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POTENTIAL ENVIRONMENTAL IMPACTS OF OPEN-CYCLE THERMAL ENERGY CONVERSION

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Ocean Thermal Energy Conversion (OTEC) is a power-generating system that uses the temperature difference between warm surface water in the tropical ocean and the cooler water at depth to run a Rankine-cycle heat engine. For the temperature difference typically available in the upper 1000 meters in tropical and subtropical waters, 20–25°C, energy extraction efficiencies are low, two to four percent (Dugger *et* al. 1981), compared to conventional steam generation plants. Because of the low efficiencies involved, large flows of ocean water (the fuel in an OTEC system) are required: about 10 m^3/sec per megawatt (DOE 1979a). Two OTEC operating cycles are currently under development in the United States at Argonne National Laboratory, Argonne, Illinois and at the Solar Energy Research Institute at Golden, Colorado: closed- and open-cycle. Because the technology is highly experimental, most of the technical details have not yet appeared in the literature. In closed-cycle systems a low-boiling point working fluid (ammonia or Freon) is evaporated by warm surface waters. The vapor is expanded to drive a turbine. The expanded vapor is then condensed by cooler deep ocean water and returned to the warm side. In open-cycle operations warm surface water is used as the working fluid. Surface sea water is introduced into a evaporator under partial vacuum separating the sea water into steam and brine. The steam, after passing through a turbine, is condensed using cold ocean water.

Several configurations for OTEC plants have been considered to date: free-floating plants (grazing and moored), bottom-resting facilities (at various distances from shore), and shore-based plants. The floating and far-offshore con-

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figurations currently are not being actively pursued in the US Program due to increased technical and safety risks associated with them (Lewis 1983). Also, use of open-cycle technology for fresh water generation and mariculture requires land or proximity to land. Accordingly, this paper focuses on shore-based configurations identifying various options for operations and the discharges associated with each of them.

Numerous documents have addressed the environmental effects of closed-cycle OTEC (DOE, 1979a,b, 1980, 1981). Although the earliest OTEC experiments were on open-cycle systems (Claude, 1930), the environmental effects of open-cycle OTEC have not yet been thoroughly investigated. This document identifies the potential impacts of open-cycle OTEC on terrestrial, atmospheric, and marine environments suggesting the environmental studies which would elucidate the importance of potential impacts to the environment.

Open-Cycle OTEC

Open-cycle OTEC uses warm ocean water as the working fluid. Prior to evaporation the water is degassed, removing dissolved oxygen, nitrogen, carbon dioxide, and trace gases from sea water. Once in the evaporator under partial vacuum, the fluid is separated into a somewhat more concentrated warm water effluent (Conc. WW effluent), more noncondensable gases, and water vapor. The vapor is used to drive a turbine. The spent vapor can be converted to liquid water in a conventional surface condenser using a heat exchanger or by direct contact condensation.

Conventional condensation using a surface condenser is expected to result in higher parasitic power requirements (assuming that direct contact condensation operates as well as expected). Conventional condensation will result in fresh water as a by-product. Because of the higher parasitic power requirements, conventional condensation may require larger Rows than would condensation by direct contact **heat exchange.**

For open-cycle systems using direct contact heat exchangers, the cold water stream may be degassed prior to use in the condenser. Inside the direct contact condenser, the cold water will release more noncondensable and trace gases.

In addition to atmospheric releases, a number of fluid streams result from open-cycle operations:

Operation	Stream Generated
Evaporation	Concentrated Warm Water Effluent
Condensation. Surface	Fresh Water
	Cold Condenser Water (CW)
Condensation, Direct Contact	Direct Contact, Mixed Effluent Discharge (DC-MED).

