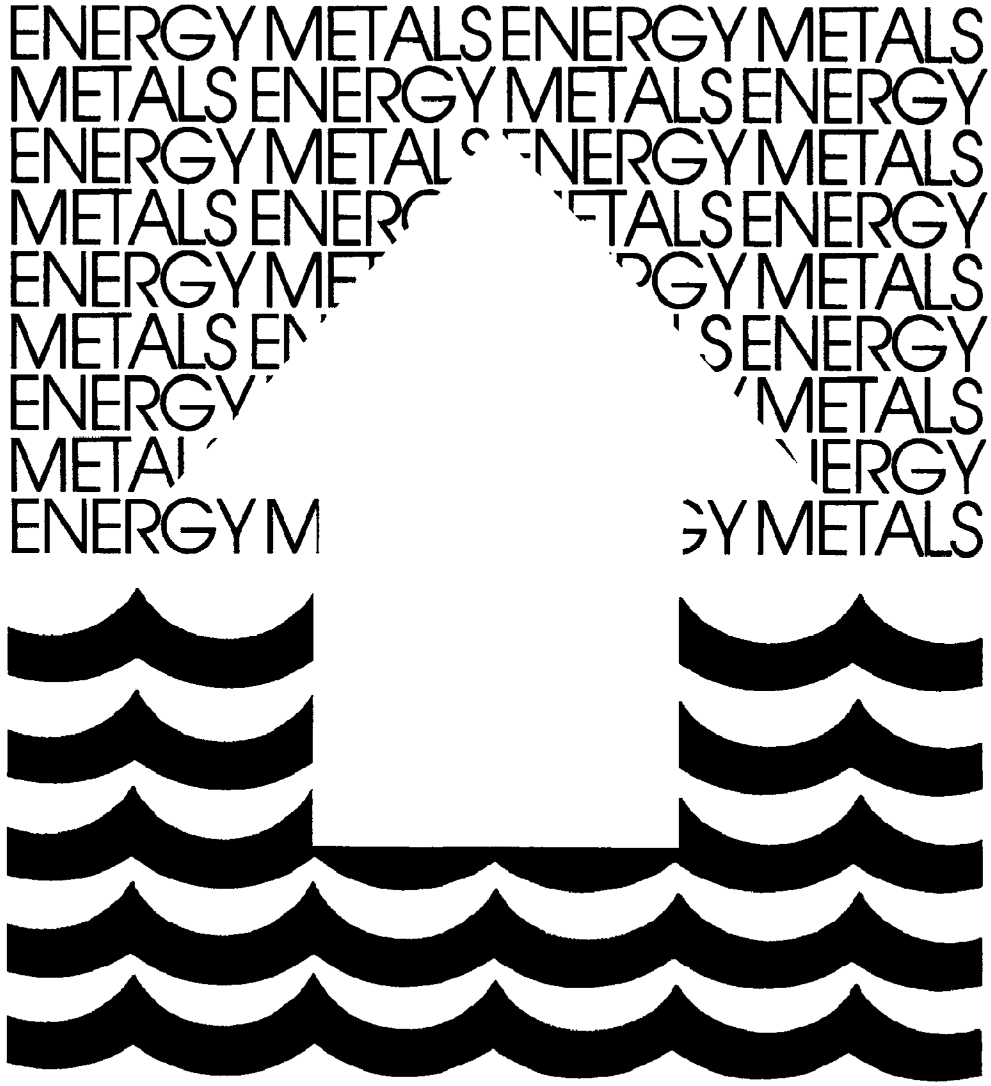

Ocean Thermal Energy Conversion

Environmental Effects Assessment Program Plan
1981 - 85

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Office of Ocean Minerals and Energy
June 1982

Ocean Thermal Energy Conversion: Environmental Effects Assessment Program Plan 1981-85

Prepared by:
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June 1982

U. S. DEPARTMENT OF COMMERCE
Malcolm Baldrige, Secretary

National Oceanic and Atmospheric Administration
John V. Byrne, Administrator

Office of Ocean Minerals and Energy
James P. Lawless, Acting Director

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Washington, D.C. 20230

THE ADMINISTRATOR

JUN 30 1982

Honorable George H. Bush
President of the Senate
Washington, D.C. 20510

Dear Mr. President:

It is my honor to transmit the Ocean Thermal Energy Conversion Environmental Effects Assessment Program Plan 1981-1985 of the National Oceanic and Atmospheric Administration pursuant to Section 107 of the Ocean Thermal Energy Conversion Act of 1980 (P. L. 96-320). This plan describes the program of research for FY 1981-1985 that is necessary to begin to assess the effects on the environment of ocean thermal energy conversion facilities and plantships.

Sincerely yours,

John V. Byrne

Enclosure

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Washington, D.C. 20230

THE ADMINISTRATOR

JUN 30 1982

Honorable Thomas P. O'Neill, Jr.
Speaker of the House of Representatives
Washington, D.C. 20515

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Enclosure

Ocean Thermal Energy Conversion Environmental Effects Assessment Program Plan

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1. BACKGROUND

1.1 INTRODUCTION

Public Law 96-320, the Ocean Thermal Energy Conversion (OTEC) Act of 1980, was enacted on August 3, 1980. The Act sets as its primary goal the establishment of a legal regime which will permit and encourage the development of ocean thermal energy conversion as a commercial energy technology. This goal is to be achieved while providing for protection of the oceanic and coastal environments where OTEC facilities are to be sited and while giving due consideration to preventing or minimizing adverse impacts on other users of the ocean.

Among the provisions of this law is a requirement, in Section 107, that the Administrator of NOAA, ". . . . initiate a program to assess the effects on the environment of ocean thermal energy conversion facilities and plantships." The law further requires (Sect. 107(c)) that The Administrator prepare a plan to carry out this program.

The Administrator has delegated NOAA's responsibilities under P.L. 96-320 to the Office of Ocean Minerals and Energy which, among other activities, has developed the plan, as presented in this document. It is a generic plan regarding the environmental effects of OTEC development and thus extends beyond NOAA's purview. The NOAA part of the plan is discussed in Chapter 3.

The Plan has the primary objective of obtaining the environmental information and knowledge required to allow the commercial development of OTEC to the maximum extent that is compatible with acceptable environmental risk. Such development would provide a solar-based renewable energy source that, in certain areas, can replace energy generated by burning imported and other nonrenewable fossil fuels, such as oil and natural gas.

The development of OTEC will become viable earlier in U.S. tropical and subtropical island communities than on the mainland because OTEC-produced electricity will be cost competitive in those areas sooner. Electricity costs range from two to eight times higher in island communities which are almost totally dependent on imported oil. In addition, many island communities require fresh water, which is a direct beneficial byproduct of open cycle OTEC plants and could be a product of a closed cycle plant if the power was utilized for desalination. As OTEC designs are improved and conventional power costs continue to increase, OTEC power is expected to become cost competitive in certain mainland areas also.

The development of the Plan has had the great advantage of being able to build on a substantial body of on-going and completed research directed toward evaluating the potential environmental effects of the development of OTEC. We gratefully acknowledge the very great role the publications documenting these studies have had in providing the scientific basis for development of the Plan. We especially appreciate the expert advice and guidance that certain Department of Energy (DOE) personnel have provided.

The development of the Plan has also drawn upon the Final Environmental Impact Statement for Commercial OTEC Licensing (NOAA, 1981a) by responding to the research needs related to the potential environmental consequences. It is also responsive to the final regulations for OTEC licensing (NOAA, 1981b) that call for minimal regulation of OTEC activities. Under this regulatory approach, case-by-case (e.g., site-specific) license terms and conditions will be developed so as to allow for variabilities in both the OTEC resource environments and the designs of OTEC plants.

1.2 OCEAN THERMAL ENERGY CONVERSION TECHNOLOGY

Ocean thermal energy conversion (OTEC) is a process for using solar energy stored in the warm surface waters of the tropical and subtropical oceans to perform useful work. This may be generating electricity for domestic and industry consumption, or providing energy for industrial refining and manufacturing activities. Several different techniques have been considered as the basis for OTEC power generation (NOAA, 1981a). These techniques utilize either a closed cycle process or an open-cycle process, or a combination of these basic processes (hybrid systems). The generating capacity of these plants refers to the net power produced and accounts for inherent losses related to plant operation.

1.2.1 Closed Cycle System

The closed cycle system (Figure 1) employs a working fluid (most likely ammonia, although a number of candidates are being considered) enclosed in a system of piping. This fluid is exposed across a heat exchanger surface to oceanic surface waters that have been warmed by the sun. As the working fluid warms, it vaporizes and this expanding vapor passes through and drives a gas turbine, producing electricity. The electricity can be distributed to industrial and residential users, or used directly on site to power energy-intensive processing or manufacturing activities. After passing through the turbine, the working fluid is returned to the liquid phase by exposure in a heat exchanger to cold water drawn from the deep ocean. The working fluid is then revaporized by being pumped back through the warm water heat exchanger, and the cycle is repeated. This means of power generation does not use any fuel. It is based on the cyclical vaporization and condensation of the working fluid that is made possible by taking advantage of the temperature difference between the sun-heated surface waters and the perpetually cold, deep waters of the tropical oceans. Even the pumps used to draw in the warm and cold water do not need conventional fuel as they are powered by a part of the energy produced by the process itself.

1.2.2 Open Cycle System

The open cycle system (Figure 2) is, in most ways, quite similar to the closed cycle system. However, in the open system the seawater itself is the

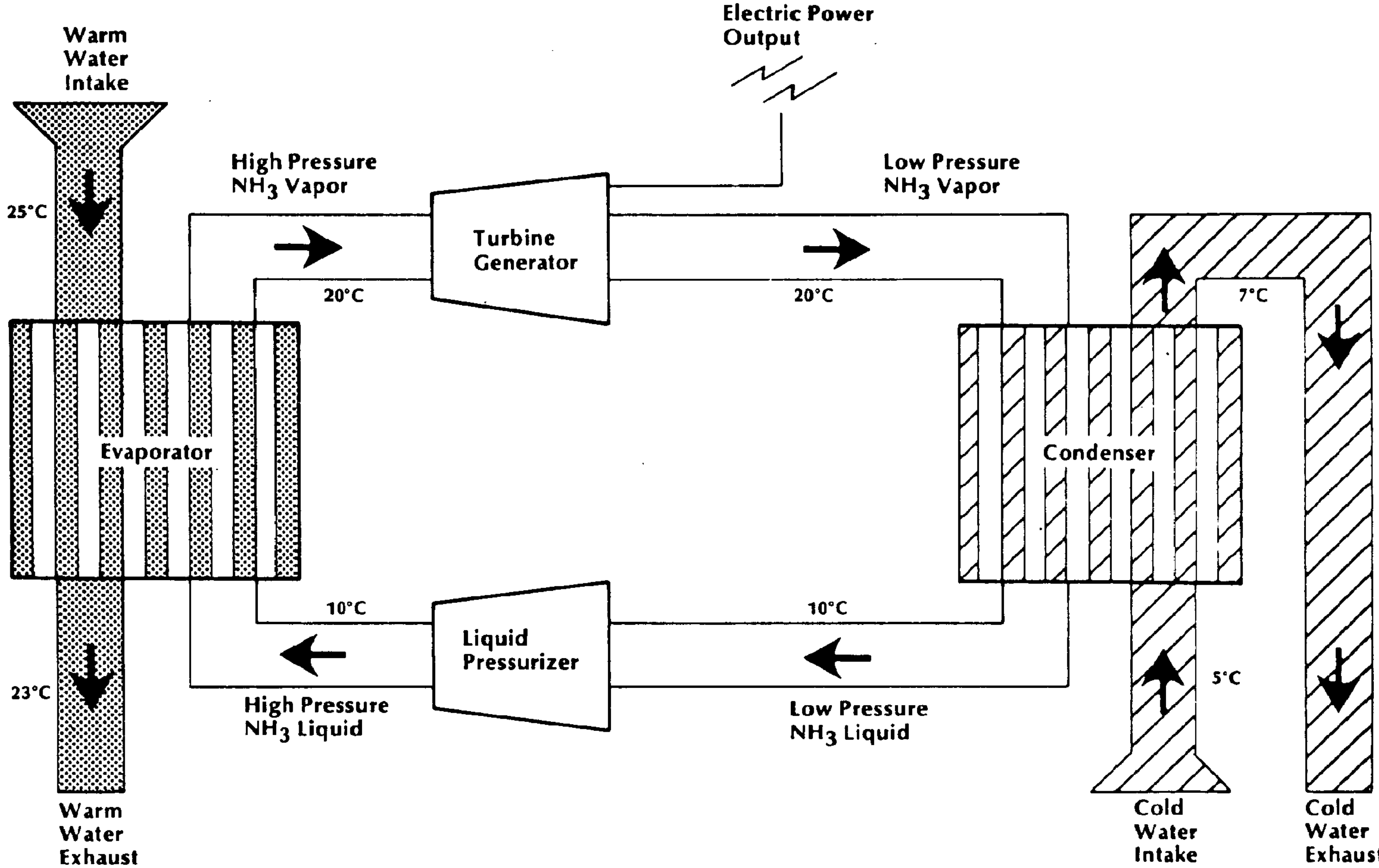


Figure 1. Schemactic Diagram of a Closed-Cycle Power System (Adapted from DOE, 1979a)

