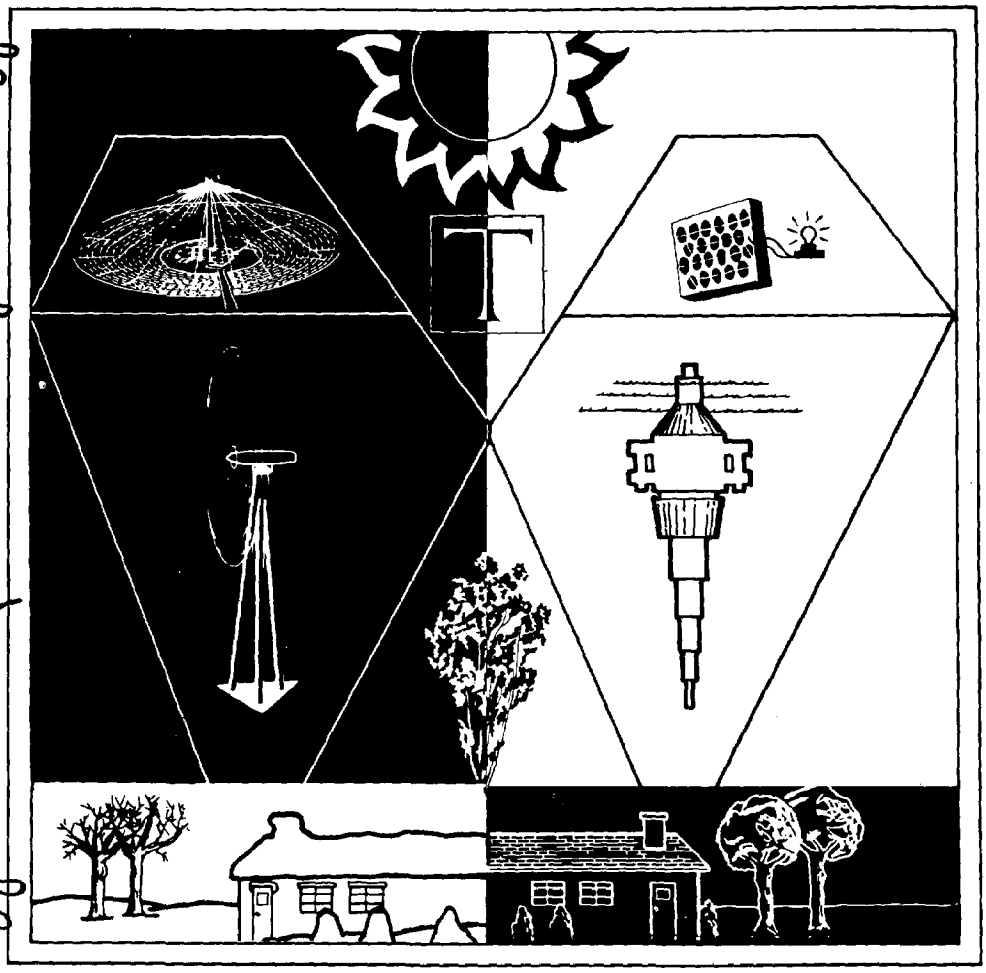
DOE/ET-0021/1

AN THERMAL ENERGY CONVERSION (OTEC) PROGRAM

FY 1977 PROGRAM SUMMARY JANUARY 1978



DIVISION OF SOLAR TECHNOLOGY

WASHINGTON, D.C. 20545

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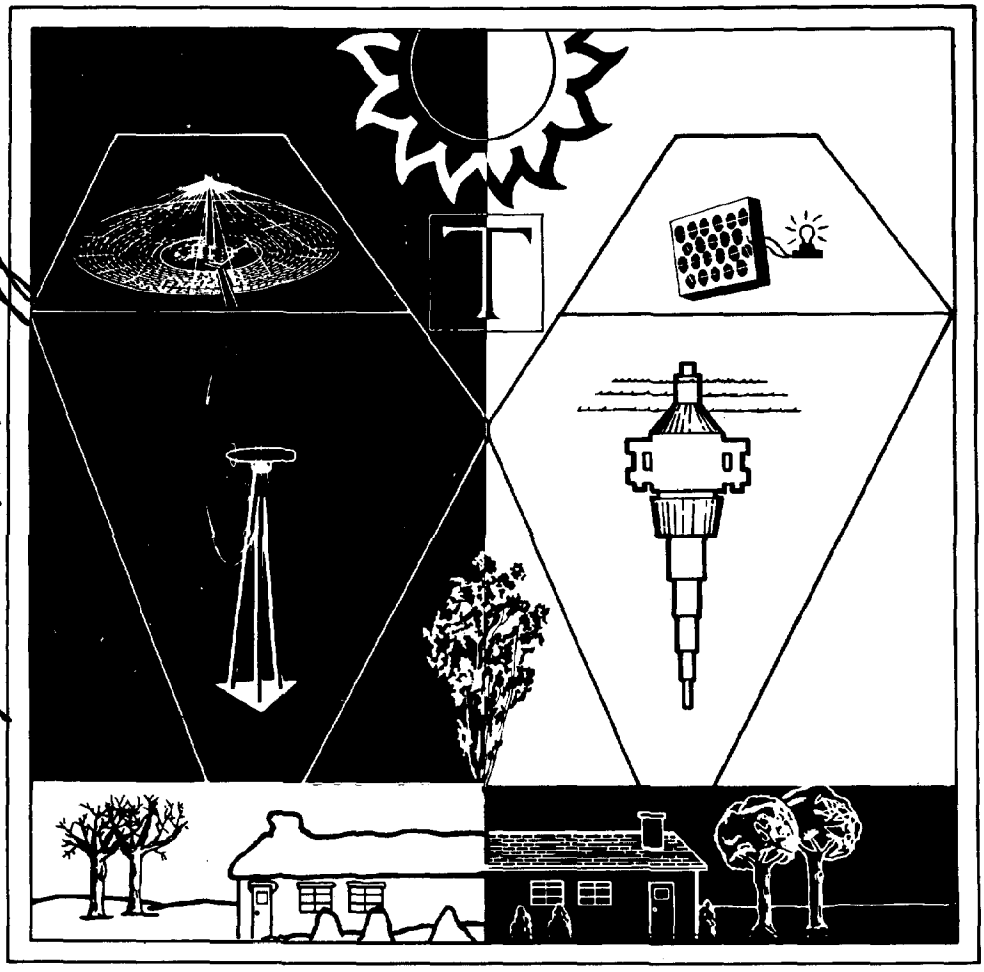