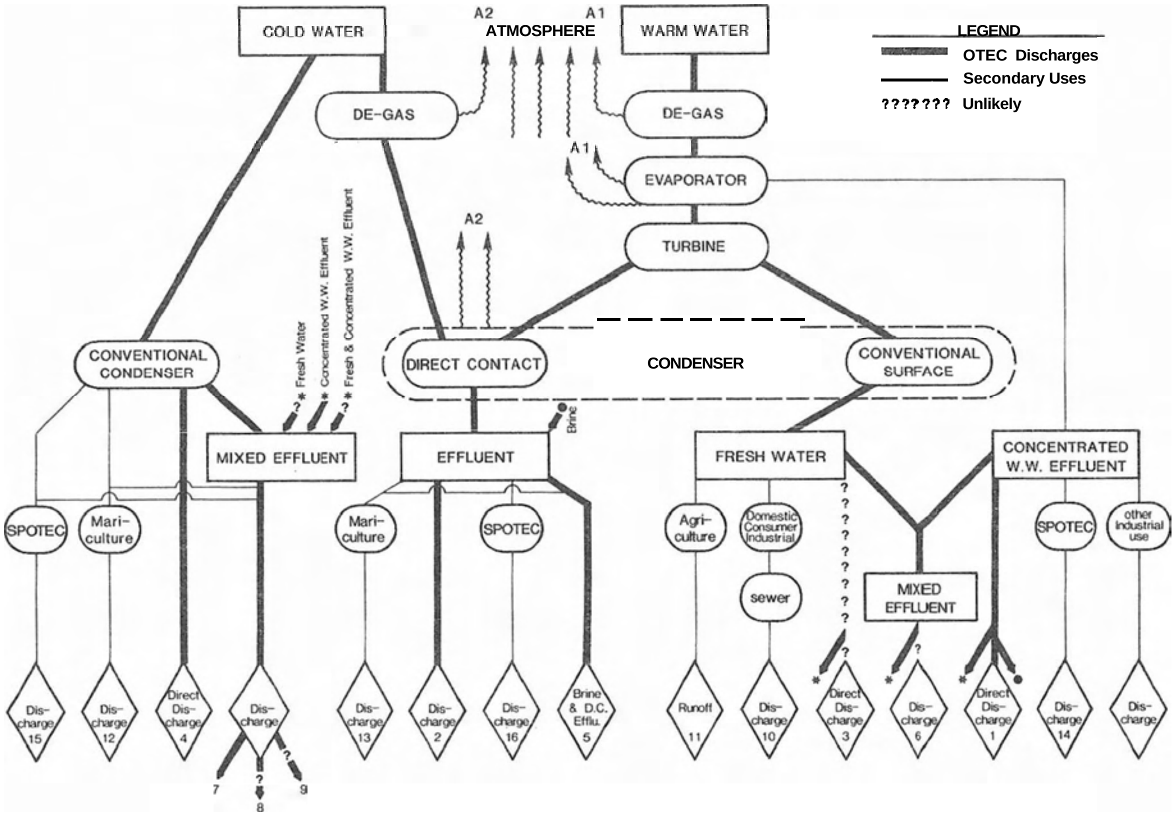

FIGURE 1. Available options for fluid stream discharge. See Table 1 for details on contents of discharges.

The fluid streams either can be discharged directly, combined and discharged, or used for other economic secondary purposes, either directly or in various combinations and then discharged (Figure 1). Current research programs call for at least part of the sea water discharges to be used for mariculture or solar ponds (SPOTEC) (SETS 1983). The fresh water could be used for domestic, industrial, or agricultural purposes. This paper also briefly identities the streams and potential impacts associated with such secondary uses. Available discharge options are displayed in Figure 1; heavy lines indicate the pure (that is, energy production only) OTEC option.

TABLE 1. Discharges Associated with Various Open Cycle **OTEC** Paths

Emission A1	CO_2, Trace gases Volatile Trace Metals. O_2, N_2
Emission A2	CO_2, Trace Gases Volatile Trace Metals, O_2, N_2
Discharge #1 Conc. WW Effluent	No Dissolved O_2 or Trace Gases Enhanced Salinity Altered pH, $CO_3^=$ Equilibria Perturbed Biocide
Discharge #2 DC effluent	No Dissolved O_2 or Trace Gases Altered Salinity Altered Temperature Altered pH, $CO_3^=$ Equilibria Perturbed Enhanced Trace Metals, Constituents Enhanced Nutrients
Discharge #3 Fresh Water	No Dissolved O_2 or Trace Gases Low Salinity Altered Temperature Altered pH. $CO_3^=$ Equilibria Perturbed
Discharge #4 CW—Direct	Low Temperature Enhanced Nutrients Enhanced Trace Metals Enhanced Salinity Low Oxygen
Discharge #5 MED—Conc. WW Effluent + DC Effluent	Salinity—Comparable to Closed Cycle Temperature—Comparable to Closed Cycle Very Low Oxygen, Very Low Trace Gases High Nutrients High Trace Metals Altered pH, $CO_3^=$ Equilibria Perturbed Biocides
Discharge #6 MED—Conc. WW Effluent + Freshwater	No Dissolved O_2 or Trace Gases Altered pH, $CO_3^=$ Equilibria Perturbed Biocides

