Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

EARTH SCIENCES DIVISION

Presented at the 7th Ocean Energy Conference,
Washington, D.C., June 7-11, 1980

OCEAN THERMAL ENERGY CONVERSION PROGRAMMATIC ENVIRONMENTAL ASSESSMENT

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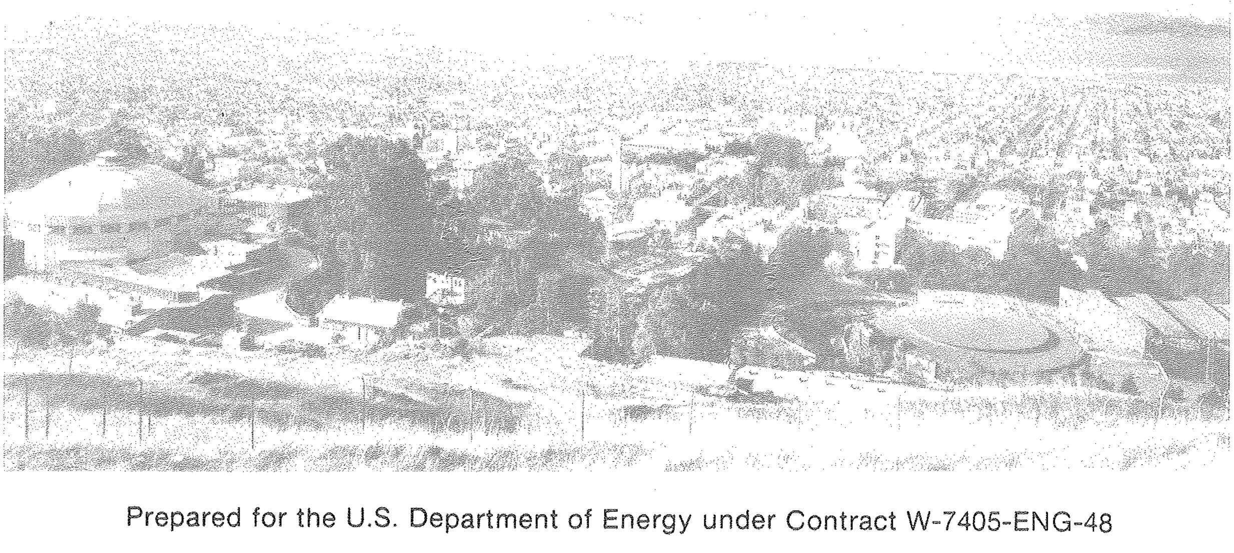
August 1980



Prepared for the U.S. Department of Energy under Contract W-7405-ENG-48

LBL-11832

OCEAN THERMAL ENERGY CONVERSION PROGRAMMATIC ENVIRONMENTAL ASSESSMENT

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Subcontract No. 4501010

to

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August 1980

Prepared for the Assistant Secretary for Conservation & Renewable Energy, Office of Solar Power Applications, Division of Ocean Energy Systems, United States Department of Energy under contract number W-7405-ENG-48.

This manuscript was printed from originals provided by the author.

OCEAN THERMAL ENERGY CONVERSION

PROGRAMMATIC ENVIRONMENTAL ASSESSMENT

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ABSTRACT

Significant achievements in Ocean Thermal Energy Conversion (OTEC) technology have increased the probability of producing OTEC-derived power in this decade with subsequent large-scale commercialization to follow by the turn of the century. Under U.S. Department of Energy funding, Interstate Electronics has prepared an OTEC Programmatic Environmental Assessment (EA) that considers the development, demonstration, and commercialization of OTEC power systems. The EA considers several technological designs (open cycle and closed cycle), plant configurations (land-based, moored, and plantship), and power usages (baseload electricity and production of ammonia and aluminum). Potential environmental impacts, health and safety issues, and a status update of international, federal, and state plans and policies, as they may influence OTEC deployments, are included.

INTRODUCTION

The Ocean Thermal Energy Conversion (OTEC) Programmatic Environmental Assessment (EA) is prepared in compliance with the National Environmental Policy Act (NEPA) of 1969 and considers OTEC development, demonstration, and commercialization. It considers both open- and closed-power cycles in land-based, moored and plantship configurations. The EA is an initial assessment of OTEC technology and will be updated in future years as the technology develops further.

This publication is a summary of the draft EA published earlier this year and presents the relevant findings(1)*. This publication follows the format of the EA describing the proposed action of the EA, characterizing the environments where OTEC may operate and assessing the potential environmental consequences of demonstration and commercialization, extending to the year 2020. The EA also considers the risk of credible accidents, as well as available mitigating measures to reduce these risks. The international, federal and state plans and policies which may influence OTEC development and commercialization are also discussed. Alternatives in the EA largely focus on various engineering designs that will mitigate or reduce impacts.