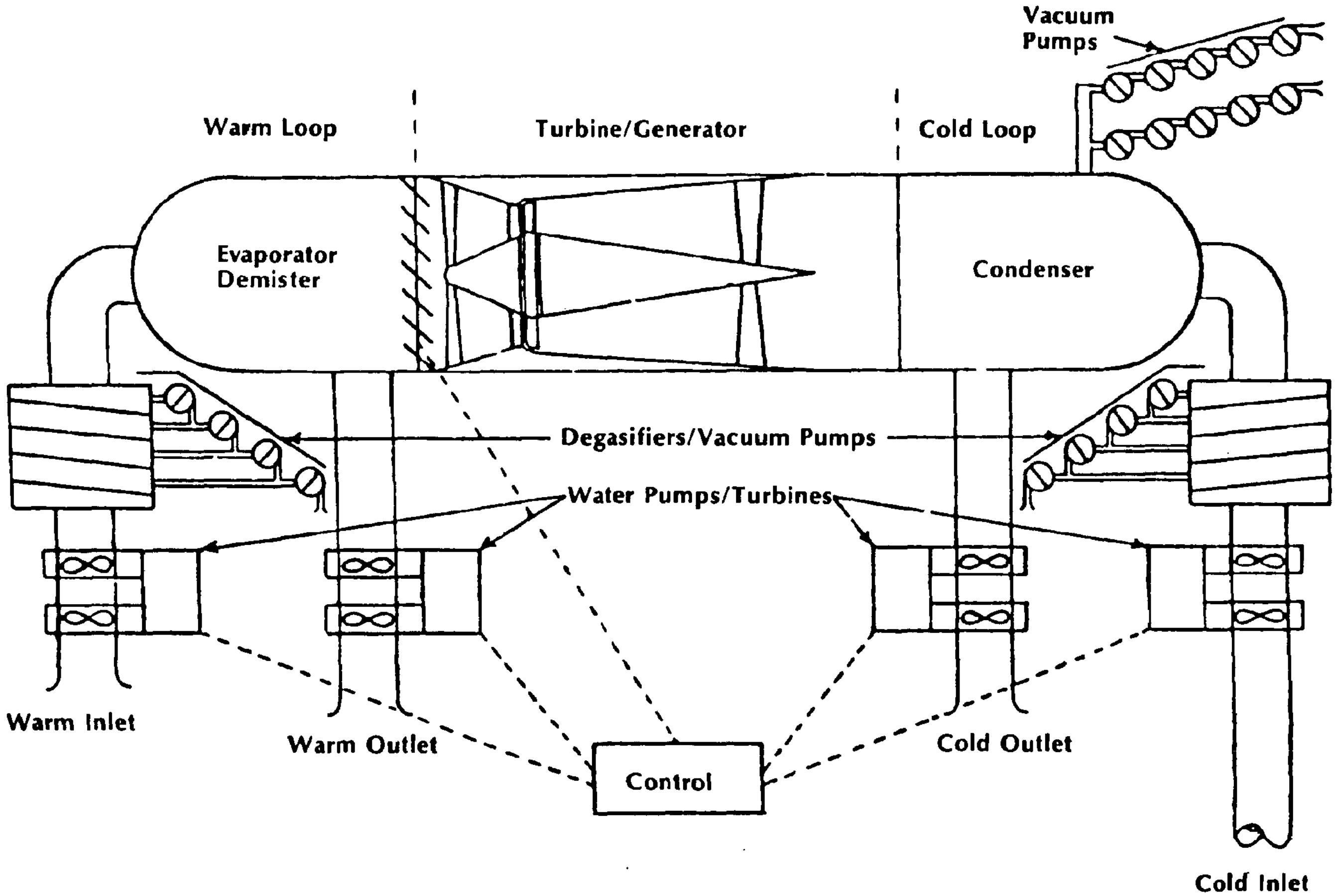


Figure 2. Schematic Diagram of an Open-Cycle OTEC Power System (Adapted from Watt et al., 1977)

working fluid. Warm surface water is pumped into an evaporator in which the pressure is reduced to the point where the seawater boils and about one-percent evaporates. The resultant steam passes through and drives a steam turbine resulting in electricity or other usable energy as in the closed system. After leaving the turbine, the steam is cooled and condensed by exposure to cold, deep water in a heat exchanger.

The open cycle technique has the advantage that the dissolved salts do not accompany the surface water when it forms steam. Thus, a valuable byproduct, fresh water, results when this steam condenses. To maintain the efficiency of the open cycle technique, however, it is necessary to remove non-condensable gases, such as oxygen and carbon dioxide, before the steam passes through the turbine. These gases must be either discharged into the atmosphere or injected into the water being discharged from the plant.

The earliest commercial applications of the OTEC principle are expected to use the closed cycle process. There is, however, considerable interest in open cycle applications because of the additional benefit of fresh water production.

1.2.3 OTEC Applications

Generation of electricity is expected to provide the first commercial application of the OTEC process. This will probably be from facilities which are moored to or mounted directly on the ocean floor, or located partly on land with their intake and discharge pipes extending out into the ocean. The electricity from moored or bottom-mounted facilities will be brought to shore by transmission cables. OTEC facilities located partly on land could be located in areas where deep water is found very close to shore; such sites exist in Hawaii, Guam, and other U.S. islands. OTEC facilities are expected to vary in size from about 10 megawatts-electric (MWe) (a size suitable for small islands) to about 400 MWe (about half the size of a large nuclear power plant).

Another possibility for the implementation of the OTEC process is to use the energy produced directly on the site. It could be used for production of energy-intensive products, such as hydrogen or ammonia, or for energy-intensive processing activities, such as aluminum smelting.

Such onsite manufacturing or processing could take place on facilities situated on, or close to, shore. For the offshore facilities, the product would be moved ashore by a product pipeline or by vessels. However, the onsite application of OTEC does not require a direct connection with land, as vessels can transport the products to their destinations. Thus, self-contained plantships that would use OTEC techniques to obtain the energy needed to run onboard manufacturing or processing activities could float unmoored or move slowly under their own power as they sought out and followed optimum thermal gradient conditions. Such plantships are expected to employ closed cycle systems. Ammonia will probably be the first product produced on OTEC plantships. Within this document, stationary facilities and moving plantships are collectively referred to as plants.

1.2.4 Thermal Resource Requirements

OTEC plants will depend on the temperature difference between warm water withdrawn near the surface and cold water withdrawn 500-1500 meters below the surface to drive a heat engine. A thermal difference of 18° to 20°C is required to make the operation of an OTEC facility cost-effective. The maximum difference available in the tropical oceans of the earth is about 22 to 24°C (Figure 3). Around the shores of the United States, a somewhat lower value, approximately 22°C, is the maximum available. With a difference of 20°C, a 100 MWe plant will require intake of surface water at a rate of 400-700 cubic meters per second (Allender et al. 1978); larger flows will be required for lower temperature differences and, conversely, smaller flows will be required for larger temperature differences. The Gulf of Mexico area on the mainland as well as tropical islands such as Hawaii, Puerto Rico, and Guam are the locations where thermal differences provide the most promising conditions for OTEC development (Figures 3 and 4).

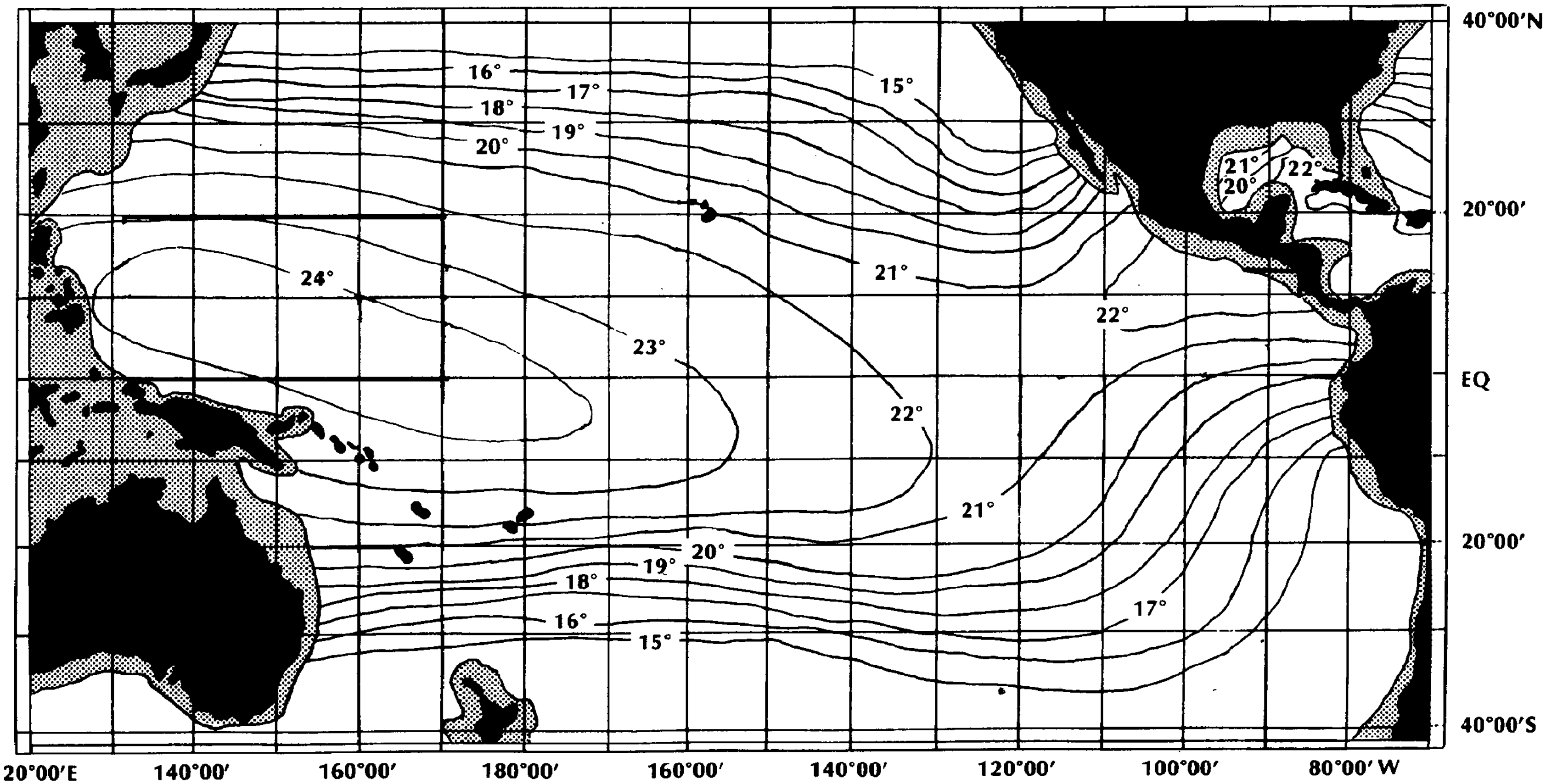
1.3 DEVELOPMENT SCHEDULE

The basic idea for OTEC development has been in existence for a number of years. Several other nations have explored and are continuing to investigate the possibilities for commercialization of OTEC technology. The French funded but then abandoned a large-scale OTEC development project in the 1930's.

The developing domestic shortage of oil reserves and the resulting dependence on foreign sources of supply and higher prices awakened U.S. interest in this process in the early 1970's. Development of OTEC technology was especially stimulated by the passage of the Solar Energy Research, Development, and Demonstration Act (P.L. 93-473) in 1974. Since that time the Department of Energy and its predecessor organizations have been vigorously conducting a program to develop and introduce economically competitive and environmentally acceptable OTEC systems.

At present OTEC development has progressed to a point where ocean tests of the system are feasible. A "proof of concept" demonstration using an experimental, barge-mounted, closed cycle power system with cold water pipe (Mini-OTEC) was successfully deployed in August, 1979 off Keahole Point, Hawaii, by a consortium including several major corporations and the State of Hawaii. The 50-kilowatt (kw) generators on this system ran two 20 horsepower seawater pumps and produced slightly in excess of 10 kw of net electric power.

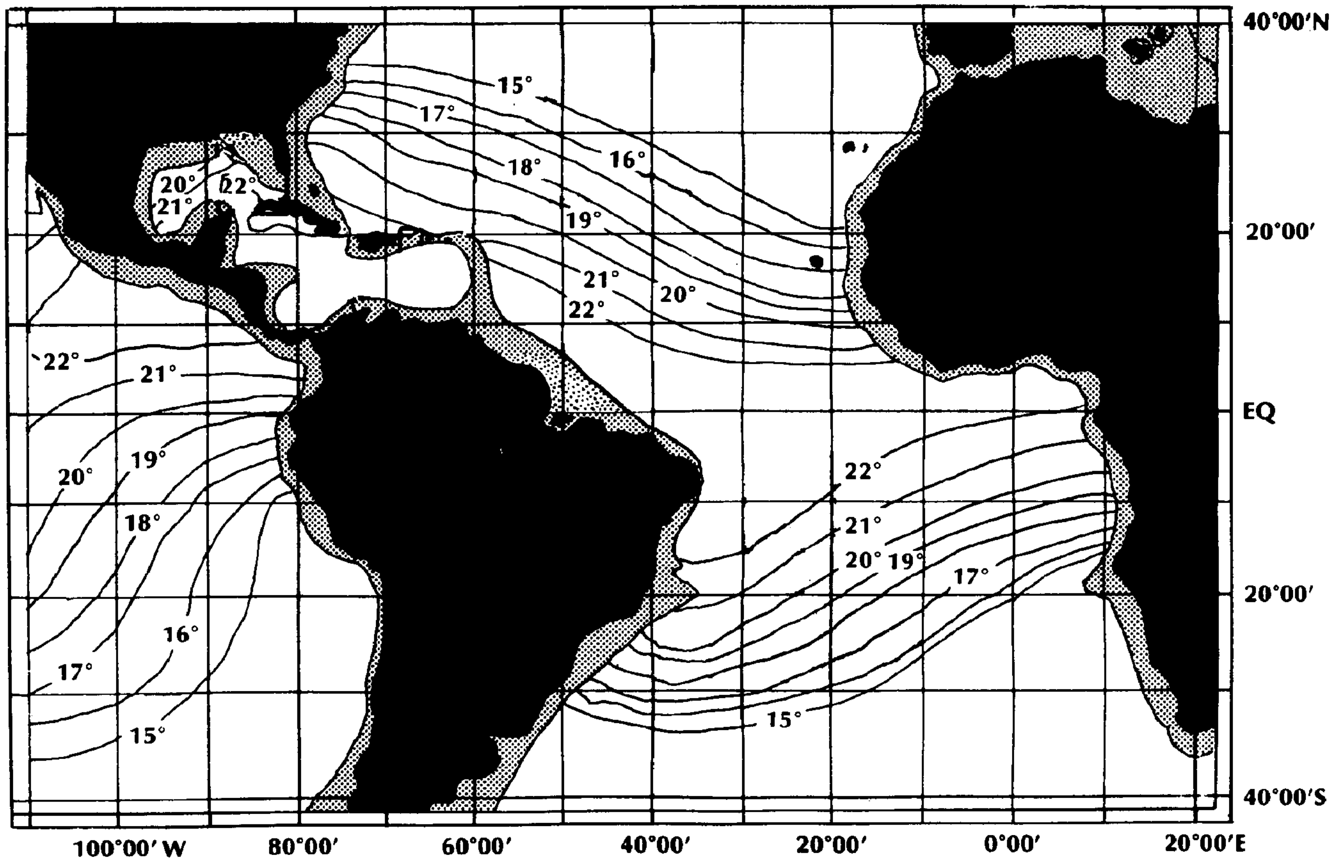
The Department of Energy also supported a larger scale at-sea test of OTEC technology, using a former Navy Reserve Fleet tanker which was modified to support closed cycle components, including heat exchangers, pumps, cold water intake pipes, and working fluid systems. This system, the OTEC-1 Engineering Test Facility, served as an at-sea testing platform for heat exchangers and biofouling control measures. OTEC-1 was deployed in late 1980 off Keahole Point, Hawaii, and tests were concluded in April, 1981. The results of these tests are still being analyzed.