TABLE 1. *(Continued)*

Discharge #7 MED—Freshwater + Coldwater	Trace Gases Returned Very Low Oxygen Altered Salinity Enhanced Nutrients Altered Salinity Low Temperature Enhanced Trace Metals Altered pH, $CO_3^=$ Equilibria Perturbed
Discharge #8 MED—Conc. WW. Effluent + Coldwater	Low Oxygen Enhanced Salinity High Nutrients High Trace Elements Altered pH, $CO_3^=$ Equilibria Perturbed Biocide
Discharge #9 MED—Conc. WW. Effluent Freshwater, Coldwater	Salinity--Comparable to Closed Cycle Temperature-Comparable to Closed Cycle Low Oxygen, Low Trace Gases High Nutrients High Trace Metals Altered pH, $CO_3^=$ Equilibria Perturbed Biocides
Discharge #10 Fresh Water—Dom, Ind User	No Dissolved O_2 or Trace Gases Low Salinity Altered Temperature Altered pH, $CO_3^=$ Equilibria Perturbed Possibly Reoxygenated, Trace Gases Returned Domestic, Industrial Wastes Domestic, Industrial Perturbation
Discharge #11 Agricultural Runoff	No Dissolved O_2 or Trace Gases Low Salinity Altered Temperature Altered pH, $CO_3^=$ Equilibria Perturbed Reoxygenated, Trace Gases Returned High Nutrients Pesticides
Discharge #12 Mariculture with Convention Cond.	D4, D7, D9, D10 Plus Altered Nutrient Status Detritus, Enhanced BOD, COD Reaerated, Altered Temperature Non-native Species and Diseases
Discharge #13 Mariculture with Direct Contact	D2, D12 Plus Altered Nutrient Status Detritus, Enhanced BOD, COD Reaerated, Altered Temperature Non-native Species and Diseases
Discharge #14 Conc. WW. Effluent in SPOTEC	D1 plus Enhanced Salinity

TABLE I. *(Continued)*

Discharge #15 Conventional with SPOTEC	D4. D7. D9, D10, plus Altered Salinity Biocides Altered Temperature Trace Constituents
Discharge #16 Direct Disch MED with SPOTEC	D4, D7, D9, D10, plus Altered Salinity Biocides Altered Temperature Trace Constituents
Discharge #17 Conc. WW. Effluent Ind. Use	Any Discharge plus Whatever industry does— difficult to define

Paths to the Environment

The nature of the releases to the atmosphere and to the marine environment will depend upon the type of heat exchanger used, any secondary uses, and the chosen discharge configuration.

Atmospheric Releases

Carbon dioxide, oxygen, nitrogen, other atmospheric trace gases, and volatile metals will be released during degassing of the warm and cold water. Due to the difference in solubility among atmospheric gases in sea water, the ratio of $N_2 : O_2 : CO_2 = 28 : 19 : 1$ dissolved in sea water differs from the ratio 2400 : 630 : 1 found in the atmosphere (Skirrow 1975). The solubility for these gases also increases with pressure. Thus sea water from depth naturally will degas when brought to the surface. The volume of each gas released by degassing at any given pressure will vary inversely with the ambient temperature of sea water (Weiss 1970), with warmer surface waters having less dissolved gases than colder deep waters. Further noncondensable and trace gases will be released from the warm water stream during evaporation and from the cold water during direct condensation (Table 1, Emissions A1, A2).

Marine Discharges

Depending on the heat exchanger, discharge configuration, and secondary uses chosen, a number of diferent discharges will result, each reaching the point of discharge by a different path (Figure I). As the composition and other physical and chemical properties of these discharges differ, so will their potential impacts. Seventeen paths for releases to the environment are shown in Figure 1. Table 1 characterizes the composition of the discharges. Briefly stated, the paths and their potential uses are as follows:

Uncombined OTEC Discharges

1 Warm water is degassed then moves to the evaporator. In the evaporator further noncondensable gases and vapor are removed. Concentrated WW effluent will result which is discharged directly to the ocean (Conc. WW effluent).

