Multi-use ocean thermal energy conversion (OTEC) platforms

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Abstract—[1] **Ocean Thermal Energy Conversion (OTEC) generates power from a heat exchange process using the temperature differential between warm tropical surface water and cold deep ocean water and is a unique marine energy technology with a long history of development on- and offshore. With the ability to generate power 24 hours a day, OTEC can provide a more significant baseline power potential than any other offshore renewable technology. Pathways to widespread OTEC production indicate the potential to bring its levelized cost of energy (LCOE) down to levels that rival solar and wind energy on land. The potential for incorporating other value streams with OTEC was examined, and the trade-offs assessed for adding those additional products or services including seawater air conditioning, desalination, supporting aquaculture, critical mineral extraction, and generating efuels. A use case at the site of the existing 100 kW onshore OTEC plant at the National Energy Laboratory of Hawaii Administration (NELHA) was developed to examine the potential uses and trade-offs.**

Keywords—**Multi-use, ocean thermal energy conversion, OTEC, seawater air conditioning, SWAC, trade-offs.**

I. Introduction

Ocean Thermal Energy Conversion (OTEC) generates continuous power by exploiting the temperature difference between warm surface water and cold deep water [1]. OTEC can provide 24/7 baseload power and potential cost reductions comparable to solar and wind, but operates at low thermal efficiencies, from 4.7% to 6.7% [2], [3]. This low efficiency necessitates building large plants that pump large volumes of deep water for processing with even larger volumes of surface water, resulting in high capital costs. These factors have limited its commercial adoption, with initial 10-100 MW projects estimated to cost between USD 500M and 800M [4], [5]. In addition to power generation, OTEC infrastructure can support additional end uses such as seawater air conditioning (SWAC) and other cooling uses, which is particularly beneficial for tropical islands that rely heavily on imported diesel fuel and face high energy costs [6], [7]. Volcanic islands, characterized by steep bathymetry that brings cold deep seawater close to shore, are ideal candidates for integrating OTEC with other services such as seawater desalination, aquaculture, critical mineral extraction, and efuels production. Internationally, many volcanic islands and coastal areas in tropical regions may be candidates for OTEC development. In addition, U.S. islands in the Pacific and Caribbean could benefit from OTEC and other end uses including SWAC.

The most prominent environmental effect of OTEC development is the potential disruption of biota and local oceanography from the return of large volumes of cold deep ocean water to near-surface waters [8]. This paper outlines design considerations and trade-offs among the various end uses for OTEC, in addition to power production, taking into account the potential environmental effects of multiple uses of an OTEC platform.

II. Methods

Preliminary design considerations for OTEC that will accommodate multiple end uses have been developed, for both onshore (1–5 MW) and offshore (10–100 MW) plants. In addition to OTEC power production, other uses have been considered including SWAC, support for aquaculture operations, seawater desalination, critical mineral extraction, and e-fuel (ammonia and hydrogen) production.

A use case for an onshore OTEC plant near Kona, Hawaii, at the Natural Energy Laboratory of Hawaii Administration (NELHA) site, was developed. The thermal resources for OTEC power were modeled using

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Semi-implicit Cross-scale Hydroscience Integrated System (SCHISM; [9]); in addition, a new open-source cold water return model was developed to address the most important potential environmental effect, likely to drive permitting and licensing decisions. The potential for use of SWAC for building and industrial cooling, as well as the use of cold deep ocean water to support aquaculture facilities were examined at the site. Future uses of an offshore OTEC plant were also considered, including critical mineral extraction and generation of efuels. A trade-off analysis was conducted to determine compatible end uses for onshore and offshore platforms, identifying key missing information, and offering recommendations for further multi-use OTEC platform development.

A site visit was made to the site of the existing OTEC plant at NELHA, to discuss the operation of the plant with Makai Engineering and the NELHA administrators, and to discuss the value of the OTEC deep ocean water with select tenants at the NELHA site. In addition, a semi-structured survey was sent to all the tenants at the NELHA site, asking their opinions of the value of the deep ocean water, and whether additional OTEC development at the site would be of beneficial to their businesses.

III. Results

The design considerations for OTEC power production and other end uses were first determined, taking into account the environmental effect, community acceptance, and the compatibility of additional uses with both onshore and offshore plants, as well as with each other. Limitations to development were also carefully examined.