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Preface

On October 26, 1974, the Solar Energy Research Development and Demonstration Act (Public Law 93–473) was signed into law, authorizing a vigorous Federal program of research, development and demonstration. Its goal was to provide the nation with the option of using solar energy as a viable source for meeting future energy requirements. In response to the mandates of this act, major efforts were conducted within the Division of Solar Energy of the Energy Research and Development Administration (ERDA) to work with industry to develop and introduce, at the earliest possible date, economically competitive and environmentally acceptable solar energy systems.

These responsibilities were transferred to the new U.S. Department of Energy (DOE) on October 1, 1977. ERDA's Division of Solar Energy (SOLAR) was simultaneously reorganized into two distinct organizational components:

- The Division of Solar Technology (SOLAR/ET), which functions as a part of the Office of the Assistant Secretary for Energy Technology.
- The Division of Solar Applications (SOLAR/CS), which functions as a part of the Office of the Assistant Secretary for Conservation and Solar Applications

As a result of this reorganization, the Solar Heating and Cooling Program, and the Technology Transfer Program, were transferred into SOLAR/CS. An overview of the current DOE organization is shown in Figure 1.

Program planning continues under the guidelines established by PL 93–473 and by three other legislative acts passed by the 93rd Congress: the Solar Heating and Cooling Demonstration Act of 1974 (PL 93–409), the Energy Reorganization Act of 1974 (PL 93–438), the Federal Nonnuclear Energy Research and Development Act of 1974 (PL 93–577). Together these four laws grant DOE and other Federal agencies the authority to pursue a research program aimed at effective solar energy use. Under this authority, SOLAR/CS and SOLAR/ET will work to promote a fully coordinated solar energy program and to complement efforts in the private sector to develop solar energy resources.

The major programs and subprograms of the Solar Energy Program during 1977 were:

a. Solar Electric Systems
   (1) Wind Energy Conversion.
   (2) Photovoltaic Energy Conversion.
   (3) Solar Thermal Electric Conversion.
   (4) Ocean Thermal Energy Conversion (OTEC).
   (5) Solar Satellite Power Systems.
b. Fuels from Biomass
   (1) Production and Collection of Biomass.
   (2) Conversion of Biomass.
c. Technology Support and Utilization
   (1) Technology Transfer.
   (2) Environmental and Resource Assessment.
d. Solar Heating and Cooling
   (1) Barriers and Incentives.
   (2) Demonstration.
   (3) Research and Development.
   (4) Agricultural and Industrial Process Heat.

A Program Summary is issued for each program annually. It is an overview of the ongoing research, development, and demonstration efforts of the preceding fiscal year.

This Program Summary describes each of the DOE's Ocean Thermal Energy Conversion projects funded during Fiscal year (FY) 1977 (October 1, 1976 through September 30, 1977) and reflects their status as of December 31, 1977.* The accomplishments of the Ocean Thermal Energy Conversion (OTEC) Program are highlighted, and plans for continued activities in OTEC technology development are summarized. This document is a follow-up to the OTEC Program Summary (ERDA 76–142) published in October 1976. Many projects summarized there but omitted from this Fiscal Year 1977 Program Summary may still be of current interest. (ERDA 76–142 can be ordered from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 for the price of $1.70.) Certain OTEC projects reported in the 1976 Program Summary are repeated herein only when significant developments have occurred in the meantime.

The OTEC Program is also investigating three related renewable ocean energy technologies: waves, currents, and salinity gradients. These technologies are described in Part II of this Program Summary.

* Wherever funds of the Environmental and Resource Assessment Branch (ERAB) of the Division of Solar Technology were utilized to support OTEC-related projects, the phrase "ERAB Funds" is included on the project summary sheets.

