# ALTERNATIVE ELECTRICAL ENERGY SOURCES FOR MAINE

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## Appendix D
## OCEAN THERMAL ENERGY CONVERSION

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This appendix is one of thirteen volumes; the remaining volumes are as follows: A. Conversion of Biomass; B. Conservation; C. Geothermal Energy Conversion; E. Fuel Cells; F. Solar Energy Conversion; G. Conversion of Solid Wastes; H. Storage of Energy; I. Wave Energy Conversion; J. Ocean and Riverine Current Energy Conversion; K. Wind Energy Conversion, and L. Environmental Impacts.

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# Preface

The Energy Laboratory of the Mass. Inst. of Tech. was retained by the Central Maine Power Company to evaluate several technologies as possible alternatives to the construction of Sears Island #1 (a 600 MWe coal fired generating plant scheduled for startup in 1986). This is an appendix to Report MIT-EL 77-010 which presents the results of the study for one of the technologies.

The assessments were made for the Central Maine Power Company on the basis that a technology should be:

1) an alternative to a base-load electric power generation facility. Base-load is defined as ability to furnish up to a rated capacity output for 6570 hrs. per year.

2) not restricted to a single plant. It may be several plants within the state of Maine. The combined output, when viewed in isolation, must be a separate, "stand-alone", source of power.

3) available to deliver energy by 1985.

# APPENDIX D

## OCEAN THERMAL ENERGY CONVERSION


| | | Page |
|---|---|---|
| 1.0 | INTRODUCTION | D-1 |
| 2.0 | OCEAN THERMAL ENERGY CONVERSION (OTEC) TECHNOLOGY | D-1 |
| | 2.1 Description | D-1 |
| | 2.2 Status of Development | D-3 |
| 3.0 | APPLICABILITY TO MAINE | D-7 |
| 4.0 | ENVIRONMENTAL IMPACTS | D-7 |
| 5.0 | ECONOMICS | D-8 |
| 6.0 | CONCLUSIONS | D-8 |
| 7.0 | REFERENCES | D-9 |

LIST OF TABLES

Page

Table 2.1 Issues Clarified or Resolved To Date - OTEC Program D-6

Table 2.2 Programmatic Issues to be Resolved - OTEC Program D-6

LIST OF FIGURES

| | | Page |
|---|---|---|
| Figure 2.1 | Closed Cycle OTEC System | D-1 |
| Figure 2.2 | The Moored, Spar-Buoy Type, 160 MWe Plant Design Concept of the Lockheed/Bechtel Corporation/T.Y. Lin Team | D-2 |
| Figure 2.3 | Cutaway View of the Overall Plant | D-3 |
| Figure 2.4 | Ocean Thermal Program Engineering Development and Demonstration Milestones | D-4 |
| Figure 2.5 | Ocean Thermal Program Heat Exchanger Development Milestones | D-5 |
| Figure 3.1 | Areas of the Atlantic, Caribbean, and Gulf of Mexico Suitable for OTEC Operation | D-7 |

## 1.0 INTRODUCTION

As early as 1881 d'Arsenval proposed the extraction of energy from the temperature difference between water at the surface of the ocean and water at greater depths. Modern concepts based on the utilization of the same temperature difference have come to be called Ocean Thermal Energy Conversion (OTEC) plants. OTEC plants, along with wind power, biomass, solar thermal power, and solar photovoltaic power, represent one of the main technological alternatives for extracting useful energy from the solar radiation striking the earth's surface.

OTEC plants are not a practical alternative for the production of electricity for Maine. This appendix, which briefly describes OTEC technology, has been prepared to complete our discussions of alternative solar technologies. The interested reader should consult (Dugger, 1975) (Heronemus, 1975), or (ERDA, 1976) for more information.