A. *OTEC design considerations*

OTEC plants can be shore-based or constructed on floating barges or vessels, anchored to the seabed or possibly free floating (Fig. 1). Onshore systems for OTEC power and other end uses rely on the piping of cold deep water and warm near-surface water to shore through pipe laid along the seafloor to the appropriate depth. The water piped to shore is run through the OTEC plant, and other processes as appropriate, then returned to the ocean through a single mixed discharge or separate cold and warm water discharge pipes. As commercial OTEC systems are developed, they are more likely to move offshore, with larger power capacities (~10-100 MW) on floating platforms. Deep cold and surface warm process water, as well as discharge water, will be pumped by pipes originating on the platform. Power from floating OTEC platforms will be dispatched to land through an export power cable.

Additional end uses for OTEC water and processes will require design changes that might entail: the amount or distribution of the cold deep water taken up; resizing or relocation of water pumps and piping; additional infrastructure added to the OTEC plant; and choices between OTEC systems to include closed-system, open-system, or hybrid systems.

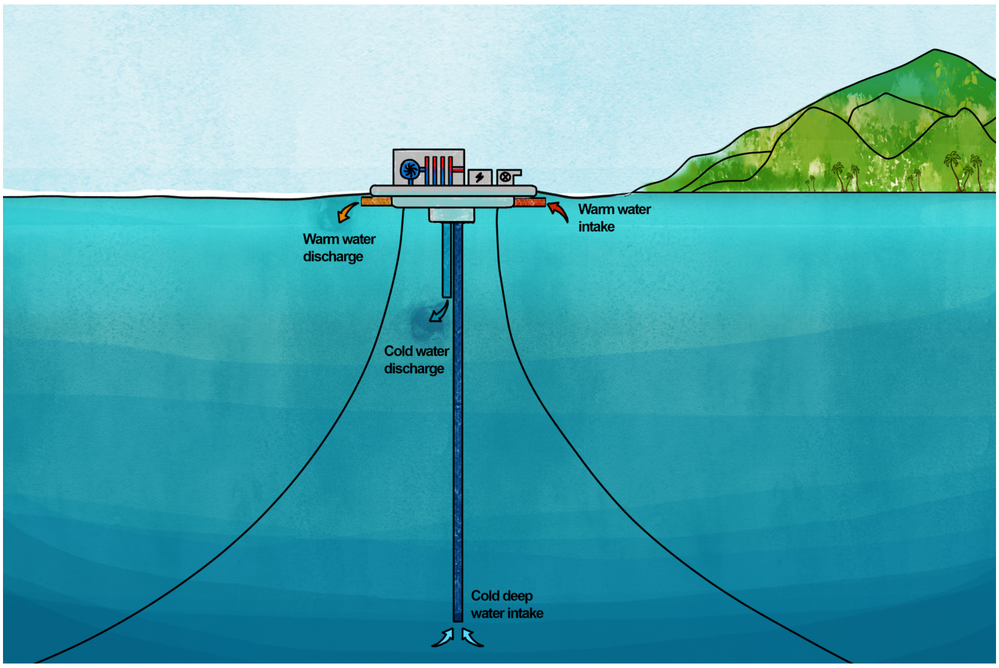


Fig. 1. Ocean thermal energy conversion (OTEC) process of cold deep water and warm surface water intake, and discharge following power production. The process is the same whether placed on shore or floating at sea (Stephanie King, PNNL).

B. *Seawater air conditioning (SWAC), industrial cooling, district cooling*

Deep cold ocean water can also be used for cooling through SWAC, used in conjunction with OTEC, or stand alone. SWAC can be used for residential, industrial, or district cooling. Typically, cold seawater is used in a heat exchange process at a central location to cool freshwater circulated through buildings to cool and reduce humidity [10].

A shore-based SWAC plant is more feasible than an offshore one due to cost and complexity. Integrating SWAC with OTEC requires rerouting cold water before or after power generation, each presenting challenges such as reduced power output, extra piping, or insufficient cooling for humidity control [11]

C. *Use of deep ocean water for aquaculture enhancement*

Deep ocean water, rich in nutrients, has the potential to enhance phytoplankton and seaweed growth when brought to the surface; but the deep water has a high carbon load which should not be exposed to the atmosphere [12]).

However, deep cold ocean water is valuable for cooling aquaculture systems, enabling the onshore cultivation of microalgae, macroalgae, and larval shellfish in hot tropical regions.

