1.0

Marine Renewable Energy and Ocean Energy Systems–Environmental

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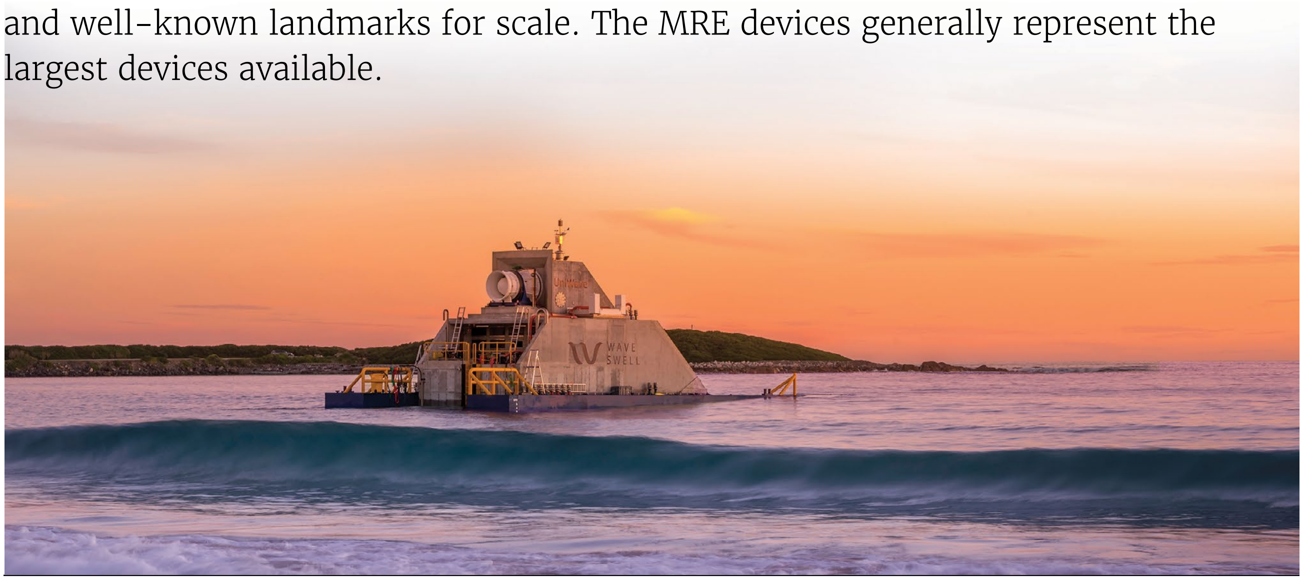
For many countries, marine renewable energy (MRE) is the most recent entry into their renewable energy portfolio. MRE involves the generation of energy from the movement of seawater including tides, waves, and persistent ocean currents, as well as from the gradients of temperature and salinity in the oceans. Some countries also include energy generation from the open waters of large rivers as part of MRE. Each MRE resource requires a different type of device to harvest that energy, placed in the appropriate portion and depth of the ocean or large river and secured to the seabed either by weight or by anchors. At full scale, these devices are large; Figure 1.1 puts the size of these devices in the context of other technologies and well-known landmarks for scale. The MRE devices generally represent the largest devices available.