*Numbers in parentnesis refer to References listed at the end of the paper.

THE PROPOSED ACTION

The Proposed Action considered in this Environmental Assessment (EA) is the development, demonstration, and commercialization of Ocean Thermal Energy Conversion. This EA is programmatic in scope, considering several technological designs (open- and closed-power cycle), plant configurations (land-based, moored, and plantship), and power usages; it will be periodically updated as further information is obtained on OTEC technology and the environmental factors.

OTEC uses the temperature differential between warm surface seawater and cold deep ocean water to produce electrical power by means of gas or steam turbines. The minimal temperature difference required is approximately 20°C, thus the usable geographical regions are limited to those areas where such temperature differentials prevail.

As the first step in EA preparation, an OTEC deployment scenario was developed from several of the scenarios previously completed(2,3,4). From a review of these studies, an estimate was projected of the types and numbers of plants to be deployed by the years 1995 to 2020. The deployment scenario projects that populated island communities will be the first market penetration of OTEC platforms, followed by large numbers of moored plants in the Gulf of Mexico and plantships producing ammonia and aluminum in open ocean regions. Under a very conservative estimate, approximately 60 GW of baseload electricty could be produced by OTEC platforms. The majority of this production would be from moored platforms in the Gulf of Mexico with smaller installations in Hawaii, Puerto Rico, and Guam(1).

In terms of the plantship option, approximately 55 GW of OTEC-produced power could be used to produce ammonia and aluminum(1). The distribution of these platforms is illustrated in Figure 1.

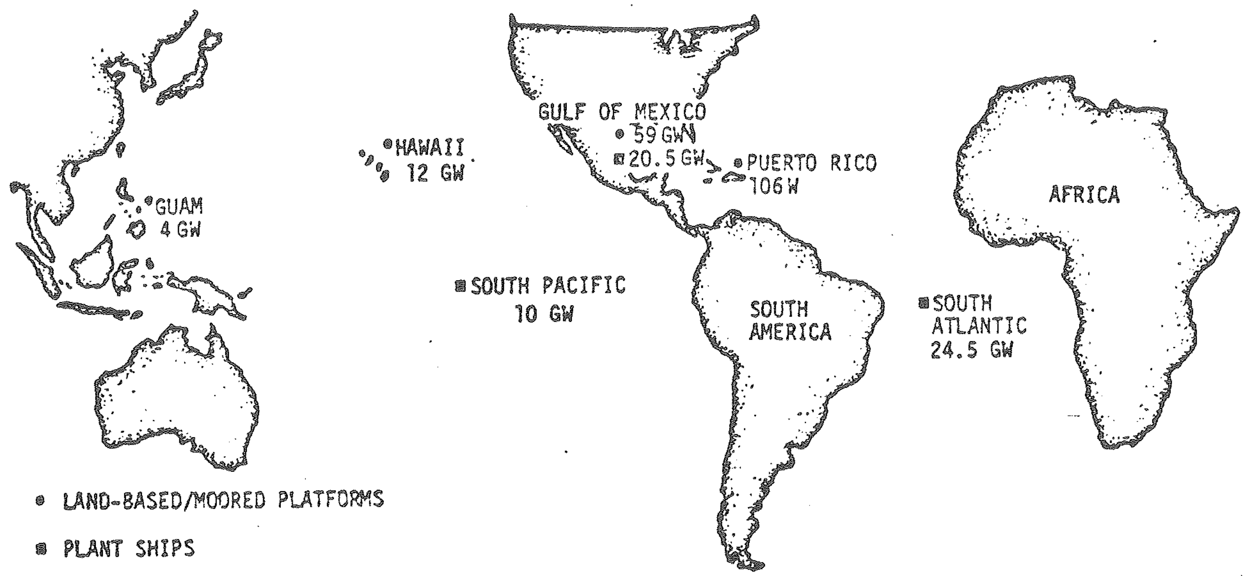


Figure 1. OTEC Programmatic Deployment Scenario

The greater probability of achieving OTEC performance goals with the closed-cycle system has led to its selection as the baseline power system for initial demonstration. The closed-power cycle may be used for land-based, moored, or grazing plantships which produce over 400-MW of power. The open-cycle system is under consideration for possible second-generation application, as warranted by technological developments and analysis. Open-cycle systems will probably be small plants, about 40-MW in size, primarily land-based on island communities, and will produce baseload electrical power and fresh water.

