Feasibility of Ocean Thermal Energy Conversion (OTEC) Development for U.S. Islands

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I. Introduction

The United States has not engaged heavily in ocean thermal energy conversion (OTEC) research and development over the past decade. However, with increasing concerns over climate change and a favourable policy landscape, there is renewed interest in OTEC, particularly for remote coastal areas and tropical islands. While most of the United States lies in the temperate zone, the State of Hawaii, Caribbean islands including Puerto Rico and the U.S. Virgin Islands, and Pacific islands including Guam, are situated in waters that could be favourable for harvest of ocean thermal energy.

II. Methods

This research examined the feasibility of developing small-scale OTEC (3-10 MW) in U.S. waters through case studies in four locations (i.e., Hawaii, Puerto Rico, St. Croix, and Guam). In addition to talking to local leaders and experts in OTEC development and processes, we examined the likely environmental effects that will drive permitting (consenting) and licensing processes in the U.S. and discussed the need for community involvement to ensure social license and stewardship of OTEC projects developed in the four locations.

The U.S. islands of interest for OTEC include tropical islands in the Caribbean Sea, notably Puerto Rico and St. Croix in the U.S. Virgin Islands, as well as the Island of Hawaii (Big Island) in the State of Hawaii in the Pacific and the island of Guam, part of the Marianas Island chain in the eastern Pacific (Figure 1). Each island was examined for the potential for OTEC, the needs for power and other services that OTEC could provide (e.g., seawater air conditioning [SWAC]), potential environmental effects, potential hazards to an OTEC plant, and preliminary interest and concerns from communities on each island.

The major environmental effects of concern for OTEC are the return of the large amounts of cold deep seawater brought up for heat exchange with warmer surface waters.

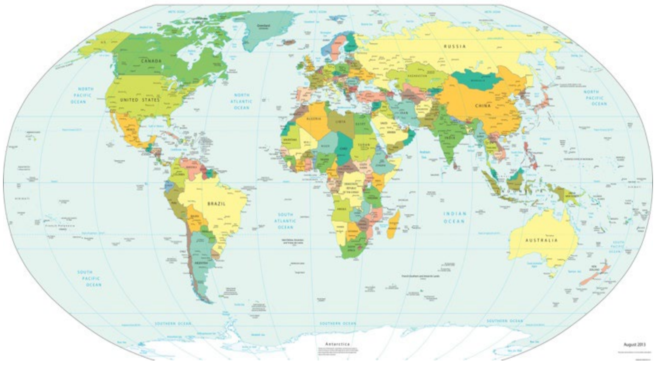

Fig. 1. Locations for evaluating feasibility of OTEC development in islands of the U.S. – Puerto Rico and St. Croix in the Caribbean, and Hawaii and Guam in the Pacific Ocean.

Return of the cold water near the surface could thermally shock organisms and potentially affect mixing of the water column, further disrupting marine life. The cold water must be dispersed at a depth where it will mix with ambient waters to minimize the temperature differential.

Additional concerns might include the use of hazardous chemicals on offshore platforms and ammonia as the working heat exchange fluid in the OTEC systems. Both these hazards can be addressed through hazardous waste management plans, as for other industrial developments.

A use case that describes the likely needs, location, and potential for an initial OTEC installation in each of the four islands was created to explore the feasibility of development.

III. Results

Each of the four islands examined is volcanic with deep ocean water close to shore, making them strong candidates for OTEC development. The location, specifics of the island, needs of the community, and potential hazards differed for each of the islands (Figure 2).