< 1000 m deep

***Contours indicate temperature differential (°C) between surface and 1000 m depth**

Figure 3. The OTEC Thermal Resource Area (Pacific)



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*Contours indicate temperature differential (°C) between surface and 1000 m depth

Figure 4. The OTEC Thermal Resource Area (Atlantic)

If the economics are favorable, large OTEC plants may be producing substantial amounts of baseload electricity for transmission to utility grids by the 1990's. Smaller plants to serve U.S. tropical and subtropical islands may be developed even faster than this, and several of these could start operations in the present decade.

Electric generating plants will very likely be the first large-scale commercial use of the OTEC concept. However, stationary OTEC platforms and moving plantships with on-board energy-intensive manufacturing and processing facilities also hold high promise. The first of these may well be built within the next ten years and substantial development may have taken place by early in the next century.

1.4 LEGAL AND REGULATORY FRAMEWORK

The stated purposes of the Ocean Thermal Energy Conversion Act of 1980 (P.L. 96-320) are, "To regulate commerce, promote energy self-sufficiency, and protect the environment, by establishing procedures for the location, construction and operation of ocean thermal energy conversion facilities and plantships to produce electricity and energy-intensive products off the coasts of the United States; to amend the Merchant Marine Act, 1936, to make available certain financial assistance for construction and operation of such facilities and plantships; and for other purposes." The development of OTEC technology is to be achieved with due regard for other uses of the coastal seas and open oceans and for avoiding or minimizing environmental damage.

The Act directed the Administrator of the National Oceanic and Atmospheric Administration (NOAA) to establish a licensing program governing the ownership, location, construction, and operation of OTEC facilities and plantships other than demonstration projects so designated by the Secretary of Energy. This was accomplished in August, 1981 (NOAA, 1981b) and governs OTEC activities conducted by United States citizens on the high seas and the ownership, construction, and operation of OTEC facilities and plantships documented under United States law, located in the territorial seas of the United States, or connected to the United States by pipeline or cable. The licensing program ensures that OTEC facilities are constructed and operated with due regard for national interest and security, the jurisdictions of other nations, environmental protection, other uses of the oceans and coastal zone, other OTEC facilities, and the avoidance of antitrust violations. The Administrator is empowered to prescribe the conditions when issuing a license that he deems necessary to protect these interests or that are required by any Federal department or agency. The licensing regulations also provide for consultation and cooperation with all other interested Federal agencies and departments, with potentially affected coastal states, and with the views of interested members of the general public.

The Act further directs NOAA to initiate a program to assess the environmental effects of OTEC facilities and plantships. It specifies that this program must address the short- and long-term effects of individual and multiple deployments of OTEC facilities and plantships, as well as submarine electric transmission cables and other associated equipment located in the water column or on the seabed. Specific areas which are to be considered include the nature and magnitude of any oceanographic, atmospheric, weather, climatic, and biological changes associated with OTEC development as a commercial energy technology. The research program is to be designed to provide the information necessary to determine whether or not the potential cumulative environmental effects of OTEC development require placing an upper limit on the number or total capacity of the OTEC plants that receive licenses must also be addressed. This document contains the initial plan for carrying out this environmental assessment.

The Secretary of the department in which the Coast Guard is operating is required by the Act to establish by regulation and to enforce procedures with respect to the equipment, training, and maintenance required for OTEC facilities and plantships to promote safety of life and property at sea, prevent pollution of the marine environment, clean up any pollutants which may be discharged from OTEC facilities and plantships, and prevent or minimize any adverse impacts from construction and operation of OTEC facilities and plantships. The Secretary is further directed to promulgate (after consultation with NOAA) and enforce regulations governing the movement and navigation of OTEC plantships to ensure that their discharge plumes do not interfere with the operation of other OTEC plantships or facilities, or adversely affect the territorial sea or area of national resource jurisdiction of any nation.

The Administrator of NOAA and the Secretary of the Department in which the Coast Guard is operating share responsibilities for enforcement of the Act and regulations issued under it. The Administrator is charged with establishing compliance monitoring requirements on OTEC licensees. These requirements may include placing Federal officers or employees aboard OTEC facilities and plantships, as well as requiring monitoring of environmental effects of OTEC operations conducted by licensees.

2. ENVIRONMENTAL RISK

The net environmental impacts due to commercial OTEC development are expected to be minimal compared to the impacts from fossil-fuel and nuclear power production; however, there are uncertainties associated with the redistribution of large volumes of ocean water that must be more adequately assessed (NOAA, 1981a). This chapter discusses the environment of the thermal resource area, the environmental concerns, and the research needed to reduce or mitigate these uncertainties to an acceptable level.

2.1 THE POTENTIALLY AFFECTED ENVIRONMENT

This section, condensed directly from the Final Environmental Impact Statement (FEIS) for commercial OTEC licensing (NOAA, 1981a) provides a generic description of the oceanic, nearshore, and coastal environments within the OTEC thermal resource area. As noted in Figure 3, the thermal resource area includes the eastern Gulf of Mexico, several island communities (Hawaiian Islands, Puerto Rico, U.S. Virgin Islands, Guam, and the Pacific Trust Territories), and various plantship areas in the open ocean.

2.1.1 The Atmosphere

2.1.1.1 Climate - Climates within the OTEC resource area are influenced by large-scale atmospheric patterns, the sea-surface temperature of surrounding ocean waters, and proximity of landmasses. Two basic types of climates, maritime and oceanic, occur within the OTEC resource area. Maritime climate is strongly influenced by continental landmasses and is characaterized by larger, more rapid temperature changes than the oceanic climate. The oceanic climate is influenced to a greater degree by the ocean's sea-surface temperature than the maritime climate, and is therefore characterized by smaller, more gradual temperature changes.

Local maritime climates within the OTEC resource area are often influenced by an onshore-offshore wind cycle caused by differential heating of land-masses and ocean waters. In areas with steep coastal mountain ranges, such as the Hawaiian Islands, this wind cycle causes moisture-laden marine air to cool as it rises against the coastal mountains, losing its moisture as precipitation. Consequently, the windward sides of such islands typically experience heavier rainfall than the leeward side (University of Hawaii, 1973). Strong upwelling zones nearshore, although unlikely sites for OTEC development, can modify this pattern. Surface layers of cold upwelled water can cause the moisture-laden marine air to precipitate before reaching land. Such regions have heavy fogs and arid desert-like coastlines.

2.1.1.2 Tropical Storms and Hurricanes - The OTEC thermal resource area is within the tropical trade wind belt. Large-scale atmospheric disturbances in this area are known as tropical cyclones and are classified according to windspeed: tropical depressions are cyclones with maximum sustained windspeeds below 119 kilometers per hour; hurricanes are cyclones with windspeeds exceeding 119 kph. Tropical cyclones commonly occur from May to November in the northern half of the trade wind belt, and from December to June in the southern half (Crutcher and Quayle, 1974). Tropical cyclones are most frequent in the eastern and western North Pacific. In the western North Pacific and the North Atlantic, cyclones reach hurricane intensity more often than in the eastern North Pacific. Hurricanes are frequent occurrences in the Gulf of Mexico and Carribean Sea. No hurricanes have been observed in the South Atlantic.

2.1.1.3 Carbon Dioxide - The atmosphere and the world oceans are the two major reservoirs of carbon dioxide. The oceanic reservoir is estimated to contain 3.5×10^{16} kilograms of carbon dioxide in its various chemical forms, whereas the atmosphere contains about 6.4×10^{14}kg (Brewer, 1978); however, the atmospheric carbon dioxide concentration is steadily increasing. Carbon dioxide levels before the industrial revolution have been estimated at 270 to 290 parts per million (ppm) by volume; present-day levels are approximately 330 to 335 ppm (Keeling and Bacastow, 1977). The combustion of fossil fuels is the major source of atmospheric carbon dioxide increases; additional sources are cement production, which involves the removal of carbon dioxide from limestone, and massive reductions in terrestrial biomass from the clearing of forests, burning of firewood, and large-scale agricultural practices (Brewer, 1978).

The influence of vegetation on atmospheric carbon dioxide concentration is evident in seasonal cycles of carbon dioxide concentrations. This annual variation, averaging 6 to 7 ppm in the tropics, is attributed to the uptake of carbon dioxide by green plants during summer growth periods and release of carbon dioxide through decomposition and respiration during winter months (Brewer, 1978). Large-scale destruction of forests in the tropical-subtropical regions has released large amounts of carbon dioxide and significantly reduced the land's capacity to absorb atmospheric carbon dioxide.

The deep ocean is a major sink for carbon dioxide. Since carbon dioxide is less soluble in warm water than cold water, warm ocean waters contain less carbon dioxide than colder ocean waters. In equatorial waters, carbon-dioxide-rich water is sufficiently warmed to release carbon dioxide to the atmosphere. This region is an area of carbon dioxide outgassing, whereas polar areas, where cold bottom waters are formed, are sinks for atmospheric carbon dioxide.

Although the increase in atmospheric carbon dioxide can be readily measured, the oceanic carbon dioxide increase is more difficult to detect. Presently, the detection limit for carbon dioxide measurement in seawater is 50 parts per million, which approximates the total atmospheric increase of carbon dioxide since the beginning of the industrial revolution. Consequently, it is difficult to estimate the impact of industrial atmospheric increases in carbon dioxide on oceanic carbon dioxide concentrations and to predict the capacity of the oceans to assimilate further increases in atmospheric carbon dioxide.

2.1.2 The Marine Environment

Physical, chemical, and biological properties in marine waters within the OTEC resource area are not homogeneous but do exhibit some continuity and uniformity, especially in terms of horizontal and vertical trends.

Circulation patterns within the OTEC resource area are important because they affect thermal resource renewal and discharge plume dynamics. Circulation patterns should both replenish the withdrawn water and disperse the discharged water used by OTEC plants, thereby maintaining the thermal resource. Subsurface currents and internal waves will apply stress to the cold-water pipe; winds, waves, and tidal currents will apply forces that act on the platform.

Chemical characteristics relevant to OTEC environmental assessments include nutrient and dissolved oxygen profiles from the surface to the intake, discharge, and plume stablization depths. These values are necessary for assessing the effect of water mass redistribution. Tables 1 and 2 summarize the available physical and chemical data for several major regions of the OTEC resource area.

One of the most marked features of the marine environment is the transition from nearshore to offshore marine environments. The nearshore environment is the region extending seaward from the shore that is influenced by continental conditions, such as terrestrial runoff, tidal mixing, and coastal upwelling. The nearshore region is highly productive and the location of most of the major world fisheries, thus its extent varies both geographically and seasonally. The offshore environment is minimally influenced by continental conditions.

2.1.2.1 Nearshore Environment - The nearshore marine environment can generally be defined as the region between the shoreline and continental shelf break, encompassing the intertidal, subtidal, inner-continental shelf, and outer-continental shelf regions. Circulation patterns of nearshore areas are variable, and are primarily driven by winds and tides, with some influence from large-scale oceanic currents. Tidal currents frequently reach velocities of 100 to 150 centimeters per second. Strong tidal currents, seasonably variable winds, and irregularities in circulation patterns cause high mixing of surface and bottom waters in nearshore areas.

Physical processes along the edge of continental margins cause upward mixing of nutrient-rich deep waters, resulting in higher productivity at some distance offshore of the continental shelf. Additionally, coastal upwelling of nutrient-rich deep waters usually occurs in areas with narrow continental shelves (e.g., west coast of North America, most island systems), and is caused by: (1) winds blowing parallel to shore, or (2) current divergences towards the surface caused by continental features (e.g., escarpments, headlands, submarine canyons). The upwelled nutrient-rich waters that result from mixing over the continental shelf may be transported offshore by prevailing current systems.