Several different platform configurations, designs, and design components were considered in the EA, with particular emphasis placed on the environmentally significant design components. These elements of the programmatic were previously described in a presentation at the Sixth OTEC Conference(5). One particular contraint for moored OTEC platforms was the inability to moor these larger platforms in waters deeper than 2,150 m. This constraint reduces the siting area in the Gulf of Mexico, as illustrated in Figure 2.

EXISTING ENVIRONMENT

Siting of OTEC plants is geographically restricted between approximately 30° north and 30° south of the equator, where annual surface-to-1,000-m temperature differentials of 20°C prevail. The parameters considered in characterizing the environments were those which (1) describe the salient environmental and economic features under which a platform or cluster of platforms may operate, and (2) facilitate the assessment of impacts. Typical values or characteristics for the parameters were presented, several sources of data were pooled to prepare a generic oceanic characterization.

Data used to describe the OTEC regions included geology (stratigraphy, soil mechanics, bathymetry), physical oceanography (thermal resource, circulation, and light profiles), chemical oceanography (nutrients), marine biology (plankton, nekton, benthos), and socioeconomic profiles (population, economy, power grid sources, natural resources).

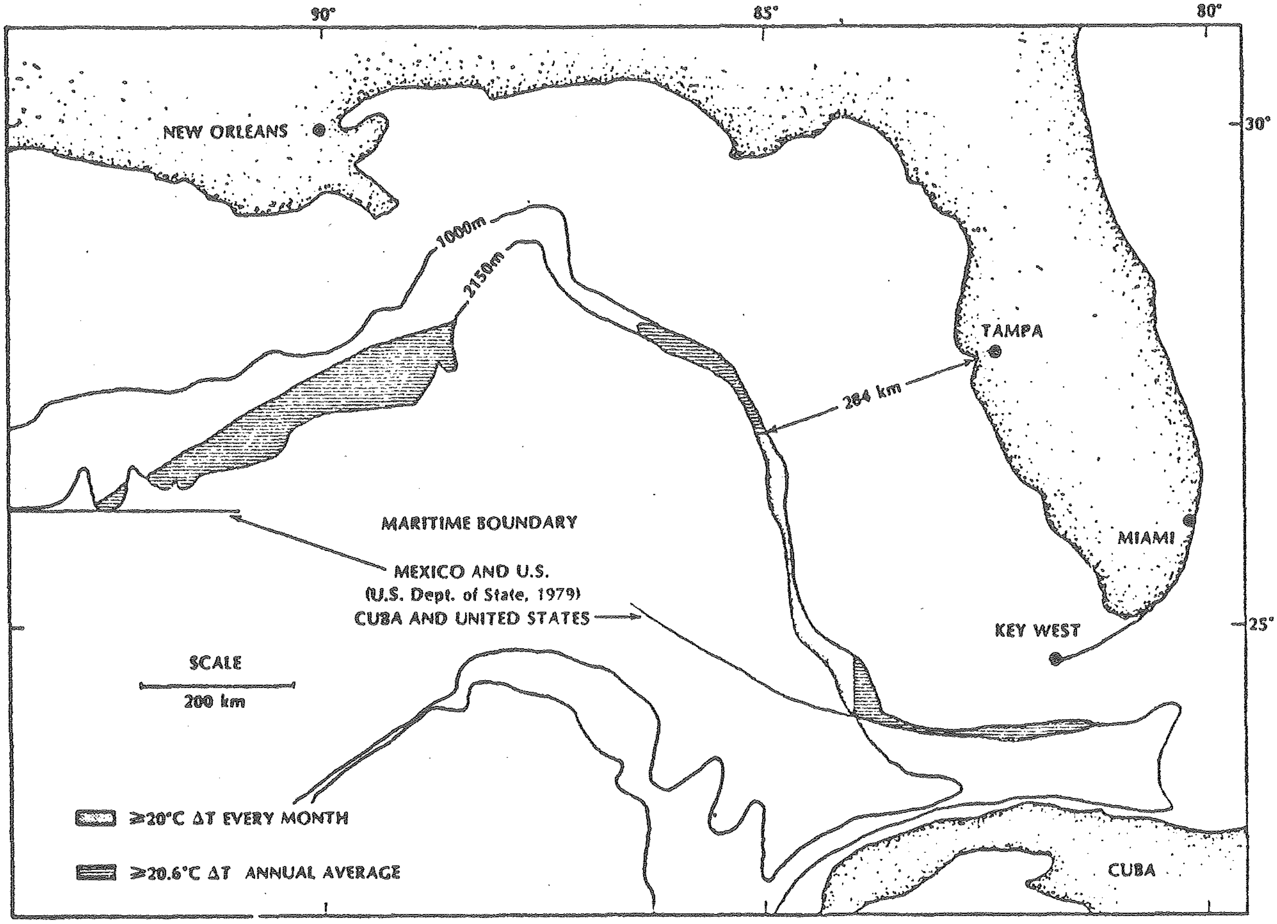


Figure 2. Gulf of Mexico Moored OTEC Resource Area

Generally, the OTEC resource areas may be generically characterized as oceanic, as opposed to coastal or neritic. Oceanic ecosystems are located in stable environments and are responsive to stress. The economic environments range from island communities (such as Hawaii, Puerto Rico, and Guam) totally dependent on imported oil to the Gulf coast of the United States with reserves o. coal, gas, and oil.