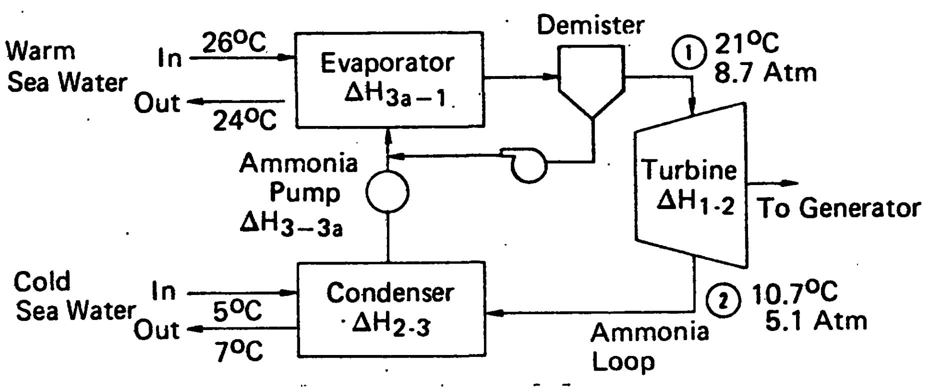
## 2.0 OCEAN THERMAL ENERGY CONVERSION (OTEC) TECHNOLOGY

### 2.1 Description

As solar radiation strikes the surface of the ocean, it warms the uppermost layers of water. Depending on latitude and time of year, surface temperatures may approach 80°F (26°C). In the tropics, surface temperatures are near 77°F (25°C) year-round (CEQ, 1974, pp. 11-25). Beneath the surface, at depths greater than about 1500 ft., the water temperature approaches 39°F (4°C), since, at that temperature, water has its maximum density. This temperature is also relatively constant all year.

Both open and closed thermodynamic cycles can be used to extract energy from the temperature difference between the surface and bottom waters of the oceans. Although open-cycle OTEC technology is also the subject of current research, closed-cycle systems are considered to be closer to implementation (Dugger, et al., 1976, p. 12) and receive the bulk of OTEC research support. Closed-cycle systems use warm surface water to evaporate working fluids with low boiling points (e.g., ammonia, propane or Freon-type refrigerants) (Lawson, et al., 1976, p. 507). The vaporized working fluid drives a turbine, producing electricity, and is then condensed. The condenser uses the cool bottom waters to remove the waste heat (Figure 2.1).

Figure 2.1




CLOSED CYCLE OTEC SYSTEM

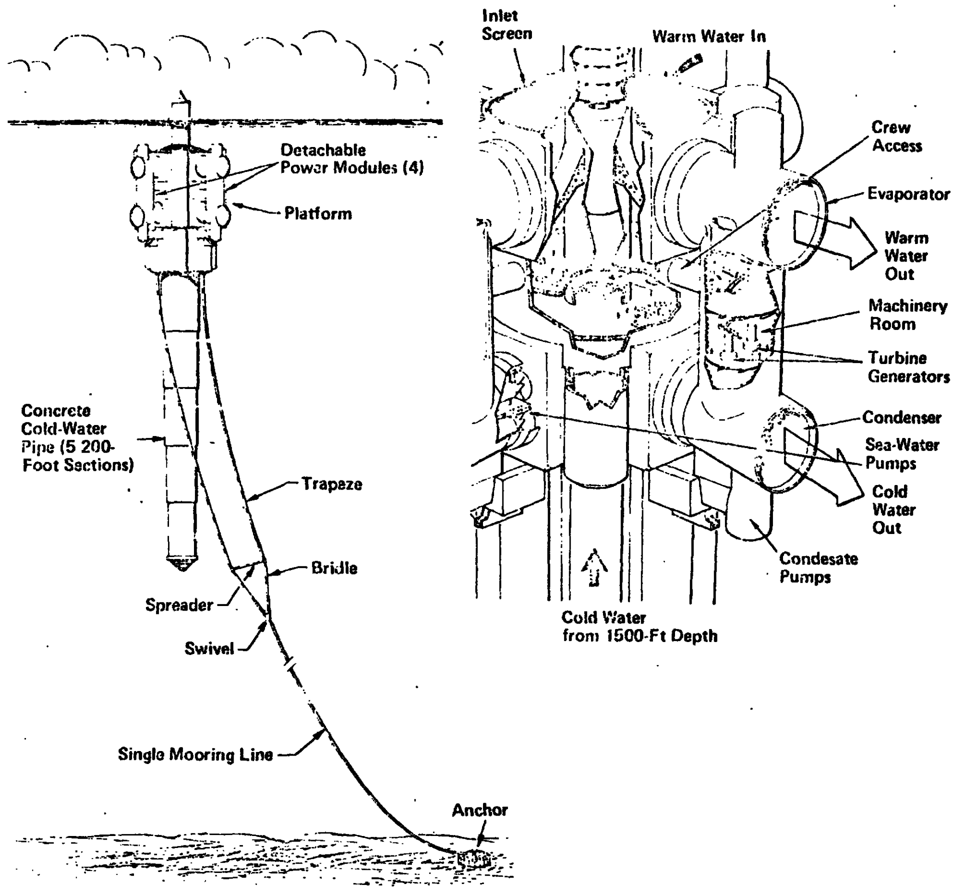
from (Dugger, et al., 1976, p. 12).