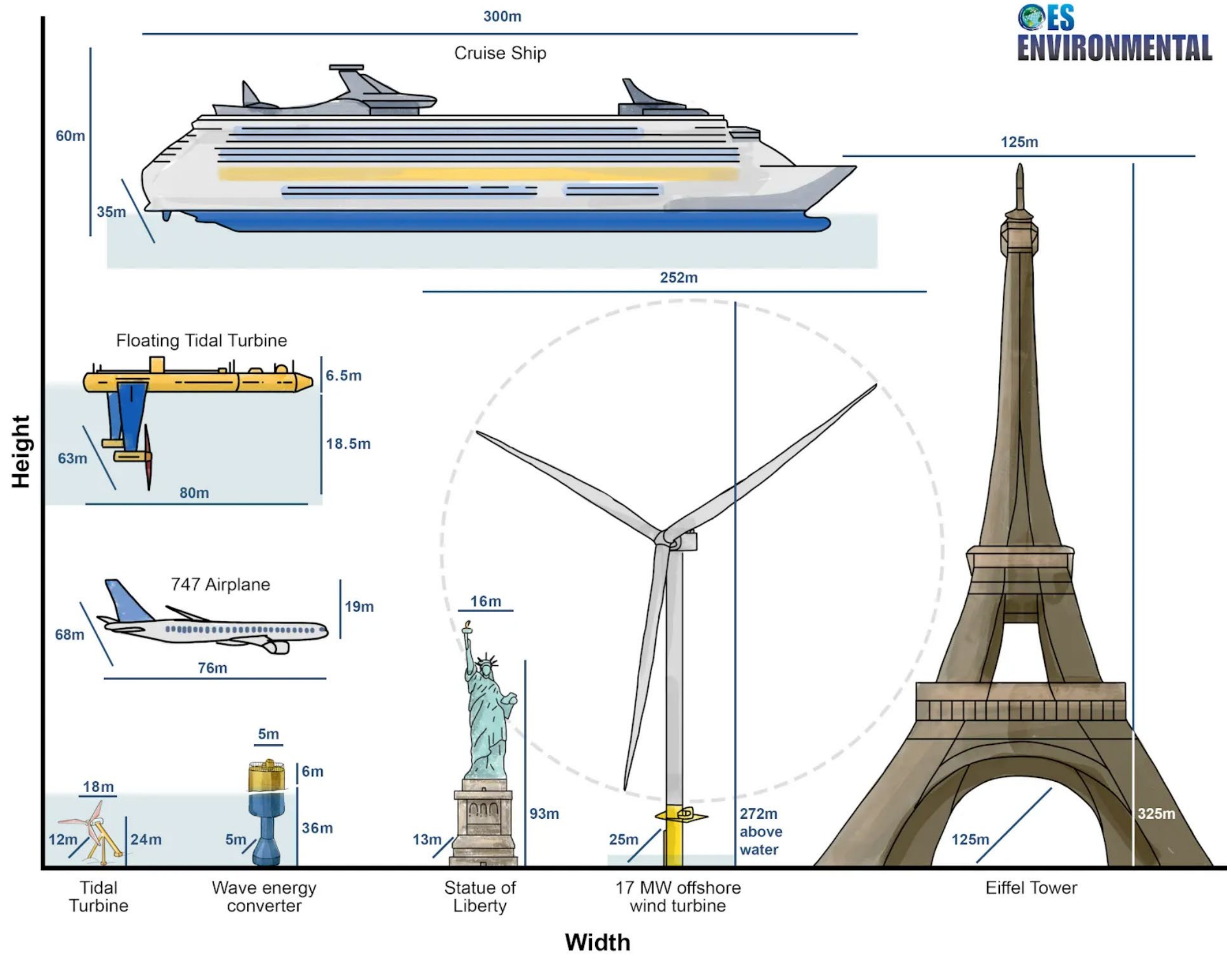


Figure 1.1. Size comparison of marine renewable energy (MRE) devices (a bottom-based tidal turbine, a floating tidal turbine, and a floating wave energy converter) with other technologies and well-known landmarks. The MRE devices generally represent the largest devices available. (Illustration by Stephanie King)

1.1.
BENEFITS OF MRE

MRE continues to be an active area of development, deployment, research, and financing. With accelerating concerns about the effects of climate change, cultivating new renewable and sustainable energy sources has become more urgent in developed and developing countries. It has been estimated that as the world transitions to renewable energy forms, up to 80% of the world's energy needs could be met by wind and solar energy (Bogdanov et al. 2021). The final 20% remains elusive and MRE is suited to fill much of this need. MRE can be used to augment grid-scale energy in coastal areas, and also as the sole renewable source of energy in remote coastal areas and for islands (LiVecchi et al. 2019). Additional opportunities can be created at sea, including powering offshore aquaculture, extending the missions for ocean observations, extracting critical minerals from seawater, decarbonizing shipping, and other blue economy uses (Copping et al. 2019).

1.2.
ENVIRONMENTAL RISKS OF MRE DEVELOPMENT

Wave energy converters (WECs), turbines for deployment in tidal, riverine, and ocean current areas, and ocean thermal energy conversion (OTEC) plants are in various stages of development throughout the world, and multiple different types of devices are under consideration. However, questions remain about the risk that the operation of these devices might pose to marine animals, habitats, and ecosystem processes. These potential effects continue to create uncertainty around the regulatory processes required to protect ocean resources and ensure that present uses of the ocean, such as fishing, boating, navigation, and cultural uses are protected.

