




Ocean Thermal Energy Conversion:
Assessing Potential Physical, Chemical and Biological Impacts and Risks

June 22 – 24, 2010

National Oceanic and Atmospheric Administration
National Ocean Service
Office of Ocean and Coastal Resource Management

Coastal Response Research Center
University of New Hampshire

University *of* New Hampshire

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FOREWORD

The Coastal Response Research Center, a partnership between the National Oceanic and Atmospheric Administration (NOAA) Office of Response and Restoration (ORR) and the Environmental Research Group at the University of New Hampshire (UNH), develops new approaches to marine environmental response and restoration through research and synthesis of information. In 2010, the center partnered with NOAA's Office of Ocean and Coastal Resource Management (OCRM) to host a workshop to assess the potential physical, chemical and biological impacts of Ocean Thermal Energy Conversion (OTEC) development in Hawaii. As the primary licensing agency for OTEC projects, NOAA OCRM sponsored this workshop, developed the agenda and workshop goals, and was integral in the synthesis of information obtained from the workshop.

The workshop, held June 22-24, 2010 in Honolulu, Hawaii, focused on how to assess the potential physical, chemical and biological impacts and risks associated with development of OTEC in the waters surrounding Hawaii. The report is designed to serve as a resource for NOAA OCRM and governmental decision makers, as well as the OTEC community.

I hope you find the report interesting. If you have any comments, please contact me. I look forward to hearing from you.

Nancy E. Kinner, Ph.D.
UNH Co-Director, Coastal Response Research Center
Professor of Civil/Environmental Engineering

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Appendices are available on our website at http://www.crrc.unh.edu

EXECUTIVE SUMMARY

Ocean Thermal Energy Conversion (OTEC), a process by which energy from natural temperature differentials in the ocean are converted to mechanical and electrical energy, is a renewable energy source that has experienced a resurgence in interest in recent years. As the lead licensing agency for OTEC facilities under the *Ocean Thermal Energy Conversion Act* (OTECA), NOAA's Office of Ocean and Coastal Resource Management (OCRM) is responsible for evaluating the potential impacts and risks that the construction, installation, and operation of an OTEC facility poses to the environment. To understand these risks, a thorough understanding of the magnitude and extent of likely physical, chemical and biological impacts is required. In order to aid NOAA OCRM in the permitting process, a workshop was held to identify: 1) the baseline data and monitoring requirements needed to assess the potential physical, chemical and biological impacts related to the construction, installation and operation of a OTEC facility; 2) technology and methods to measure impacts; 3) research needed to adequately determine the degree of potential impacts; and 4) approaches to mitigate and/or avoid the impacts within the operational and design parameters of an OTEC system. The findings and recommendations of this report are based on assumed potential environmental impacts and should not be exclusively relied upon.

While it is certain that physical, chemical and biological impacts will occur during the installation and operation of an OTEC facility, the magnitude and extent of these impacts are not known. This workshop did not reach any conclusions in regards to cumulative or secondary impacts which, at this point in time, are largely undeterminable without long-term monitoring and additional research. It was recognized at the workshop that potential cumulative and secondary impacts may be more significant from an ecosystem perspective than immediate localized impacts from OTEC operations given expected operational lifetime of 25 - 40 years.

In order to better understand the risks that these impacts represent, a minimum temporal baseline is required prior to installation that includes monitoring for presence and abundance of large and small biota, as well as the physical and chemical characteristics of seawater in the region. For certain impacts, a longer baseline may be desired in order to capture multi-year variability. This will provide scientists and engineers with a better understanding of potential impacts and a basis for comparison to changes in the marine environment and ecosystem. Monitoring for changes to this baseline should occur during the installation and operation phase, and will provide information on how the facility is impacting the local environment. Many physical, chemical, and biological criteria should be monitored, including, but not limited to: temperature; salinity; dissolved oxygen; pH; trace metals; and abundance, diversity, mortality and behavioral changes in plankton, fish, marine mammals, turtles, and other biota.

Tables 1, 2, and 3 show specific information needed for baseline assessment, monitoring strategies, and modeling methods. The information contained in these tables, while useful, should not be relied upon exclusively in reaching conclusions regarding the development of baseline data, monitoring plans, sampling frequency and analytical methods. The extent and depth of discussion of the information contained in the tables varied among the break-out groups which developed them, and the information presented does not necessarily represent the consensus of the break-out groups.

Table 1: Baseline Assessment

Category	Impact	Baseline Data Needed	Minimum duration for Baseline Data	Justification of duration
Fisheries and Corals	**Entrainment**	Larval community surveys to cover all management unit species (MUS); biota density at intake and discharge depth; specific catch and effort information for site (i.e., grids, interviews with fishermen)	Varies with spawning season. 4-5 locations for more data over 1 year	Inter-year variation can be significant and would require long sampling duration to capture; multiple sampling locations required
	Impingement			
	Physical Damage to Shallow Corals	Community structure of corals, including size and frequency of species. Spatial and temporal survey of species within region.	1 year and after hurricane	
	Physical Damage to Deepwater Corals	Survey of sub-bottom profiling; bathy structure and composition data; optical imagery	1 survey/map is sufficient	
Oceanography	**Oxygen, Temperature, Salinity, and Nutrients**	Climatological data with spatial and temporal coverage of the region where the model anticipates the plume will be located. Sampling over a range of frequencies to capture variability. Intensive sampling at one location	1 – 3 years	Duration will depend upon variability in data; if little variation, shorter duration required
	Trace elements and EPA regulated substances	Need background concentrations of baseline EPA regulated trace elements/regulated substances, OTEC facility construction materials (e.g. Ti, Al), antifouling agents and plasticizers	Quarterly for 1 year	Unlikely to have significant temporal or spatial variability
Marine Mammals and Turtles	**Entrainment/Impingement**	Distribution, abundance and diving depth	1 year assuming normal conditions	
	Migratory pattern shift	Distribution, abundance and movement patterns, satellite tracking data	1 year assuming normal conditions and control sites are adequate	
	Entanglement	Some data from the Hawaii marine debris program, however not the same as entanglement with mooring or transmission lines		
	Behavioral changes	Species diving depths, basic distribution and abundance, "habitat use maps"	1 year adequate as long as sample size is sufficient for statistical analyses	
	Attractant/Repellant	Distribution, abundance and diving depth		
Plankton	**Bacteria**	Spatial and temporal abundance and distribution; fate after entrainment	2 years at multiple locations. If data is variable, increase duration	Need to ensure temporal, seasonal, and spatial variations are captured
	Phytoplankton and Zooplankton		Several samplings in one location	
	Eggs/Larvae			
	Micronekton			

Table 2: Monitoring Strategies

Category	Impact	What should be monitored?	How should this be monitored?	How often?
Fisheries and Corals	**Entrainment**	Water at intakes, fishery catch and effort, status of fishery stocks, control sites, density and type of all MUS, eggs/larvae density and type; effect of light on biota	Net collection and plankton tows; intake flow rate; multiple control sites, fishery catch data and interviews with fishermen; stock assessment; experimental fishing	Increase according to expectation of density of eggs and larvae for different periods of the year; diel 24 hr assessments; life history: monthly; interview fishermen: as needed
	Impingement	Biota on screens, fishery catch and effort, status of fishery stocks, control sites, all MUS. eggs/larvae density and type	Bongo nets; plankton tows; intake flow rate; use of multiple control sites, fishery catch data and interviews with fishermen; stock assessment	
	Physical Damage to Shallow Corals	Community structure and baseline parameters of corals, including size and frequency of species	Diver surveys to evaluate community abundance and composition	Once during baseline and once after construction is complete
	Physical Damage to Deepwater Corals		Submersible, ROV or towed camera surveys along route	
Oceanography	**Oxygen, Temperature, Salinity and Nutrients**	Spatial and temporal monitoring of dissolved oxygen, temperature, salinity and nutrients within the plume and in the vicinity	Appropriate use of combinations of CTD casts; gliders; fixed moorings; monitoring needed at the discharge	Sampling over a range of frequencies to capture variability.
	Trace Elements and EPA regulated substances	Spatial and temporal monitoring of trace metals, EPA regulated substances, and OTEC facility fluids and components (e.g. Ti and Al).	Measurement of concentrations in discharge plume and surrounding area; in accordance with EPA methods	Once a month at discharge; quarterly for receiving waters
Marine Mammals and Turtles	**Entrainment/Impingement**	Distribution, abundance, CWP flow	Acoustic sensors, flow monitoring	Continuous, automatic
	Migratory pattern shift	Migratory pathways (abundance and distribution)	Autonomous acoustic recorder, aerial/visual surveys	Continuous, automatic
	Entanglement	Marine debris in region	Visual survey	Daily at surface, quarterly at depth
	Behavioral changes (i.e., Attractant/Repellant)	Presence, diversity and behavior	acoustics and visual	Acoustics: continuous; visual: 1/season for 4 years
Plankton	**Bacteria**	Fate after entrainment (i.e., live/deceased abundance), community composition, population density	Acoustics to measure density; advanced molecular techniques for composition; three sampling stations surrounding OTEC facility plus control	Dependent on baseline information
	Phytoplankton and Zooplankton			
	Eggs/Larvae			
	Micronekton			