Two types of nearshore environments are present in the OTEC resource area. The Gulf of Mexico has a wide (hundreds of kilometers), shallow shelf strongly influenced by coastal processes. Wind-induced turbulence, freshwater input, tidal mixing, and partial isolation from the major ocean basins by the wide continental shelf significantly affect the nearshore environment in the Gulf of Mexico, causing high seasonal variability of physical, chemical, and biological properties. Conversely, near-shore environments near islands are

Table 1. Physical and Chemical Characteristics of OTEC Resource Areas

Parameter		ISLANDS (Hawaii, Puerto Rico, Virgin Islands, Pacific Trust Territories, Guam)	OCEAN (Atlantic and Pacific)	Gulf of Mexico
Mixed-Layer Depth (m)		40-100 [a,b,c]	10-80 [d,e]	60-120 [f]
Photic-Zone Depth (m)		120-140 [g,h]	120-140 [g,h]	50-125 [i]
Nitrate	0-50 m	0.05-0.7 [j,k,l]	0.04-0.2 [m,n]	0.17-1.0 [i,o]
($mg\text{-}atom\ m^{-3}$)	125 m	0.6-0.7 [k,l]	0.2-0.5 [j,o]	7 [o]
	900 m	23-45 [j,k,p]	29-34 [q]	30 [o]
Phosphate	0-50 m	0.2-0.4 [j,l.r]	0.1-0.26 [n,q,s]	0.07-0.5 [i,t]
($mg\text{-}atom\ m^{-3}$)	125 m	0.2-0.5 [j,l,r]	0.3-0.6 [q]	0.5 [t]
	900 m	2.0-3.0 [j,r]	1.4-2.0 [m,q]	1.9 [t]
Silicate	0.50 m	1.0-4.8 [o,j]	0.0-2.4 [n,q]	0.5-4.4 [i,o]
($mg\text{-}atom\ m^{-3}$)	125 m	1.0-3.7 [o,j]	5-25 [q]	2 [o]
	900 m	25-86 [o,j]	20-150 [q]	25 [o]
Dissolved	0-50 m	4.8-7.5 [j,l,u]	4.3-4.8 [m,n,u]	4.8 [v]
Oxygen	125 m	3.0-7.4 [j,l,u]	3.0 [n,u]	3.6 [o]
($ml\ liter^{-1}$)	900 m	1.0-3.4 [j,u,w]	3.4 [u]	3.9 [o]

(a) ODSI, 1977a
(b) ODSI, 1977b
(c) ODSI, 1979a
(d) ODSI, 1979b
(e) Molinari and Chew, 1979
(f) ODSI, 1977c
(g) Hargraves et al., 1970
(h) Gundersen et al., 1976
(i) EL-Sayed et al., 1972
(j) Lawrence Berkeley Laboratory, 1980
(k) Atwood et al., 1976
(l) Gunderson and Palmer, 1972
(m) Arsen'ev et al., 1973
(n) Love, 1971
(o) Cummings et al., 1979
(p) Gundersen et al., 1972
(q) Sverdrup et al., 1942
(r) Halminski, 1975
(s) Schulenberger, 1978
(t) Churgin and Halminski, 1974
(u) Gross, 1977
(v) Michel and Foyo, 1976
(w) Gordon, 1970

Table 2. Characteristics of the Plankton in the OTEC Resource Area

Parameter	Depth	ISLANDS (Hawaii, Puerto Rico, Virgin Islands)	OCEANIC Atlantic and Pacific (Tropical)	Gulf of Mexico
Primary Productivity mg C m^{-2} day	0-130 m	30-280 [a,b]	50-375 [c,d,e]	60-100 [f]
Chlorophyll-a mg m^{-3}	0-50 m	0.03-0.25 [a,d,g,h,i]	0.03-0.12 [a,d,g,h,j,k,l,m]	0.05-0.20 [n]
	80-130 m	0.12-0.39 [a,d,g,h,i]	0.1-0.3 [j,k,l,m]	0.05-0.40 [n]
Microzooplankton mg C m^{-3}	0-200 m	0.8 [d]	1.0 [o]	No Data
	200-350 m	No Data	0.1 [p]	No Data
	350-1000 m	No Data	0.01 [q]	No Data
Macrozooplankton Night/Day Biomass Ratio	0-150 m	1.25-1.65 [c]	1.1-1.8 [o,r,s]	2.3 [t]
Macrozooplankton Biomass mg C m^{-3}	0-150 m	0.5-0.8 [u,v,w,x]	0.1-3.0 [o,p,r,s]	0.1-6.0 [t,y]
	150-350 m	0.2 [v]	0.1-0.7 [s,z]	No Data
	350-1000 m	No Data	0.4 [o]	0.25 [v]

(a) Gilmartin and Revelante, 1974
(b) Beers et al., 1968
(c) Koblentz-Mishke et al., 1970
(d) Gunderson et al, 1976
(e) Mahnken, 1969
(f) Jones et al., 1973
(g) Johnson and Horne, 1979
(h) Bathen, 1977
(i) Hargraves et al., 1970
(j) Scripps Institute of Oceanography, 1969
(k) Venrick et al., 1973
(l) Eppley et al., 1973
(m) Schulenberger, 1978
(n) El-Sayed et al., 1972
(o) Hirota, 1977
(p) Beers and Stewart, 1969
(q) Beers, 1978
(r) Vinogradov and Rudyakov, 1973
(s) Youngbluth, 1975
(t) Howey, 1976
(u) Nakamura, 1955
(v) King and Hida, 1954
(w) King and Hida, 1957
(x) Shomura and Nakamura, 1969
(y) Bogdanov et al., 1969
(z) Vinogradov, 1961

characterized by a narrow continental shelf and thus are greatly influenced offshore oceanic processes and experience less seasonal variation.

Differences in physical characateristics between island environments and the Gulf of Mexico become evident when comparing the organisms comprising the major fisheries in each region. Gulf of Mexico fisheries are primarily benthic in nature (shrimp and demersal fishes), reflecting the enhanced benthic productivity resulting from mixing over the shallow continental shelf. Fisheries around islands are mainly composed of offshore pelagic fish and small reef fish, illustrating the influence of offshore and extreme nearshore processes in these areas.

2.1.2.2 Offshore Environment - The offshore marine environment is generally defined as the oceanic region seaward of the continental shelf break. Large-scale oceanic currents prevail over most of this region and tidal and continental influences are minimal. Vertical mixing occurs slowly, causing offshore waters to become vertically stratified. Vertical stratification hampers the recirculation of nutrients into the surface layer, resulting in typically low productivity (Table 3). In areas such as the equatorial Pacific and the North Atlantic, where conditions allow the transport of nutrients to the surface layer, the open ocean is moderately productive. Although the unit-area productivity in offshore surface waters is low, the large area of the open ocean results in a major contribution to total world productivity.

Table 3. Division of the Oceans into Provinces According to Their Level of Primary Productivity (Ryther, 1969).

Province	Percentage of Ocean	Area (km^2)	Mean Primary Productivity (g dry weight m^{-2} year $^{-1}$)	Total Primary Productivity (metric tons year $^{-1}$)	Percentage of Total Productivity	Number of Trophic Levels	Ecological Efficiency (percent)	Fish Production (metric tons)
Open Ocean	90.0	326×10^6	50	16.3×10^9	81.5	5	10	1.6
Nearshore Zone*	9.9	36×10^6	100	3.6×10^9	18.0	3	15	120
Upwelling Area	0.1	3.6×10^6	300	0.1×10^9	0.5	1-1/2	20	120

*Includes highly productive areas over the continental shelf.

2.2 ENVIRONMENTAL PRIORITIES

The potentially significant environmental effects associated with commercial OTEC development center on the marine environment because it is the source of evaporator and condensing waters and the receiver of discharge waters used by the plant. In the long term, there is also concern over potential climatic effects if extensive development were to take place. As part of their research and engineering studies directed toward development of OTEC technology, the DOE and other organizations have devoted considerable attention to identifying and studying potential environmental problems. Numerous reports describing the results of these studies have appeared, and these have provided the primary source material for preparing this section. Reports by the DOE (1979a and b) have been especially useful in this regard.

2.2.1 General Statutory Requirements

Section 107 of the OTEC Act requires NOAA to initiate a program to assess the effects on the environment of OTEC facilities and plantships. "The program shall include baseline studies of locations where ocean thermal energy conversion facilities or plantships are likely to be sited or operated; and research; and monitoring of the effects of ocean thermal energy conversion facilities and plantships in actual operation" (§107(a)). Among other things, the program shall be designed to determine (§107(b)):

> "(1) any short-term and long-term effects on the environment which may occur as a result of the operation of ocean thermal energy conversion facilities and plantships;
>
> (2) the nature and magnitude of any oceanographic, atmospheric, weather, climatic, or biological changes in the environment which may occur as a result of deployment and operation of large numbers of ocean thermal energy conversion facilities and plantships;
>
> (3) the nature and magnitude of any oceanographic, biological or other changes in the environment which may occur as a result of the operation of electric transmission cables and equipment located in the water column or on or in the seabed, including the hazards of accidentally severed transmission cables; and
>
> (4) whether the magnitude of one or more of the cumulative environmental effects of deployment and operation of large numbers of ocean thermal energy conversion facilities and plantships requires that an upper limit be placed on the number or total capacity of such facilities or plantships to be licensed under this Act for simultaneous operation, either overall or within specific geographic areas."

In order to analyze the environmental concerns and trends, it is necessary to have access to baseline information for those locations where ocean thermal energy conversion facilities or plantships are likely to be sited or operated. The Department of Energy has been conducting such baseline studies at a variety of OTEC sites. This information, in addition to that developed by others, will be used to discern the general level of environmental risk posed by OTEC development. Because of the high costs of baseline studies, NOAA will rely upon the existing baseline information, and new site-specific baseline information supplied by applicants for a commercial license, to meet the baseline study requirements of the Act (§107(a)).

The potential effects of electric transmission cables will be site-specific in nature and will also be addressed by an applicant for an OTEC license. Probably the major potential effect here will be due to the placement of cables in or on the seabed, where the effects will be very localized.

The more significant environmental concerns relating to the other statutory requirements are discussed below, including for each concern, a discussion of our present understanding and a summary of the research required to assess the potential environmental effects. Each research need has been categorized as of low, medium, or high priority, based on a judgment of the urgency of meeting the need. The basis of these judgments was provided by an evaluation of several factors, including: (1) the likelihood that the potential detrimental effects would really occur, (2) the severity of these effects if they did occur, and (3) the potential that research in the area of concern has for aiding in prevention or mitigation of these effects. The identified needs are those judged pertinent to commercial OTEC development. NOAA would address some of these needs and would rely upon certain States, industry, and universities to address others.

2.2.2 Environmental Effects of Individual OTEC Plants

Each separate OTEC facility or plantship will have the potential for causing environmental changes in its own immediate zone of influence. This subsection presents a discussion of the aspects of greatest concern regarding the environmental effects of individual plants.

2.2.2.1 Water Mass Displacements - OTEC plants will require the flow of very large volumes of water. A closed cycle plant will need approximately 5 cubic meters per second of both warm, surface water and cold, deep water for each megawatt of net power generated, resulting in a total flow of 10 cubic meters per second. The water taken in will, of course, also have to be returned to the environment. The outflow may be through separate warm and cold water discharges or as a mixed release. The discharges may also be at various depths in the water column and may even vary as to whether they are above or below the thermocline. Whatever the specific details, however, it is certain that the intake and outflow of water associated with OTEC facilities of any appreciable size will cause large-scale redistribution of ocean water and of its physical, chemical, and biological properties.

2.2.2.1.1 Changes in Distribution of Temperature and Salinity - The natural thermal structure and salinity gradients near and downstream of OTEC plants will be altered by large-scale releases of water. The inflows to these plants may also disturb the distribution of these properties, although to a lesser extent, as water near the intakes is pulled both vertically and horizontally to meet the intake needs.

These alterations in the basic properties of the ocean have the potential for causing environmental damage. Marine organisms are sensitive to the level and degree of fluctuation in the temperature and salinity of their environment. Relatively large changes in these properties can directly kill the exposed organisms. Smaller changes can have less obvious, but none the less highly detrimental, impacts by affecting basic metabolic and other physiological processes.

The potential for detrimental impacts exists for all the organisms exposed to OTEC-induced changes in distribution of temperature and salinity. However, this potential is especially great for the open-ocean plankton. Because of their requirement for deep, cold water, OTEC facilities will be sited in the open ocean or in coastal areas where open ocean waters come close to shore. Yet the open ocean organisms are well known to have very narrow tolerance limits for changes in the properties of their environment. Thus, there is concern that the OTEC facilities may cause large detrimental impacts on the open-ocean planktonic community.

Status of Present Knowledge - In order to assess the biological effects of OTEC-induced alterations in temperature and salinity, it is necessary to estimate what changes will occur in the distribution of these properties. As the primary effects are anticipated to be caused by the discharge plumes, it is especially necessary to understand their behavior. In an attempt to do this, efforts have been made to develop predictive mathematical models describing the behavior of such plumes.

These models have been of two primary types, near-field and far-field, depending on the scale of water movement being investigated. Near-field models are concerned with simulating plume behavior near the plant discharge in the region where the geometry of this discharge, the initial density and momentum of the outflow, and the density of the receiving water are the primary controlling factors. This near-field zone is usually found to be limited to within about 1 kilometer of the point of discharge and is the region of rapid initial mixing.

Far-field models that predict plume movement and dispersion beyond the near-field region have also been developed. In this region natural processes such as the ocean currents, turbulence, and planetary rotation control plume behavior. Dilution of the plume usually proceeds at a much slower rate in this region than in the near-field.

The models presently available provide gross estimates of plume behavior in the near- or far-field. Further development and refinement of such models may be required. Such research will have to include the development of mathematical formulations, as well as the collection and analysis of data which describe the temperature and salinity distributions associated with OTEC discharges. Such descriptive data will provide a basis for testing the mathematical models and identifying their weaknesses so that they can be improved.

In addition to the mathematical models, actual scaled-down physical models of OTEC discharges have been used to aid in understanding plume behavior (Allender et al., 1978). These are useful for studying near-field plume behavior, but are much less practical for use in estimating plume characteristics beyond the immediate vicinity of the discharge.

Predicting the OTEC-induced alterations in temperature and salinity distributions is only the first part of assessing the environmental effects of these discharges. It is also necessary to estimate what influence these altered distributions will have on the exposed biota. In this area our knowledge is especially weak, and this is particularly true with regard to the open-ocean plankton of the tropical oceans. The great majority of the studies that have dealt with open-ocean plankton have been carried out in temperate areas, relatively close to the major scientific nations. There have been a number of expeditions and other cruises that have collected tropical open-ocean plankton, so we have a fairly adequate picture of the gross composition and relative abundance of the forms in this assemblage. However, little systematic physiological or ecological work has been attempted with tropical plankton species, so we have little basis on which to predict what effect a specific OTEC-induced alteration in temperature or salinity would have on the organisms involved. Beyond the effects on individual species, moreover, we have even less capability to predict the consequences of an OTEC facility on the biological system in general. The planktonic species are all members of the open-ocean planktonic ecosystem and undoubtedly interrelate with each other in a complex network of ways, as is generally true within ecosystems. However, we have practically no understanding of the functional relations in the open-ocean tropical system, and so we can not presently even attempt to predict the consequences to them of OTEC-induced environmental alterations.

Summary of Research Needs: (1) Develop improved capabilities to predict the water mass displacements and consequent alterations in distribution of temperature and salinity caused by OTEC plants (High priority). (2) Determine the tolerance of important individual member species of the tropical plankton, especially open-ocean species, to temperature and salinity changes of the magnitude likely to be caused by OTEC plants (High priority). (3) Determine what effect temperature and salinity changes of this size are likely to have on the functioning and ecological integrity of the open-ocean plankton communities (High priority).