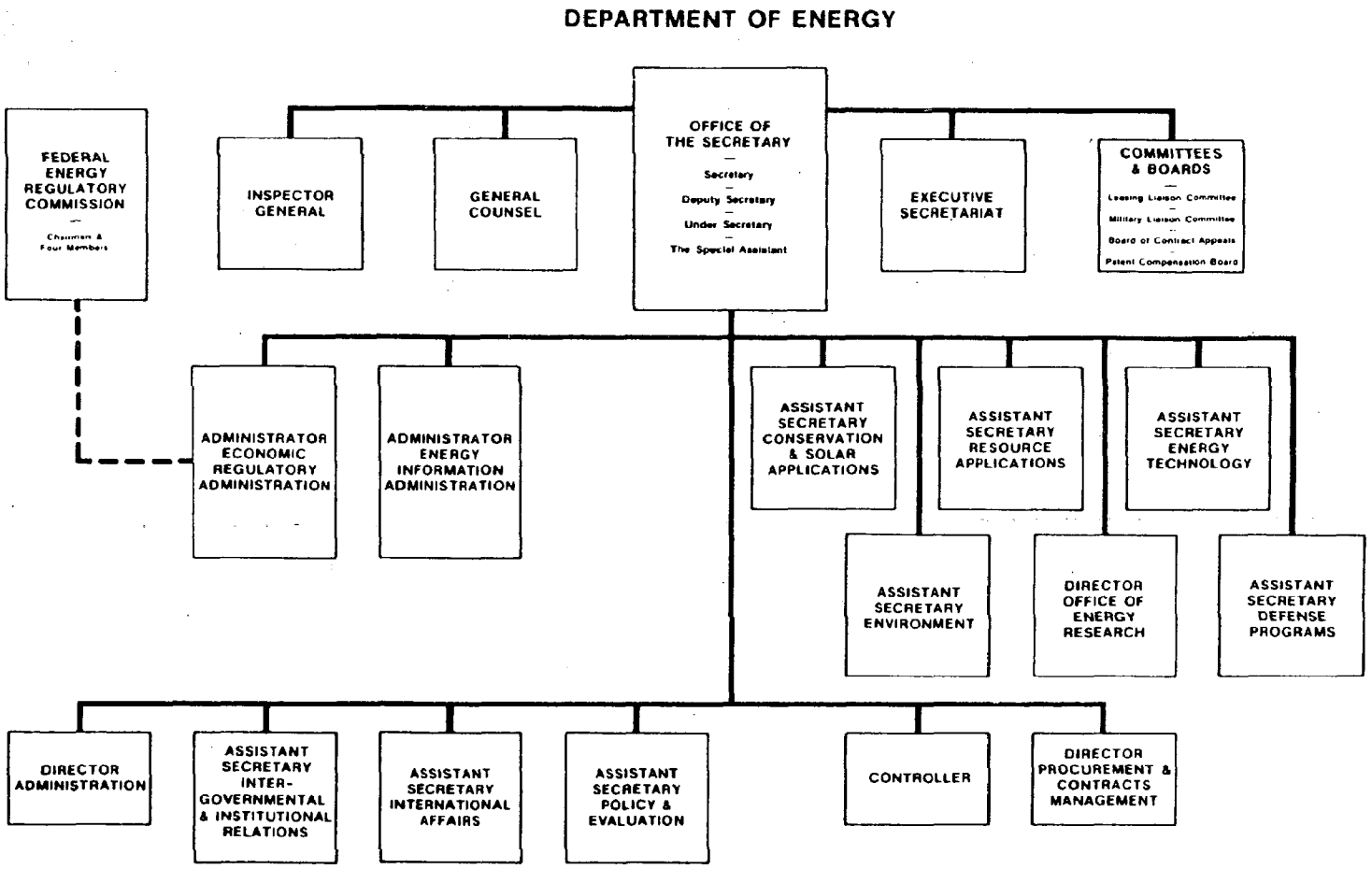

Figure 1. DOE Organization Overview

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OCEAN THERMAL ENERGY CONVERSION

INTRODUCTION

Ocean Thermal Energy Conversion (OTEC) is one of eight solar energy technologies being developed by the United States Department of Energy. These technologies were selected as potentially viable energy options that could provide substantial savings in the use of fossil fuels and contribute meaningful quantities of energy to the nation by the turn of the century.

BACKGROUND

The oceans are the earth's largest continuously operating solar energy collector. The energy collected is in the form of heat stored in the upper ocean layers. In tropical and subtropical waters, the temperature differential between the warmed surface layer and deep cold water is great enough to provide economic energy production by offshore ocean thermal power plants. Thus, solar heating of the ocean provides a continuous, renewable source of baseload OTEC electricity, since the heat absorbed by the surface water is sufficiently abundant to permit 24 hour operation at constant power output. Electrical energy generated on floating OTEC power plants can be transmitted to land and be utilized for off-shore, energy-intensive processes, such as the manufacture of NH_3 (ammonia), hydrogen, and metals.

CURRENT TECHNOLOGY

The technology being developed for OTEC power systems is based upon the "closed" Rankine thermodynamic cycle. The Rankine cycle utilizes a working fluid (e.g., ammonia) capable of evaporating and condensing over small temperature ranges. This approach has been chosen because it presents the best balance between economics and technical risks to achieve commercial OTEC performance goals in an early time-frame. Meanwhile, other candidate cycles—the "open" and "hybrid" cycles—are being examined in case they happen to prove more attractive in the future.

The closed-cycle system is shown schematically in Figure 2. In the configuration illustrated, warm surface waters of the ocean are pumped into the OTEC plant where ammonia is vaporized in a large evaporator. The expanding ammonia vapor drives a low-pressure gas turbine, which provides power for electrical generators. The exhaust vapor then passes into a condenser which is cooled by sea water (pumped from ocean depths of about 3,000 feet). The condensed ammonia, once more a liquid, is pumped back to the evaporator, and the cycle is repeated. The product baseload electricity can either be transmitted ashore as AC electricity or be converted to DC electricity onboard the OTEC platform, transmitted ashore by submarine cable and converted back to AC. An alternative to transmission ashore is to manufacture electrically intensive products on or near the OTEC plant.