Table 3: Modeling Methods

Category	Impact	What existing models can be used?	Improvements to existing models	New models
Fisheries and Corals	**Entrainment**	Empirical Transport Model (ETM), Adult Equivalent Loss Model (AELM), Fecundity Hindecast (FH)	Addition of life history for species of concern	Include current patterns and intake draw field; comprehensive ecosystem-based model of the area near site
	Impingement	Estimated catch blocks, Fisheries models		
	Physical Damage to Shallow Corals	Use existing cable laying software to optimize route		
Oceanography	**Oxygen, nutrients, temperature, salinity**	EFDC model; HIROMS model input; Ocean observing models; Discharge plume model	Further developed and peer reviewed. Modify to be an assimilative model; incorporate bio-geochemical components; validate by field experiments, including near field current measurements	
	Trace elements	Not necessary/applicable in this situation.	Not applicable/necessary	Not applicable/necessary
Marine Mammals and Turtles	**Behavioral changes**	Acoustic propagation/animal movement models (acoustical integration model (AIM); marine mammal movement and behavior model (3MB); NMFS TurtleWatch	Integrate animal behavior; modification for different species; validation	
Plankton	**Bacteria**	Chlorophyll models from 20yrs hindcast; data set diurnal and seasonality for 4 years off Kahe (1, 5, 15 yrs offshore); use HiROMand existing current models	Fate of organic carbon	
	Micronekton	Models available in University of Hawaii reports		

I. INTRODUCTION

As one of the most remote island chains in the world with few sources of local energy, the islands of Hawaii are home to some of the most expensive fossil fuel based energy in the world. Gasoline is, on average, 20% more expensive than in the continental United States, and electricity is typically twice as expensive than most of the nation. With few local energy sources, Hawaii is dependent on external sources for the bulk of its energy needs. The volatile economics and shrinking supply of petroleum have led to increased energy costs, and intensified the search for local, renewable energy alternatives. Although typically more expensive, renewable energy sources have many advantages, including increased national energy security, decreased carbon emissions, and compliance with renewable energy mandates and air quality regulations. Further, Hawaii is home to several strategic military bases with high energy demands that would greatly benefit from a more secure, reliable source of energy independent of the volatile fossil-fuel based economy.

The oceans are natural collectors of solar energy and absorb a tremendous amount of heat from solar radiation daily. One method of extracting this energy is ocean thermal energy conversion (OTEC), which converts thermal energy into kinetic energy via turbines. The turbines can then be used to drive generators, producing electricity. Expectations for OTEC were high following the passage of the *Ocean Thermal Energy Conversion Act of 1980* (OTECA), and was forecast to generate > 10,000 megawatts electrical (MWe) of energy by 1999. However, as oil prices declined in the late 1980's and 1990's, interest in OTEC and other renewable energy sources declined. Recently, the volatility of the petroleum industry and renewable energy mandates has led to renewed interest in OTEC. Interest is especially strong in islands such as Hawaii that seek to offset their high-cost fossil fuel based energy with locally-generated renewable energy. Because of this, Hawaii is likely to be the first location for demonstration and future commercial development of OTEC.

As the primary licensing agency for OTEC, NOAA's Office of Ocean and Coastal Resource Management (OCRM) must evaluate the risk that the construction, installation, and operation of an OTEC facility poses to the environment. In order to understand these risks, a thorough understanding of the magnitude and extent of likely physical, chemical and biological impacts is required. This can only be done through scientifically robust field monitoring and comparison to baseline conditions. Baseline conditions are those which exist in the environment prior to construction and operation of a facility. These data are obtained by conducting physical, biological and chemical monitoring.

In order to aid NOAA OCRM in the permitting process, a workshop was held to identify: 1) how to assess potential physical, chemical and biological impacts related to the installation and operation of a OTEC facility; 2) appropriate methods and technology to measure impacts of an OTEC facility; 3) research needed to adequately assess impacts; and 4) approaches to mitigate and/or avoid the impacts within the operational and design parameters of an OTEC system, and identify if potential impacts will trigger additional regulation (i.e., Endangered Species Act). With this information, NOAA OCRM can gain a better understanding of the type and quantity of baseline data that is required of permit applicants, as well as what monitoring strategies and tools can be used to adequately capture potential OTEC-related impacts.

II. OTEC BACKGROUND

A. Principles and History of OTEC

In the waters surrounding Hawaii and many other tropical and subtropical locales, intense sunlight and long days result in significant heating of the upper 35 to 100 m of the ocean, yielding comparatively warm (27 - 29°C) oceanic surface waters. Below this warm layer the temperature decreases to an average of about 4.4°C (Avery, 1994). This temperature differential represents a significant amount of potential energy, which, if harnessed, is a renewable source of energy. One potential method to extract this energy is OTEC.

There are two major OTEC facility designs: open-cycle, and closed-cycle. Open-cycle facilities were not discussed at this workshop, as it is generally agreed the first demonstration and commercial offshore facilities will be a closed-cycle design. A description and discussion of open-cycle design is included in the previous report: Technical Readiness of Ocean Thermal Energy Conversion (CRRC, 2010).

In a closed-cycle facility, both the warm and cold water pass through heat exchangers which transfer the heat to the working fluid, usually a liquid with a low boiling point (i.e., ammonia), which then vaporizes and condenses, driving a turbine and converting thermal energy into mechanical energy (Figure 1). While closed-cycle facilities are more complex than open-cycle, they are significantly more efficient and result in greater net energy production.

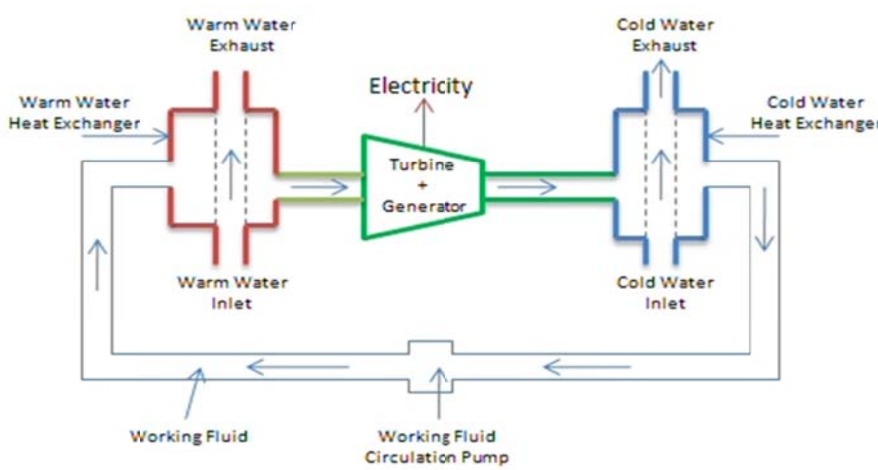

Figure 1: Principles of operation of a closed-cycle OTEC facility

One of the most important considerations when planning an OTEC facility is location. Large differences (Δ > 20°C) in temperature between the cold water intake and the warm water intake are required. As a result, the facility must be located in a region with access to warm surface waters and deep, cold water. An OTEC facility can be located on land if adjacent to a narrow shelf or a rapid decrease in depth, however, the long length of the cold water intake pipe needed to reach the required temperature differential may make this impractical in most locations. Alternatively, an offshore, floating, moored, facility with a vertical cold water intake pipe may be more practical. Floating platforms can be located above deep water as long as they can be adequately moored, and the power cable can be connected to a land-based power grid for electricity transmission.

The concept of energy extraction from naturally-occurring temperature gradients in large bodies of water dates back to the late 1800s, however, construction of the first operational OTEC facility did not occur until 1930 off the coast of Cuba. This facility produced a net 22 kilowatts electrical (kWe) for 11 days before the facility was destroyed in a storm. The next major milestone came in 1979 when a project dubbed "mini-OTEC" was launched, and marked the first successful operation of a closed-cycled OTEC facility. Mini-OTEC produced a net 15 kWe for three months before its planned shutdown, and was widely considered a success. The next major advancement in OTEC came in 1980 – 1981 with the experimental OTEC-1 facility. This facility was designed as a platform to test various OTEC-related technologies, and was not designed to generate electricity. OTEC-1 reached several important milestones, including successful deployment of a 670 m long cold water pipe, and mooring in 1,370 m of water in the waters off Hawaii. The cold water pipe from OTEC-1 was subsequently re-used for a land-based facility on the island of Hawai'i, which successfully operated from 1993 – 1998, and produced a net 103 kW, and still holds the world record for OTEC output (Vega L. A., 2002/2003).

Although the focus of OTEC is typically on production of electricity, several co-generation products are possible, including desalinization of seawater, mariculture, liquid fuels production (e.g., hydrogen and ammonia), and seawater air conditioning (i.e., SWAC), all of which would add to the economic viability of OTEC and further reduce dependence on fossil fuels.