POTENTIAL ENVIRONMENTAL IMPACTS

The installation and operation of OTEC plants may potentially affect the terrestrial and marine environment, as well as the atmosphere. The potential environmental impacts center on the marine ecosystem because it is the environment most influenced by OTEC operation. Atmospheric effects include climatic disturbances due to carbon dioxide releases and sea-surface temperature cooling. Measurable atmospheric effects are not anticipated from the deployment of single-platform installations; however, the carbon dioxide releases from large-scale regional deployments of OTEC plants could combine with other man-induced carbon dioxide releases to result in measurable climatic alterations and, therefore, further investigations are warranted.

Land effects will result from the construction of plants and transmission cable entry points. Further site selection studies are necessary to collect terrestrial ecology data to assess these impacts.

OTEC platforms will principally affect the marine ecosystem. The key issues associated with platform(s) deployment and operation include:

- Biota attraction
- Organism impingement/entrainment
- Ocean water redistribution
- Biocide release
- Industrial effluent discharge
- Protective hull coatings release
- Trace element release
- Working fluid release
- Sanitation discharge
- Mooring and cable implantation

The various components of the marine ecosystem by these elements are presented in Table 1.

Table 1. Potential Biological Impacts Resulting From Otec Deployment and Operation

Issue	Chemical Categories		Biological Categories							
	Nutrients	Dissolved Oxygen	Phyto-plankton	Micro-zooplankton	Macro-zooplankton	Gelatinous* Organisms	Micro-nekton	Nekton	Mammals, Birds	Benthos
Platform										
Biota Attraction										
Structure					Major		Major	Major	Major	
Lights					Major		Major	Major	Major	
Oil Releases									Potential	Potential
Protective Hull Coatings Release			Minor	Minor	Major	Minor	Major	Major	Major	
Sanitation Discharges	Minor	Minor	Minor							
Mooring/Cable/Pipe Implantation										Minor
Cold & Warm Water Withdrawal										
Impingement						Major	Major	Major		
Entrainment			Major	Major	Major					
Water Discharge										
Water Redistribution	Minor		Minor							
Biocide Release			Major	Major	Major	Major	Major	Major	Major	
Working Fluid Release			Potential	Potential	Potential	Potential	Potential	Potential	Potential	
Trace Constituent Release			Minor	Minor	Minor	Minor	Minor	Minor	Minor	

Major = Deployment and operation effects potentially causing adverse environmental impacts.
Minor = Deployment and operation effects causing insignificant environmental disturbances.
Potential = Environmental disturbances which occur only during accidents.
Blank spaces imply no environmental effect.

The magnitude of impact resulting from OTEC platform operation will, in large degree, be influenced by the amount of biota attraction. OTEC platforms will provide food and protection to macrozooplankton, micronekton, and nekton. The presence of platforms will increase existing populations as well as establish new communities producing larger biomass abundances than those observed prior to OTEC deployment and operation. This increased biomass will be exposed to the effects associated with routine plant operation, such as organism impingement and entrainment, trace constituent release, and risk of nonroutine events such as spills.

One of the most frequently overlooked characteristics of OTEC platform operation is the immense volume of water that will be circulated. In general, OTEC platforms will circulate over a hundredfold more water per megawatt, than conventional power plants, thus serving to impinge or entrain a much larger biomass quantity and release considerably more biocide used for biofouling control.

The primary factors which determine impingement and entrainment rates are intake flow rates and population desities at the intake depths. Entrainment mortality may approach 100% as a result of mechanical abuse and exposure to large pressure and temperature differentials. Micronekton and nekton are likely to be impinged and will have a mortality rate of nearly 100%. Single-plant installations will affect only localized areas around the plant by reducing standing stocks; however, large-scale deployments may alter the entire regional ecosystem.

OTEC plants will redistribute large quantities of ocean waters which will alter water column thermal structures, salinity gradients, and concentrations of dissolved gases, nutrients, turbidity, and trace constituents. A potential serious effect may result from bringing nutrient-rich deep ocean waters to the surface, which, if discharged in the photic zone, may stimulate primary production in the receiving waters. However, discharge configurations may mitigate or reduce this effect. Large-scale OTEC deployments may influence regional primary production, particularly in the event of severe storms where upper-surface waters would be well-mixed. The combined flow of several OTEC plants may form small-scale "water masses" identifiable downstream of the plants.