The potential environmental effects of MRE can be assessed systematically within the framework of stressor and receptor interactions (Boehlert & Gill 2010), where stressors are the MRE devices or other parts of the associated systems (anchors, floats, mooring lines, foundations, cables) that may cause stress, injury, or death to marine animals or habitats, or disrupt ecosystem processes. The receptors include marine animals, with particular emphasis on marine mammals, fish, sea turtles, and seabirds; marine habitats that support these and other species; and biotic and abiotic portions of the marine ecosystem processes that function together to create the living ocean. After more than a decade of research, there is a consensus among MRE researchers that there are seven key stressor-receptor interactions potentially affecting marine animals, habitats, and ecosystem processes (Figure 1.2):

- **Collision risk** - Risk of marine animals colliding with rotating turbine blades and other moving parts of MRE devices.
- **Underwater noise** – Disruption of marine animal navigation and communication from the noise of operational MRE devices.
- **Electromagnetic fields (EMFs)** – Disruptions to marine animal movement and behavior due to EMF emissions from energized power export cables.
- **Changes in habitats** – Alterations in benthic or pelagic habitats that support marine animals from the presence and operation of MRE devices.
- **Entanglement** – Risk of large marine animals becoming entangled in mooring lines or draped cables in the water column.
- **Changes in oceanographic systems** – Decreases in wave heights or changes in ocean water circulation due to the presence and operation of MRE devices.
- **Displacement** – Changes in the migratory pathways or other movements of marine animals due to the presence and operation of many MRE devices.

The status of knowledge about each of these interactions will be examined in detail in Chapter 3 of this report.