B. Environmental

As with all energy projects, there are concerns about the potential environmental impacts of OTEC's widespread implementation. OTEC is unique in that very large flows of water are required to efficiently operate. It is estimated that 3-5 m^3/sec of warm surface water and a roughly equivalent amount of cold water from the deep ocean are required for each MWe of power generated (Myers *et al*., 1986). Therefore, for a small commercial sized facility (i.e., 40 MWe), this requires flows of 120 – 500 m^3/sec (i.e., between 2 and 11 billion gallons per day).

In July 1981, NOAA issued the Final Environmental Impact Statement (EIS) for commercial OTEC licensing. Based on information available at the time, potential impacts were divided into three categories: major effects, minor effects and potential effects from accidents (Table 4).

Table 4: OTEC Effects Categories From NOAA's Final EIS (NOAA, 1981).

Category	Stressor	Effect
Major Effects:	Platform presence	Biota attraction
	Withdrawal of surface and deep ocean waters	Organism entrainment and impingement
	Discharge of waters	Nutrient redistribution resulting in increased productivity
	Biocide release	Organism toxic response
Minor Effects:	Protective hull-coating release	Concentration of trace metals in organism tissues
	Power cycle erosion and corrosion	Effect of trace constituent release
	Installation of coldwater pipe and transmission cable	Habitat destruction and turbidity during dredging
	Low-frequency sound production	Interference with marine life
	Discharge of surfactants	Organism toxic response
	Open-cycle plant operation	Alteration of oxygen and salt concentrations in downstream waters
Potential Effects from Accidents:	Potential working fluid release from spills and leaks	Organism toxic response
	Potential oil releases	

In 1986, NOAA's National Marine Fisheries Service (NMFS) built upon the 1981 EIS and developed a report entitled "The Potential Impact of Ocean Thermal Energy Conversion (OTEC) on Fisheries" (Myers *et al.,* 1986). This report attempted to quantify the impact of an OTEC facility to marine biota, and estimated losses due to entrainment (i.e., entering the system through an intake) and impingement (i.e., held against a surface by water flow). The report concluded that:

> "The potential risk to fisheries of OTEC operations is not judged to be so great as to not proceed with the early development of OTEC. Due to the lack of a suitable precedent, there will remain some level of uncertainty regarding these initial conclusions until a pilot plant operation can be monitored for some period of time. In the meantime, further research on fisheries should be undertaken to assure an acceptable level of risk regarding the larger commercial OTEC deployments" (Myers *et al*, 1986).

While the NOAA NMFS report provides an overview of the types of impacts that could be expected, it did little to quantify the magnitude of the impact, as the estimates generated were speculative and relied on now outdated techniques and methods. An example of this is the entrainment and impingement estimates, which were generated using an average composite of biomass in the Hawaii region. This technique ignored the ability of the facility to act as a fish attractant, thus increasing the concentration of organisms subject to entrainment and impingement.

Some impacts may be minimized or mitigated through changes in operational or design parameters. However, the feasibility of design modifications due to environmental concerns needs to be weighed against the efficiency of energy production. Mitigation measures that result in substantial reductions in the efficiency of an OTEC facility could cause a project to be economically unviable, and thus cancelled.

While the easiest to identify impacts may be direct (i.e., biota directly killed through entrainment or impingement), cumulative and secondary ecosystem impacts may be much more of a concern and are much more difficult to assess. Cumulative and secondary ecosystem impacts will likely require careful long-term monitoring to distinguish effects, and may be impossible to fully evaluate due to ecosystem complexity.

C. Regulatory Considerations

The construction, installation and operation of an OTEC facility in U.S. waters will need to comply with many state and federal regulations. Under the *Ocean Thermal Energy Conversion Act* (OTECA), an OTEC facility developer must obtain necessary authorizations from NOAA and the U.S. Coast Guard (USCG) in order to construct and operate an OTEC facility. Apart from the USCG authorization, all other federal license and permit requirements are incorporated into the NOAA OTECA license. In addition to federal authorization, OTECA also provides approval authority to those states whose waters are adjacent to federal waters for which an OTEC facility has been proposed. States also have authority under the *Coastal Zone Management Act* to review OTECA licenses.

Regulatory drivers include both direct and indirect impacts to biota and water quality, as well as food-chain and ecosystem impacts. Although a regulation does not directly require protection of smaller organisms (i.e., prey species), if the absence of these organisms impacts protected species then they must protected as well. Some of the federal regulations applicable to the construction, installation and operation of an OTEC facility identified at this workshop include:

Clean Water Act (CWA): The requirements of the *Clean Water Act* apply to several aspects of an OTEC facility, including any changes to the chemical and thermal composition of the discharge plume, cold and warm water intakes, as well as installation of the mooring and transmission lines on the seabed.

Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA): The Magnuson-Stevens Act requires review of any federal authorization for an activity that may adversely affect “essential fish habitat” which includes "those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity.”

Endangered Species Act (ESA): The *Endangered Species Act* regulates any activity affecting threatened and endangered plants and animals and the habitats and ecosystems in which they are found. The law requires federal agencies, in consultation with the U.S. Fish and Wildlife Service and/or the NOAA Fisheries Service, to ensure that actions they authorize, fund, or carry out are not likely to jeopardize the continued existence of any listed species or result in the destruction or adverse modification of designated critical habitat of such species. The law prohibits any action that causes a "taking" of any listed species of endangered fish or wildlife. Several species listed in the ESA inhabit the region surrounding Hawaii where the first OTEC facility is likely to be built, including numerous species of whales and sea turtles, as well as the Hawaiian Monk Seal.

Marine Mammal Protection Act (MMPA): The *Marine Mammal Protection Act* establishes requirements to prevent marine mammal species and population stocks from declining beyond the point where they cease to be significant functioning elements of ecosystems of which they are a part. Any aspect of an OTEC facility which harms or influences the behavior of a marine mammal will be regulated under the MMPA.

Migratory Bird Treaty Act (MBTA): The *Migratory Bird Treaty Act* protects migratory birds and establishes Federal responsibilities for the protection of nearly all species of birds, their eggs and nests. The MBTA makes it illegal for people to "take" migratory birds, their eggs, feathers or nests. Take is defined in the MBTA to include by any means or in any manner, any attempt at hunting, pursuing, wounding, killing, possessing or transporting any migratory bird, nest, egg, or part thereof. A migratory bird is any species or family of birds that live, reproduce or migrate within or across international borders at some point during their annual life cycle. Migratory birds may use an OTEC facility as a resting point during migration, requiring the facility to comply with the MBTA.

National Environmental Policy Act (NEPA): The *National Environmental Policy Act* requires federal agencies to incorporate environmental values into the decision making process through consideration of the short and long term environmental impacts of any decision. OTECA requires that an environmental impact statement be developed for each license. Greatly complicating this requirement is the statutory timeframe established under OTECA for reviewing license applications of 356 days. In order to complete a defensible NEPA analysis within the OTECA timeframe, it will be imperative that license applicants conduct thorough baseline assessments prior to the submission of a license application.

Additional federal and regulations apply to OTEC facilities beyond those discussed above and the discussions at the workshop.

III. WORKSHOP PURPOSE AND SCOPE

This workshop was preceded by a workshop in 2009 (CRRC, 2010) which focused on the technical readiness of OTEC given advancements since the mid-1980s. The technical readiness workshop found that there have been significant advancements in the design and fabrication of the OTEC components and subsystems since the 1980's. The report concluded that construction, installation, and operation of a demonstration (i.e., ≤ 10 MWe) closed-cycle OTEC facility is technically feasible. Experience gained from a demonstration system would greatly aid in the understanding of the challenges associated with a larger commercial facility. Despite being technically feasible, the extent of design and operational changes required to limit environmental impacts remain unclear. Compounding that uncertainty is the lack of knowledge of the impacts and risks of OTEC. The type and magnitude of potential impacts are largely unknown and must be reasonably ascertained prior to the commitments to design, construct and authorize an OTEC facility. As a next step in establishing the regulatory feasibility OTEC, a second workshop was held to develop a better understanding of impacts and risks of construction, installation and operation of an OTEC facility, as well as to identify the baseline and monitoring requirements to assess potential impacts.

When evaluating environmental impacts, it is important to consider the scale and overall effect of the impact (i.e., an impact may be devastating to a local population, but inconsequential to the species or ecosystem). Workshop participants were not given specific guidance or limitations on scale or greater effects of the impact, however, most participants focused on localized impacts with some consideration for ecosystem-level impacts.

In order to provide the workshop participants with common design assumptions, the workshop Organizing Committee (OC) limited discussion to a floating, closed-cycle, moored OTEC facility producing electricity transmitted to shore via an undersea cable, with both demonstration (e.g., 5 MWe) and commercial scale (e.g., 100 MWe) facilities being considered. Discussions at the workshop were limited to electrical generation, and did not include any co-generation of potable water or liquid fuels. Table 5 outlines the characteristics given to participants prior to the workshop:

This report is a qualitative analysis of the potential environmental impacts, monitoring and baseline assumptions, and is meant to inform NOAA OCRM, regulatory agencies and stakeholders. This report is not an exhaustive ecological analysis, nor does it claim to identify every potential environmental impact associated with OTEC. The workshop participants expressed their individual opinions and ideas during the sessions; this report is not the participants' consensus advice to NOAA, but does summarize information gained by NOAA as a result of the workshop. This report does not consider economic, military, technical and social impacts and/or constraints, and is not part of the decision and permitting process for an OTEC facility within U.S. waters.