2 The vapor resulting from evaporation of the degassed warm water drives the turbine, is condensed by direct contact with degassed cold water, and is discharged directly (DC effluent).

3 The vapor resulting from evaporation of degassed warm water drives the turbine, is condensed by a conventional condenser forming fresh water, and is discharged directly.

4 The cold water used in conventional condensation is discharged directly.

Combined OTEC discharges

5 Direct contact effluent (path 2) is mixed with concentrated WW effluent (path 1) and discharged.

6 Concentrated WW effluent from path 1 and fresh water resulting from conventional condensation (path 3) are recombined and discharged.

7 Concentrated WW effluent (path 1) and cold water used in conventional condensation (path 4) are combined and discharged.

8 Fresh water (path 3) and cold water used in conventional condensation (path 4) are combined and discharged.

9 Combined fresh water and concentrated WW effluent (path 6) are mixed with cold water from the conventional surface condenser and discharged.

Fresh Water Uses

10 Fresh water produced by conventional condensation of the working fluid is distributed to domestic or industrial consumers. It is discharged with other domestic or industrial effluents.

11 Fresh water produced by conventional condensation is used for agriculture. Its discharge would be part of the runoff.

Mariculture Uses

12 Cold water from the conventional surface condenser is used for aquaculture.

13 The effluent from direct contact condensation (path 2) or the mixed effluent resulting from combination of the concentrated WW effluent with the DC effluent (path 5) are used for mariculture.

SPOTEC Uses

14 Concentrated WW effluent (path 1) is further concentrated for use in solar ponds, used to flush the upper layer of the pond, or as the cold-water side of the SPOTEC condenser.

15 Cold water used in conventional condensation (path 4) is used to flush the surface of solar ponds or used as the cold-water side of the SPOTEC condenser.

16 DC effluent (path 2) is used to flush the surface of solar ponds or used as the cold-water side of the SPOTEC condenser.

Other Uses

17 The concentrated WW effluent (path 1) is used for industrial purposes other than mariculture or SPOTEC.

Ranking of Pathways Associated with Early Open-Cycle OTEC Development

The paths are ranked for the near term development of the technology as (1) Probable: likely to be developed with minimal environmental and/or economic risk; (2) Possible: technically feasible, but with unknown or poorly known risks compared to (1); and (3) Unlikely: technically conceivable but improbable due to practical considerations or poorly known feasibility.

Probable Open-Cycle OTEC Options

Both direct contact or conventional condensation are viable options at this time. There are advantages to either. Direct contact requires less parasitic power and a less costly condenser but conventional condensation may yield potentially commercial or potable fresh water as a by-product. Several paths must be considered as probable options when considering the oceanographic and environmental research required to support open-cycle development.

Paths 1, 2, 4, 5, and 7 involve the direct discharge of effluents from open-cycle operations excepting the fresh water generated with conventional condensation. The relative desirability among Paths 1, 2, 4, 5, and 7 can not be determined at this stage of' development. Accordingly, all these paths would be considered viable.

Possible Open-Cycle OTEC Water Use

After water has passed through the OTEC plant, several uses of the effluent streams appear possible. Whether or not the effluent streams actually are used for these purposes will depend on the physical, chemical, and biological nature of the effluents involved, or development of an experimental technology. Oceanographic and environmental research will be required to determine the viability of these uses and the acceptability of the environmental effects resulting from each use.

Paths 10 and 11 will generate fresh water through conventional condensation for domestic, industrial, and agricultural use. These options all seem viable, should conventional condensation be used. The quality of the water produced as well as community needs will influence the extent of their use. The quality of water produced is still unknown and should be determined.

Path 12 will produce cold water from closed-cycle operations. Cold water already has been used successfully in various experimental aquaculture projects (NELH 1983). The cold water used in open-cycle with conventional condensation also would be applicable. A number of environmental questions must be addressed concerning use of cold ocean water for mariculture (see below).

Path 13, the desirability of using the degassed effluent from open-cycle OTEC for aquaculture has not been demonstrated. Before the advisability of following this path can be determined, it will be necessary to understand the composition of the streams themselves.

Paths 14, 15, and 16 involve the use of the open-cycle OTEC streams for additional power generation by augmenting the solar pond concept (SPOTEC). Although the viability of the SPOTEC technology has not yet been demonstrated, plans to test its viability have been prepared (SETS 1983).