2.2.2.1.2 Nutrient Redistribution - Besides affecting the distribution of temperature and salinity, water mass displacements caused by OTEC plants will lead to a redistribution of many chemical properties. The most significant redistributions will probably be those of the nutrients, especially nitrogen, since it is often the limiting nutrient in ocean waters. The deep oceanic waters are relatively enriched with regard to nutrients (Table 1) including carbon dioxide (source of carbon), while in almost all tropical areas the surface waters above the thermocline have much lower concentrations. Thus, OTEC discharge plumes that stabilize above the thermocline may cause large-scale nutrient enrichment of these impoverished near-surface waters. In almost all cases phytoplankton productivity in tropical surface waters is limited by the availability of useable forms of nitrogen (i.e., primarily ammonium and nitrate nitrogen). Consequently, adding nutrient-enriched water could result in large increases in phytoplankton production and quite probably also in the types and relative abundances of the forms that make up this assemblage. These changes will, in turn, undoubtedly cause secondary effects on the herbivorous zooplankters that feed on the phytoplankton and so on up the trophic network of the ecosystems involved.

The exact effects of OTEC-induced nutrient redistributions will be very dependent on the depth at which the discharge plumes stabilize. Phytoplankton production is only nutrient limited near the surface. Below a certain depth, light becomes limiting. In oceanic waters this depth is often about the level where light penetration falls to 10 percent of the surface value (MacIssac and Dugdale, 1972). Thus, plumes that stabilize below this depth will have much less effect on productivity and the ecosystem in general than those that stabilize at a higher level.

Status of Present Knowledge - As was true regarding the effects of alterations in temperature and salinity distributions discussed in the preceding subsection, the first requirement for assessing the effects of OTEC-induced nutrient redistributions is to determine how the distributions will be altered. Beyond this need is a requirement to assess the biological consequences of nutrient redistributions.

A first attempt at estimating the biological response to OTEC-related nutrient alterations is reported by Sands (1980). Although these results can only be taken as rough approximations, they indicate the possibility of large increases of phytoplankton within discharge plumes. For a 40 MWe plant, the estimates indicate as much as a 30-fold increase in phytoplankton biomass in the plume 30 to 60 kilometers downstream of the discharge. Such large increases would certainly have an appreciable effect on the entire biological community involved. Thus, although no firm conclusions can be drawn from the limited work conducted so far, the preliminary results show potential for substantial impact and clearly indicate the need for further investigations.

Summary of Research Needs: (1) Develop improved capabilities to predict the water mass displacements and consequent nutrient redistributions caused by OTEC plants (High priority). (2) Determine the effects of these redistributions on the productivity and other properties of the phytoplankton involved, with a special focus on the relation between the depth and other characteristics of the OTEC discharges and the resultant biological effects (High priority). (3) Determine the secondary effects of nutrient redistribution on zooplankton, fish, benthos, and other components of the ecosystems involved (High priority).

2.2.2.1.3 Redistribution of Other Chemical Properties - Although the redistribution of nutrient concentrations is expected to be the most significant chemical result of OTEC-induced water mass displacements, a number of other properties vary in concentration between surface and deep water and so will have their distributions altered by such displacements. Present estimates of these alterations have not indicated any area of appreciable concern, although the chemical changes caused by operating OTEC facilities should be monitored when this is possible and the potential environmental effects reevaluated at that time.

There is one further chemical redistribution that may be caused by OTEC plants, but only by those utilizing the open cycle process. Non-condensable gases (e.g., oxygen, nitrogen, carbon dioxide, etc.) can accumulate in open cycle plants and cause adverse operating affects; thus will have to be removed. This will mean that the water released from these plants will be very low in dissolved gases, particularly dissolved oxygen. As oceanic plankton organisms require concentrations of this gas that are near the saturation level for water, the releases of deoxgenated water from open cycle facilities poses the potential for environmental degradation.

Status of Present Knowledge - Some very simple calculations are reported by Sands (1980) concerning the potential of environmental harm from the lowered oxygen concentrations in the plume from a 40 MWe open cycle OTEC plant. It is estimated that rapid dilution of the plume with fully oxygenated ambient water will result in oxygen concentrations in the centerline of the plume reaching 80 percent of ambient within 200 meters downstream of the discharge. Based on this rapid replenishment of oxygen in the near-field, it is concluded that no significant adverse effects should occur from such discharges. Thus, although these calculations are admittedly rough, there seems little basis for concern regarding releases of deoxygenated water by open cycle plants.

Summary of Research Needs: (1) Develop improved capabilities to estimate plume behavior for separate or mixed discharges of deoxygenated water from open cycle OTEC plants (Low priority). (2) Determine the ecological and other environmental effects of such discharges (Low priority).

2.2.2.1.4 Climatic Effects - Sea surface temperature is one of the controlling factors for climate, as is obvious in many coastal areas. OTEC plants have the potential for altering the climate in their vicinity since they operate on the basis of extracting heat from surface waters, and will be responsible for redistributing waters that are pumped through or entrained by the discharge from a plant. Since the cooling of surface waters would jeopardize the performance of a plant, proper engineering and site selection should minimize any such possible climate implications. However, theoretically there is an upper limit to the number of plants that may be placed in certain regions without reducing the surface temperature. Consideration must be given to this for extensive development scenarios.

OTEC operations also have another potential for causing climatic alterations. This is related to the fact that the deep water discharged near the surface will undoubtedly be supersaturated with regard to carbon dioxide (CO_2) at times and may release quantities of this gas to the atmosphere. Changes in the concentration of atmospheric CO_2 can have the potential for impacting global or possibly regional temperatures.

Status of Present Knowledge - Bathen (1975), as reported in Sands (1980), has used an advection model to investigate what effects the water discharged from OTEC plants moored off the big island of Hawaii would have on the temperature of the upper or mixed layers of the surrounding ocean. He estimates that the presence of a 100-MWe plant would change the temperature by 0.24 to 0.33°C in summer in an impacted area of 3.5 to 11 square kilometers (km^2), depending on current conditions. For a larger 240-MWe plant the temperature change in summer was estimated to be 0.54°C with an impacted area of 42 km^2. These estimated OTEC-induced temperature alterations are as large or somewhat larger than the natural diurnal temperature fluctuations in the area, which are in the range of 0.1 to 0.3°C. However, they are still small and are predicted to affect only a relatively limited area. Thus, there seems little basis for concern that the plumes from any one OTEC plant, unless it is much larger than any presently contemplated, will cause appreciable climatic effects.

With regard to CO_2 release, calculations of an upper bound (based on the CO_2 in deeper waters in excess of that in surface waters) on the potential release from a 400-MWe closed cycle plant indicate it to be only about one-fourth of that given off by a typical coal-fired power plant of the same size (Sands, 1980). Thus, it is concluded that single plants are unlikely to have any appreciable large-scale effects.

Summary of Research Needs - (1) Estimate the magnitude of the temperature changes and CO_2 releases caused by the operation of typical OTEC plants (Low priority). (2) Determine the climatic effects that result at likely OTEC sites due to such temperature changes and CO_2 releases (Low priority).

2.2.2.2 Inflow and Discharge of Water and Contained Organisms - OTEC plants will take in large quantities of water. It is estimated that OTEC plants will need approximately 100 times more water than nuclear plants with similar net generating capacities. The pumping and movement of this water will transport many of the ambient organisms through the plants, and these organisms will be subject to the threat of serious damage in two ways. The smaller forms will be carried along or entrained with the inflowing water and will be exposed to a variety of hazards as the water passes through, and discharges from, the plant. Some larger organisms will also be unable to resist the flow of the intake water. However, these forms will be too large to pass through the screens placed along the inflows to exclude large objects. Instead they will be caught or impinged on the screens and probably killed.

2.2.2.2.1 Entrainment - The exact mesh size of the screens that will be used in OTEC plants is not known and will undoubtedly vary to some extent among facilities. However, it will probably be in the range from 0.95 to 1.3 centimeters (cm) (Sands, 1980). Organisms larger than about three times the mesh size usually impinge on intake screens. Smaller organisms pass through, although if they are larger than the mesh size, they may impinge for a time before they extrude through the mesh and are carried along in the inflow stream. Thus, as a rough approximation, it can be assumed that organisms less than about 3 to 4 cm in length will be entrained.

At this size, a variety of small forms, including the phytoplankton, most of the members of the zooplankton and meroplankton, and many of the forms in the ichthyoplankton, will be entrained with the water flowing through OTEC plants. These organisms will enter with both the warm and cold water inflows. However, the numbers will undoubtedly be higher in the warm water flows because near-surface concentrations of organisms are almost always higher than those found deeper in the water column. This is especially true for the phytoplankton forms which can only grow and reproduce in the upper lighted waters.

The organisms entrained with the cold water inflows will be placed under extremely unfavorable conditions. They will be exposed to large temperature and pressure changes as well as the physical abuse of passing through the system and the chemical stress associated with the biocides used to reduce biofouling of heat exchangers. It is anticipated that all or almost all of these organisms will be killed.

The organisms entrained with the warm water inflows, at least those in closed cycle plants, will be exposed to much smaller changes in temperature and pressure, although they will experience the same physical abuse and biocide stresses. It is possible that some substantial fraction of these organisms will survive. This is not true for organisms entrained in the warm water intakes for open cycle plants. These organisms will be exposed to rapid decreases in pressure in the flash evaporator of such plants and will be left behind in the residual water that results when steam is formed.

One of two strategies employed after the two intake water streams have served their purpose: they may be discharged separately, or they may be discharged as a mix (combined). Although the choice may depend upon site-specific considerations, current thought leans toward the mixed discharge. In either event, and despite what depth the discharge(s) is (are) made, the effluents will initially seek an area somewhere near the bottom of the mixed layer at the pycnocline or the seabed itself, whichever occurs first. The dilution achieved at this point, defined as initial dilution, will be due to entrainment (defined as secondary entrainment) of surrounding ambient waters along the effluent plume's trajectory. Initial dilution of about 10 to 1 is expected for an averaged size OTEC plant. Assuming that marine organisms are concentrated and uniformly distributed within the mixed layer of the ocean, an initial dilution of 10 to 1 means that the total entrainment (e.g., that due to the warm water intake and that due to secondary entrainment by a mixed discharge) will be about 20-fold that pumped into the warm intake.

Status of Present Knowledge - Some first approximation calculations concerning the amounts of biomass that will be entrained by OTEC power plants of 40 MWe and 400 MWe capacity are reported by Sands (1980). It is assumed that only low amounts of phytoplankton and microzooplankton will be entrained because the major concentrations of these forms will lie deeper than the warm water intakes of these plants. This assumption may not be entirely valid, at least for certain plants. However, given this assumption, the calculations suggest little likelihood of damage to the populations of these forms because relatively few of their members would be entrained. For the macrozooplankton, on the other hand, the calculations suggest a much greater amount of biomass will be entrained because many of these forms undergo a diurnal vertical migration that will cause them to be in the zone of inflow of near-surface intakes for part of each day. Even for these forms, however, it is concluded that any detrimental effects are likely to be quite localized.

Going beyond these generalized calculations, consideration is given (Sands, 1980) to the special problems related to entrainment at OTEC plants located on, or in close proximity to, shore. As many of the benthic invertebrates and fishes that inhabit such coastal regions have larval and/or egg stages that are part of the plankton, there is great potential for OTEC plants to impact the populations of these forms. This problem could be especially acute for certain larval forms as many of these are attracted by structures in the water or by lights. Using a set of simplifying assumptions, calculations are made of what impact a 400-MWe plant would have if it drew in only coastal waters. The calculations indicate that such a plant would entrain each day approximately 0.05 percent of the total plankton in the coastal waters around the Hawaiian Islands and 0.2 percent of that around Puerto Rico. Obviously, if a plant actually did this and destroyed the plankton contained in these waters, it would almost assuredly have a very serious impact on the ecosystems involved. This could have especially serious consequences, from an economic standpoint, on certain commercial and sport fishery stocks.

Considerations of secondary entrainment significantly complicate the whole entrainment issue. Although secondary entrainment does not involve transport through a plant, it does involve the potential redistribution of a significant number of organisms, as well as the exposure of these organisms to trace constitutents and biocides. The effects of redistribution are not known but have the potential for being significant. For some situations, it may well be that the discharge of OTEC waters should be through a discharge pipe that extends to near the bottom of the mixed layer. This would result in minimal initial dilution that would negate effects associated with secondary entrainment of upper waters and the contained biota.

Summary of Research Needs: (1) Determine, for representative potential OTEC sites and operating conditions, the composition and abundance of the organisms likely to be entrained at the cold and warm water intakes and by the discharge (High priority). (2) Estimate what fraction of these are likely to suffer mortality or impairment (High priority). (3) Estimate what effect the estimated levels of mortality or impairment of these organisms will have on their populations, and secondarily on the entire ecosystem (High priority). Furthermore, this work should pay particular attention to the effects on species that are commercially or recreationally important.

2.2.2.2.2 Impingement - Certain nektonic and large planktonic organisms that have limited avoidance capabilities will be subject to impingement on the intake screens of OTEC facilities. The organisms most likely to be affected include small epipelagic and mesopelagic fish, small planktonic cephalopods, macroplanktonic crustaceans, and large gelatinous zooplankters, such as jellyfish and comb jellies. Almost all impinged organisms will undoubtedly be destroyed by the severe physical abuse involved. This may cause significant reductions in the levels of the populations of the impinged forms which occur downstream of OTEC plants and so may result in adverse impacts on the downstream ecosystems.

Status of Present Knowledge - Planktonic organisms have such weak powers of locomotion that they tend to be carried along by water currents, although some of them can migrate vertically and so alter the current regime to which they are subject. Thus, as a first approximation in calculating entrainment, one can simply assume that the plankters present in a parcel of water will accompany this water if it is drawn into an OTEC plant. This assumption is not valid for the larger forms that are subject to impingement. Most of these forms have quite strong powers of locomotion and so can take action to help them avoid OTEC inflows. Thus, one must take not only the abundance, but also the behavior, of these forms into account if the impacts of impingement are to be evaluated.

Unfortunately, the abundance and behavior of the tropical planktonic and nektonic forms likely to be impinged on OTEC intake screens are very poorly understood. An attempt to evaluate the impingement problem for the nekton concluded that the status of knowledge is so inadequate that it is not possible to do this at present (Sands, 1980).

Operating experience with fossil fuel power plants has shown that impingement of nekton can often be kept to a minimum by proper design and positioning of intakes. This may well be possible with OTEC plants. However, the knowledge concerning the forms that are likely to be impinged is presently so weak that it is not possible to determine what effect design considerations will have.