Table 5: OTEC Facility Characteristics

	5 MWe	**100 MWe**
Type of Facility	Demonstration	Commercial
Location	3 – 4 miles (4.8 – 6.4 km) offshore Hawaii	
Warm Water Intake Depth	20 m	
Warm Water Intake Temperature	25°C	
Warm Water Intake Flow	25 m^3/s	500 m^3/s
Warm Water Intake Velocity	0.15 m/s	
Warm Water Intake Antifouling	Intermittent Chlorination (50 – 70 mg/L for 1 hr)	
Cold Water Intake Depth	800 – 1000 m	
Cold Water Intake Temperature	5°C	
Cold Water Pipe Diameter	2 – 4 m	10 m
Cold Water Intake Flow	25 m^3/s	500 m^3/s
Cold Water Intake Velocity	2.5 m/s	
Cold Water Intake Antifouling	None	
Discharge	Combined or Separate, Depth to be Determined	

IV. WORKSHOP ORGANIZATION AND STRUCTURE

The workshop, held in Honolulu, Hawaii on June 22 – 24th, 2010, consisted of plenary sessions where invited speakers discussed their experiences with OTEC and gave their opinions on the state of the technology and potential environmental impacts. Participants for this workshop were selected from a variety of fields and expertise, and included members from State and Federal government, academia, industry, and non-government organizations with expertise in policy, engineering, biology, ecology, and oceanography.

Five breakout groups discussed potential impacts from key OTEC sources, including: 1) warm water intake; 2) cold water intake; 3) discharge (including biocides and working fluid leaks); 4) physical presence, construction, and accidents; and 5) noise and electromagnetic fields. The workshop agenda (Appendix A), participants (Appendix B), discussion questions (Appendix C), and breakout groups (Appendix D) were identified and developed by the organizing committee comprised of members of government and , academia (Appendix B). As preparation, each participant was given an "OTEC Primer", containing historical and technical background information on OTEC, as well as a summary of potential impacts identified in the 1981 EIS and 1986 NMFS reports (Appendix E).

The workshop participants were divided into the five groups based upon their expertise by the organizing committee. Each breakout group identified: additional potential impacts not identified in the 1981 EIS and 1986 NMFS reports (summarized in the OTEC primer); prioritized impacts in a regulatory context; the baseline assessments, monitoring strategies and modeling methods needed to develop quantifiable levels of impact and risk; the best available technologies and methods to assess OTEC impacts and risks; additional research needed to assess potential biological impacts; and ways in which potential physical, chemical and biological impacts can be avoided, minimized or mitigated within the operational and design parameters of an OTEC system. This report summarizes the group discussions on potential biological, chemical and physical impacts of OTEC.

V. BREAKOUT GROUP REPORTS

A. Warm Water Intake

The warm water intake group examined the potential physical, chemical and biological impacts from the warm water intake system. The warm water intake system consists of the warm water intake pipe, intake screening, and any component with which warm water comes into contact with. The warm water intake is likely to be in relatively shallow water in an effort to capture the warmest water while at the same time avoiding surface disturbances such as wind and waves. Due to its relatively shallow depth, the principal impacts from the warm water intake system are likely to be entrainment and impingement.

Entrainment, when an organism or particle passes through screening or filters and enters the warm water intake system, mostly affects small organisms that lack adequate mobility to escape the intake current. Classes of biota likely to become entrained in the warm water intake include: phytoplankton, zooplankton (including microzooplankton, meroplankton (e.g., larvae), icthyoplankton and possibly macrozooplankton), as well as small fish. Once entrained, the biota may be subjected to mechanical and shear stresses from the intake pumps, periodic chemical stresses from the application of anti-fouling biocides, and temperature stress. The impact due to entrainment will vary with the intake screen mesh size, intake velocity and flow rate, survivability characteristics of organisms, and biological community composition and abundance in the region. For the warm-water intake discussions, it was assumed that there would be a low survival rate for organisms entrained.

Impingement, when an organism is held against a surface by water flow or becomes stuck within a structure, is more likely to affect larger organisms. Classes of biota likely to become impinged against the warm water intake screening include macrozooplankton, cnidarians, small fish, and larger weak or sick fish. Healthy juvenile and adult sea turtles are unlikely to become entrained or impinged in the warm water intake, however, it is possible that sick or weakened individuals could. The magnitude, size and type of impinged organism would depend on the screen mesh size and design, intake velocity and flow, community composition and abundance of biota present in the area.

If the magnitude of the direct effect (e.g., injury or death due to impingement, entrainment) is large enough, there are likely to also be indirect impacts, such as changes in the food web and behavior (i.e., shifting from predation to scavenging). The warm water intake system may also potentially impact diel migrations of micronekton, and may alter their local distribution and abundance. This will have a direct impact on the micronekton and their primary predators. The group concluded that 100% mortality of impinged or entrained organisms is likely.

Baseline Assessments, Monitoring Strategies and Modeling Methods

Some baseline physical, chemical and biological data for the past 30 years exists for the waters surrounding Hawaii (i.e., Hawaii Ocean Time Series (HOT), National Energy Laboratory of Hawaii Authority (NELHA)), and fisheries data, and can be used for initial assessments, however, additional monitoring will be required using current methods and technology to confirm the validity of the historical data. Monitoring strategies will depend upon likelihood and magnitude of the potential impact, with frequent, high resolution monitoring of high priority groups (i.e., endangered species), and infrequent monitoring of groups unlikely to be impacted. As a starting point, plankton should be sampled at least monthly and analyzed for abundance and community composition using visual identification or advanced molecular techniques. Monitoring strategies and modeling should be tailored to ensure that impacts from the warm water intake are fully understood. Biological modeling should be included in the assessment of impacts, and models such as Ecopath with Ecosim, adult equivalent loss (AEL), empirical transport model (ETM), fecundity hindcast (FH), and modification of other existing power plant models should be considered to accurately estimate the impacts to biota from an OTEC warm water intake.

Assessment of OTEC Impacts and Risk

In order to determine the impact of the warm water intake, multiple technologies are required. To assess micronekton and ichthyoplankton impacts, a multiple opening and closing net environmental sensing system (MOCNESS) should be used. These sampling devices are deployed by boat and contain multiple openings at varying depths in order to sample the water column. The use of an acoustic Doppler current profiler (ADCP) can determine particle movement at multiple depths, and would allow continuous assessment of micronekton. Numerous remote sensing technologies exist, including video plankton recording, satellite imaging, and ocean observing systems (OOS) that may allow monitoring of plankton and some nekton. The Natural Energy Laboratory of Hawaii Authority (NELHA) and Kahe power plant both operate pipes similar in size to the pipe required for a 10 MWe OTEC warm water pipe, and examination of entrainment and impingement from these facilities, as well as additional biomass sampling, would provide a better understanding of the sampling requirements and likely impacts due to entrainment and impingement. Advanced molecular techniques (e.g., molecular biology, metagenetics) should be used to characterize plankton and microbial species and their relative abundance relative to a baseline. Table 6 summarizes likelihood, significance, and regulatory implications of potential impacts resulting from the warm water intake system.

Table 6: Prioritization of Impacts in a Regulatory Context for the Warm Water Intake System

Impacted Population	Regulatory Driver?	Is it Likely?	Significance?	Unique to OTEC?	Regulatory Priority
Entrainment:					
Phytoplankton + Bacteria	MSFCMA	Yes	Unknown	No for demonstration plant Yes for commercial scale	Yes
Zooplankton + Meroplankton	MSFCMA	Yes	Unknown	No for demonstration plant Yes for commercial scale	Yes
Benthos (eggs and larvae)	ESA (possibly for corals)	Unknown	High, if listed	No for demonstration plant Yes for commercial scale	Yes
Fish (indirect impacts)	MSFCMA	Yes	Unknown	No for demonstration plant Yes for commercial scale	Yes
Eggs and larvae (direct impacts)	ESA, MSFCMA	Yes	High	No for demonstration plant Yes for commercial scale	Yes
Micronekton (indirect impacts)	MSFCMA	Yes	Unknown	Yes	Yes
Micronekton (direct impacts)	ESA, MSFCMA	Yes	High	No for demonstration plant Yes for commercial scale	Yes
Impingement:					
Macrozooplankton (adults)	MSFCMA	No	Low	No for demonstration plant Yes for commercial scale	No
Fish	ESA, MSFCMA	Yes	Unknown	No	Yes
Sea Turtles	ESA	No	High, if listed	No	Yes
Diving Sea Birds	ESA, MBTA	No	Unknown	No	No
Micronekton	MSFCMA	Yes	Unknown	Yes	Yes

MSFCMA - Magnuson-Stevens Fishery Conservation and Management Act *EFH – Essential Fish Habitat*

ESA – Endangered Species Act *MBTA – Migratory Bird Treaty Act*

Additional Research and Data Gaps

In order to better understand the potential impacts of the warm water intake system, interdisciplinary research is required. Data gaps include: general biota stock structure; early life history studies; quantitative spatial (including water column) and temporal data on abundance and distribution of all biota; mortality of larval and juvenile fish; factors affecting recruitment and compensation for mortality; and effects of cold water shock once discharged on biota at the OTEC-relevant temperature ranges. Research requirements are similar for entrainment and impingement, and include: updating site specific baseline ecosystem studies, quantification of biota entering the system compared to the total available resource, analysis of larval abundance and distribution, mortality resulting from the warm water intake system, update of existing stock assessments based upon larval mortality, quantification of swimming speed of both fish and micronekton to assess entrainment and impingement potential.