Because the temperature differences are so small, efficiencies are low and the volume of water which must be processed is large. In tropical regions, theoretical efficiencies are on the order of 6% and actual efficiencies are expected to be between 2.5 and 3.0% (Czikk, et al., 1976, p. 461). Thus roughly 10 times as much heat must be discarded with OTEC plants as with conventional generation.

Large water volumes also mean large equipment sizes. Typical designs for 100 MWe capacity OTEC plants are several hundred feet in diameter and extend 1500 to 3000 feet below the ocean surface (Figures 2.2, 2.3). OTEC plants will float in the ocean with mooring systems or position-keeping schemes using directed water jets. It is hoped that most of the OTEC plant fabrication can be done at a single shore-based drydock facility, thus avoiding the problems of open ocean construction.

Transferring energy from OTEC facilities to utility transmission grids will not be easy. One alternative is to use underwater cable systems. It has also been proposed to produce fuels such as hydrogen, for shipment to shore, or to create floating industrial complexes which would use the power where it is produced and ship processed energy-intensive materials to shore (Hornburg, et al., 1976, p. 413).

Figure 2.2



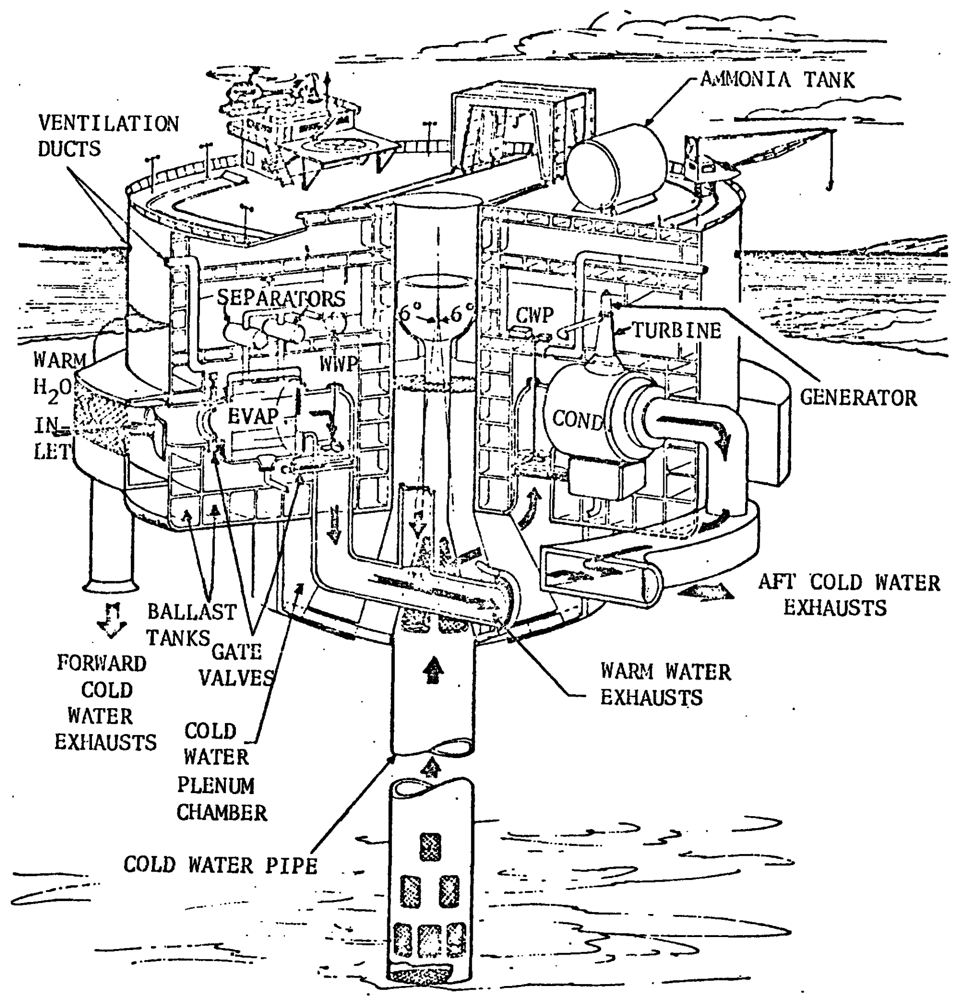

The Moored, Spar-Buoy Type, 160-MWe Plant Design Concept of the Lockheed/Bechtel Corporation/T.Y. Lin Team. Inset is close view of one power module.
from (Dugger, 1976, p. 16).

By far the most critical element is the heat exchanger subsystems in both the evaporator and condenser. These represent about 40% of the investment of a plant and must operate in a hostile environment where corrosion and fouling will be constant problems (Fetkovich, et al., p. 446). Significant materials, fabrication and maintenance problems may exist.

2.2 Status of Development

The ERDA research program for OTEC development is shown in Figures 2.4 and 2.5. Note that if the program plan is met there will be one 100 MW prototype (comprised of four 25 MW modules on the same hull) being tested by 1986. The critical program issues which have been resolved and those which still remain are shown in Tables 2.1 and 2.2. At this point, OTEC must be considered an emerging, unproven technology.