Sands (1980) also discusses an attempt to evaluate the magnitude of the impingement problem for micronekton and gelatinous zooplankton. This suggests that the gelatinous plankters may experience the most serious consequences because they have such limited powers of locomotion that they will be able to do little to avoid the intake flows. For a typical 400-MWe plant, a daily impingement of over 2000 kilograms (kg) of micronekton and 148 kg of gelatinous forms is estimated. It is concluded that these rates may well cause a localized depression in the abundance of these organisms immediately downstream from such a plant, but, because they reproduce quite rapidly, the ecological impacts will probably be insignificant.

All of these estimates are very preliminary. Because biota avoidance behavior, which is a very important determinant of amount of impingement, is so poorly understood, it is not really possible to assess the significance of the impingement problem. Obtaining the information on the behavior of tropical planktonic and nektonic species that is needed to make theoretical estimations would be a very time consuming and expensive proposition. Of necessity, assessing the significance of the impingement problem will have to rely heavily on a more empirical approach based on actual operating experience with representative OTEC facilities.

Summary of Research Needs: (1) Determine, for representative potential OTEC sites and operating conditions, the composition and abundance of the forms likely to be subject to impingement (High priority). (2) Estimate the impacts that the estimated levels of impingement will have on downstream populations and ecosystems (High priority). This work should also give special attention to the effects on commercially and recreationally important species and on mitigating strategies.

2.2.2.3 Biota Attraction and Avoidance - Based on experience with offshore oil platforms and other structures in the oceans, stationary at-sea OTEC facilities will attract concentrations of organisms. The planktonic larval stages of sessile forms, such as barnacles and mussels, will use the structures as a base for settlement. Some motile forms will live on and among these sessile organisms. All of this will increase the food supply for predaceous organisms in the area. This, together with the protection offered by the structures and the use of lights on the platforms at night, will attract such predators, especially fish. Conversely, organisms sensitive to human activities and presence may avoid OTEC areas as a result of construction activities, plant operational support activities, and plant operation noise.

Status of Present Knowledge - The ecological significance of an OTEC platform on biota attraction or avoidance is not clear at present. It is possible that attracting fish to the vicinty of OTEC intakes will increase the impacts on their populations. Studies at operating OTEC plants are needed to assess such effects.

Summary of Research Needs: (1) Determine the kinds and amounts of organisms attracted or repulsed by typical stationary at-sea OTEC facilities (Medium priority). (2) Estimate the population and ecosystem impacts of the estimated attraction or avoidance effects of such facilities (Medium priority). This work should pay special attention to commercially and recreationally important species.

2.2.2.4 Biocide Releases - The biocides used to reduce biofouling in OTEC plants will, by definition, be toxic to marine organisms. The presence of these chemicals will contribute to the mortality of organisms entrained with the water passing through these plants. Also, if a biocide persists in a plume after discharge, it may have detrimental effects on organisms that migrate into, or are entrained with, dilution water entering the plume.

The magnitude of the detrimental effects will not depend solely on the amount and type of biocide. Different species have quite different tolerances to various biocides, and so the severity of problems involved with the use of a biocide will vary depending on which organisms will be exposed. Also, seawater contains a multitude of inorganic and organic chemicals. The biocide will interact chemically, to a greater or less extent, with these substances forming new compounds, some of which may be toxic themselves. Thus, determining the potential toxicity of biocides used in OTEC plants is a complex problem.

Unfortunately, there is even one further complication. With the large surface areas of the heat exchangers used in closed cycle OTEC plants, there is great potential for the working fluid to leak into the seawater flows. As pointed out earlier, chlorine will probably be the biocide and ammonia the working fluid in most closed cycle OTEC plants. When mixed, these two substances interact and form products that may be more toxic than the chlorine by itself.

Status of Present Knowledge - The toxicity of the biocides proposed for use in OTEC plants will have to be determined. As chlorine will usually be employed as the biocide, these determinations should focus on the effects of this substance. Unfortunately, our present knowledge concerning the toxicity of chlorine includes very little information on the tolerance limits for the tropical/subtropical organisms that are the principal inhabitants of potential OTEC sites. However, a review of the toxicity work that has been conducted does reveal that phytoplankton tend to be the most sensitive organisms and may even be harmed at levels below the detection limit for chlorine of 0.1 milligrams (mg) per liter (Department of Energy 1979c). As the photosynthesis carried out by the phytoplankton directly or indirectly provides the basis for all the other living components of the ecoysytem, they will have to receive special attention to assure that chlorine additions are kept within tolerable limits.

It will also be necessary to study the chemical reactions of chlorine in seawater in order to estimate the major chemical products that will be formed by chlorine additions. This subject is very poorly understood at present (e.g., Block et al., 1977). Beyond this the toxicity of the major products will need to be determined, and potential effects of these substances estimated.

Some first order approximations of the chlorine concentrations that might be expected downstream from 40-MWe and 400-MWe OTEC plants are reported by Sands (1980). It is estimated that the maximum concentration of chlorine in the plume from a 40-MWe plant will be reduced to 0.01 mg per liter within about 12 hours (5 km downstream) of discharge. However, the calculations show that the plume from a 400-MWe plant will still have a maximum concentration 0.03 mg per liter after 10 days (100 km downstream). Thus, it is concluded that 40-MWe plants will affect exposed organisms for less than a day and probably have only localized impacts. However, very large plants such as a 400-MWe one may result in impacts that extend over rather large areas.

Summary of Research Needs: (1) Determine the toxicity of proposed OTEC biocides (particularly chlorine) to representative species that are important ecosystem compartments at potential OTEC sites (High priority). (2) Determine the chemistry of proposed OTEC biocides (particularly chlorine) in seawater (both with and without working fluid leaks) and the toxicity of the major compounds that are produced (High priority). (3) Estimate the type and amount of environmental risk on downstream populations and ecosystems arising from the estimated biocide toxic effects (High priority). This work should give special, but not exclusive, attention to species of major commercial and recreational importance.

2.2.2.5 Working Fluid Losses - The working fluid used in a closed cycle OTEC plant may leak into the environment. It is also possible that some catastrophic event, such as a major storm or a collision with a ship, could cause a large volume spill. As all of the substances proposed as working fluids can, under certain conditions, cause deleterious biological effects, the possibility of such leaks and spills presents an environmental concern.

Status of Present Knowledge - A number of substances have been examined as working fluid candidates for closed-cycle heat exchangers. These include common refrigerants (i.e., the Freons™) and other substances such as propane, sulfur dioxide, and ammonia (Anderson, 1973).

A major consideration in choosing a working fluid is the amount of heat exchanger surface area required per kilowatt of net power produced. Ammonia has been found to be the most cost effective (Coffay and Horazak, 1980) and require the least amount of heat exchanger surface area (Owens, 1978). Estimated amounts of ammonia working fluid range between 200 and 1000 cubic meters for a 40-MWe plant to 10,000 cubic meters for a 400-MWe plant. As ammonia may be the working fluid used in the initial development of OTEC facilities, it is the only substance for which a serious attempt at evaluating environmental impacts has been made.

Ammonia is soluble in seawater, with the un-ionized ammonia form being equilibrium with ionized ammonium hydroxide. In low concentrations ammonia can act as a nitrogen source for phytoplankton and so serve as a stimulant to biological production. However, at higher concentrations it becomes toxic.

The toxic effect is increased at high pH levels because these favor the presence of un-ionized ammonia which is the primary toxic form.

Most of the information available on ammonia toxicity toward aquatic organisms relates to freshwater species. The limited studies that have been conducted with marine organisms have almost always used temperate zone forms. Thus, we have practically no ability to make detailed estimates of the impacts that ammonia leaks would have on typical inhabitants of potential OTEC sites. However, there is little doubt that large leaks or spills would cause toxic effects on the environment.

Summary of Research Needs: (1) Determine the toxicity of proposed OTEC working fluids (particularly ammonia) to representative species that are important ecosystem components at potential OTEC sites (Medium priority). (2) Estimate the type and amount of environmental risk to exposed downstream populations and ecosystems arising from the estimated working fluid toxic effects (Medium priority).

2.2.2.6 Trace Releases of Toxic Constituents - The release of trace amounts of toxic constituents will arise from at least two aspects of OTEC facilities. First of all the metallic structural elements will experience seawater corrosion and erosion which will release metal ions. Secondly the hull will be covered with a protective coating that will consist of a matrix containing a soluble toxic compound. This coating will protect the hull surfaces and will also retard biofouling, but will slowly release its toxic component to the environment. Both of these types of releases give rise to environmental concerns.

A third possible source for release of trace amounts of toxic constituents is the process wastewater generated from manufacturing or refining activities, especially in plantships. Present plans for such activities involve primarily production of ammonia or refining of aluminum. Both of these would potentially involve the release of toxic constituents in the waste water. However, there is little information available at present on the types and amounts of such discharges, and there seems no reason to believe that presently anticipated developments will lead to appreciable environmental impacts. Consequently such discharges will receive no further consideration here, although a research program in this area may possibly need to be added in subsequent revision of this OTEC environmental assessment plan.

2.2.2.6.1 Corrosion and Erosion of Metal Surfaces - OTEC structural components will release trace metals as they are corroded and eroded by seawater. Because of their very large surface areas, the heat exchangers will provide the major sources of these releases. However, the piping, pump impellers, and other minor components will also have metal surfaces that will be exposed to corrosion. Metal ions are toxic in high enough concentrations, although the level where this starts to occur varies greatly among the various metals. Thus, there is some potential for environmental impacts from the toxic effects of these metal releases.

Status of Present Knowledge - The heat exchangers will probably be constructed of aluminum, titanium, or stainless steel, although 90/10 copper nickel alloy has also received consideration. Based on limited data, aluminum and titanium have been found to be toxic only at relatively high concentrations (Department of Energy 1979c). Stainless steel also seldom seems to cause toxicity problems. Thus, there seems little reason for concern regarding the release of these materials by corrosion or erosion of OTEC facilities. Copper, on the other hand, is relatively toxic to aquatic life and might possibly cause toxic effects if used, but this seems unlikely at present.

Summary of Research Needs: (1) Determine the toxicity of likely structural component materials (particularly aluminum and titanium) to representative important species from potential OTEC sites (Low priority). (2) Estimate the type and amount of environmental risk to exposed downstream populations and ecosystems from the estimated toxic effects of trace releases of structural materials (Low priority).

2.2.2.6.2 Hull Coating Releases - The toxic compounds present in the hull coatings of OTEC plants will either slowly diffuse into the water or will be released gradually as the entire hull coating erodes. In the past these compounds have usually been salts of heavy metals (e.g., copper, mercury, zinc, and lead). However, more recently organometallic compounds, such as organolead, organotin, organofluorides, and tributyl tin oxides, have received more common use. All of these materials are, of course, quite toxic to marine organisms if they are present in any appreciable concentration.

Status of Present Knowledge - Little information exists on the tolerances of the organisms likely to inhabit OTEC sites to the toxic compounds in hull coating materials. However, for most of the more commonly used of these substances, the EPA has established allowable limits that provide for protection of the environment when they are used as a hull coating. OTEC facilities will have to conform to these limits. Based on this and the fact that it is presently unclear exactly what types of hull coatings will be used, there seems little reason to devote appreciable research efforts to this concern, at least at present.

Summary of Research Needs: (1) Determine the toxicity of likely hull coating materials to representative important species from potential OTEC sites (Low priority). (2) Estimate the type and amount of environmental risk to exposed downstream populations and ecoysystems from the estimated toxic effects of release of these hull coating materials (Low priority).

2.2.2.7 Other Environmental Concerns - This section has attempted to consider the major environmental concerns that have been identified related to individual OTEC facilities. However, the list is not intended to be all-inclusive, and other concerns have been identified such as release of sanitation wastes from the crew operating OTEC facilities, disruptions of the benthic community from implantation of OTEC mooring anchors and plant-to-shore transmission cables, and interference with marine mammal communications due to OTEC generated underwater noise. At present, the environmental threat appears to be minimal for these potential problems; however, such problems may be judged at a later date to pose a more significant danger. At present the plans for OTEC plants are too vague to allow clear assessment of all potential problems. As planning progresses, it will be necessary to reevaluate the situation. If such evaluations reveal additional significant concerns or a need to change priorities, a change in emphasis will be required.

2.2.3 Cumulative Environmental Effects of OTEC Plants

The preceding section has discussed the major concerns related to the environmental impacts of individual OTEC plants. These impacts, even where possibly serious, will be limited to rather restricted areas. However, the effects of siting multiple facilities may reinforce each other, causing impacts over an entire region. On an even larger scale, the operation of a large number of OTEC facilities throughout the world could affect the global oceans and atmosphere with potentially serious large-scale consequences.

The OTEC Act of 1980 specifically expresses concern regarding such cumulative environmental effects. It requires that determinations be made as to whether limits are required in the numbers or capacities of OTEC facilities either overall or in specific geographical regions.

Status of Present Knowledge - Man's past and present use of the oceans does not include actual experience with anything which approaches the scale of the operation of multiple, large OTEC plants. Thus, direct observations pertaining to the effects of such operations are not available, and any attempt to estimate them must be based on extrapolating from the observed or estimated impacts of much smaller scale activities, and from pertinent information on the effects of natural upwelling in the oceans.

A first attempt at assessing the potential for serious environmental impacts from the operation of multiple OTEC plants is discussed by Sands (1980). He presents simple calculations estimating some of the cumulative effects of an OTEC "park" in the eastern Gulf of Mexico containing 146 moored platforms of 400-MWe capacity.

The calculations indicate that the water flow from such a park would be approximately 0.5-percent of the flow of the Gulf Stream. This might well result in small-scale "OTEC water masses" being identifiable for long distances downstream of such parks. As with the discharges from an individual facility, these water masses will tend to exhibit higher nutrient values than would occur naturally. These altered conditions will affect biological production and quite probably result in substantial changes in ecosystem structure and function over a large area downstream. In many ways these impacts will probably parallel the biological and chemical successional changes that occur naturally downstream from areas of oceanic upwelling.

These water masses will, of course, also carry along any toxic substances that they have acquired while passing through the OTEC park. If the OTEC plants use chlorine as a biocide, residual concentrations of this substance may be present appreciable distances downstream from the park. Sands does not attempt to calculate the concentrations or biological effects of the residual chlorine, but he does indicate that serious problems may occur.