Mitigation of Impacts

In order to reduce potential physical, chemical and biological impacts of the warm water intake system, it is important to design the warm water intake to reduce the likelihood of entrainment and impingement. For larger organisms like fish, this can be done by increasing the size of the pipe opening to reduce intake velocities, however, the preferred method of minimizing entrainment and impingement for all species is through careful selection of intake depth, mesh size, and location. The group concluded that intake mesh size and design is likely to be plant-specific, and could be tailored to minimize biological impacts. Minimizing lighting on the facility would reduce attraction and should be considered. Deterrent strategies, such as high intensity strobe lights and sound should be considered to repel sensitive species (i.e., juvenile and adult fish). The practicality of these methods will need to be carefully evaluated since some of these mitigation methods could reduce the efficiency of the OTEC facility. Decreased intake velocity and changes to the depth may substantially reduce efficiency of energy production.

B. Cold Water Intake

The cold water intake group examined the potential physical, chemical and biological impacts of the cold water intake system. Like the warm water intake, entrainment and impingement are likely to be the primary impacts from the cold water intake system. However, due to the depth of the cold water pipe intake (e.g., 1000 m) the biomass concentration is anticipated to be less than at the warm water intake. Mesopelagic microzooplankton would likely be entrained, however, not enough is known about deep-water ecosystems to determine if this would include meroplankton or ichthyoplankton. Entrained organisms would be subject to extreme pressure changes on the order of 100 atmospheres (1,422 PSI), mechanical and shear stress from the intake pumps and water flow, as well as extreme temperature changes. Impingement of organisms in the cold water intake is likely to be limited to macrozooplankton and small fish. However, because it is anticipated the debris screens would be located on the surface (to aid in cleaning) rather than at the deep water intake, mortality is most likely to be caused by extreme pressure changes associated with entrainment prior to impingement. A low survival rate is anticipated. The large volume of seawater transported by the cold water intake system will likely entrain a significant amount of microorganisms. Those that survive will be ultimately released either via a cold water return or mixed return at a much shallower depth. This disruption in vertical stratification could disrupt the community composition and ecological functions, possibly resulting in disruptions to the local food web.

Subsea currents and associated shearing forces will cause the cold water pipe to oscillate on the order of one pipe diameter. This will create noise and vibration, which may impact organisms. The magnitude and nature of this impact is unknown. These oscillations, caused by fluid movement around the pipe, are also likely to shed vortices, which also create an unknown impact.

The ocean is not homogeneous, and some locations will be more sensitive than others. Site selection will affect the type and magnitude of the impact. For example, submarine canyons, while potentially thermodynamically ideal for placement of the cold water intake, contain organisms endemic to that environment and may be unable to survive if disruptions (i.e., change in currents, temperature, chemical characteristics) occur. The distance between the bottom of the cold water pipe and the seafloor will also be a consideration in the site selection. Impacts resulting from material selection and pipe cleaning may also occur, however, these cannot be predicted without further design and maintenance information.

Baseline Assessments, Monitoring Strategies and Modeling Methods

In order to develop an acceptable baseline, a mooring sampling system could be used to sample at the depth of the intake. Sampling would need to occur at least monthly for one year, however, this will likely collect too little data (i.e., under sample). Baseline sampling should occur at day and night to capture diurnal movements, and should be conducted in permanent sampling grids so that once the OTEC facility begins operation, long term impacts can be assessed. Intensive, multi-depth hourly trawls should be considered for periods of up to 5 days to capture vertical movements. Climate patterns (e.g., El Niño, La Niña) should also be considered when developing monitoring strategies.

While studies exist that characterize organisms present at the depth of the cold water intake, these studies used methods that are now considered obsolete with the advent of advanced molecular techniques. In addition, there is some evidence that conditions have changed since the publication of many of these studies, and their findings may differ from current conditions. While these studies can be used for an initial baseline, further sampling and analysis are needed to validate these results prior to their use in any models.

The cold water intake should be closely monitored for impingement, and water in the intake should be sampled frequently (> 2/day) and analyzed using molecular methods to gain a better understanding of what species and quantity of organisms are being entrained.

Assessment of OTEC Impacts and Risks

In order to assess the impact of the cold water intake and risk to species in the region, the type and abundance of organisms present must be known. To assess the micronekton and ichthyoplankton at depth, a MOCNESS sampling device should be used. Remote sensing using passive acoustic arrays, hyperspectral satellite monitoring, cameras placed at the intake, and autonomous underwater vehicles (AUVs) can be used to monitor larger organisms in the region. The 1986 NOAA NMFS report relied on visual identification of plankton and microorganisms to determine impacts. Detection capabilities have advanced considerably since then and now allow positive identification using molecular techniques. Abundance and community composition should be analyzed with these techniques to provide the best possible data. Continual monitoring of the seawater being transported by the cold water pipe is desirable for demonstration plants, as grab and composite samples may not adequately define the impacts. Bioluminescent system monitors or photomultiplier tubes can also be used to detect organisms in the region, however, cannot be the sole method of detection as they only target organisms with bioluminescent properties. Optical particle counters can be considered for continuous monitoring, however, additional analysis is required, as particle counters cannot easily distinguish between inorganic and organic particles.

In order to gain a better understanding of localized changes to seawater chemistry, water in the vicinity of the cold water pipe intake should be analyzed for numerous constituents, including: nitrogen (e.g., nitrate, nitrite, ammonia); phosphorous, phosphate, silica, pH, and dissolved gasses. Significant changes in the source water may indicate shifts in subsea currents and stratification. Table 5 summarizes likelihood, significance, and regulatory implications of potential impacts resulting from the cold water intake system.

Additional Research and Data Gaps

The majority of data gaps associated with impacts to the cold water pipe focus on the presence and abundance of species at the depth of the intake. Additional research is needed to quantify mesopelagic biota, and gain a better understanding of their behavior. Once the organisms present at depth are characterized and their role in the ecosystem and food web better understood, improved models of the impact the cold water pipe system will be possible. Research should also investigate the fate of entrained organisms. Further investigation of foraging patterns of endangered species in the region should be considered, as well as archival tagging and acoustic monitoring to better understand their presence at these depths.

Mitigation of Impacts

The best way to mitigate potential impacts of the cold water intake system without affecting operational efficiency is to prevent the impacts from occurring through careful site selection. Locations that have deep water corals, submarine canyons, high abundance of prey communities, and locations with high currents should be avoided. To minimize impacts, the intake should have a vertical orientation and at a depth which optimizes the reduction of impacts to organisms.

Table 7: Prioritization of Impacts in a Regulatory Context for the Cold Water Intake System

Impact Population	Affected Organism/Process	Regulatory Driver?	Is It Likely?	Significance?	Unique to OTEC?	Regulatory Priority
Marine Mammals	Whales	MMPA	Unknown	High	Yes	Yes
Endangered species	Leatherback turtles	ESA	No	High	Yes	Yes
	Monk seals, small cetaceans	ESA, MMPA, MSFCMA	No	High	Yes	No
Fish	Pelagic Adults (tunas, billfish and sharks)	MSFCMA	Unknown	Low	No	No
	All except for coral (larvae and eggs)	MSFCMA	No	Low	No	No
	Bottom fish, coral reef, crustacean	MSFCMA, ESA	No	Low	No	No
	Precious Coral	MSFCMA, ESA	No for adults Unknown for larvae	Unknown	Yes	Yes
Prey	Prey for marine mammals	ESA	Unknown	Unknown	Yes	Varies with species
	Prey for turtles	ESA	Yes	Low	Yes	Yes
	Prey for pelagic and bottom fish species	MSFCMA	Unknown	Unknown	Yes	Yes

MSFCMA – Magnuson-Stevens Fishery Conservation and Management Act *ESA- Endangered Species Act*

MMPA- Marine Mammals Protection Act

C. Discharge

The discharge group examined the potential physical, chemical and biological impacts of the discharge from the OTEC facility, including biocides and working fluid leaks. After water from the cold water and warm water pipes has passed through heat exchangers and heat has been extracted, the water is returned to the ocean via discharge pipes. Discharge configurations may include individual cold and warm water return pipes, or a combined return where the cold and warm water are mixed and returned above the thermocline. If a combined discharge is selected, the temperature and salinity of the water released would be an average of the cold and warm water discharge. This water would sink to a depth of comparable density, which will vary with location. This may result in localized changes to the temperature and currents, in addition to the plume-induced currents. The discharge pipe will be at a depth below the warm water intake in order to ensure the effluent discharge is not re-circulated into the warm water intake which would reduce the overall efficiency of the facility.