Figure 2.3



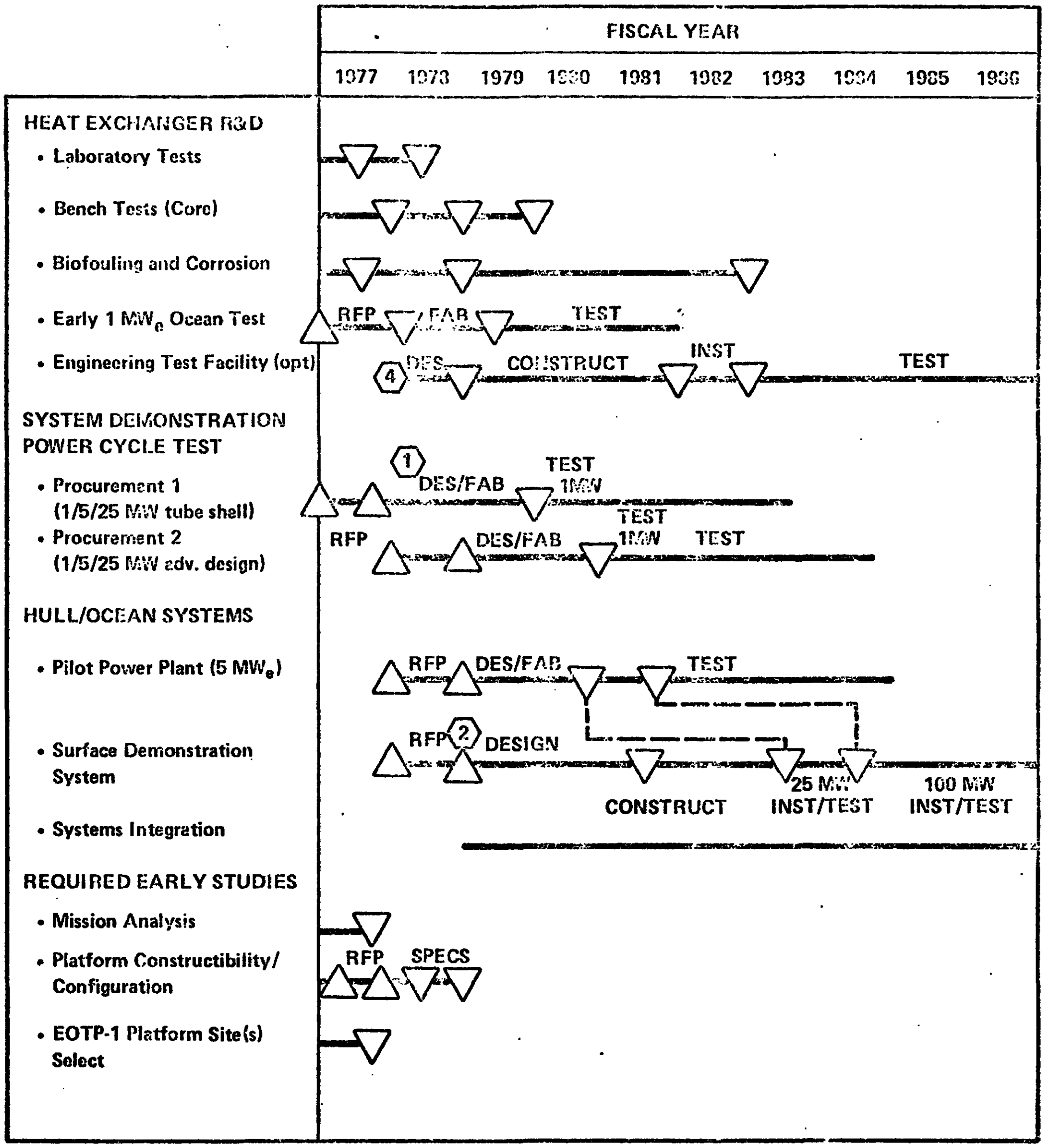

CUTAWAY VIEW OF THE OVERALL PLANT

DESIGNED BY TRW

CONCEPTUAL OTEC BASELINE DESIGN

from (Zener, 1976, p. 54 ).