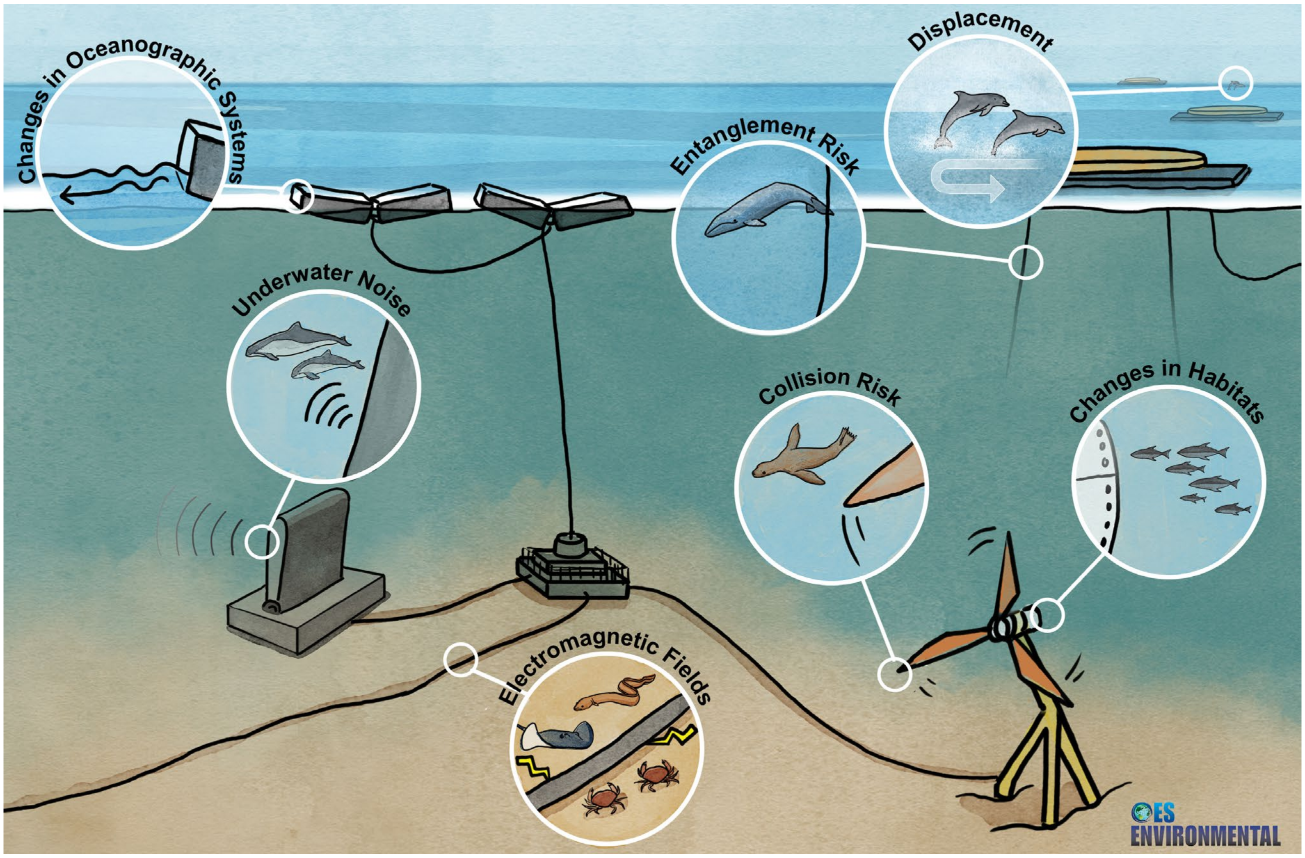


Figure 1.2. Stressor-receptor interactions potentially arising from various marine renewable energy devices. (Illustration by Stephanie King)

1.3.
OES-ENVIRONMENTAL

OES-Environmental is a coalition of 16 countries focusing on the examination of the environmental effects of MRE. OES-Environmental is a task enabled by Ocean Energy Systems (OES), a Technology Collaboration Programme of the International Energy Agency, consisting of 25 countries and the European Commission committed to developing MRE for the benefit of their countries and the world. OES authorized OES-Environmental for a fourth phase over the period 2020–2024. This report provides an update of the state of the research and understanding of the effects of MRE as they affect consenting or permitting (hereafter consenting) in OES countries. The U.S. Department of Energy's Water Power Technologies Office leads OES-Environmental, in cooperation with the National Oceanic and Atmospheric Administration and the Bureau of Ocean Energy Management. The task is implemented by the U.S. Department of Energy's Pacific Northwest National Laboratory.

The goal of OES-Environmental is to understand and resolve the risks of MRE development and operation to the marine environment to accelerate the deployment of devices in a responsible manner. The 16 countries under OES-Environmental strive to reach this goal via:

- continuous international collaboration among representatives of the OES-Environmental countries to support international efforts and leverage international knowledge expertise;
- data collection and curation on the Tethys online platform;
- dissemination of knowledge and information broadly; and
- international engagement with stakeholders, developers, regulators, and advisors.

At the end of the third phase of OES-Environmental, the *2020 State of the Science* report (Copping & Hemery 2020) documented the state of the knowledge of the environmental effects of MRE to that date. Throughout Phase 4 (2020–2024), the knowledge gathered was disseminated and used to develop publications and engagement opportunities, including:

- translating the *2020 State of the Science* Executive Summary from English to five other languages;
- creating 13 Short Science Summaries that condense the information about individual stressor-receptor interactions and strategies for addressing them;
- recording five podcasts about MRE and its environmental effects;
- developing four videos hosted on YouTube that describe environmental interactions with MRE; and
- writing a 24-page MRE brochure designed to provide new regulators with a primer about these topics.

A significant amount of time during Phase 4 of OES-Environmental was devoted to building out the concept of risk retirement of stressor-receptor interactions that complicate consenting processes (see Chapter 6). Risk retirement, in the context of facilitating consenting for small MRE deployments, means that each potential risk need not be fully investigated for every project, but rather that MRE developers, consultants, regulators, and advisors rely on what is known from already consented projects, from related research studies, or from findings from analogous offshore industries (Copping et al. 2020). Risk retirement will not take the place of any existing regulatory processes, nor will it completely replace the need for appropriate data collection before and after MRE device deployment. As new information becomes available, for example as larger arrays are deployed, additional examination may be required for stressor-receptor interactions that were considered retired for small numbers of devices.

OES-Environmental developed several subsystems for the risk retirement process:

- **Risk Retirement Pathway** – an organized methodology for working through consenting processes, applying datasets at strategic times, and providing "off ramps" that allow particular stressor-receptor interactions to be "retired" for the purposes of consenting.
- **Data Transferability** – a process for the discovery and comparison of datasets and information from consenting MRE projects, studies, or other industries to determine whether they can be applied to new project applications.
- Best Management Practices for applying data transferability processes.
- **Monitoring Datasets Discoverability Matrix** – an interactive tool that catalogs existing datasets and provides location or contact information for obtaining the datasets.