The depth of discharge is crucial and will affect the magnitude and extent of impacts. Organisms that survive the entrainment process may ultimately die if they are released at an unsuitable depth. Organisms in the vicinity of the discharge may be entrained in this plume (i.e., secondary entrainment). The cold water discharge will contain dissolved gasses and nutrients transported from the deep. If released close to the surface, the change in pressure will cause release of some of the gasses, and will likely change the chemistry of the surrounding water. Dissolved carbonates in the discharge may change the pH in the local receiving water, potentially inhibiting the shell production of foraminifera and veliger larvae. Some concern has been expressed over dissolved carbonates released in the form of CO_2 into the atmosphere in this process and thus increasing global carbon dioxide emissions. While possible, the magnitude of the release would depend upon the depth and density of the discharge.

Nutrients in the discharge may enhance primary productivity, decrease dissolved oxygen levels, or cause toxic algal blooms (i.e., similar to coastal upwelling). Dead organisms in the discharge plume may act as food source, attracting fish to the vicinity of the plume. The discharge water may also contain particulates and dissolved constituents from erosion and corrosion of facility components, living or dead entrained organisms, biocide from anti-fouling treatment, nutrients, and potentially small working fluid releases from normal operations. The discharge may contain low concentrations of contaminants, however this will vary with the age, design, construction material, and maintenance of the facility, as well as the overall quality of ocean water in the region (i.e., turbid water will result in greater erosion). The toxicity of these contaminants will vary with concentration, exposure, bioavailability and bioaccumulation potential. The toxicity, water chemistry, and secondary entrainment impacts addressed above apply to separate and combined discharges.

Biological impacts associated with the plume will might include: acute or chronic toxicity; behavioral changes; reduced fecundity; attraction or repulsion from the OTEC facility; and changes to the local ecosystem structure.

Baseline Assessments, Monitoring Strategies and Modeling Methods

Monitoring frequency will be dependent on the variability in the data collected, and is difficult to predict without further site-specific information. However, monitoring should be continuous during construction and installation, as well as the first year of operation for the demonstration plant. The region should be monitored for an additional 3 – 5 years thereafter to ensure there are no significant changes in the chemical or physical characteristics of the water column. While 20 years of Hawaii Ocean Time series (HOT) data exists, it was collected monthly and not necessarily at locations under consideration for OTEC, and therefore, is not suitable as a sole source of baseline data and information. The baseline should be measured at specific sites surrounding the proposed OTEC facility location and continue after operation of the demonstration plant commences to better capture any changes. The sampling design for monitoring and assessment should be statistically robust and use the best available and practical technologies. For anticipated discharge flows, there are research plume models (e.g., Makai OTEC plume model) that can predict the fate and transport of the discharge plume. Model development must include spatial and temporal components and include multiple constituents (e.g., temperature, nutrients, dissolved oxygen, salinity).

Assessment of OTEC Impacts and Risks

The assessment of impacts and risks from the discharge pipe are dependent upon accurate measurements of the physical and chemical characteristics of seawater, as well as direct measurements of the biological impacts in the region. Direct measurement of the biological impacts can be accomplished through various monitoring technologies including optical plankton counters, fluorometers, and collection of samples via AUVs, gliders, ships and stationary mooring sampling devices. Assessment of chemical and physical impacts can be made via frequent sampling and analysis of seawater collected with buoyant drifters. Sensors used should be equipped to monitor: nitrate, including other surrogates, hydroacoustics to measure changes in transition layers, *in situ* ultraviolet sensors (ISUS), acoustic receivers on gliders, and dissolved inorganic carbon (DIC) and optical characteristics. Temperature changes can be measured using remote loggers, conductivity, temperature and depth (CTD) systems, and gliders. Direct impacts to biota due to changes in the chemical and physical characteristics of the seawater can be measured through chronic and acute bioassays. Table 8 summarizes the likelihood, significance, and regulatory implications of potential impacts resulting from the discharge from an OTEC facility.

Table 8: Prioritization of Impacts in a Regulatory Context for the Discharge Plume

Impact	Regulatory Driver?	Is it Likely?	Significance?	Unique to OTEC?	Regulatory Priority
Oxygen	CWA	Yes	Low	No	Unknown
Nutrient Upwelling	CWA	Yes	Unknown	Yes	Unknown
CO_2, pH, Dissolved inorganic Carbon	CWA	Unknown	Unknown	Unknown	Unknown
Ammonia Release	CWA	Yes	Low	Yes	No
Metals	CWA	Yes (Low concentrations)	Low	No	No
Anti-biofouling Agents	CWA	Yes	Unknown	No	Unknown
Salinity		Yes	Low	No	No
Temperature Changes	CWA	Yes	High	No	Unknown
Ciguatoxin		Unknown	Low-medium	Unknown	Unknown
Fish and Fish Habitat	MSFCMA	Yes	Medium	Yes	Yes
Zooplankton	MSFCMA	Unknown	Low	Yes	No
Microzooplankton	MSFCMA	Unknown	Low	Yes	No
Microorganisms	MSFCMA	Unknown	Unknown	Yes	Unknown
Benthic Effects	MSFCMA	Yes	Low	No	No
Threatened and Endangered Species	ESA	Yes	Low	No	Yes

CWA- Clean Water Act   *ESA- Endangered Species Act*

MSFCMA – Magnuson-Stevens Fishery Conservation and Management Act

Additional Research and Data Gaps

Additional research is needed to validate plume models, specifically using inert tracers to model plume fate and behavior. This will provide a better understanding of the fate and behavior of chemical and physical constituents of the plume, and how they may impact the region. In order to better understand the impact to the microbial and nanoplankton communities, advanced microbial and molecular techniques should be used to characterize the communities present at the discharge depth. In addition, an in-depth characterization of the biological community should be conducted at intake and discharge depths.

Mitigation of Impacts

Potential impacts can be mitigated by reducing the effect of the discharge through greater dilution or elimination of the causative agents. Dilution can be increased through changes in depth of the pipe, addition of diffusers, enhanced mixing (e.g., creation of turbulent mixing), or use of multiple pipes. Elimination of the impact can also be accomplished through minimizing: biocide use, temperature changes in plume, release of working fluids, and selection of construction materials that reduce the release of toxic compounds. From an environmental standpoint, a mixed discharge is preferable because it results in a plume that is closer in temperature to the receiving water, minimizing temperature effects in the region surrounding the discharge plume.

D. Physical Presence, Construction, and Accidents

The physical presence, construction, and accidents group examined the potential physical, chemical and biological impacts associated with the physical presence, construction, and accidents associated with an OTEC facility. Construction impacts will vary with: location and design of the facility, extent of construction that takes place at sea, type and installation method of the power cable, and type of mooring selected. The platform will likely be built at a shore-based facility and towed to the site. The cold water pipe may be constructed on land and towed to the site, or constructed/manufactured on-site. The most disruptive aspects of installation are likely to be the placement of anchors, moorings and power cables. The installation and presence of these components may require blasting, drilling and excavation of the seafloor, and could disrupt benthic and pelagic communities, including deep corals and crustaceans, vertebrate fish, marine mammals, sea birds, sea turtles, invertebrates, and microbial communities. In particular, the installation and presence of the power cable will: increase suspended sediment, disturb or destroy coastal resources and coral reefs, as well as alter the behavior of invertebrate and vertebrate in the region. The installation of these components will disrupt habitat heterogeneity, and may have secondary long-term impacts to the ecosystem. Construction, installation and vessel traffic activities are likely to generate noise, and may disrupt movement and communication of fish, marine mammals and reptiles (e.g., whales, dolphins, sea turtles) in the area. Platform lighting may disrupt the normal behavioral patterns of sea birds, turtles, marine mammals, plankton, squid and fish in the region.

Noise and EMF generated during construction and operation of an OTEC facility are addressed in Section E, Noise and EMF.

The physical presence of the platform will most likely serve as a fish attraction device (FAD). This may increase the number of impinged and entrained organisms, and could change local migratory patterns. Accidental release of chemicals, while unlikely, has the possibility of disrupting all life within the plume and in the region surrounding the facility. Direct toxicity, chemical oxidation, and indirect toxicity (i.e., drop in pH increases certain metals, causing toxic effects) can potentially result from a chemical release.

When examining potential impacts due to physical presence, construction and accidents, it is important to take into consideration the size of the system (i.e., the physical size of a 100 MWe plant is much larger than a demonstration 10 MWe facility). Different size plants will likely have significantly different impacts. The component type will also play a significant role in the type of impact (i.e., a drilled mooring could be disruptive to the benthos, but all mooring/anchors can potentially impact deep sea corals and other biota). Table 9 summarizes likelihood, significance, and regulatory implications of potential impacts resulting from physical presence, construction and accidents.

Baseline Assessments, Monitoring Strategies and Modeling Methods

The baseline assessment may be seasonally dependent, and sampling should take this into consideration. Benthic site surveys should be conducted pre and post-construction to evaluate the impact to the seafloor and the biota that inhabit it. Pre-construction surveys can also be used to avoid particularly sensitive habitats (e.g., deep water corals). Water column assessments should vary in temporal and spatial scales, and should continue for a minimum of three years. Assessments should include sampling via trawl nets, collection and reporting of downed birds to the U.S. Fish and Wildlife Service, as well as multiple surveys to monitor changes in distribution, habitat use, frequency and abundance of marine mammals.