Unlikely Pathways

Unlikely pathways are those which are improbable but cannot be discounted entirely.

Paths 3, 6, 8, and 9 would all result in direct discharge of freshwater collected from conventional condensation. The additional expenses involved in conventional condensation, used largely to obtain fresh water, make it improbable that the product achieved at such cost will be discharged without being used. Such water could be used as nonpotable industrial water in the plant, for purposes such as watering plants and washing equipment. .

Path 17 would direct concentrated WW effluent to users other than mariculture or SPOTEC. At least during early stages of OTEC development, it is improbable that an industrial user would want highly degassed sea water. A technological use based on the availability of such water is conceivable once open-cycle plants are operating.

Potential Environment Impacts of Open-Cycle OTEC

Terrestrial Concerns

The impacts of open-cycle OTEC to the terrestrial environment are similar to those associated with closed-cycle OTEC. These include impacts to threatened, endangered and endemic species; socioeconomic conditions; land-use: aesthetics, and geotechnical stability.

Due to the inherent differences between open-cycle and closed-cycle such as greater parasitic power losses associated with open-cycle and so on, for open-cycle one may expect larger flows, and consequently larger pipes, more extensive construction, and larger buildings.

All these could cause potentially significant impacts. Site- and design-specific investigations are required to determine the extent of impact of extensive excavation and construction. Local opinion surveys may be required so that the structures associated with open-cycle OTEC arc aesthetically pleasing or at least acceptable to the local community particularly in nonindustrial resort areas.

Atmospheric Effects

The impacts associated with release of atmospheric gases (primarily CO_2), trace gases including volatile trace metals, and particles generated during construction are environmental concerns for open-cycle OTEC operations.

The concentration of atmospheric CO_2 has been increasing during the past 100 years presumably due to the industrial revolution (Brewer 1978). Additional carbon dioxide absorbs more infrared solar radiation, thereby warming the atmosphere. Physicists helieve that increased levels of carbon dioxide may increase the equilibrium temperature of the planet with the potential for climatic change (NAS 1983; EPA 1983).

The CO, released from occm water during degassing of warm and cold water during the open-cycle process will not be new CO_2. That is, this gas is not the product of combustion, but is the result of recycling atmospheric gases initially dissolved naturally in ocean water at high latitudes during major water mass formation. Extensive outgassing of colder and deeper sea water occurs naturally in surface tropical waters by warming and depressurization during upwelling (Keeling 1968)

The extent of perturbation of natural equilibria by acceleration of natural degassing associated with open-cycle OTEC has not been calculated, because of the uncertainties in the rates of natural outgassing due to oceanic circulation. The impact of such perturbation is not expected to be significant on the basis of area or volume because open-cycle systems would be constructed in the tropics where it would be difficult to discriminate OTEC effects from natural inputs including volcanic emissions.

In any case, the maximum CO, released per unit of power produced for OTEC systems is one-third of the minimum released by conventional power plants burning fossil fuel (Bailey and Vega 1981). Accordingly, substitution of OTEC power for conventional power will result in less CO_2 introduced into the atmosphere. However, the actual amount of CO_2 released by open-cycle OTEC option should be quantified.

Trace gases including Ar, He, and Xe and volatile trace elements such as mercury will be released during degassing in proportion to their solubility in sea water and rate of formation in situ through biological processes. The impact of such releases has not yet been evaluated, but it is known that mercury is released during natural upwelling in detectable concentrations (Fitzgerald, Gill and Kim 1984). Mercury in certain forms is highly toxic (EPA 1980). Generic studies to evaluate the quantity of mercury and other volatile metals released and the impact of such release are needed particularly for projected OTEC sites in nonupwelling areas.

With on-shore winds, natural upwelling causes the formation of fog. In open-cycle operations the artificial upwelling of large volumes of cold sea water will come into direct contact with warm saturated air, potentially causing local fogs. This may be a concern in resort areas or other areas where good visibility (airports, rocky or hazardous coast lines) is desirable.

Marine Impacts

Many of the environmental concerns raised for the operations of a closed-cycle OTEC plant also can be raised for open-cycle. These include:

Physical Concerns such as impeding of water current and sediment transport, presentation of navigational hazards, and degradation of the thermal resource through lower temperature;

Geological Oceanographic Concerns such as sediment loading during construction (see below), steep-slope operations, and site stability;

Chemical Oceanographic Concerns such as modification of oceanic properties, interaction of discharged modified sea water with ambient sea water, trace constituent release, and biocide release; and

Biological Oceanographic Concerns such as impingement, entrainment and redistribution of native species, biota attraction, and destruction of habitat and breeding grounds for threatened, endangered and endemic species.