- **Evidence Bases** – databases of the most relevant information from research papers and monitoring data that support risk retirement for specific stressor-receptor interactions.
- **Guidance Documents** – documents that move the content of scientific publications and knowledge into formats accessible to MRE developers, consultants, regulators and advisors, including the overall pathway, interaction-specific information, and country-specific documents that reflect differences in national regulations.

During Phase 4, OES-Environmental completed:

- risk retirement for four stressor-receptor interactions for small numbers of devices;
- guidance documents that address the overall process, six stressor-receptor interactions, and 13 countries; and
- evidence bases for six stressor-receptor interactions.

Outreach and engagement with stakeholders allow OES-Environmental to disseminate information about the environmental effects of MRE, as well as gather and assimilate the most up-to-date findings from around the world. During the COVID pandemic, OES-Environmental rapidly switched many of the planned in-person activities to online activities, and increased the communication and outreach to the MRE community during a time of limited in-person engagement. During Phase 4, OES-Environmental:

- hosted 17 webinars,
- delivered 23 conference presentations (online and in-person),
- organized and hosted 14 workshops,
- published six journal publications and four conference papers,
- organized three environmental effects tracks at conferences, and
- organized and hosted four online expert forums.

OES-Environmental also began to look at the potential environmental effects of MRE at larger scales. The majority of available information about stressor-receptor interactions is concerned with single devices or very small arrays, generally six or fewer devices. Three white papers and accompanying journal publications were prepared by OES-Environmental country representatives about topics that look to the future of MRE development:

- scaling the understanding of the effects of MRE development from single devices to arrays (Hasselman et al. 2023),
- investigating the effects of MRE on ecosystems in a holistic approach, and
- examining the cumulative effects of MRE combined with other anthropogenic activities.

Research and collection of monitoring data around deployed MRE devices have been derived largely from projects and studies in temperate areas of the world's oceans. MRE development in tropical and subtropical areas is becoming of increasing interest to governments and stakeholders around the world. OES-Environmental has examined the body of knowledge about environmental effects and determined that additional approaches beyond those applied to temperate areas are needed for tropical and subtropical ecosystems. These ecosystems host a diverse range of habitats and species compared to temperate ecosystems and have higher biodiversity (Myers et al. 2000). In the tropics, OTEC has emerged as a potentially viable renewable energy source for coastal areas and islands. OTEC may create new challenges for the marine environment that differ from those of turbines and WECs (see Box 1.1).

1.4.
2024 STATE OF THE SCIENCE REPORT

The culmination of Phase 4 of OES-Environmental is the preparation of this document, the *2024 State of the Science* report. The remainder of this report is organized as follows:

- Chapter 2 provides a summary of the MRE projects around the world for which environmental effects have been assessed.
- Chapter 3 examines the status of our understanding of the effects that MRE devices and development have on the marine environment, from the perspective of the effects of the various stressors of these systems on marine animals, habitats, and ecosystem processes.
- Chapter 4 addresses the social and economic effects of MRE development.
- Chapter 5 looks at the importance of stakeholder engagement related to MRE development.
- Chapter 6 summarizes key strategies for facilitating the consenting of MRE devices, including risk retirement,

data transferability, guidance documents, adaptive management, and marine spatial planning.

- Chapter 7 summarizes the outreach and engagement activities around the environmental effects of MRE.
- Chapter 8 presents the key data and information systems pertinent to MRE development.
- Chapter 9 examines the environmental effects of MRE beyond single devices, including scaling up effects of arrays, ecosystem effects, and the cumulative effects of MRE development combined with other anthropogenic stressors.
- Chapter 10 brings information forward about the potential environmental effects of MRE in tropical and subtropical ecosystems.
- Chapter 11 summarizes key points from the report and looks forward at pathways for the future development of MRE.

BOX 1.1.