Sands does present estimates of the concentration of hull coating material that would result in the eastern Gulf of Mexico from the siting of an OTEC park in this area. The calculations show the release of amounts that are equivalent to those needed to produce a concentration of 2.7 grams per cubic meter (2.7 ppm) in a layer 60 meters deep over the entire area. He has no information on the biological effects of maintaining such low, but still elevated, concentrations of toxic materials over such a large area. However, he points out that bioaccumulation of such substances might pose a hazard to sport and commercial fishes and to those who consume them.

Sands also presents calculations on the amounts of biomass that would be entrained and impinged by an OTEC park. The rough calculations indicate that such a park might impinge over 300,000 kg of micronekton each day. This is equivalent to destroying about 1-percent of the entire daily potential nekton production of the eastern Gulf of Mexico. Further, almost 130,000 kg of macrozooplankton are estimated to be entrained each day. This is equivalent to about 3-percent of the total macrozooplankton biomass in the upper 1,000 meters of the eastern Gulf of Mexico region. With our present state of knowledge, it is not possible to assess the ecological consequences of environmental disruptions of this magnitude. However, these preliminary calculations certainly give rise to serious concern over large-scale OTEC development scenarios, and indicate the need for research directed toward predicting the consequences.

Finally Sands reports the potential effects of an OTEC park on climate. Interpolating from calculations of Martin and Roberts (1977), estimates indicate that a park with 146 large OTEC platforms in the Gulf of Mexico could cause a decrease in sea surface temperature of about 0.1 to 0.15°C. Although the resulting effects on the climate of a change of this magnitude cannot be made, it is concluded large enough to indicate the necessity for further study.

A rough estimation of the amount of CO_2 that would be released from the oceans due to the operation of an OTEC park is also made. Sands reports that the CO_2 efflux from such a park would be in the range from 2.18×10^8 kg per day to 3.74×10^8 kg per day. As it is believed that such releases are much less than would occur with coal-fired plants of the same capacity, it is suggested that they do not present a great problem. However, it is concluded that they might have an effect on the regional climate if all the plants of an OTEC park were sited in a relatively small area.

Summary of Research Needs: (1) Estimate the cumulative effects on oceanic physical properties (especially water movements and temperature) of siting multiple OTEC plants in specific regions and basins (High priority). (2) Estimate the cumulative effects on oceanic chemical properties (especially concentrations of nutrients and toxic substances) of siting multiple OTEC plants in specific regions and basins (High priority). (3) Estimate the cumulative effects on biological properties (especially production and ecosystem integrity) of siting multiple OTEC plants in specific regions and basins (High priority). (4) Estimate the cumulative effects on the climate of specific regions of siting multiple OTEC plants in those regions and on the global climate of siting many OTEC facilities throughout the world (High priority).

2.2.4 Direct Licensing Requirements

The regulatory approach preferred by NOAA for licensing commercial OTEC development is that of minimal regulation (NOAA, 1981a and b). Under the minimal regulation alternative, NOAA will use minimal guidelines and performance standards to conform to the goals and provisions of the OTEC Act of 1980. These guidelines will be in conformance with NPDES regulations, Ocean Discharge Criteria, and other applicable regulations as agreed upon by the Administrator of NOAA, the Environmental Protection Agency, and other pertinent responsible agencies. Simultaneously, NOAA is also required to ensure that OTEC plants do not interfere with each other. This will require knowledge of the physical and bio-chemical characteristics of the intake and discharge flows in the vicinity of OTEC plants. Although the minimal regulation alternative results in maximum flexibility for plant design and operation, it also is dependent upon monitoring to ensure environmental compatibility. The monitoring of environmental effects, which the licensee is required to perform by Section 110(3) of the OTEC Act, will alert NOAA to significant problem areas which might need to become the subject of future license terms and conditions. To ensure the cost-effectiveness of such regulatory monitoring, careful thought must be given to the design and implementation of monitoring programs. There is need for research related monitoring of full-scale OTEC plants in order to gain a better grasp of actual environmental effects. This research monitoring could provide verification of theoretical and other assessment techniques regarding OTEC environmental effects.

Status of Present knowledge - Under the minimum regulation approach, NOAA will consider and respond to proposals made by license applicants, instead of prescribing uniform standards for the applicant to follow, except where such standards are mandated by regulation. The flexibility afforded the applicant under this approach will allow the prospective OTEC plant owner to propose what he considers to be the best environmental and engineering design for the plant and to design a cost-effective means of mitigating or reducing adverse environmental impacts resulting from plant operation. The flexibility would allow incorporation of new technology into OTEC plant design as the technology is developed, and provide for site-specific license terms and conditions to protect the environment.

One primary reason for adapting the minimal regulation approach is that there is little experience with a full scale OTEC plant. Although physical (hydraulic) and numerical models have been utilized to predict the intake and discharge flow behavior near a plant (Ditmars, 1979), such predictions are valuable but limited. While monitoring observations are being made on the operation of OTEC-1, these results are also limited since they reflect the operation of a scaled down plant in the full-scale environment.

The discharge from one OTEC plant may reduce the thermal resource available to other plants by either entering the warm water intake of a plant downstream or by effectively "thinning" the mixed layer downstream and therefore increasing the likelihood that cooler water near the bottom of the mixed layer will be drawn up into the intake of neighboring plants (Ditmars and Paddock, 1979).

Jirka (1978), as noted by Ditmars and Paddock (1979), has examined the minimum plant spacing that would preclude the discharge from one plant from interfering with the effective thermal resources available to neighboring plant. For a row of plants oriented perpendicular to the dominant current direction and an ambient mixed current depth of 70 meters, a minimum lateral spacing of 480 meters is indicated for 100 MWe plants and 36,000 meters for 400 MWe plants. For the case of a rectangular grid of plants where the mixed-layer depth is 70 meters, the ambient current 0.1 meters per second, and five rows, a minimum spacing of 5,570 meters is estimated for 100 MWe plants, and 160,000 meters for 400 MWe plants.

The above estimates only provide a perspective of OTEC plant spacing; further work on plant spacing should address the problem of other environmental impacts that may also bear on plant spacing limitations (Ditmars and Paddock, 1979). The predictions resulting from such studies could be verified through monitoring efforts.

Summary of Research Needs: (1) Develop a model that provides a conservative estimate of the boundary surrounding a proposed OTEC plant, outside of which another plant's efficiency would not be impacted (High priority). (2) Design a monitoring program that will cost-effectively provide generic information on the operation and impacts of OTEC plants (High priority). (3) Implement research-related monitoring programs for approved OTEC plants (High priority).

3. ENVIRONMENTAL RESEARCH PLAN

3.1 STRATEGY

The preceding section has identified the major research categories that require attention in order to reduce the uncertainties regarding the relationship between environmental risk and commercial OTEC development. Based on preliminary evaluation of the environmental concerns (NOAA, 1981a), it is felt that the environmental risk associated with the development is minimal; however, there are areas that require better definition to assure this to be the case.

NOAA and DOE both have authority to address the environmental compatibility of OTEC technologies; however NOAA's responsibilities here focus on licensing and facilitating commercial development of OTEC whereas DOE's responsibilities have focused on the technology development.

It is apparent that, to avoid duplication, NOAA and DOE must coordinate with each other in such a manner as to facilitate commercial application of OTEC technology. Such has already been the case and, to this end, the research plan is designed to build on the studies conducted by DOE. The DOE studies primarily address relatively small scale (as compared to regional or ecosystem level) single plant effects. The research program needs discussed herein primarily focus on the large-scale and long-term ecosystem implications, and on multiple facility impacts. Furthermore, the research elements that NOAA will address are those judged to be critical to NOAA's regulatory responsibilities.

3.2 RESEARCH ELEMENTS

The following research elements of the research plan are based on the needs identified in Chapter 2 and on an assessment of studies completed by DOE or now being completed in support of OTEC. They represent those topics that should be addressed by NOAA, certain States, industry, and the academic sector in order to provide more certainty about the environmental implications of OTEC. Section 3.3 then discusses those elements that NOAA considers essential to its responsibilities under the OTEC Act.

3.2.1 Water Mass Displacements

3.2.1.1 Temperature and Salinity Effects - This research element responds to the need to determine what effects temperature and salinity changes will have on the ecological integrity of the open-ocean plankton community. Using information on discharge plume characteristics and species tolerance, a determination will be made of effects on the mortality and distribution of the open-ocean plankton community for variable plume configurations (single and multiple plants) and variable distances from the near- to far-field. (High Priority)

3.2.1.2 Secondary Effects of Nutrient Redistribution - The most immediate effect of nutrients in the open ocean is the assimilation by phytoplankton and conversion to biomass. The effects of this conversion on the rest of the ecosystem are referred to as secondary effects and can be either beneficial (e.g., increased fisheries) or detrimental (e.g., eutrophication with associated problems).

This research element will focus on the secondary effects of nutrient redistribution on zooplankton, fish, benthos, and other involved components of the ecosystem. The long-range implications to fisheries is of particular concern. (High Priority)

3.2.1.3 Effects of the Redistribution of Other Chemical Properties - Chemical properties other than temperature, salinity, and nutrients will be directly or indirectly affected by the water mass displacements resulting from from OTEC operations. Such changes could relate to turbidity and dissolved gases. For the latter category, the major concern relates to the discharge of deoxygenated water from open-cycle OTEC plants. Such discharges could impact certain biota if sufficient dilutions are not achieved quickly.

This research element will determine the potential environmental effects of the redistribution of other chemical properties, focusing primarily on the potential problems of discharging deoxygenated water from open cycle plants. Results of plume studies, combined with advective/diffusive laws, will be used to determine the characteristics of the discharge plume downstream of a plant. This information will be coupled with knowledge of species tolerances to assess the ecological impacts. (Low Priority)

3.2.2 Inflow and Discharge of Water and Contained Organisms

3.2.2.1 Entrainment Effects - One of the major concerns of OTEC development is the potential for adverse impacts on fisheries and other biota by primary entrainment, due to the pumping of large volumes of water into and through an OTEC plant. Secondary entrainment that results when the discharged waters entrain surrounding ambient waters (process of initial dilution) will also be addressed. This research element will consider the long term impact on critical parts of the marine ecosystem, focusing on the effects to fisheries. (High Priority)

3.2.2.2 Impingement Effects - Like entrainment, impingement of organisms on OTEC intake screens is also a major concern associated with the pumping of large volumes of ocean water. This research element will focus on the longer-term effects of impingement to other critical parts of the marine ecosystem, particularly fisheries. (High Priority)

3.2.3 Biota Attraction and Avoidance Effects

Biota may either be attracted to or repelled from OTEC structures, both of which could have potential adverse effects. Based on observations near OTEC-1 and other ocean platforms and structures, this effort will assess the potential magnitude and ecosystem implications of such effects. (Medium Priority)

3.2.4 Biocide Effects

Dependent upon the biocide used to reduce the problem of biofouling in OTEC heat exchangers, the release of biocides to the ocean poses concern from the standpoint of both human and marine-ecosystem health. Information has been developed on the sea water chemistry of chlorine (currently the preferred biocide) and toxicity to certain biological species. Using such information, and information on OTEC discharge plume characteristics, this research effort will assess the primary and secondary effects on the marine ecosystem of the use of potential biocides. (High Priority)

3.2.5 Effects of Trace Releases of Toxic Constituents

The release of trace constituents from OTEC plants could also pose adverse implications for human and marine-ecosystem health. Some information has already been developed on the release of trace constituents, (e.g., corrosion and leaching products). Such information should be assessed regarding the potential for environmental risk. If significant risk is involved, this research element will focus on the marine ecosystem, and possible public health, implications. (Low Priority)

3.2.6 Cumulative Environmental Effects

Any environmental concern over OTEC development is magnified when consideration is given to multiple plants located within the same regional areas. This relates to the cumulative and interactive effects that may develop if too many facilities are placed within one geographic region. Research on such effects will include (High Priority):

Long-Range Biological Effects: OTEC involves the redistribution of large volumes of ocean waters of different chemistries, the use of biocides in this water, and the entrainment and impingement of biota. As a consequence, the potential exists for biological effects that may be of a long-term nature, involving long latencies and slow recovery.

Regional Heat Balance Alteration: OTEC relies upon extracting heat from the surface waters of the ocean to generate electricity. This heat represents the result of a number of processes including insolation, evaporation, absorption, reflectance, advection, and convection. Like any other renewable resource, this heat is renewable only at a certain rate. Heat balance alterations, and thus seawater temperature changes, could occur in certain regions if the rate at which heat is extracted exceeds the capacity for renewal.

Climatic Perturbations: Since OTEC plants have the potential for altering the heat content of ocean waters, and since they may involve the release of carbon dioxide contained at greater concentrations in deeper and colder ocean waters, there is also a potential for climatic effects. Such effects are remote under early development scenarios; however, this may not be the case for extensive development scenarios. This research element will focus on these longer term and larger scale problems. Site and regional specific environmental information will be combined with operational and discharge characteristics of potential OTEC plants located in certain regions to assess the long-term integrity of the thermal and biological resources. The probability of climatic impact due to present OTEC development scenarios is remote; thus, monitoring of single plant effects on climate can be used as part of the analytical procedure to assess the future probability of climatic perturbations.

3.2.7 Direct Licensing Requirements for Environmental Information

As discussed in Section 2.2.3, there are requirements for environmental research that are directly linked to the licensing process. These relate to developing a methodology for assessing the interference between multiple OTEC plants, designing a monitoring program for operational OTEC plants, and implementing monitoring programs. (High Priority)

Under the OTEC Act, NOAA must determine, within 21 days of receipt of an OTEC license application, the extent of the areas within which operation of the proposed OTEC plant might interfere with the operation of another OTEC plant and within which the operation of another OTEC plant might interfere with the operation of the proposed OTEC plant. This determination is a complex one based on the design and operating characteristics of the proposed plant and the physical oceanographic and meteorological characteristics of the proposed site. Research on this topic will develop a methodology for defining the areal extent of potential interference.

Monitoring programs would serve two purposes: (1) satisfy licensing requirements as called for under the NPDES permit system, and (2) provide information needed to better assess the realm and degree of impact of this new technology. Each licensee is required by law to perform monitoring in accordance with an NPDES permit. NOAA plans to take advantage of this opportunity by supporting some additional monitoring that would serve research purposes.