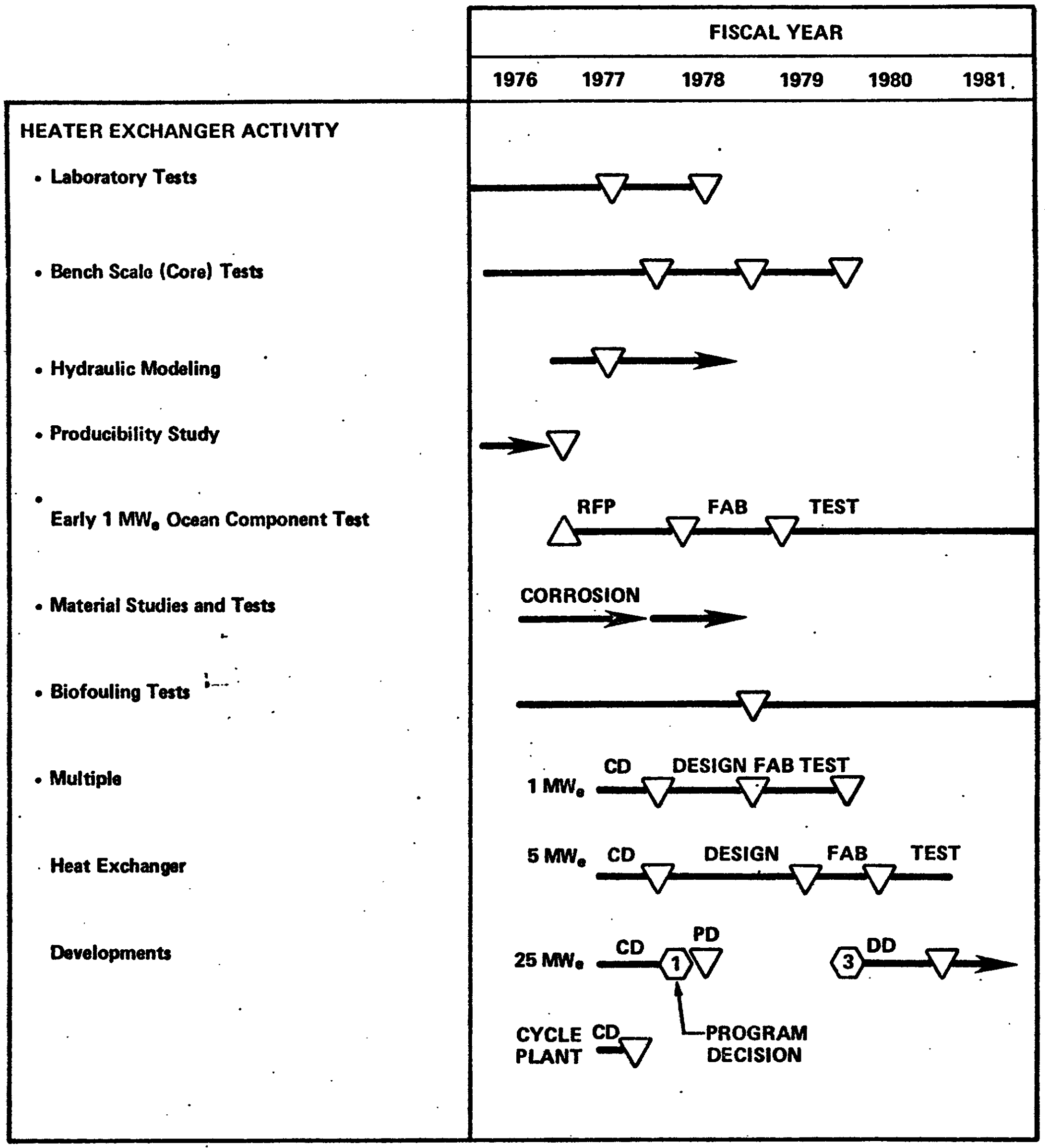
Figure 2.4




OCEAN THERMAL PROGRAM ENGINEERING DEVELOPMENT AND DEMONSTRATION MILESTONES

from (ERDA, 1976, p. 5).

Figure 2.5




CD — Conceptual design
PD — Preliminary design
DD — Definitive design

OCEAN THERMAL PROGRAM HEAT EXCHANGER DEVELOPMENT MILESTONES

from (ERDA, 1976, p. 6).

Table 2.1

**ISSUES CLARIFIED OR RESOLVED TO DATE – OTEC PROGRAM**

| Issue | Program Impact |
|---|---|
| The resource potential of ocean thermal energy has been established as substantial, and abundant sites are available | OTEC clearly satisfies ERDA requirements for providing a substantial source of energy for supplying U.S. energy needs of electricity and energy-intensive products |
| 100 MWe Ocean Thermal System module size of 25 to 40 MWe reference system for electrical application | Selection of a 100 MWe demonstration plant size (1984 time frame) and of a 25 MWe power plant module (1983 time frame) |
| Base-load application | Energy utilization and mission analysis studies oriented toward base-load options (unlike other solar-electric applications) |
| Closed cycle power plant with ammonia as the working fluid | The open cycle option and on other closed cycle working fluids are being examined as exploratory technology under strategic alternatives category. Review Dec. 77. |
| Emphasis on shell-tube and tube heat exchangers for initial core tests and early ocean testing | Permits development of heat exchangers that are technologically closest to current state of the art, hence most likely to operate successfully |
| "Early" ocean test platforms | Provide early component and system testing, allowing an earlier opportunity for testing large-size heat exchangers (compared to land-based facilities) |
| Pilot floating power plant of 5 MWe in a conventional hull (no OTEC requirement was established for a specialized OTEC hull at this stage) | Provide for an early system test to obtain performance verification and valuable operational information |