Assessment of OTEC Impacts and Risks

Technology and methods to assess the impact and risk of the physical presence and construction of an OTEC facility should include remote sensing (submersibles, multi-beam side scan sonar, ROV, AUV), satellite telemetry of tagged biota, and visual and genetic surveys to identify any potential shifts in community composition. Many impacts are likely to be similar to those observed during construction and installation of oil platforms and offshore windfarms, and techniques and methods used to monitor impacts could be used to assess impacts and risk at an OTEC facility.

Table 9: Prioritization of Impacts in a Regulatory Context for Physical Presence, Construction, and Accidents

OTEC Component/Activity/Event	Impacted Resource	Potential Impact	Regulatory Driver?	Is it Likely?	Significance?	Unique for OTEC?	Regulatory Priority
Construction of Anchors and Dragging of Anchors and Cables	Deep Coral	Destruction	MSFCMA ESA, CRCA	Yes	High	No	Yes
	Benthic Invertebrates	Destruction, Displacement	MSFCMA	Yes	Low	No	No
Power Cable- Installation	Corals	Disturbance or Destruction	CWA,ESA MSFCMA	Yes	Low	No	Yes
OTEC Physical Presence (Platform, pipe, mooring cable, anchors, power cable)	Other Protected Species	Behavioral alteration	ESA	Unknown	Unknown	Unknown	
	Mobile Invertebrates	Behavioral alteration	MSFCMA	Unknown		No	
	Turtles	Behavioral alteration, Entanglement, collision	ESA	No	Low	No	Yes
	Marine Mammals	Behavioral alteration, Collision, entanglement, attraction	ESA, MMPA	Unknown	Medium/ High	Yes	Yes
	Fish	behavioral alteration, habitat displacement	MSFCMA	Unknown		No	Yes
	Birds	behavioral alteration, landing and nesting	MBA, ESA	Yes	Low	No	No
Lighting	Birds	behavioral disturbance	MBA, ESA	Site Specific	High	No	Yes
	Mobile Invertebrates	behavioral disturbance		Species specific	Unknown	No	Unknown
	Turtles (Hatchlings)	behavioral disturbance, attraction	ESA	No	High	No	Yes
	Fish	behavioral disturbance: attractant or avoidance	MSFCMA, EFH	Yes	Low	No	Yes

EFH - Essential Fish Habitat *ESA - Endangered Species Act*
CRCA - Coral Reef Conservation Act *MMPA - Marine Mammal Protection Act* *MBA - Migratory Bird Act*
CWA – Clean Water Act *MSFCMA – Magnuson-Stevens Fishery Conservation and Management Act*

E. Noise and Electromagnetic Fields

The noise and electromagnetic fields group examined the potential physical, chemical and biological impacts associated with the production of noise and electromagnetic fields associated with an OTEC facility. The generation of noise and electromagnetic fields (EMF) are of concern due to the large number of marine organisms that regularly use acoustics (e.g., dolphins, whales, fish) and electromagnetic fields (e.g., sharks, turtles) for communication, detection of prey/predators, and navigation.

There are likely to be impacts associated with noise and electromagnetic fields, however, the magnitude and extent of the impact is not known and will likely depend on many factors. Sources of construction-related noise are likely to include: deployment of moorings, anchors and the power cable; deployment of the cold water pipe; and associated boat traffic. Sources of operational noise include turbines, pumps, discharge turbulence, cable strum (both mooring and power cable), cold water pipe vibration, boat traffic, and frictional noise from water movements. To date, very little direct measurements of the noise associated with OTEC facilities exist. The impact of noise will vary with receptor and exposure (i.e., magnitude, temporal, spatial, spectral), and will most likely manifest themselves as a physiological or behavioral impacts. Physiological impacts could include: hearing damage and loss (e.g., permanent threshold shift (PTS); temporary threshold shift (TTS)) and, in some species, could lead to death through inability to complete basic biological functions (e.g., echolocation for prey detection in dolphins). Behavioral changes may include local or widespread changes in movement (e.g., attractant, deterrent), communication difficulty due to masking, and changes in feeding and breeding habits (e.g., larval recruitment). If these behavioral changes persist, an ecosystem level impact may occur, potentially resulting in localized changes to community structure and food web dynamics.

Electromagnetic field generation is likely limited to the power cable, with the section that is suspended between the seafloor and the platform most likely to cause impacts. The receptivity and sensitivity to EMF is unknown for many species. Sensitive species (i.e., sea turtles, sharks) are most likely to be impacted, and if exposed, are likely to exhibit changes in behavior, including attraction and avoidance.

Baseline Assessments, Monitoring Strategies and Modeling Methods

A baseline assessment of ambient noise can be determined prior to construction with stationary monitoring equipment. Monitoring should continue throughout the construction, installation and operational phase using the same equipment and locations to facilitate comparison. Autonomous broadband acoustic recorders coupled with validated acoustic propagation models can be used to determine the range of impact. Pre- and post-monitoring of species abundance, behavior and distribution will be required to validate models and laboratory tests.

Assessment of OTEC Impacts and Risk

Sound and EMF are relatively easy to monitor and model using acoustic and EMF monitoring equipment positioned on stationary buoys, however effort is required to filter out extraneous sounds. Impacts to biota from noise and EMF are more difficult to quantify, and frequent monitoring for behavioral changes and physiological damage would be required during construction and operation to ensure the impact to the biota is understood. Changes to behavior and physiological damage for smaller species can be assessed in the lab or aquaculture cage studies, while tagging and telemetry using passive acoustic monitoring devices can be used for larger organisms. Table 10 summarizes likelihood, significance, and regulatory implications of potential impacts resulting from acoustics and EMF.

Additional Research and Data Gaps

In order to better understand the magnitude and type of impact likely to occur, additional research is needed to better understand the tolerance thresholds of marine organisms for sound and electromagnetic fields. While some animals have been widely studied, little is known about the response to sound and electromagnetic fields by the majority of biota that exist in the open ocean. In addition, further research is needed to understand the role sound has on larval recruitment, and if OTEC-related sounds will impact it.

Mitigation of Impacts

The most effective way to prevent or limit noise and EMF impacts is to reduce exposure. This can be accomplished through careful site selection to avoid sensitive species, or through a reduction in the sound or EMF generated. Little can be done to reduce the impact of sound once it is generated, and mitigation efforts should focus on reducing the amount generated, or shifting it to a frequency that is less harmful. Acoustic deterrent devices can be used to repel animals from the area, however, this will increase the overall level of noise and may have unintended impacts on other species. EMF size and strength can be reduced through shielding. This can be accomplished on the seafloor by burying the cable. Shielding is more difficult on the riser section of the power cable (i.e., from the seafloor to the OTEC facility). Shielding is typically heavy, and current platform-power cable connections may not be able to support the additional weight.

Table 10: Prioritization of Impacts in a Regulatory Context for Noise and Electromagnetic Fields

<table>
<tr><th>Impact Source</th><th>Impacted Resource</th><th>Potential Impact</th><th>Regulatory Driver?</th><th>Is it Likely?</th><th>Significance?</th><th>Unique for OTEC?</th><th>Regulatory Priority</th></tr>
<tr><td>Low Frequency Noise</td><td>Baleen whales, sea turtles, pinnipeds, fish, rays</td><td rowspan="2">Masking, threshold shift, behavioral changes</td><td rowspan="3">ESA if listed
MMPA
MSFCMA</td><td rowspan="3">Unknown</td><td rowspan="3">High</td><td rowspan="3">No</td><td rowspan="3">Yes, if endangered or protected species is impacted</td></tr>
<tr><td>High Frequency Noise</td><td>Toothed whales</td></tr>
<tr><td>Electromagnetic Fields</td><td>Sharks, sea turtles</td><td>Behavioral changes</td></tr>
</table>

ESA- Endangered Species Act *MMPA- Marine Mammal Protection Act*

MSFCMA – Magnuson-Stevens Fishery Conservation and Management Act

VI. BASELINE ASSESSMENTS, MONITORING STRATEGIES AND MODELING METHODS

On the final day of the workshop, the participants were divided into four groups: Fisheries and Corals (Table 11 – 13); Marine Mammals (Table 14 – 16); Oceanography (Table 17 – 19); and Plankton (Table 20 – 22). Each group was asked to identify: 1) baseline data needed and minimum baseline duration; 2) monitoring strategies and methods; and 3) modeling strategies and methods. Each group was asked to fill out the following tables. All groups assumed a minimum baseline duration of 1 year; deviations from this are noted and justified in the tables. The 1 year timeframe was chosen as a starting point, not an acceptable minimum, and should not be relied upon as such. Sampling frequency and specific methods were not addressed, and will need to be addressed in a fully developed monitoring plan at a later time.