Large quantities of chlorine will be used to control the rate of biofouling on the heat exchanger surfaces, and subsequently will be released with the discharged waters to the marine environment. Chlorine reactions in seawater are not well understood and potentially could result in the formation of several new, unidentified compounds of unknown toxicity(6). Chlorine also has been reported to adversely affect phytoplankton at concentrations below the analytical detection limit. Discharge of chlorinated cooling waters for more than 2 hours in any one day is restricted(7) and allowable discharge must average 0.2 mg $liter^{-1}$ over 30 days, with a maximum of 0.5 mg $liter^{-1}$. Therefore, a maximum of 3,700 kg day of chlorine could be discharged to the surface layers of the water column from a 400-MW closed cycle OTEC platform(1). Further laboratory and field studies are required to evaluate the effects from this large-scale chlorine release to the tropical-subtropical oceanic regime.

RISK OF CREDIBLE ACCIDENTS

Crew members of OTEC plants, the adjacent population, and communities served by OTEC plants will be exposed to potential accidents and power failures. Large volumes of the working fluid (ammonia or Freon™) will be stored onboard and present certain health hazards should a collision or large leak occur. Concentrated ammonia is an irritating and corrosive compound which can damage mucous membranes and inhibit respiration of humans and animals.

Ammonia combined with chlorine is an explosive mixture. Freon™ boils at ambient seawater temperatures. Offshore ammonia plantships will present risks to the crew, since production of the explosive ammonium nitrate is a potential intermediary compound. The hazards which exist for aluminum production include the use of fluorine-producing gases and other hazards specific to the manufacturing processes.

Based upon the various agents carried onboard the OTEC platform, a health risk assessment model should be developed for a region basis in order to fully assess the potential of both man-made and nature-induced accidents. A typical hazards summary chart for many of the OTEC chemicals is presented in Table 2.

INTERNATIONAL, FEDERAL, AND STATE PLANS AND POLICIES

OTEC platforms will operate in three jurisdictions: (1) the territorial seas which fall under the jurisdiction of the coastal

Table 2. Potential Hazards Summary

Agent	Source (a)	Physical State (b)	Handling Procedures (c)	Crew Hazard Level (d)	OTEC Hazard Level (e)	Type of Hazard (f)	Neutralizing Agent	Hazard Maintenance (g)	Comments
Anhydrous Ammonia NH_3	1	1,2	1,2,3	1-2	3	1,2,3	Water	1,2,3,4,5,6	Protective clothing and breathing equipment may be required
Carbon Dioxide CO_2	3	2	5	3	4	4	Air Circulation	1	Breathing equipment may be required. Diver hazard.
Chlorine Cl	3	1,2	1,2,3,4,5	1-2	3	3,6	Ventilation	1,2,3,4,5,6	Protective clothing and breathing equipment may be required.
Sodium Hydroxide NaOH	3	1,3	1,2,3,4	3	3	3	Water	3,4,6	Protective clothing and breathing equipment may be required.
Electrical Connections	2,3	—	3	1	4	5	Insulation	2,3,4,5	Protective clothing and devices required
Lubricating Oils	3	1	2,3	3-4	3	1	Containment Boom-Absorbents	3,4,5,6	Spill hazard
Oxygen	4	1,2,4	1,2,3,5	1	1-2	2	Ventilation	1,2,4,5,6	Supports combustion

(a) Source	(b) Physical State	(c) Handling Procedure	(d) Crew Hazard Level	(e) OTEC Hazard Level	(f) Type of Hazard	(g) Hazard Level Maintenance
1. Working Fluid	1. Liquid	1. Containment	1. High	1. High	1. Flammable	1. Circulation
2. Process Product	2. Gas	2. Storage	2. Medium	2. Medium	2. Oxidant	2. Sensor Monitoring
3. Process Requirement	3. Solid	3. Transfer	3. Low	3. Low	3. Toxic/Irritant	3. Visual Monitoring
4. Support Requirement	4. Cryogen	4. Controlled Application	4. None	4. None	4. Sufficant	4. Special Precaution
		5. Ventilation			5. Shock	5. Personnel Training
					6. Corrosive	6. Containment

Note: Other hazardous materials such as acetylene, paints and thinners, etc., will be carried aboard; however, they have not been listed above due to their being carried in minimal quantities and their hazards should be readily discernible.