Table 2.2

**PROGRAMMATIC ISSUES TO BE RESOLVED – OTEC PROGRAM**

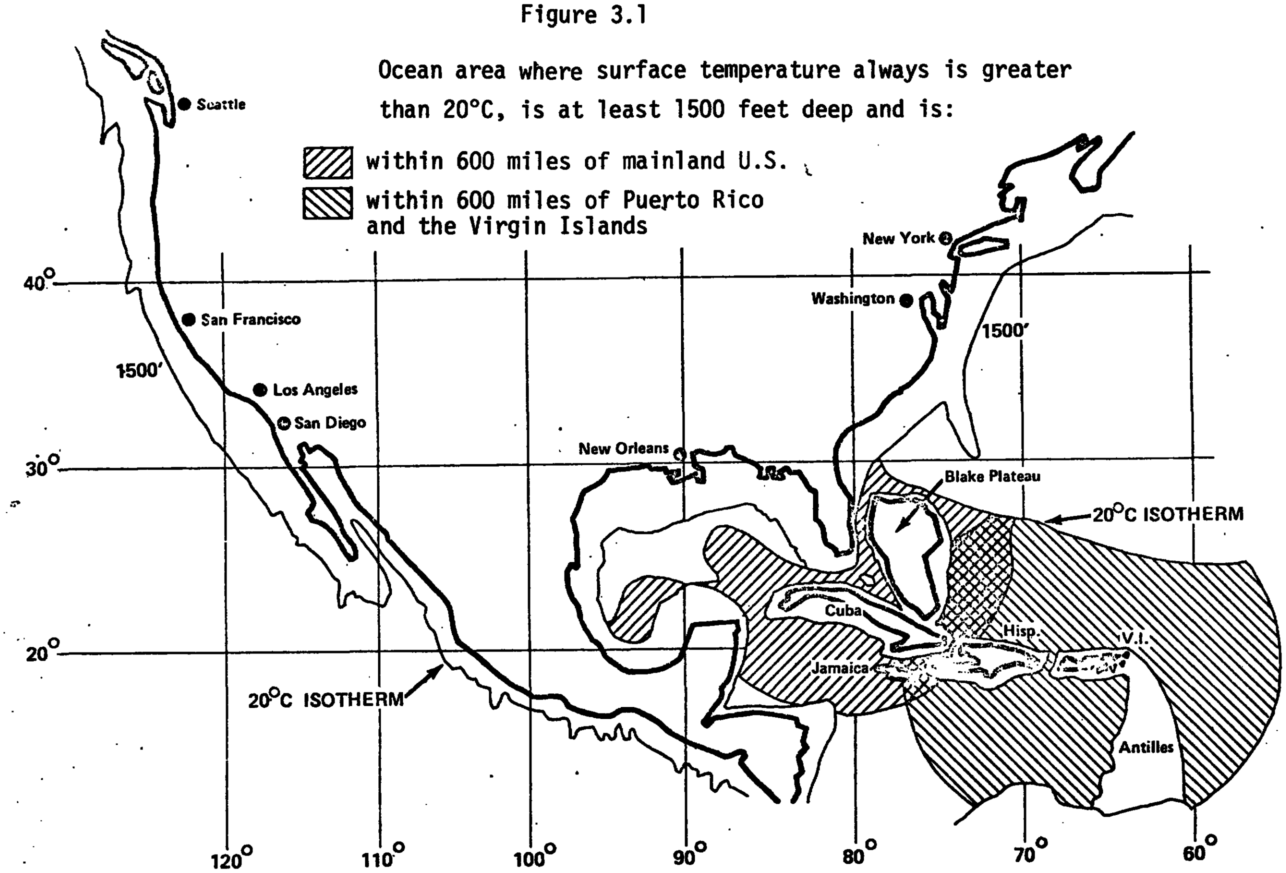
| Issue | Program Phase |
|---|---|
| Product mix, marketability, thermal resource and siting assessments | Strategy and Definition Planning |
| Technical and economic viability of OTEC heat exchangers | Engineering Development and Demonstration |
| | Technology Base |
| Impact of biofouling and corrosion on system performance | Engineering Development and Demonstration |
| | Technology Base |
| Interest of utility and industrial user groups | Commercialization |
| Hull/structure platform configuration | Strategy and Definition Planning |
| | Engineering Development and Demonstration |
| Evaluate requirement for a land-based Engineering Test Facility | Strategy and Definition Planning |
| Evaluate potential applications of alternate cycles and demonstrate critical feasibility | Strategy and Definition Planning |
| | Technology Base |
| Possible impacts on biota, thermocline, and climate | Strategy and Definition Planning |

from (ERDA, 1976, p. 2).

### 3.0 APPLICABILITY TO MAINE

OTEC systems are <u>not suitable</u> for the ocean environment off the coast of New England. With ocean surface temperatures varying seasonally between roughly 60°F (15°C) and 40°F (5°C), OTEC theoretical efficiencies would vary from about 4% to under 1%. Actual efficiencies would be less than 2% in the summer to a fraction of a percent in the winter. Furthermore, ocean depths off the Maine coast are inadequate to allow the deep collection of cool water (Figure 3.1).