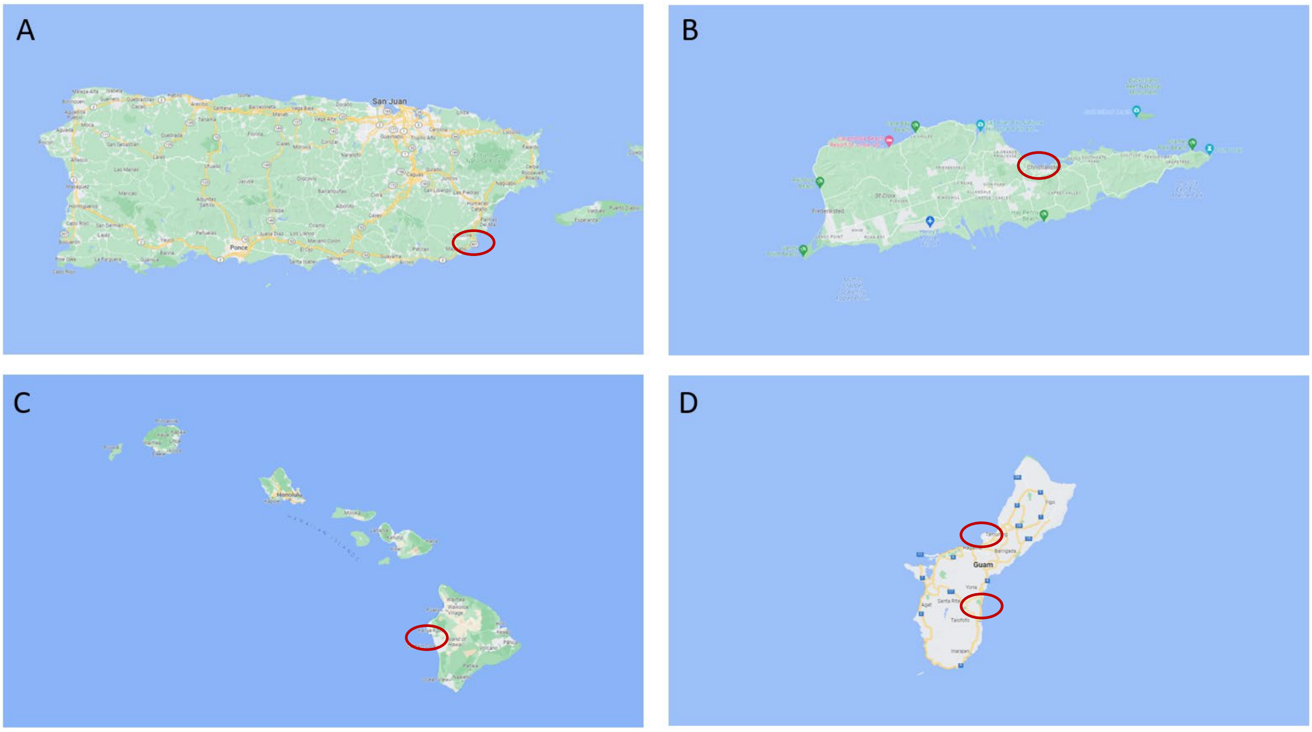

Fig. 2. Locations for evaluating feasibility of OTEC development in islands of the US: (A) Puerto Rico and (B) St. Croix in the Caribbean, and (C) Hawaii and (D) Guam in the Pacific Ocean. The approximate locations of the use case locations for OTEC development are shown by the red ovals.

A. Environmental Effects

Potential environmental effects may affect the ability to permit and license the deployment and operation of an OTEC plant. There are three potentially important environmental effects of OTEC development, as well as some other speculative effects [1,2]. Each effect will need to be examined in more depth; however, none appear to be overly challenging and can most likely be avoided or mitigated. The three effects that need particular scrutiny are: cold water return; entrainment of marine life in cold water pipes; and chemical discharges (detailed below). Other potential effects include reefing, effects on habitats, migratory routes, entanglement, and pathways for invasive species.

The cold deep ocean water brought to the surface for heat exchange in the OTEC process must be returned to the ocean. However, this water could be up to 20°C colder than ambient surface water, creating a thermal shock to organisms if discharged at the surface or in subsurface waters, and potentially destabilizing the stratification of ocean water that maintains warm water at the surface [3]. To mitigate these effects, the cold water must be discharged at an intermediate depth (which can be determined by numerical modelling) in such a manner that it rapidly sinks to the appropriate density of the surrounding seawater and/or is diluted to match ambient water temperatures. Designing discharges is a well-established field of environmental engineering, following that of wastewater disposal.