OVERALL PROGRAM OBJECTIVES

The OTEC program goal is to stimulate the development of commercially viable OTEC technology that will contribute substantial amounts of energy toward national needs and lessen demand for imported oil in accordance with the goals of the President's National Energy Plan.

In order to meet this goal, candidate technologies are being investigated and developed to establish those most suited to the economics of commercial application. Land and ocean testing and evaluation projects are examining several alternative technologies, configurations, and overall systems.

NEAR-TERM OBJECTIVES (THROUGH 1985) are as follows:

- To develop a technology for demonstrating the technical and economic feasibility of commercial offshore OTEC power plants capable of economically converting ocean thermal energy into substantial quantities of useage electrical energy by:
  a. Developing economically viable heat exchangers and power systems through research and development, including bench scale (core) tests, ocean tests of large components, and modular system experiments on large floating test facilities.
  b. Demonstrating by 1983 the technical operation and performance of ocean thermal power plants having sufficiently advanced power systems designs to project economic viability.
  c. Adapting and developing the technology of submarine electrical cables.
  d. Assess the ocean thermal resource and possible environmental consequences of large-scale OTEC implementation.

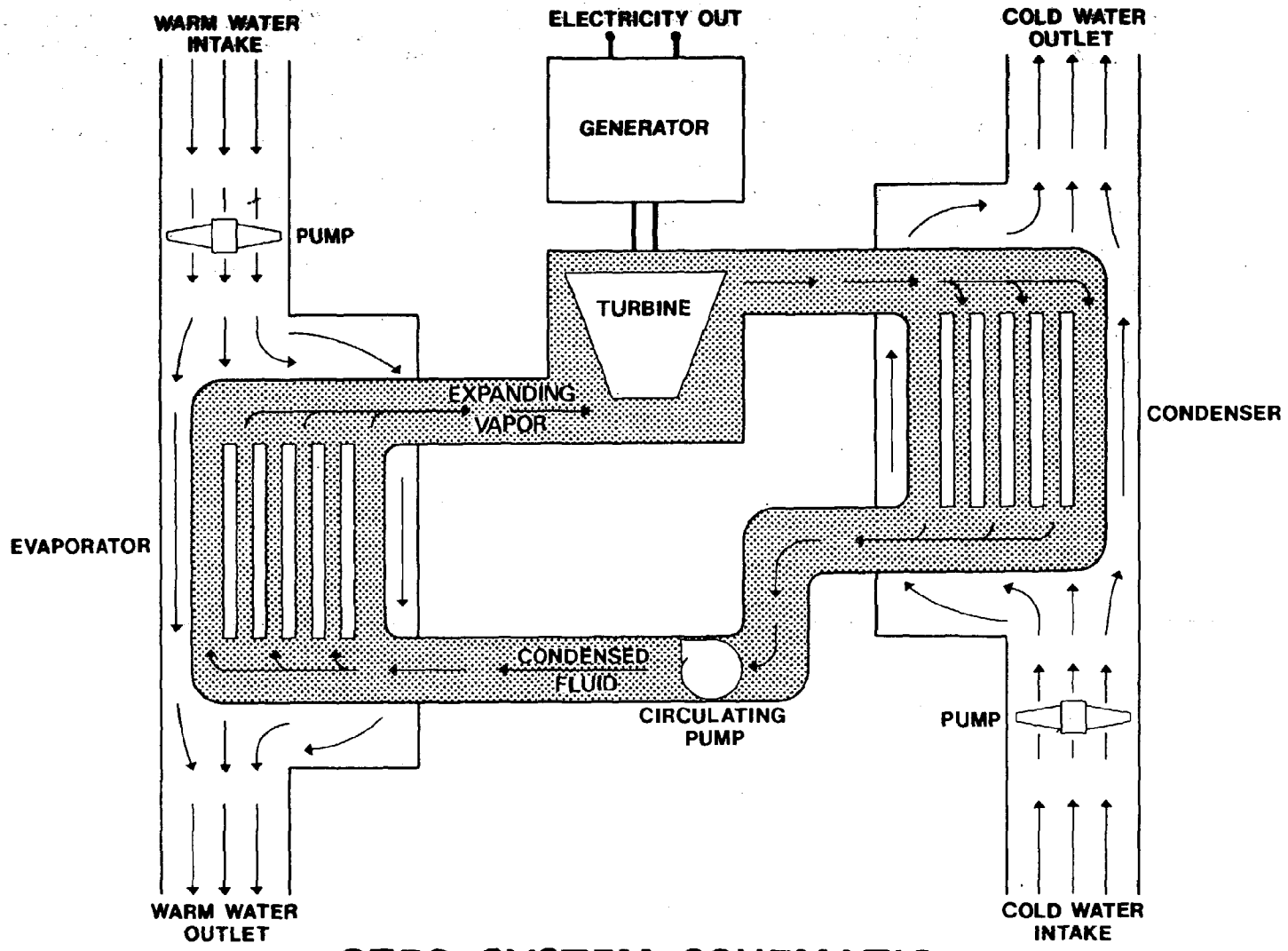

Figure 2. OTEC Closed Cycle System Schematic (For Electric Power Generation)

LONG-TERM OBJECTIVES (THROUGH 2000) are as follows:

- To assist the private sector in the development of technology leading to full commercialization of OTEC systems.
- To evaluate candidate technologies developed in parallel to the closed-cycle, ammonia-vapor, first-generation plants in order to establish the most economical and most reliable technology to transfer to the private sector.
- To be cost-competitive. To achieve this objective, several long-term, high-risk components and subsystems require continued research and development: heat exchangers, biofouling and corrosion control subsystems, cold water pipe, turbines, and submarine power transmission cables. Of these, the heat exchangers have highest priority because they represent more than half the total OTEC power plant cost and because large, highly efficient and economical Rankine cycle systems operating under OTEC conditions have never been built before. Therefore, a major research effort is underway to investigate heat transfer technology and methods to improve performance and reduce cost. Shell-and-tube configurations, panel configurations, enhancement techniques, and biofouling and corrosion countermeasures are being explored and tested. The testing will be done on successively larger units leading to large, modular heat exchangers. Potential environmental consequences will be mitigated through suggested design modifications. Work will continue on refining thermal resource assessments.