The need to conduct generic studies to investigate these concerns has been addressed elsewhere (DOE 1979b, 1980; Meridian 1983). The need to understand their implications is equally important to the development of open-cycle OTEC.

Concerns Specific to Open-Cycle Systems

In addition to thk above concerns common to all OTEC options, a number of issues, uniquely associated with the development of open-cycle OTEC, must be investigated. Degassing and evaporation will remove gases from the warm water stream. Because a conventional surface condenser creates a better vacuum, more of the noncondensable gases will be removed from the warm water if a conventional condenser is used. During direct contact condensation, noncondensable gases will be removed from the cold water stream. These operations result in effluent streams that contain only small amounts, if any, of oxygen, nitrogen, trace gases and volatile metals, and less CO_2. Open-cycle OTEC effluents must be chemically characterized before the significance of their discharge can be assessed, or their use in other applications can be evaluated.

In addition to characterizing effluent screams from open-cycle OTEC using direct contact and conventional condensation, the impacts of discharging these streams separately, in combination and after use in conjunction with aquaculture, SPOTEC, and other potential secondary uses, must be investigated. Specific concerns include the impacts of discharging degassed water and the viability of reaeration; the effect of discharging sea water with an altered pH (-log of the hydrogen ion activity) and buffer capacity on the chemistry of ocean water and on coral and benthic communities; and the manner of and optimal location for disposing of the effluents. The most serious concern is the effect of discharging a sea water with a modified chemistry and an altered pH and buffer capacity, as in general true marine organisms are adapted to the limited range of chemical variation found in sea water.

The pH of sea water is regulated by the dissolved carbonate and borate buffer system (Harvey 1957) and ranges naturally from *7.5* to 8.4 (Sverdrup et *al.* 1942) with a mean value of about 8. The pH affects the degree of dissociation of weak acids and bases and salts and thus the solubility, formation, alteration, and dissolution of particulate minerals (Wilde 1978; Stumm and Morgan 1981). Chemical speciation or type of metal and other complexes dissolved in the sea water also is affected by pH. In general, metal species are more toxic at lower pH than complexes formed at higher pH (NAS 1973).

When CO_2 is removed from ocean water the pH increases. If the effluent were discharged at this point it could have a pH above ambient. If degassing proceeds, above pH 9, at naturally occuring sea water concentrations, magnesium hydroxide and calcium carbonate precipitate (Edmond 1970). Because tropical waters are greatly supersaturated with respect to calcium carbonate (Edmond and Gieskes 1970), carbonates could precipitate at even lower pH. Preliminary calculations by Morse (based on Mucci and Morse 1983) showed that the rate of calcium carbonate precipitation could double with 20 percent degassing and increase by at least *50* times at 99 percent outgassing. Due to the kinetics of the system (Morse and Berner 1972), once precipitated the minerals may not redissolve even if the pH of the stream is lowered by reaeration. In the case where degassing has resulted in precipitation of minerals, the effluent sea water, even if reaerated, would be depleted in magnesium, calcium, and carbonate alkalinity, and have increased turbidity. It would have lower pH and buffer capacity than any ambient receiving oceanic water. In addition, a considerable volume of $CaCO_3$ may be generated. Sea water includes about 400 kg/m^3 of Ca (Sverdrup *et al.* 1942). If *50* percent were precipitated, about *5* kg/m^3 $CaCO_3$ per second could result for each megawatt of power generated.

The natural variation of the pH of oceanic waters is small due to its high buffer capacity. Accordingly, marine organisms are not accustomed to changes above 0.5 pH units about 8.0. Fish appear to be less sensitive than are plankton and benthic invertebrates (NAS 1973). Coral and other reef forming organisms have skeletons composed primarily of $CaCO_3$. Such organisms are exclusively marine and are not found in estuarine or fresh water environments with highly variable salinity or pH. The discharge of large volumes of water with either higher or lower than ambient pH, lowered buffer capacity, increased turbidity, and undersaturated in calcium carbonate on or near coral reefs and algae and backreef communities is not likely to be beneficial to organisms living in such a restricted environmental range (Dodge and Vaisnys 1977; Knutson ***et al.*** 1972; Smith and Pesret 1974).