The cold water pipe that pumps ocean water from 800-1000 m or more in most OTEC operations has the potential to entrain fish or other marine organisms, bringing them up to the surface where they are unlikely to survive the change in pressure [4,5]. The presence of marine life in the deep sea is sparse, as there is little food at these depths to sustain a complex food web. Evidence from the operational OTEC plant in Okinawa province in Japan over 8 years indicates that this event is very rare—less than one fish is seen a year [6]. Similarly, evidence from the Natural Energy Laboratory of Hawaii Authority (NELHA) plant in Hawaii indicates that this event is so rare it is never recorded. While regrettable that deep marine life might be lost, this event is certain to remain below detection in targeted monitoring programs. Special consideration would be given to threatened and endangered species that might encounter an OTEC platform or pipes.

Depending on the system type, OTEC platforms will likely have some harmful chemicals on board, notably petroleum products for lubricating turbines (although biobased oils may be substituted). Closed OTEC systems use ammonia or other chemicals as the heat exchange medium. Leakage of these chemicals in gaseous form could be harmful to human and marine life. As part of any permitting process, a hazards analysis and a hazardous waste mitigation plan will be required. This plan will also address the potential loss of portions of the platform, moorings, pipes, and other hardware that might occur during a storm.

Other environmental effects that may be raised by stakeholders or regulators are likely to be manageable and can be informed by other developments and offshore industries. These potential effects include: effects on habitats, including crossing sensitive coral reefs with piping to shore; reefing of fish and other organisms; displacement of migratory species due to large numbers of offshore OTEC platforms; entanglement of large marine animals in mooring lines of floating platforms; and a pathway for introducing invasive species. Of these potential effects, only the crossing of coral reefs and other sensitive nearshore habitats will require careful planning and consideration as the OTEC industry begins to expand. The other potential effects are unlikely to arise until larger numbers of OTEC plants are deployed.

B. *Potential Social Concerns and Benefits*

There is little information available in the literature documenting or addressing societal concerns of OTEC development for onshore or offshore plants, partially due to the lack of deployments to date. Additionally, the experts interviewed had little insight into potential concerns. From the information available, it appears that, for island nations and areas where OTEC has been proposed, there is strong community support for the power and potential for additional benefits to improve the lives and livelihoods of the people (e.g., seawater air conditioning [SWAC], seawater desalination, access to deep nutrient-rich water for aquaculture). To date, discussions with local communities by the experts have involved questions around siting of the cold and warm water piping (for onshore plants) crossing the intertidal and shallow subtidal, as these areas are rich habitats and important economically to support fishing and tourism. Careful siting of these infrastructure components in collaboration with local communities will be needed. Clearly health and safety issues will need to be addressed as well, including the potential for release of ammonia or other toxic gasses near communities for closed cycle systems, and potential leaks of other hazardous materials.

Although there are few studies of benefits or effects of OTEC on communities, anecdotally communities that have obtained OTEC plants with desalination systems have reported a significant increase in public health and individual well-being [7].

C. *Four Use Cases for Islands*

For each of the four use cases, a description of an OTEC plant, the ancillary services and products that might be added to power production, potential hazards to development and operation of an OTEC plant, potential environmental effects, and the likely community benefits and concerns, are summarized in Table 1.

IV. DISCUSSION & CONCLUSION

This brief initial assessment of the feasibility of developing OTEC in islands of the U.S. did not uncover any strong barriers to development and provides promising pathways for further consideration. All four areas under consideration (Puerto Rico and St. Croix in the Caribbean Sea, and Hawaii and Guam in the Pacific Ocean) have all the necessary attributes for OTEC deployment and operation, including strong needs for power and ancillary services and products that OTEC may be able to supply. The overall environmental effects of OTEC, both shore-based and floating offshore, will need site-specific consideration in order to pass regulatory requirements, but no strong concerns or barriers were identified that could not be mitigated to protect marine animals, habitats, and ecosystem processes. A new open-source numerical model is being developed at Pacific Northwest National Laboratory to determine effects of the cold water return plume and to assist in planning for the depth and means of dispersal to minimize environmental harm.