VII. CONCLUSIONS

The 1981 EIS and 1986 NMFS report identified numerous potential impacts related to the construction and operation of an OTEC facility in Hawaiian waters. The participants of this workshop concurred with these potential impacts, and were able to expand the list based upon 25+ years of knowledge and experience gained in similar fields. The results of this workshop show that physical, chemical and biological impacts of an OTEC plant in Hawaiian waters are likely to occur during the installation and operation of an OTEC facility. However, due to a lack of appropriate field data, the magnitude and extent of these impacts are not known. In order to gain a better understanding of the risk installation and operation of an OTEC facility represents, a baseline consisting of a minimum of one year of data is required prior to construction and installation. While in some cases one year may be sufficient, unusual weather, currents, high sample variability and other factors may require longer baseline sampling, and in many circumstances, a longer baseline may be desired in order to capture multi-year variability and annual variations. Baseline and monitoring data collected should include the abundance and community composition of large and small biota, as well as well as the physical and chemical characteristics of seawater in the region. Examples of parameters that should be monitored include, but are not limited to: temperature; salinity; dissolved oxygen; pH; trace metals; and abundance, diversity, and behavioral changes to plankton, fish, marine mammals, turtles, and other biota. Sampling frequency during this baseline should be constituent specific, and follow a sampling plan designed to adequately capture natural variations and cycles. It is worth repeating that this report is not an exhaustive ecological analysis, nor does it claim to identify every potential environmental impact associated with OTEC or provide a detailed baseline and monitoring sampling plan.

An environmental baseline assessment must be conducted prior to the project installation. Once construction, installation and operation of the facility commences, baseline parameters should be monitored for deviations to provide information on how the facility is impacting the local environment. Once likely impacts are established, steps can be taken to ameliorate these impacts through careful site selection, modifications to the facility, or changes to facility size or scope. Secondary and indirect impacts are not likely to be immediately evident, and long-term monitoring, possibly for the life of the facility, may be required. These impacts have the potential to play a large role in ecosystem-level impacts of an OTEC facility, and further research is needed to quantify the risk involved and develop better methods of detection.

Table 11: Baseline Assessment for Fisheries and Corals

Impact	Baseline Data Needed	Minimum duration for Baseline Data	Justification of duration
Entrainment	Larval community surveys to cover all management unit species; density at intake and discharge depth; More specific catch and effort information for site (i.e., grids, interviews with fishermen)	Varies with spawning season of MUS species. 5 control sites for more data over 1 year	Inter-year variation can be significant and would require long sampling duration to capture; multiple sampling locations required
Impingement			
Physical Damage to Shallow Corals	Community structure of corals, including size and frequency of species. Spatial and temporal survey of species within region.	1 year and after hurricane	
Physical Damage to Deepwater Corals	Survey of sub-bottom profiling; bathy structure and composition data; optical imagery	1 survey/map is sufficient	

Table 12: Monitoring Strategies for Fisheries and Corals

Impact	What should be monitored?	How should this be monitored?	How often?
Entrainment	Water at intake, fishery catch and effort, status of fishery stocks, control sites, density and type of all management unit species (MUS), eggs/larvae density and type; effect of light on biota	Net collection and Plankton tows; intake flow rate; multiple control sites, Fishery catch data and interviews w/ fishermen; Stock assessment; experimental fishing	Increase according to expectation of density of eggs and larvae for different periods of the year; diel 24/hr assessments; life history: monthly; interview fishermen: as needed;
Impingement	Biota on screens, fishery catch and effort, status of fishery stocks, control sites, all management unit species (MUS). Density and type of eggs and larvae	Bongo nets; plankton tows; intake flow rate; use of multiple control sites, fishery catch data and interviews w/ fishermen; stock assessment	
Physical Damage to Shallow Corals	Community structure and baseline parameters of corals, including size and frequency of species	Diver surveys to evaluate community abundance and composition	Once during baseline and once after construction is complete
Physical Damage to Deepwater Corals		Submersible, ROV or towed camera surveys along route	

Table 13: Modeling Methods for Fisheries and Corals

Impact	What existing models can be used?	Improvements to existing models	New models
Entrainment	Empirical transport model (ETM), Adult equivalent loss model (AELM), Fecundity hindecast (FH)	Addition of life history for species of concern	Include current patterns and intake draw field; comprehensive ecosystem based model of the area near site
Impingement	Estimated catch blocks, fisheries models		
Physical Damage to Shallow Corals	Use existing cable laying software to optimize route		

Table 14: Baseline Assessment for Oceanography

Impact	Baseline Data Needed	Minimum duration for Baseline Data	Justification of duration
Oxygen, Temperature, Salinity, and Nutrients	Climatological data needed. Need spatial and temporal coverage of in the region where the model anticipates the plume will be located. Sampling over a range of frequencies to capture variability. Intensive sampling at one location.	1 – 3 years	Duration will depend upon variability in data; if little variation, shorter duration required
Trace elements and EPA regulated substances	Background concentrations of baseline EPA "hot list" compounds, OTEC facility construction materials (e.g. Fe, Ti, Al), and antifouling agents and plasticizers.	Quarterly for 1 year	Unlikely to have significant temporal or spatial variability

Table 15: Monitoring Strategies for Oceanography

Impact	What should be monitored?	How should this be monitored?	How often?
Oxygen, Temperature, Salinity and Nutrients	Spatial and temporal monitoring of DO, temperature, salinity and nutrients within the plume and in the vicinity.	Appropriate use of combinations of CTD casts; gliders; fixed moorings; monitoring needed at the discharge	Sampling over a range of frequencies to capture variability.
Trace Elements	Spatial and Temporal monitoring of trace metals and OTEC facility fluids and components, EPA hot list plus system materials (e.g. Ti and Al). Seasonal profiles.	In accordance with appropriate EPA sampling and analysis methods	Once a month at discharge; quarterly for receiving waters
EPA regulated substances (e.g., anti-fouling agents, plasticizers)	Concentration in Discharge plume	In accordance with appropriate EPA sampling and analysis methods	Once a month at discharge; quarterly for receiving waters

Table 16: Modeling Strategies for Oceanography

Impact	What existing models can be used?	Improvements to existing models	New models?
Oxygen, nutrients, temperature, salinity	EFDC model; HIROMS model input; ocean observing models; discharge plume model	Model should be further developed and peer reviewed. Modify to be an assimilative model. Should incorporate bio-geochemical components. Needs to be validated by field experiments, including near field current measurements	
Trace elements	Not necessary/applicable in this situation.	Not applicable/necessary	Not applicable/necessary

Table 17: Baseline Assessment for Marine Mammals and Turtles

Impact	Baseline Data Needed	Minimum Duration for Baseline Data	Justification of duration
Entrainment/Impingement	Distribution, abundance and diving depth	1 year assuming normal conditions	
Migratory pattern shift	Distribution, abundance and movement patterns, satellite tracking data	1 year assuming normal conditions and control sites are adequate	
Entanglement	Existing data from Hawaii Marine Debris Program, however not necessarily relevant to entanglement in transmission and mooring lines		
Behavioral changes	Species diving depths, basic distribution and abundance, "habitat use maps"	1 year adequate as long as sample size is sufficient for statistical analyses	
Attractant/Repellant	Distribution, abundance and diving depth		

Table 18: Monitoring Strategies for Marine Mammals and Turtles

Impact	What should be monitored?	How should this be monitored?	How often?
Entrainment/Impingement	Distribution, abundance, changes to CWP flow	Acoustic sensors, flow monitoring	Continuous, automatic
Migratory pattern shift	Migratory pathways (abundance and distribution)	Autonomous acoustic recorder, aerial/visual surveys	Continuous, automatic
Entanglement	Marine debris in region	Visual survey	Daily at surface, quarterly at depth
Behavioral changes (i.e., Attractant/Repellant)	Presence, diversity and behavior	Acoustics and visual	Acoustics: continuous; Visual: Once per season for 4 seasons

Table 19: Modeling Strategies for Marine Mammals and Turtles

	What existing models can be used?	Improvements to existing models	New models?
Behavioral changes	Acoustic propagation/animal movement models (AIM, 3MB); NMFS TurtleWatch	Integrate animal behavior; Modification for different species; validation	

Table 20: Baseline Assessment for Plankton

Impact	Baseline Data Needed	Minimum duration for Baseline Data	Justification of duration
Bacteria	Spatial and temporal abundance and distribution; fate after entrainment	2 years at multiple locations. If data is variable, increase duration	Need to ensure temporal (diel), seasonal, and spatial variations are captured
Phytoplankton and Zooplankton		Multiple sampling events in one location	
Eggs/Larvae			
Micronekton			

Table 21: Monitoring Strategies for Plankton

Impact	What should be monitored?	How should this be monitored?	How often?
Bacteria	Fate after entrainment (i.e., live/deceased abundance), community composition, population density	Acoustics to measure density; advanced molecular techniques for composition; Three sampling stations surrounding OTEC facility plus control.	Dependent on baseline information
Phytoplankton and Zooplankton			
Eggs/Larvae			
Micronekton			

Table 22: Modeling Strategies for Plankton

Impact	What existing models can be used?	Improvements to existing models	New models?
Bacteria	Chlorophyll models from 20yrs hindcast; data set diurnal and seasonality for 4 years off Kahe (1, 5, 15 yrs offshore); use HiROMand existing current models	Fate of organic Carbon	
Micronekton	Models available in University of Hawaii reports		

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