states; (2) the exclusive economic resource zone, which falls under the administration of the Federal government, and, (3) the high seas which are internationally regulated. Thus, several legal, health, and safety plans and policies come into focus concerning plant licensing, siting, monitoring, and operation. The OTEC thermal resource area is schematically illustrated in Figure 3 as it is influenced by the proposed exclusive economic resource zone.
No legal framework is presently applicable to OTEC platforms. Internationally, OTEC will likely fall under the "Reasonable Use" theory and no regulations will be developed. Alternatively, existing legislation may be amended to include OTEC platforms. At the Federal level, there is no single legal route which applies to siting, licensing, or regulating OTEC platforms: responsibilities and authorities are spread across several governmental agencies. One solution, offered in pending legislation (Studds Bill), may be the designation of a single lead Federal agency. State issues are similarly not clear. Studies are underway to resolve relationships between Federal regulatory laws, civil and criminal laws, maritime laws, and state laws(1).

Crew health and safety is a crucial aspect of OTEC operation in the marine environment, and, it is under a state of flux with the jurisdiction for marine safety given to the U.S. Coast Guard in the Department of Transportation and process safety falling under the Occupational Safety and Health Administration of the Department of Labor(1).

Several aspects of OTEC operation are not currently regulated and will require modification of existing regulations or creation of new laws. Actions in process would bring all responsibilities under Coast Guard jurisdiction. Responsibilities for compliance with U.S. Coast Guard regulations apply to all vessels owned or operated by U.S. companies. The Department of Energy will require the preparation of a Safety Analysis Report that identifies the hazards associated with operation and describes an approach to eliminate or control the hazards.

ALTERNATIVES

The alternatives considered in the EA are within the OTEC technology and include the choice of power cycle (open or closed), platform configuration (land-based, moored, or plantship), discharge design (mixed or separate releases), and intended power use (baseload electricity or at-sea production of ammonia and aluminum).

REOMMENDATIONS OF THE EA

In preparing this initial EA of OTEC technology, several areas were defined which required further study; the recommendations include:

- Large-scale commercialization of OTEC parks within a region (e.g., eastern Gulf of Mexico) may adversely affect the region's ecosystem and have large-scale impacts. Further studies are required to determine the spacing requirements of OTEC platforms in order to minimize environmental impacts.

- Single-platform deployments up to 400-MW potentially offer advantages and minimal environmental risks. However, future impact study efforts should examine site- and platform-specific effects with environmental impact statements for demonstration-size platforms. These impact statements must be completed in advance of construction to examine design options that mitigate or reduce expected enviornmental impacts.

- A thorough report should be prepared that would describe the viable OTEC power cycles and platform options available, as well as discount those options not deemed feasible for early design efforts.

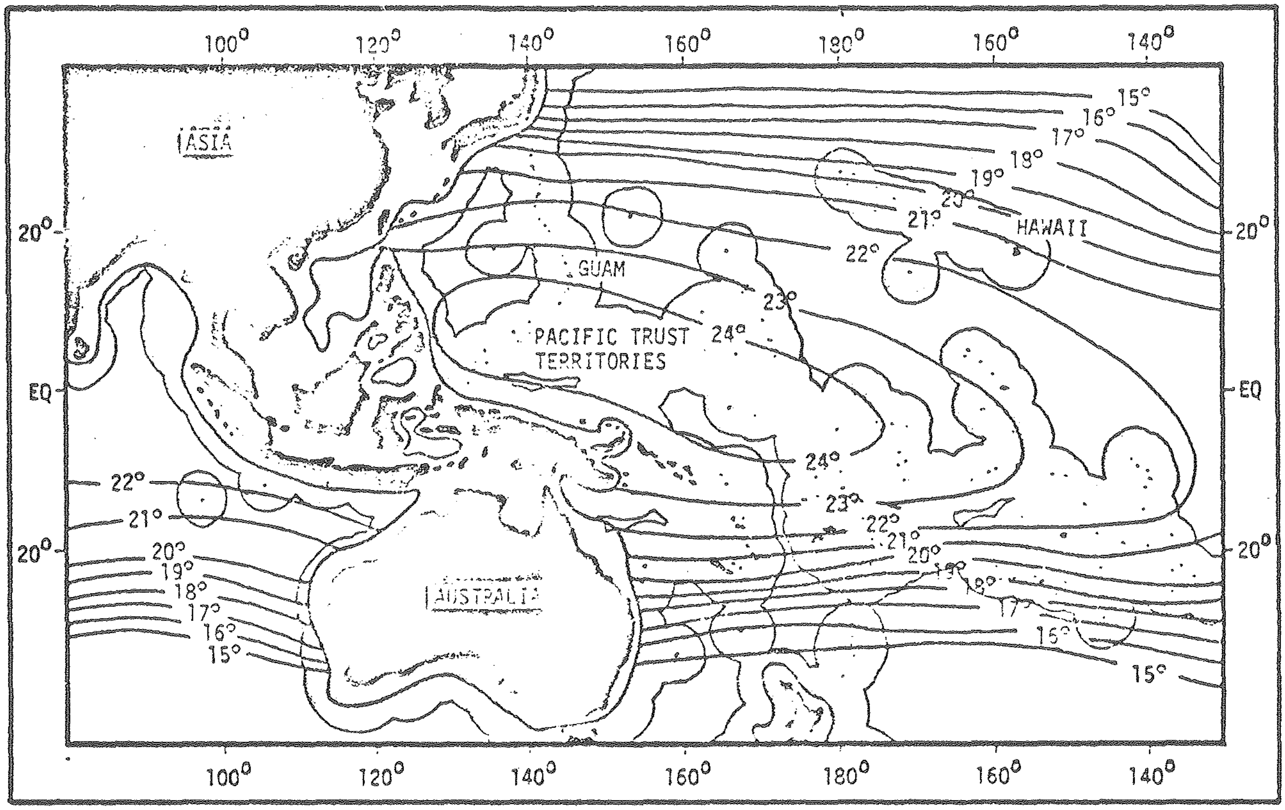
- An OTEC program deployment scenario should be prepared to consider both the open-cycle and closed-cycle systems, different platform design configurations, and various power uses. This scenario would then serve as the basis for future OTEC program plans.