Program History

The history of the OTEC program in the United States, and of OTEC activities in foreign countries, is described in various reports and publications, many of which are cited in the bibliography of this document. In order to maintain a constant interchange of technical information among all participants in the U.S. OTEC program, a series of annual public workshops has been held. The Fourth OTEC Workshop was held at the University of New Orleans in March 1977. Preparations are currently underway for the 1978 workshop, to be held in February 1978.

The principle of using ocean thermal gradients has been known for decades. Successful experiments have been carried out in the laboratory and at ocean sites. Development of OTEC technology for use in commercial plants was infeasible in a era of inexpensive electricity derived from oil, gas, and coal.

The rise in energy costs since 1970 reestablished OTEC as a potentially viable candidate for the production of electricity. A Federal OTEC development program began in 1972 under the auspices of the National Science Foundation's Research Applied to National Needs (RANN) program. In early 1975 the OTEC program was transferred to the Energy Research and Development Administration which became the United States Department of Energy (DOE) on October 1, 1977.

Summary of Document Content

This Program Summary encompasses the ERDA and DOE activities in the OTEC technical area since the publication of the October 1976 OTEC Program Summary (ERDA 76–142). It briefly describes the OTEC principle and the technologies under consideration to convert that principle to commercial OTEC systems. It then describes the OTEC program plan and the ongoing OTEC projects. The objectives and accomplishments to date of those projects are summarized. Projects are grouped according to OTEC program elements.

Ocean Thermal Energy Conversion Program

The OTEC program is organized so that programmatic goals are achievable through basic management principles. The OTEC Program Office is incorporating such activities as work breakdown structuring, mission analysis, and design-to-cost so that it can assess program status and provide inputs to the policy and budget development process. The following discussion of the OTEC program organization includes a description of OTEC test facilities.

The objectives of the OTEC program are accomplished through activities organized into one or more areas defined as program elements:

- Program Support
- Definition Planning
- Engineering Development
- Engineering Test and Evaluation
- Advanced Research and Technology

Program Support manages the activities of the OTEC program with the participation of both Division of Solar Technology (SOLAR/ET) personnel and contractors. Activities include the development of management systems, control systems, planning, programming, budgeting, and review.

Definition Planning identifies the baseline reference OTEC plant in terms of functions and requirements. It establishes the design-to-cost goals of major subsystems, and defines the overall economics of an integral OTEC system. It provides a means for considering new OTEC-related ideas and evaluating them against existing constraints, such as OTEC missions and potential markets. Definition planning efforts also formulate guidelines on OTEC testing, health and safety, environmental impacts, quality assurance, reliability, siting, legal, institutional, and financial questions.

Engineering Development provides the beyond-the-state-of-the-art hardware susbsystems and components that require technical verification and testing. Included are subsystems of the ocean systems, power cycle systems, control and instrumentation systems, electrical systems, and electrical power transmission systems. Engineering development efforts integrate the developed hardware into a recommended testing configuration and produce test articles for performance verification. Within this category are the heat exchangers for OTEC–1 and power plants for modular experiments.

Engineering Test and Evaluation uses subscale experimental units for subsystem proof-of-concept via integration, testing, and evaluation. Based on the engineering development and advanced research and technology activities, suitable major integrated systems will be tested on an ocean-going engineering test facility (OTEC–1) and in OTEC modular system experiments. The accumulated test data will be utilized in system studies to develop cost data for baseline designs of commercial OTEC systems to help determine optimum configurations for OTEC demonstration efforts. Modular experiments will provide for the building and operation of OTEC power plants of about 10 MWe during the mid-1980's. The results of these modular experiments will be available to interested utility and industrial-user groups, so that commercialization can follow.

Advanced Research and Technology (AR&T) provides for the development of components and subsystems that require extensive scientific evaluation and testing before the decision is made to begin concept component design and development. AR&T will support all major elements of the program, but it is primarily directed toward the heat exchangers, and biofouling and corrosion. In many cases, AR&T is expected to advance the state-of-the-art in such areas as marine biofouling, corrosion, materials, heat exchangers, power systems, and ocean engineering.

Over the past year, candidate processes and configurations that were not considered for first generation OTEC plants have been undergoing evaluation. Some may be able to effect greater efficiencies and economies in second generation plants. The OTEC program as it evolves identifies problem areas of varying magnitudes. Some issues have been solved, others are under active investigation. Table 1 delineates the issues that have been resolved or clarified by OTEC activities to date, while Table 2 identifies programmatic issues requiring resolution in the near term (through 1985).

OTEC FACILITIES

Current OTEC engineering development activities have identified requirements for essential OTEC facilities (refer to Table 3). These facilities will provide test beds for OTEC components in order to demonstrate OTEC technical feasibility.