3.3 NOAA RESEARCH PLAN

NOAA has carefully assessed the relative roles of the various research elements listed above in terms of NOAA's responsibilities, timeliness, and cost-effectiveness. It has decided that there are two general areas of research that are critical to its responsibilities in the early commercial stages of OTEC, and which will be addressed with the available funding:

(1) Effects to fisheries

(2) Direct licensing requirements

In the next few years, NOAA will focus on developing methodologies to determine the flow and circulation that will be induced by an OTEC operation, the resulting redistribution of physical-chemical properties, and the potential effects to fisheries. Studies to be initiated during FY 81-83, and the projected budgets, are noted in Table 4.

As a start, $60K was directed in FY 81 towards a study on initial screening procedures for discerning the general interaction of an OTEC plant with the marine environment. The strategy for this consists of three steps: characterization of the plant and site, characterization of the seawater intake and discharge flow fields, and consideration of the major marine environmental issues associated with OTEC operations. The final report, to be completed in FY 82, will aid NOAA in responding to early applications for a commercial OTEC license.

During FY 82-83 ($125K in FY 82, $150K in FY 83), a study of the flow and circulation induced by an OTEC plant will couple what has been learned through past research efforts on the vertical redistribution of water column properties to a larger scale model, or models, that will account for regional circulation. The intent will be to provide an estimate of the regional influence of an OTEC plant. This study will address NOAA's responsibilities for determining the area of influence of OTEC operations, and therefore the interference between multiple OTEC plants. It will also provide a means for assessing the redistribution of physical, chemical, and biological properties. Definition of the redistribution of properties will, in turn, provide NOAA with the means for assessing biological and other effects. The intent of this study will be to provide a conservative methodology, so as to identify plausible worst case possibilities.

NOAA believes that the "Achilles heel", if any, to OTEC siting and operation could be the effect to fisheries or other biologically important resources such as corals. Thus, the second emphasis of the NOAA research effort in FY 82-83 will be the potential effects to such resources. The key concerns here will be entrainment and impingement; however, consideration will also be given to the effects of nutrient and seawater redistribution, and biocide usage. NOAA further believes that there is much information that has been gained in this regard from the operations of nuclear and fossil-fueled power plants. Thus, as a first step, NOAA will conduct a review of what has been learned from such operations within the context of an OTEC operation ($125K in FY 82). The product will include an assessment of risk to fisheries by an OTEC operation, and the identification of potential mitigation strategies. It will also outline the details of research efforts on fishery effects that would reflect an up-to-date appraisal of needs that are consistent with OTEC development scenarios at the end of FY 82. Based on the results of this synthesis, $200K will be directed in FY 83 towards additional research on fishery effects.

The other research elements listed in Section 3.2 will be addressed by the staff in the NOAA Office of Ocean Minerals and Energy, working with available and developing knowledge including the oceanographic and other site-specific information that will be submitted to NOAA by applicants for commercial OTEC licenses. NOAA will also be exploring cost-sharing arrangements with certain States, and the private and academic sectors, to seek further support for research needed beyond FY 83.

Table 4. NOAA OTEC ENVIRONMENTAL RESEARCH BUDGET: FY 81-83

FY		RESEARCH ACTIVITY		BUDGET PROJECTIONS [a] $K
1981	1.	OTEC License Screening Procedures		60
			Totals	$60K
1982	1.	Direct Licensing Requirements		125
	2.	Fishery Effects		125
			Totals	$250K
1983	1.	Direct Licensing Requirements		150
	2.	Fishery Effects		200
			Totals	$350K

Notes:

a) Budget figures include estimated management costs.

3.4 MANAGEMENT

3.4.1 Planning

This document presents NOAA's initial development of an overall plan for conducting a program to assure the environmental compatibility of OTEC operations. This planning activity will obviously need to be a continuing process. As results are obtained, new concerns will be identified and old ones found to be of greater or lesser significance than previously believed. Shifts in the direction in which OTEC development is proceeding may require changes in emphasis in the assessment program. Thus, the plan for environmental assessment will need to be updated and revised. This will be carried out on a regular basis, and a revised version of the plan will be issued every two years. The information and opinions on which each revision will be based will be drawn from as wide a range of sources as possible, including public interest groups and industry.

3.4.2 Program Implementation

The OTEC environmental assessment program will be accomplished using a variety of means to carry out the required research. A certain amount of analysis and synthesis, especially regarding overall impacts, will be conducted by staff within the NOAA Office of Ocean Minerals and Energy. Additional support will be sought from other organizational elements of NOAA and, in some cases, other organizations. The latter will include certain States, the private sector, and universities.

The personnel responsible for directing the OTEC environmental assessment will be part of the group in the Office of Marine Minerals and Energy that is responsible for NOAA's involvement in OTEC development. In addition to directing the environmental assessment program, this group will be responsible for writing all required environmental impact statements and establishing the environmental terms and conditions of an OTEC license. The assignment of the management of all of NOAA's activities regarding OTEC to one group is intended to ensure that the program is well-coordinated and that there is continuity and consistency in the policies adapted.

Investigators that are funded by the program will be periodically required to submit written reports on the technical progress of their projects and to participate in review and evaluation meetings. They will be strongly encouraged to publish the results of their work in the open scientific literature in order to obtain peer review and better dissemination of their results to the scientific community.

3.4.3 Review and Evaluation

A working group made up of individuals involved in the issues associated with OTEC development will be established to provide advice and recommendations on the relevance and timeliness of the program in terms of: (1) legal and regulatory requirements, and (2) scientific and engineering validity. This group will actively assist in the planning and evaluation of the program and in determining whether it is using the resources available in the most efficient and effective way to meet the stated goals.

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5. GLOSSARY

ADVECTION	The process of transport of water or of an aqueous property solely by the mass motion of the oceans, most typically via horizontal currents.
AMBIENT	Pertaining to the existing conditions of the surrounding environment.
ASSEMBLAGE	A group of organisms having a common habitat.
BATHYPELAGIC ZONE	The biogeographic realm of the ocean lying between depths of 1,000 and 4,000 meters.
BENTHOS	All marine organisms living on or in the bottom of the sea.
BENTHIC COMMUNITY	A community of organisms living on or in the bottom of the sea.
BIOACCUMULATION	The uptake and assimilation of substances, such as heavy metals, leading to a concentration of these substances within organism tissues.
BIOCIDE	A substance capable of destroying living organisms.
BIOFOULING	The adhesion of various marine organisms to underwater structures.
BIOMASS	The mass of living matter, including stored food, present in a population, expressed in terms of a given area or volume of water or habitat.
CHLOROPHYLL	A group of green plant pigments that function as photoreceptors of light energy for photosynthesis.
CHLOROPHYLL *a*	A pigment used in photsynthesis that serves as a convenient measure of phytoplankton biomass.
CONTINENTAL MARGIN	The zone separating the emergent continents from the deep sea floor; generally consists of the Continental Shelf, Continental Slope, and Continental Rise.
CONTINENTAL SHELF	That part of the Continental Margin adjacent to a continent extending from the low water line to a depth, generally 200 m, where the Continental Shelf and the Continental Slope join.
CONTINENTAL SLOPE	That part of the Continental Margin consisting of the declivity from the edge of the Continental Shelf down to the Continental Rise.
CONTINENTAL RISE	A gentle slope with a generally smooth surface between

the Continental Slope and the deep ocean floor.

CRUSTACEANS	Animals with jointed appendages and a segmented external skeleton composed of a hard shell. The group includes barnacles, crabs, shrimps, and lobsters.
DIATOMS	Microscopic phytoplankton characterized by a cell wall of overlapping ailica plates. Sediment and water column populations vary widely in response to changes in environmental conditions.
DILUTION	A reduction in concentration through the addition of ambient waters. Expressed as the ratio of the sum of the volumes of ambient water plus plume water to the volume of plume water. A dilution of 5 connotes

$$\frac{\text{4 parts (by volume) ambient water + 1 part (by volume) plume water}}{\text{1 part (by volume) plume water}}$$

DINOFLAGELLATES	A large diverse group of phytoplankton with whip-like appendages and with or without a rigid outer shell, some of which feed on particulate matter. Some members of this group are responsible for toxic red-tides.
DISCHARGE PLUME	The fluid volume, derived from the discharge pipe, which is distinguishable from the surrounding water.
DISSOLVED OXYGEN(DO)	The quantity of oxygen (expressed in mg/liter, ml/liter or parts per million) dissolved in a unit volume of water. Dissolved oxygen (DO) is a key parameter in the assessment of water quality.
ECOSYSTEM	An ecological community with its physical environment, considered as a unit, each influencing the properties of the other, and each necessary to the maintenance of life.
EPIPELAGIC	Of, or pertaining to that portion of the oceanic zone into which enough light penerates to allow photosynthesis; generally extends from the surface to about 200 m.
FAR FIELD	The region where natural ocean processes become the dominant factors in the mixing of discharge waters.
GELATINOUS ORGANISMS	Generally, the large organisms composed of a jellylike substance, including the cnidarians, salps, and ctenophores.

GRADIENT	The change in value of a quantity with change in a given variable, such as distance (e.g. change in temperature with depth).
HEAT EXCHANGER	A material (usually metal) with a high coefficient of thermal conductance which is used to exchange heat between the working fluid and the heat source or sink.
ICHTHYOPLANKTON	Fish eggs and weakly motile fish larvae.
IMPINGEMENT	A situation in which an organism is forced against a barrier, such as an intake screen, as a result of the intake of water into a facility such as powerplant.
INDIGENOUS	Having orginated in and being produced, growing or living naturally in a particular region or environment.
IN SITU	In the natural or original position; pertaining to samples taken directly from the environment in which they occur.
INVERTEBRATES	Animals without backbones
ION	An electricially charged group of atoms, either negative or positive.
KILOWATT ELECTRIC (kWe)	One thousand (10^3) watts of electric power
KILOWATT HOUR (kWh)	A unit of energy used in electrical measurement equal to energy converted or consumed at a rate of 1,000 watts during a 1-hour period.
MACROZOOPLANKTON	Zooplanktonic organisms with lengths between 200 and 2,000 microns, composed mainly of copepods, chaetognaths, and larvae.
MACROPHYTOPLANKTON	Phytoplanktonic organisms with lengths between 200 2,000 microns.
MACROFOULING ORGANISMS	Sessile organisms, visible to the naked eye, which affix themselves to structures exposed to seawater (e.g., barnacles, mussels, and sea anemones).
MEGAWATT ELECTRIC (MWe)	One million (10^6) watts of electric power.
MEGAZOOPLANKTON	Zooplanktonic organisms with lengths greater than 2,000 microns, includes euphausiids, and large copepods and chaetognaths.
MEROPLANKTON	Organisms that spend only a portion of their life cycle as plankton; usually composed of floating

developmental stages (i.e., eggs and larvae) of benthic and nektonic organisms. Also know as temporary plankton.

MESOPELAGIC	Relating to the oceanic depths between 200 m and 1,000 m.
MICRONEKTON	Small weak-swimming nekton such as mesopelagic fish, small squid, gelatinous organisms, and fish larvae.
MICROZOOPLANKTON	Planktonic animals with lengths between 20 and 200 microns, composed mainly of protozoans and juvenile copepods.
MIXED LAYER	The upper level of the ocean that is well mixed by wind and wave activity. Within this layer, temperature, salinity, and nutrient concentration values are essentially homogeneous with depth.
NANNOPLANKTON	Minute planktonic plants and animals that are 50 microns or less in size and include algae, bacteria, and protozoans. Individuals of this size will pass through most nets and are usually collected in centrifuges.
NEAR FIELD	The region in which the plume momentum is the dominant factor controlling entrainment and mixing of the plume with the ambient receiving waters.
NEARSHORE ZONE	The zone extending seaward from the shore to a distance where the water column is under minimal influence from continental conditions.
NEKTON	Free-swimming aquatic animals, essentially moving independent of water movements.
NERITIC	Pertaining to the region of shallow water adjoining the seacoast and extending from the low-tide mark to a depth of about 200 m.
NUTRIENT	Any substance that promotes growth or provides energy for biological processes.
OCEANIC	The portion of the pelagic zone seaward from the approximate edge of the continental shelf.
OFFSHORE ZONE	A region in which physical properties are influenced only slightly by continental conditions.
OPEN-CYCLE SYSTEM	A powerplant system in which the coolant and/or working fluid passes through the plant only once and is then discharged.
PELAGIC	Pertaining to the open sea or organisms not associated

with the bottom.

PHOTIC ZONE — The layer of the ocean from the surface to the depth where light has been attenuated to 1% of the surface value. The zone in which primary production shows a net increase.

PHOTOSYNTHESIS — Synthesis of chemical compounds in light, especially the manufacture of organic componds from carbon dioxide and a hydrogen source, with simultaneous liberation of oxygen by chlorophyll-containing plant cells.

PHYTOPLANKTON — Mostly microscopic passively floating plant life of a body of water; the base of the food chain in the sea.

PLANKTON — Organisms whose movements are determined by the currents and not by their own locomotive abilities.

PLUME — See DISCHARGE PLUME.

PRIMARY PRODUCTION — The amount of organic matter synthesized by organisms from inorganic substances per unit time and unit volume of water, or in a column of water of unit areas extending from the surface to the bottom.

THERMOCLINE — The region of the water column where temperature changes most rapidly with depth.

UPWELLING — The rising of water toward the surface from subsurface layers of a body of water. Upwelling is most prominent where persistent winds blow parallel to a coastline so that the resultant water current sets away from the coast. The upwelled water, besides being cooler, is rich in nutrients, so that regions of upwelling generally have rich fisheries.

WATT — A unit of power equal to the rate of work represented by one ampere under a pressure of one volt; taken as the standard in the U.S.

WORKING FLUID — The medium in an OTEC plant that is vaporized by warm ocean water, passed over a turbine to generate electricity, and finally condensed by cool ocean water.

ZOOPLANKTON — The passively floating or weakly swimming animals of an aquatic ecosystem.

6. ABBREVIATIONS

C	carbon
CO_2	carbon dioxide
cm	centimeter(s)
°C	degrees Celsius or centigrade
DOC	United States Department of Commerce
DOE	United States Department of Energy
GWe	gigawatt electric
kg	kilogram(s)
kg C	kilogram(s) carbon
km	kilometer(s)
KWe	kilowatt electric
m	meter(s)
mg	milligram
MWe	megawatt electric
ppm	parts per million
ppt	parts per thousand

Additional notation

x^{-1}, X^{-2} etc. means per x, per x squared, etc.
(i.e. m^{-2} means per square meter, m^{-3} means per cubic meter, etc.)

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