- The open-cycle OTEC system relegated to small-sized island plants, presents some advantages over the closed-cycle system, but both require a detailed environmental assessment to fully evaluate their environmental suitability.

- The use of Freon™ as a working fluid in the closed-cycle system presents undue public health hazards and risks.

- Consideration should be given to the production of shore-based aluminum plants rather than at-sea production, thereby limiting handling of bauxite or alumina.

- Complete platform health and safety plans should be developed for land-based, moored, and grazing platform configurations. This would include the preparation of a Health Risk Assessment Model to evaluate various platform designs and siting locations for overall risk of credible accidents.



SHADED AREAS REPRESENT EXCLUSIVE ECONOMIC ZONES.
TEMPERATURES ARE IN DEGREES C.

BOUNDARY REPRESENTATIONS, NAMES AND SOVEREIGNTY CLAIMS ARE NOT NECESSARILY AUTHORITATIVE.

(U.S. DEPARTMENT OF STATE, 1978)

Figure 3. Economic Resource Zone for OTEC Regimes (Sheet 1)

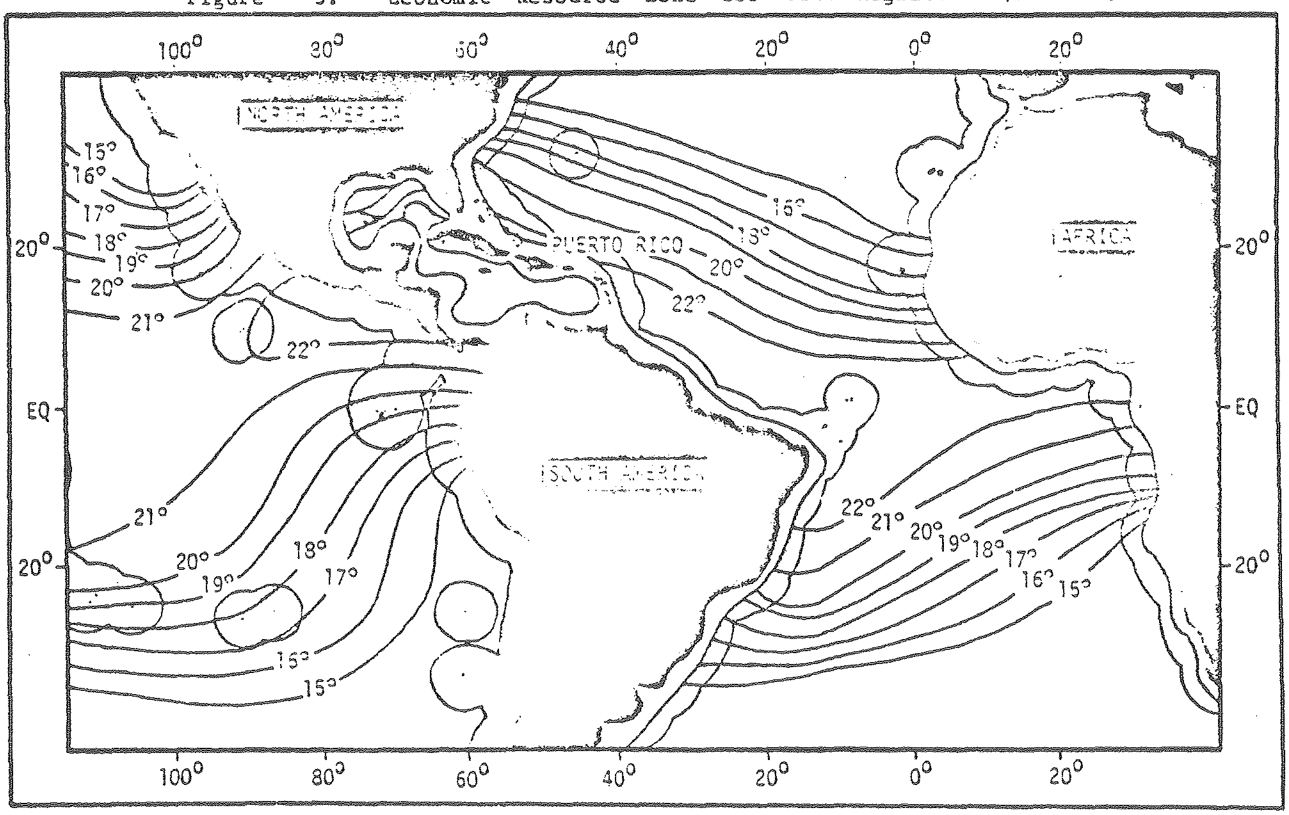


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Figure 3. Economic Resource Zone for OTEC Regimes (Sheet 2)

- An OTEC site slection tiering criterion should be developed and applied to candidate OTEC regions in order to:
  - Select optimal OTEC sites based upon engineering and environmental data requirements.
  - Group optimal locations generically by predominant features and perform environmental baseline studies that may be extrapolated to other regions. Both spatial and temporal variability of the sites must be evaluated.
  - Consider ocean space designation studies for specific types and sizes of OTEC platforms.
- The inherent disadvantage of using chlorine as a biofoulding control agent requires additional research to fully evaluate potential environmental effects. In addition, efforts should continue to select an environmentally preferable candidate for biofouling control.
- Careful examination of present coastal power plant chlorination practices should be made for plants located in subtropical or tropical environments to determine potential impacts applicable to OTEC plants.
- Chlorine-seawater research should be continued in order to identify potential residual oxidants that may be formed.
- Continue bioassay and toxicity studies to determine acute and chronic effects of potential OTEC plant releases.
- Preoperational and demonstration platform environmental impact studies should be performed to gain information that may be extrapolated to larger-scale platforms. Platform designs for intakes, discharges, and chlorine releases should be altered to determine differences in environmental effects.