D. *Seawater desalination*

Open-cycle OTEC plants are less efficient than closed-cycle plants but can support desalination of seawater using the condensation output. Shore-based OTEC plants are most viable for desalination, using the freshwater output on land. Future floating OTEC platforms with crews could use open-cycle desalination for onboard water supply. Adding a desalinization plant to OTEC will add capital and maintenance costs, as well as infrastructure to store and distribute fresh water.

E. *Critical mineral extraction and production of efuels*

All metals and minerals found on land also exist in seawater but extracting them is energy-intensive due to their dilute concentrations. As OTEC systems move large seawater volumes, critical mineral extraction could enable cost-effective mineral recovery using specialized absorbents [13].

To extract minerals on an OTEC platform, additional infrastructure is needed, including exposure tanks for absorbents, pipes, pumps, and systems for washing and reusing the absorbent material.

Offshore OTEC plants could use their generated power to produce green hydrogen through seawater electrolysis, which can be stored and transported by specialized vessels. Adding a nitrogen plant would enable ammonia production as a hydrogen carrier, leveraging existing ammonia transport infrastructure.

Producing efuels at sea will increase capital and operating costs due to the cost of operating an efuel plant, and the logistics of storing, transporting, and transferring ammonia or hydrogen on offshore platforms.

F. *Trade-offs among OTEC uses*

A trade-offs analysis for power production and additional end uses examined the effect that additional use of the OTEC process water or infrastructure may have on the overall performance of the system. These effects may render a particular end use non-viable or require mitigation through design or operational changes to the OTEC system, such as changing the order in which the seawater is used (before or after the heat exchange process), resizing of intake or discharge pipes, or resizing the project's footprint. The viability and potential combinations of end uses are illustrated in Table I. This table presents the most feasible and less likely potential end uses for an OTEC plant, developed as a consensus among the project team members.

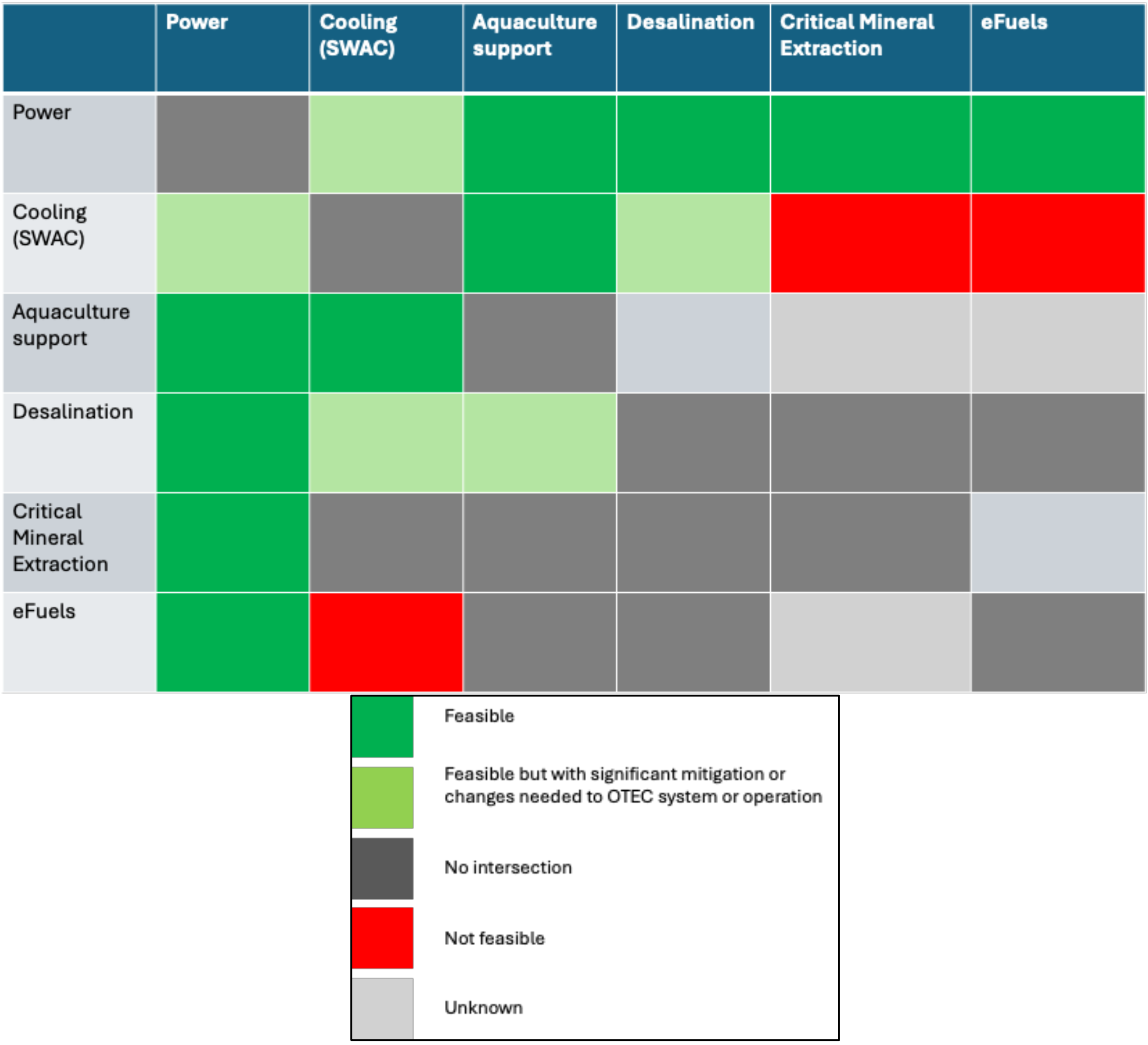
The requirements, challenges, and opportunities for each end use in conjunction with OTEC power are as follows:

1. SWAC/cooling
   - Additional piping before or after OTEC process.
   - Decrease in power production if split before OTEC heat exchange.
   - May be used before or after OTEC process, depending on the need to dehumidify.
2. Aquaculture enhancement
   - Potential for nutrient input from deep ocean water for growth of algae. Cooling water for growth of algae and larvae in land-based tropical areas.
   - Improper use of deep water would release unacceptable levels of carbon as carbon dioxide into the atmosphere. Additional piping needed for cooling water.
   - Potential to expand aquaculture in tropical islands.
3. Desalinization
   - Open cycle OTEC only. Addition of desalinization plant on platform.
   - Costs for development and operation of desalination system. Relatively high maintenance costs for osmotic exchange membranes.
   - Most suitable for shore-based OTEC plants.
4. Critical mineral extraction
   - Use of OTEC warm water before or after processing. Contact tank for extraction.
   - Need for contact tank, additional piping, controls for fill and discharge of tank.
   - Potential new source of critical minerals to alleviate mining on land.
   - Most suited for offshore floating OTEC plant.

5. Efuels
    - Addition of electrolysis plant on OTEC platform.
    - Significant expansion and cost of infrastructure on OTEC platform including the need for ship docking or lightering facilities.
    - Potential new energy storage and transport fuel. Most suited for offshore floating OTEC plant.

TABLE I

FEASIBILITY OF ADDITIONAL USES OF OCEAN THERMAL ENERGY CONVERSION (OTEC) WATER, IN ADDITION TO POWER PRODUCTION.



G. *Use case for multiple uses of OTEC off Hawaii*

Using the SCHISM model, adequate thermal resources were found to occur off the west coast of the Big Island of Hawaii, near the NELHA site [14].

The primary environmental concern for an OTEC plant is the return of large volumes of cold deep ocean water to surface waters, which may cause temperature shock to marine life and destabilize the local water column. Additional risks include entrainment of deep-sea organisms, release of toxic chemicals, and disturbance of sensitive habitats like coral reefs [15]. However, past experience suggests that entrainment is rare, hazardous waste can be managed, and careful siting can mitigate habitat disruption.

A discharge water element was developed in conjunction with the SCHISM resource characterization model to determine the optimal depth for returning process water, which is typically 6-10°C warmer for cold water and 3-5°C cooler for warm water after heat exchange. To minimize environmental risks, cold water return should occur at an intermediate depth (90-115 m in Kona) where density differences ensure it sinks and disperses without disrupting the water column. This study used three hypothetical 100 MW OTEC plants modeled discharge at 100 m depth, showing minimal temperature changes (≤0.1°C) and no significant instability in the water column (Fig. 2).

The study engaged with tenants and management at NELHA but was not able to reach the broader Big Island stakeholder community. Through site visits and surveys, insights were gathered on the current value of OTEC and interest in expanding a multi-use plant. Many NELHA tenant companies rely on deep ocean water for aquaculture, industrial cooling, and air conditioning via SWAC, with some stating their businesses would not be viable without it due to high electricity costs in Hawaii.