Analysis of these future requirements has established the need for early heat exchanger testing at large flow rates of cold and warm water which can best be satisfied by ocean testing. The urgency of completing a 1 MWe (40 MWt) test requires the use of a test platform (to be known as OTEC–1) that can be immediately available from Government inventory or obtainable on lease. To this end, the Hughes Mining Barge (HMB) has been obtained from the Navy and is being made available as a candidate platform to be modified for use as OTEC–1. Other existing or newly constructed ocean platforms are being considered for conducting OTEC modular experiments at about 10 MWe. Onshore sites will also be considered.

The primary goal of the modular experiments is to generate electricity at a sufficient scale to convince users that large commercial OTEC power plants (of about 400-500 MWe) are feasible, or that smaller units (40–50 Mwe) are then economically viable, especially for applications at islands where baseload electricity is being derived from oil. On the basis of these tests, it is anticipated that the Government role can be limited to providing economic incentives for OTEC commercialization.

Table 1. Programmatic Issues Resolved or Clarified

Issue	*Resolution*	*Impact*
Application of Ocean Thermal Energy	Thermal resource searches have indicated sufficient thermal potential in two broad regions in the Gulf of Mexico, around Hawaii and Puerto Rico, and in tropical waters to justify OTEC economic viability. Potential thermal resources near the continental U.S. are at least 200 to 400 GWe of OTEC power.	Several missions identified. 1) island option 2) baseload to U.S. electric grid 3) grazing plant-ship
Power Cycle Concept	Closed cycle ammonia plants were selected on the basis of overall system costs and useability. Questions still remain on material compatibility.	Reference system studies are being done for the closed ammonia cycle. Alternate working fluids, ammonia compatibility and open cycle systems are being studied.
Evaluation of Components	Heat exchangers were identified as the critical economic components. Heat transfer enhancements, cleaning approaches, and heat exchanger configurations have been identified, and early test data have been verified toward achieving economic viability. Cold water pipe has several key technology issues: material, modulus, and deployment approaches. Several approaches have been identified which can reach design-to-cost goals. Platform size of 400 MWe was selected as the baseline, with 50 MWe power modules.	Extensive test program was generated to evaluate critical parameters of heat exchangers: overall heat transfer coefficient, ability to control biofouling, and selection of materials. Cold water pipe studied extensively. Scaled experiments are being conducted to verify cold water pipe performance for various materials.

Table 2. Major Programmatic Issues Requiring Near-Term Resolution*

Issue	*Significance*	*Program Element*	*Description of Activity*
Impact of Biofouling and Corrosion on System Performance	Biofouling and corrosion can seriously impair the efficiency of heat-exchanger components. Even minute coating of vital surfaces can seriously reduce heat exchanger effectiveness.	Advanced Research & Technology	Significant tests on biofouling, corrosion, and cleaning are underway. Several fouling counter-measures are being studied. OTEC-1 will aid in ocean testing of biofouling counter-measures.
Platform Configuration	Size and configuration of power cycle components will determine basic payload parameters for platform. Size, shape, cost, etc., must be determined.	Systems Studies	Platform design will be determined for modular experiments. Several hull/platform designs appear promising. Floating and semi-submerged options are being considered.
Environmental Impacts	Environmental Development Plan anticipates environmental issues. These will be addressed in concert with operational testing at OTEC test facilities.	Definition Planning	The possible environmental effects of and on subsystems must be evaluated and defined. Measurements are being planned to define currents, O_2 content, pH, salinity gradients, etc. on an engineering and environmental assessment basis. Biological parameters are being monitored.
Alternative Power Cycles	The closed-cycle, ammonia vapor power cycle has been selected because it offers the best solution on the basis of thermal performance, technical risk, availability of essentially "off-the-shelf" components, and the highest probability of early commercialization.	System Studies, Engineering Development	The objective of the OTEC program is to develop commercially viable OTEC plants. Alternative power cycles are presently being examined as part of the shell-less heat exchanger activity.
Thermal Resources for Site Selection	The initial candidate sites were selected on the basis of potential for commercialization and contiguity to the U.S. mainland and to Hawaii and Puerto Rico. Additional sites require investigation.	Definition Planning	Additional site, both contiguous to the Southern USA, near major U.S. island and in international waters, are being evaluated over a number of years to provide statistical engineering data. Measurements are being performed where required.
Industry Acceptance of OTEC (Commercialization)	The reliability and economic viability of OTEC must be assured through prototype development before the utility industry can be expected to invest in commercial plants. Power cycle must be optimized for commercial viability.	Engineering Test and Evaluation Engineering Development	Several heat exchanger configurations, materials and cleaning approaches will be tested in an ocean environment on OTEC-1 to arrive at the most cost-effective solutions. Modular experiments will be conducted to demonstrate system operation, reliability and economic viability.

* Through 1985

Table 3. OTEC Facilities

Facility	*Nominal Power Level*	*Start Date For Tests*	*Purpose or Description*
Core Test Facilities	Up to 1 MWt	November 1977	Facilities either exist or are being established for testing of contractor-fabricated development hardware and materials for critical components.
Early Ocean Test Platform (OTEC-1)	1 MWe (40 MWt)	CY 1980	The facility will use an existing platform (ship, barge, etc.) to provide a test-bed for heat exchanger tests. The OTEC-1 includes a complete heat exchanger system (cold water pipe, ammonia turbine, pumps) and will provide data on biofouling, cold water plume, fluid dynamics, cleaning, and environmental impact.
Modular Experiments	10–20 MWe	CY 1982	Plan to use either surface or semi-submerged hull option(s). Will include all OTEC components required for generation of electrical power.