Figure 3.1




AREAS OF THE ATLANTIC, CARIBBEAN, AND GULF OF MEXICO SUITABLE FOR OTEC OPERATION.

from (Harrenstein, 1976, p. 528)

OTEC systems will probably only have an impact on electrical generation in those southern states having access to ocean waters with adequate surface temperatures and depths. Indirect effects in some other sections of the country due to fuel displacement or hydrogen fuel systems are possible. Maine's distance from possible OTEC sites makes any effects on Maine's electrical supply highly unlikely.

### 4.0 ENVIRONMENTAL IMPACTS

The major potential environmental impacts of OTEC power plant operation arise from the large volumes of cool water which must be brought near the surface by the condenser systems.

The warm surface waters are characterized by a region of fairly rapid falloff of temperature. Below this region, the temperature gradient is smaller. The approximate point of transition, called the thermocline, represents the bottom of the warm surface layer. Condenser water will be discharged below the thermocline and is not expected to mix with the water above. If OTEC designs successfully prevent mixing, the temperature impacts on the ocean's surface will be small, probably well within the normal diurnal variations of temperature (Dugger, 1976, p. 24). If mixing should be more complete the thermocline could be destroyed and surface temperatures reduced. Fish and surface plants could be killed by the thermal shock. Since the ocean surface is critical to weather system formation, any drop in surface temperature could change local climate. Large-scale implementation of OTEC could possibly affect the global weather system, particularly if the cooling effects concentrated around features such as the Gulf Stream.

Bottom waters contain high nutrient levels. When brought near the surface in large quantities, these nutrients could produce a variety of effects. Fish populations could be enhanced, leading to the possibility of mariculture. Or algal blooms might occur, killing fish and raising the fouling potential of heat exchange surfaces in the plant.

Entrapment and entrainment of living organisms might be an environmental problem because of the huge water flows. However, the in-plant temperature rise is much smaller (~2°C) than that of conventional plants (~20°C), so mortality might be lower.

No air pollutants would be produced in normal operations, but leakage of the turbine working fluids could pose a hazard. With standard monitoring equipment, such a problem could be anticipated and prevented.

A more complete discussion of environmental effects is found in (Harrenstein and McCluney, 1976, p. 522).

## 5.0 ECONOMICS

Three significant economic features of OTEC power plants are that they provide base load power (i.e., require no storage), can be built with components of current technology, and have no fuel costs. Despite these advantages, there remain several problems with the economic implementation of OTEC power plants. Legal issues (e.g., ownership of the seas, insurance status), policy constraints (e.g., licensing, strategic protection of industry), technical problems (e.g., lack of demonstration, environmental effects) and financial constraints (e.g., large capital needs, high-risk investment) all will affect the rate at which OTEC facilities will be built (Naef, 1976, p. 398).

At the present time all cost estimates are based on preliminary engineering design work. No pilot plant experience exists on which to base estimates of operating problems, equipment life, maintenance, etc. Considerable optimism exists for savings due to mass production and field experience with modular OTEC plants.

Capital cost estimates have been developed by Lockheed and TRW. The first plant of 100 MW or more capacity has been estimated to cost between $2660/KWe (160 MWe) and $2100/KWe (100 MWe). Estimates of later plants go as low as $1100/KWe (100 MWe) (Dugger, 1976, pp. 16-17). For capacity factors of 0.90 and 18% levelized fixed charges, these costs become 60 mills/kwh and 48 mills/kwh. Later plants would be 25 mills/kwh. These are busbar costs, i.e., they do not include transmission of the energy to shore.

Converted to 1986 dollars (at 5% simple inflation), these figures become 90 mills/kwh and 72 mills/kwh for the first plants and 38 mills/kwh for later production units.

## 6.0 CONCLUSIONS

- Ocean Thermal Energy Conversion (OTEC) power plants are <u>not</u> a practical means for electricity production in Maine because of low temperature differences and shallow water offshore.

- OTEC may contribute to the electricity supply of southern states in the late 1980's.

- OTEC is an emerging technology, based on modular combinations of existing technologies. Until pilot and demonstration plants are constructed, all estimates of costs and performance must be considered conjectural. The best available figures are for electricity costs (1986 dollars) of between 72 and 90 mills/kwh for the first OTEC plant, without transmission.

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