *Desalination*, *222*(1–3), 119–127. https://doi.org/10.1016/j.desal.2007.01.135
18. Mahmoudi, Hacene, Spahis, N., Goosen, M. F., Ghaffour, N., Drouiche, N., & Ouagued, A. (2010). Application of geothermal energy for heating and fresh water production in a brackish water greenhouse desalination unit: A case study from Algeria. *Renewable and Sustainable Energy Reviews*, *14*(1), 512–517. https://doi.org/10.1016/j.rser.2009.07.038
19. Mørk, G., Barstow, S., Kabuth, A., & Pontes, M. T. (2010). Assessing the global wave energy potential. *Proceedings of the International Conference on Offshore Mechanics and Arctic Engineering - OMAE*, *3*(June 2010), 447–454. https://doi.org/10.1115/OMAE2010-20473
20. Nick Lavars. (2014). *The Odyssée desalinator: Using the power of the ocean to cleanse its own salty waters*. https://newatlas.com/odysse-desalinator-power-ocean-clean/35276/
21. SAROS Desalination. (n.d.). *SAROS - Turning Waves into Fresh Water*. https://www.youtube.com/watch?v=0hI9YGvHBcw
22. Shannon McGarry. (2015). *SAROS is Turning Waves into Fresh Water with the Help of Fusion 360*. https://www.autodesk.com/products/fusion-360/blog/saros-is-turning-waves-into-fresh-water-with-the-help-of-fusion-360/

23. Sharmila, N., Jalihal, P., Swamy, A. K., & Ravindran, M. (2004). Wave powered desalination system. *Energy*, *29*(11), 1659–1672. https://doi.org/10.1016/j.energy.2004.03.099
24. Viola, A., Franzitta, V., Trapanese, M., & Curto, D. (2016). Nexus water & energy: a case study of wave energy converters (WECs) to desalination applications in Sicily. *International Journal of Heat and Technology*, *34*(Special Issue 2), S379–S386. https://doi.org/10.18280/ijht.34sp0227
25. Ylänen, M. M. M., & Lampinen, M. J. (2014). Determining optimal operating pressure for AaltoRO - A novel wave powered desalination system. *Renewable Energy*, *69*, 386–392. https://doi.org/10.1016/j.renene.2014.03.061