- Basic food chain studies should be conducted to determine the effects of organism impingement and entrainment from OTEC plant operation.
- Terrestrial ecology surveys should be initiated for candidate land-based locations.
- Climatic influences that may result from large scale OTEC deployments must be evaluated further.
- The development of large-scale, wide-basin models should be continued to examine physical impacts of OTEC plant operation; longer-term goals will call for the preparation of ecological models.
- A mock licensing process at the Federal and International level should be initiated to determine the involved agencies and the applicable regulations.
- An updated programmatic environmental assessment should be periodically reissue to reflect recently obtained information.

CONCLUSIONS

The programmatic environmental assessment is an initial assessment of OTEC technology considering development, demonstration, and commercialization, and concludes that the OTEC development program should continue because the development, demonstration, and commercialization on a single-plant deployment basis should not present significant environmental impacts. However, several areas within the OTEC program require further investigation to assess the potential for environmental impacts from OTEC operation, particularly in large-scale deployments and in defining alternatives to closed-cycle biofouling control:

- Larger-scale deployments of OTEC clusters or parks require further investigations to assess optimal platform siting distances necessary to minimize adverse environmental impacts.
- The deployment and operation of the preoperational platform (OTEC-1) and future demonstration platforms must be carefully monitored to refine environmental assessment predictions, and to provide design modifications which may mitigate or reduce environmental impacts for larger-scale operations. These platforms will provide a valuable opportunity to fully evaluate the intake and discharge configurations, biofouling control methods, and both short-term and long-term environmental effects associated with platform operations.

- Successful development of OTEC technology to maximize use of resource capabilities and to minimize environmental effects will require a concerted environmental management program, encompassing many different disciplines and environmental specialties.

ACKNOWLEDGEMENT

This program was supported under subcontract 4501010 to the University of California Lawrence Berkeley Laboratory as part of their contract number W-7405-ENG-48 with the United States Department of Energy. Special appreciation is extended to Technical Program Manager Dr. Pat Wilde, and to Dr. Lloyd Lewis, DOE Ocean Systems Branch, for their patience and guidance throughout the program.

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