Survey respondents, mostly in aquaculture and marine-related industries, expressed mixed interest in using renewable energy from a larger OTEC plant. Some supported expanding the shore-based plant or developing an offshore floating OTEC facility, while others raised concerns about shoreline encroachment on ancestral grounds. Additional potential uses of OTEC power and deep water noted by the tenants included large-scale direct ocean carbon capture.

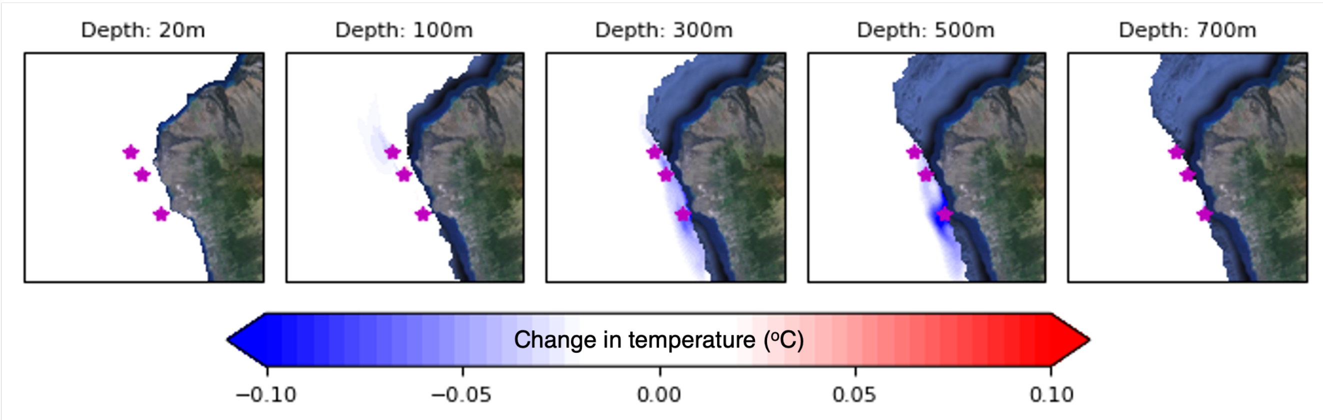


Fig. 2. The 10-year mean temperature changes by the mixed water discharge from the three ocean thermal energy conversion (OTEC) discharges (magenta stars). The stars indicate the locations of the three OTEC plants. Each frame represents a 2D map of the change in the temperature at different depths.

IV. Discussion

This study envisioned scenarios that would allow for OTEC end uses in addition to power production. The most feasible near-term applications are power generation combined with cooling or desalination, as demonstrated in small experimental plants worldwide [1]. Analysis of multi-use OTEC platforms considered available thermal resources, design trade-offs, environmental effects, and community values.

A resource characterization model confirmed sufficient thermal differential off Kona, Hawaii, for OTEC, supporting the viability of similar projects in tropical regions. However, using deep ocean water's high nutrient content for algae growth was deemed impractical due to the potential of releasing increased carbon loads into the atmosphere. The main environmental concern is returning deep cold water at the correct depth to avoid disrupting the ocean's stability. The new discharge model [14] developed as part of this study suggests that releasing process water at 100 m depth off Kona would not significantly alter the water column.

Trade-offs were analyzed between offshore uses (e.g., critical mineral extraction, e-fuels production) and shore-based uses (e.g., cooling, desalination). SWAC and aquaculture cooling are currently compatible with OTEC. Desalination is viable but will yield lower power output due to the lower efficiencies of open-cycle OTEC plants.

Further studies are needed, particularly on the economics of integrating multiple OTEC uses, as there is limited empirical data from commercial-scale operations.

Further research on multi-use OTEC platforms requires a pre-commercial or commercial plant to provide essential data for economic and technical assessments. Key areas for investigation include the economic feasibility of OTEC and additional uses, the impact of diverting deep cold water for cooling before heat exchange, and the integration of SWAC and industrial cooling. The viability of combining OTEC with desalination, critical mineral extraction, and efuels production must also be further examined.

Field validation of modeled water discharge depths and pipe sizing is necessary, alongside discussions with regulators to streamline permitting. Expanded community outreach in Hawaii will help assess public support, and further analysis is needed to determine OTEC's potential across other tropical islands.

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