While no great social or economic concerns were voiced by the experts who were consulted, it is clear that OTEC is not well known among the general public, elected officials and policy makers, or natural resource managers. Therefore, a substantial outreach and education effort is needed to accompany plans to develop OTEC in the islands of the U.S. and elsewhere around the world. With this in mind, we have developed the elements of an education program that would bring tailored messages to a range of stakeholder groups including local

TABLE I
USE CASES FOR OTEC DEVELOPMENT IN U.S. ISLANDS.

Use Case	Description	Ancillary Services	Potential Hazards	Potential Environmental Effects	Community Benefits and Concerns
Puerto Rico	10 MW closed cycle shore-based	Power for multiple uses	Hurricanes Tectonic activity	Cold water return Pipes through coral reefs	Need for island grid stability, disaster relief, aquaculture
St. Croix	3 MW open cycle shore-based	Desalinated water	Hurricanes Tectonic activity	Cold water return Pipes through coral reefs	Dry island with need for freshwater, disaster recovery
Hawaii	10 MW closed-cycle floating offshore plant	Seawater air conditioning (SWAC) Deep water for aquaculture	Tectonic activity	Cold water return	Additional power, SWAC, economic development
Guam	5-> 10 MW closed cycle shore-based	Aquaculture facility power and deep water	Typhoons	Cold water return Pipes through coral reefs	Strong community support for aquaculture development and power

communities, policy makers and financial markets, government officials, and broad public audiences. Each audience will require different vehicles for delivery of these messages, such as educational videos, handouts, and slides (e.g., Figure 3).

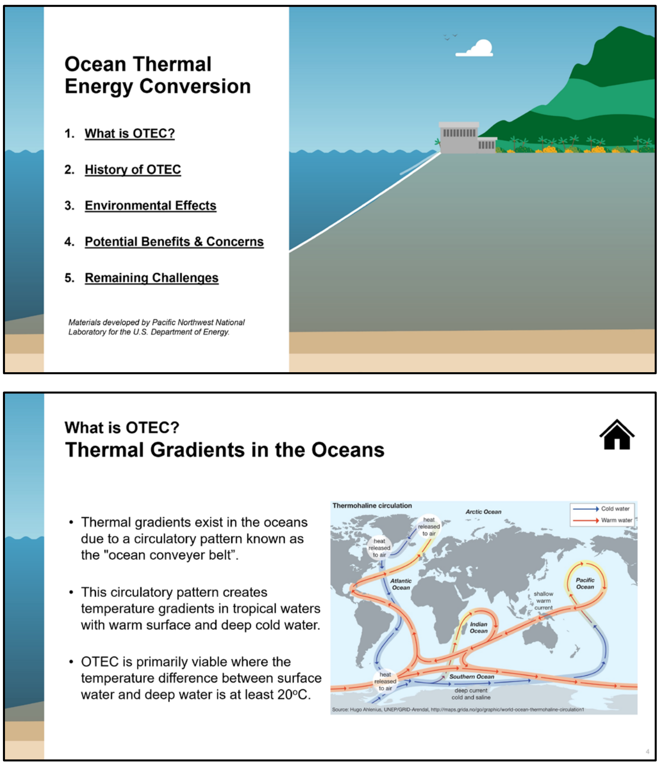

Fig. 3. Slides from draft OTEC education and outreach materials developed by Pacific Northwest National Laboratory.

In pursuing this initial feasibility study, we concur with all the OTEC experts we surveyed: the development of OTEC is technically feasible at this time, with the majority of technical details well understood and achievable. The technologies are well known, including pipes, pumps, heat exchangers, and air turbines. Additional technical aspects of OTEC are currently focused on optimizing and improving performance, survivability, and longevity of components. The environmental effects appear, especially for small-scale OTEC developments, to be entirely manageable. For island communities in the U.S. and internationally, the need for fossil fuel-free power, as well as ancillary services and products like freshwater and potential boosts in economic development from aquaculture and other industries, indicates little opposition and likely strong support and stewardship for OTEC development. It appears that the high capital costs of OTEC development and political will in the U.S. and other nations are the greatest barriers to OTEC currently.

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