Program Activities

During the past five years many projects have contributed to the advancement of OTEC technology. Accomplishments to date have helped to focus on resolving the issues identified in Table 1. The following description presents in summary form the accomplishments of the major elements of the program.

PROGRAM SUPPORT

Earlier, Program Support emphasized program planning tradeoff analysis, contract monitoring, the development of recommendations for OTEC test programs, and provided position papers. Significant support is now required to supervise major construction projects such as OTEC–1 and the modular experiments. The OTEC program has established close working relationships with the Department of the Navy, which is providing assistance in program planning, coordination of Naval facilities for use in OTEC testing, and technical direction in OTEC research and development projects. In addition, national laboratories are providing technical management for various OTEC program efforts. The Department of Commerce, through its National Oceanic and Atmospheric Administration (NOAA) and Maritime Administration (MARAD), is participating in ocean engineering and other aspects of the OTEC program.

The OTEC program continues to retain the services of an architectural/engineering contractor to assist in formulating and refining program strategy and implementation plans to meet program objectives. Assistance from other Government agencies is also continuing. The combined talents of these support groups have provided considerable technical expertise for the program in major developmental areas.

Support services will continue to be sought from the most qualified sources. As in the past, Government agencies will play a significant role in acting as Government Technical Representatives for various phases of hardware development. Support from all involved groups will include program development, systems integration, program planning, contract monitoring, and review.

DEFINITION PLANNING

Mission analyses started in 1976 are continuing to identify and evaluate commercial ventures using OTEC technology and to determine competitive OTEC applications in the marketplace. The impacts of current and advanced technology, as well as legal, political, institutional, and environmental factors, are being addressed. Product mix, site-specific economics, and the definition of appropriate commercial power plant sizes are being examined. Using cost modeling and analyses, the economics and production costs of several generations of OTEC plants are being investigated. Based on these and other related studies, system and subsystem design and environmental specifications and performance will be defined. Studies are underway, both of OTEC systems that will provide on-shore electricity as an end-use, and of systems designed for offshore manufacture of energy-intensive products.

Siting analyses and environmental assessments are underway. Data are being obtained in areas such as the Gulf of Mexico and the Caribbean. Environmental studies include efforts employing fluid dynamical computer modeling, and assessments of thermal resource and ocean circulation. Laboratory modeling studies are continuing, and the compilation and analysis of ocean data have begun. Baseline assessments of physical, biological, and chemical oceanographic conditions at OTEC sites have commenced. Environmental studies began in 1977 with the initiation of environmental impact assessment contracts for the initial OTEC facilities and environmental program definition for large OTEC facilities. An OTEC Environmental Development Plan (EDP) was published in 1977 which presents the OTEC program strategy for meeting environmental requirements. Details of the FY 1977 activity in OTEC environmental studies are presented in the January 1978 DOE Environmental Resource and Assessment Program Summary.

Studies are underway to select appropriate hull configurations, a major cost component of OTEC systems. Important criteria in this selection are: (1) the best overall economics; (2) the ability to be built without major modification to existing U.S. manufacturing facilities; and (3) minimization of cold water pipe problems. Studies on hull fabrication and siting, which began in 1977, will provide data for selection of the appropriate size and configuration.

Independent studies of commercial OTEC platform concepts were commenced in FY 1977 by three contractors. These studies considered six candidate platform shapes

so that each contractor could subsequently study the best two of those candidates. Two of the contractors are now studying a floating and a detachable (external module) semi-submerged option. The third is evaluating a spar buoy and tuned sphere. These studies will be completed in May 1978.

Station keeping can be accomplished through mooring or through dynamic positioning, both of which must consider the riser cable for electric power transmission. Current studies are developing mooring concepts and conducting trade-off analyses for a range of hull shapes and site conditions.

Major investigations are about to begin on additions or alterations to baseload electrical power production. Economical electrical power production depends on two factors: (1) the cost of producing the power at the OTEC plant; and (2) the cost of transmitting the power to shore via submarine cable. Onboard manufacturing of energy-intensive products is being studied as a key option for utilizing OTEC electricity.

ENGINEERING DEVELOPMENT

For the baseline program development option considered, the OTEC program is involved with three areas:

—the power system
—ocean systems
—energy utilization

- **The Power System**

To assess OTEC performance, and biofouling and corrosion in an ocean environment as early as possible, a 1 MWe (40 MWt) component platform (OTEC–1) is planned for ocean tests starting in early 1980. Heat exchangers for the 1 MWe tests will be shell-and-tube design (2 units) and plate design (3 units).

A major system procurement to evaluate shell-and-tube configurations was issued in FY 1977. A second procurement, for plate heat exchangers, is planned for FY 1978. An objective of each procurement is the design of the ultimate module configuration to derive overall economics for the power plant system. The contracts are for the fabrication of test hardware for OTEC–1, and eventually for modular experiments (10 MWe).

The ammonia turbine research includes selection of materials for blades, selection of designs and non-corrosive materials for seals, and demonstration of bearing life. Turbine procurement to support a module test will be initiated in FY 1980

- **Ocean Systems**

Geared to the success of the heat exchanger program is the design and development of one or more OTEC modular system experiments. The related ocean engineering requirements are considered as either state-of-the-art or requiring only application engineering. Subsystems that have been identified as requiring extensive analysis and development testing are:

—Hull/structure.
—Cold water pipe and deployment system.
—Mooring/positioning (stationkeeping) system.