OCEAN THERMAL ENERGY CONVERSION

Ocean thermal energy conversion (OTEC) harvests power from the ocean through a heat exchange process between warm surface water and cold deep water. OTEC provides the only MRE baseload power source, as the process of bringing cold and warm water together is continuous, unlike most other renewable energy sources. A temperature differential of at least 20ºC is needed, which can only be achieved year-round in tropical areas. OTEC plants can be built on land, bringing the water to shore, or on floating platforms with an export power cable to shore. Deep ocean water from 800–1000+ m must be piped to the surface to be processed with warm surface water through heat exchangers, providing power to a turbine (Figure 1.3). The warm and cold water must then be returned to the ocean. The return of large volumes of cold water to the surface ocean has the potential to temperature-shock all living organisms and destabilize the water column above the thermocline. To mitigate these potential effects, the discharge of cold water is planned to occur at an intermediate depth that will allow for its mixing with ambient water and sinking to depth without causing harm to the oceanography of the region. While deep ocean water is rich in nutrients that could be used to enhance aquaculture, it is also high in carbon, which would further exacerbate carbon dioxide in surface ocean waters unless it is segregated and returned to depth or stripped of the carbon before being released into the surface ocean or atmosphere. Other effects include potential damage from shore-based OTEC plants, such as laying water pipes through coral reefs and nearshore habitats which must be avoided. Floating plants with power export cables could cause similar challenges related to the effects of electromagnetic fields on sensitive marine species.

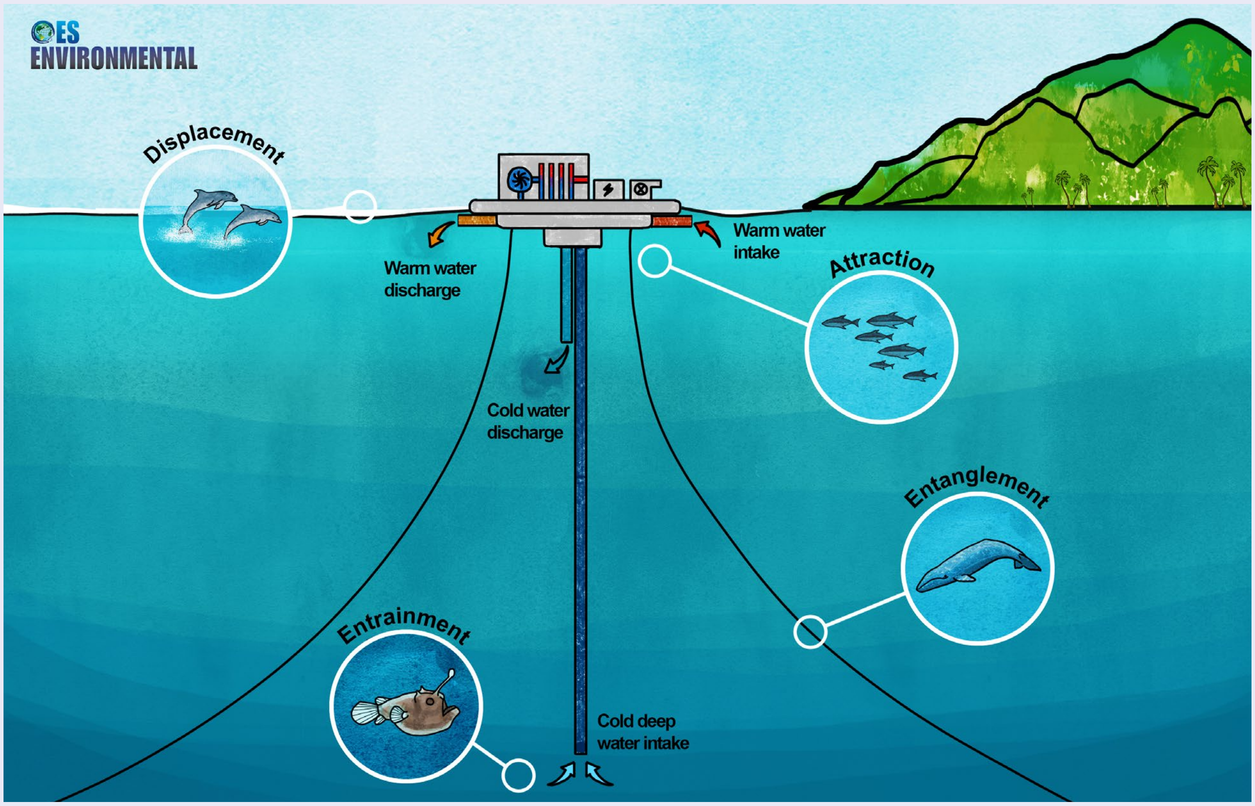


Figure 1.3. Water intake and discharge system of a floating ocean thermal energy conversion plant and potential environmental effects associated with the technology. (Illustration by Stephanie King)

1.5.
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