The extent to which the pH will be altered by open-cycle OTEC operations must be determined and the impact of discharging large volumes of waters with altered pH must be evaluated. Generic studies are needed to establish whether this issue is significant and whether impacts can be mitigated.

Continuous discharge from an open-cycle OTEC plant will most probably be into well-oxygenated surface or near-surface sea water. Water containing no or low levels of dissolved oxygen are toxic to aerobic marine species (NAS 1973). The distribution and range of vertically migrating zooplankton has been modified and restricted during naturally episodic introduction of low to anoxic water in near surface waters (Judkins 1980). Most fish and other active nekton populations such as squid and marine mammals can avoid such conditions, however species with low motility and coral reef and benthic communities could be affected (Kinsey 1973). Generic studies to identify sensitive species, determine their sensitivity, and determine rates and means of reaeration are needed.

Impacts of Construction

Open-cycle OTEC systems intrinsically use more land than closed-cycle systems. Compared to closed-cycle systems, they require more parasitic power, larger volumes of water, headers, pumps, and heat exchangers. In addition, the evaporator and vacuum system must be raised an optimal amount above the source water level. Buildings at least 25 m high have been proposed for 1 MW, plant. In addition four pools to hold warm water and cold intake and discharge waters must be constructed to regulate water flows. Construction of open-cycle OTEC facilities will involve more excavation and dredging than would a closed-cycle plant. Construction of the facility will introduce a larger number of particles and exhaust gases into the atmosphere. Particle levels associated with major construction projects frequently exceed ambient air quality standards. Construction may disturb or destroy the habitats or breeding grounds of threatened, endangered or endemic species, or archeological/historical sites. Site- and design-specific investigations are needed to establish extent of impacts.

Construction associated dredging will destroy some coral reefs and benthic communities and will increase the particles and the turbidity in the marine environment. Siltation and lower light levels associated with increased turbidity may be detrimental to corals and benthic communities (Dodge and Vaisnys 1977). As for closed-cycle OTEC. it is important to conduct site-specific investigations to determine the impact of dredging, siltation, and turbidity.

Concerns for Secondary Uses: Mariculture and Solar Pond OTEC

For mariculture, environmental concerns include the addition of nutrients, biological oxygen demand (BOD), chemical oxygen demand (COD), detritus, non-native species, and diseases to the discharge water. Generation of solid waste may also result in terrestrial concerns. For solar ponds, there is the possibility of release of thermal brines, biocide, and working fluid. All these potential impacts need to be investigated.

Summary

A number of oceanographic and environmental studies need to be undertaken to assure that open-cycle OTEC operations are environmentally benign. Those that are also necessary for the development of closed-cycle OTEC have been discussed elsewhere (DOE 1979b, 1980; Meridian 1983). The studies required for the logical development of a viable open-cycle OTEC technology and for the development of OTEC in general include studies of:

Terrestrial Impacts

1. design studies assure that an open-cycle OTEC plant is aesthetically acceptable,
2. optimization of designs to minimize building size and mass and land use, and
3. quantification of solid wastes generated (that is, shell material from mariculture, carbonates from outgassing, etc.),

Atmospheric Impacts

1. global and local climatic implications of carbon dioxide releases from open-cycle OTEC plants,
2. trace constituent releases from open-cycle OTEC plants, and
3. effects of artificial upwelling on local atmospheric conditions, and

Marine Impacts

1. influence of degassing and various evaporation and condensation strategies on the pH and buffer capacity of intake and discharge waters,
2. effect of pH and alkalinity change on the solubility of salts dissolved in seawater,

3. effect of pH change on the chemistry of ocean water and on coral and benthic communities,
4. discharge of deaerated water on marine communities, and
5. properties of reaerated seawater after degassing, and various evaporation and condensation operations.

Open-cycle OTEC can be designed as a relatively benign technology when compared with known problems related to conventional energy production. However, a number of new environmental concerns arise with the development of a new and innovative technology. Some concerns are the same as those associated with closed-cycle OTEC: Others, identified above, are unique to open-cycle systems. It is essential that all significant concerns be addressed to assure that open-cycle OTEC is an environmentally acceptable alternative to conventional energy and secondary product generation.

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