A major technology effort is being implemented to define the cold water pipe design and methods for its deployment. Concrete is considered a leading candidate for the cold water pipe. Indications are that flexible joints, lightweight concrete aggregates, and low bending moments will be required. Other leading candidate materials include steel and more compliant structures, such as fiberglass and rubber. All of these will be the subject of a comparative evaluation in FY 1978. Test programs are being developed to define the strength, modulus, and porosity of lightweight concrete. Dynamic simulation programs are being developed, and model-basin tests are to be conducted. Tests of a large-scale pipe (5 feet in diameter and 1,500 feet long) are contemplated.

Several deployment approaches are being studied: vertical assembly, onsite manufacture, as well as float and flip.

- **Energy Utilization**

1) *Electric Cable*

Present assessments of the OTEC electrical offshore application indicate that the OTEC submarine cable (except for island locations) will be high-voltage DC, with conversion subsystems at each terminal. Single or multiple submarine cables must be capable of transmitting in the 500 MWe range. Submarine cable development for OTEC was initiated in 1977 through competitive procurements, and the contractors are now in the early stages of their studies of the riser and bottom cables. Phase I of the cable development effort serves to identify and select the most promising cable systems from among several alternatives for various plant sites.

Phase II of submarine cable development will entail detailed design, fabrication, and testing of the selected cable systems. Phase III will involve the preparation of final specifications for use with OTEC plants at various sites.

2) *OTEC Industrial Complexes*

Another option for using the energy produced by OTEC plants is the on-site manufacturing of energy-intensive products and materials. Surface transportation will be used to ship these energy-intensive products. Examples of products that may be obtained from offshore manufacturing facilities are hydrogen and ammonia. Another option is to manufacture products that can be used as an "electrical bridge" for generating electricity ashore.

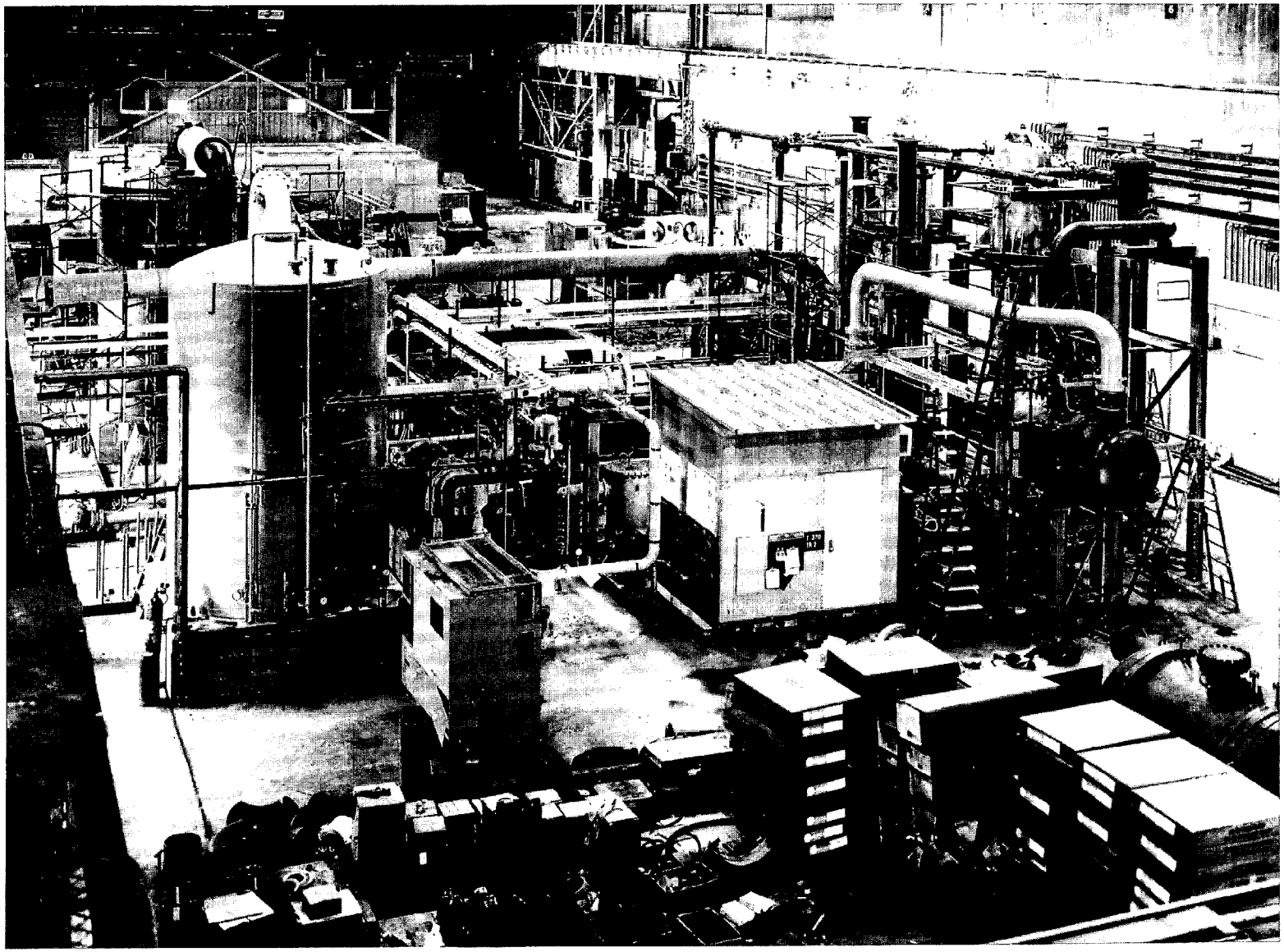

Figure 3. Overview of the Argonne Core Test Facility

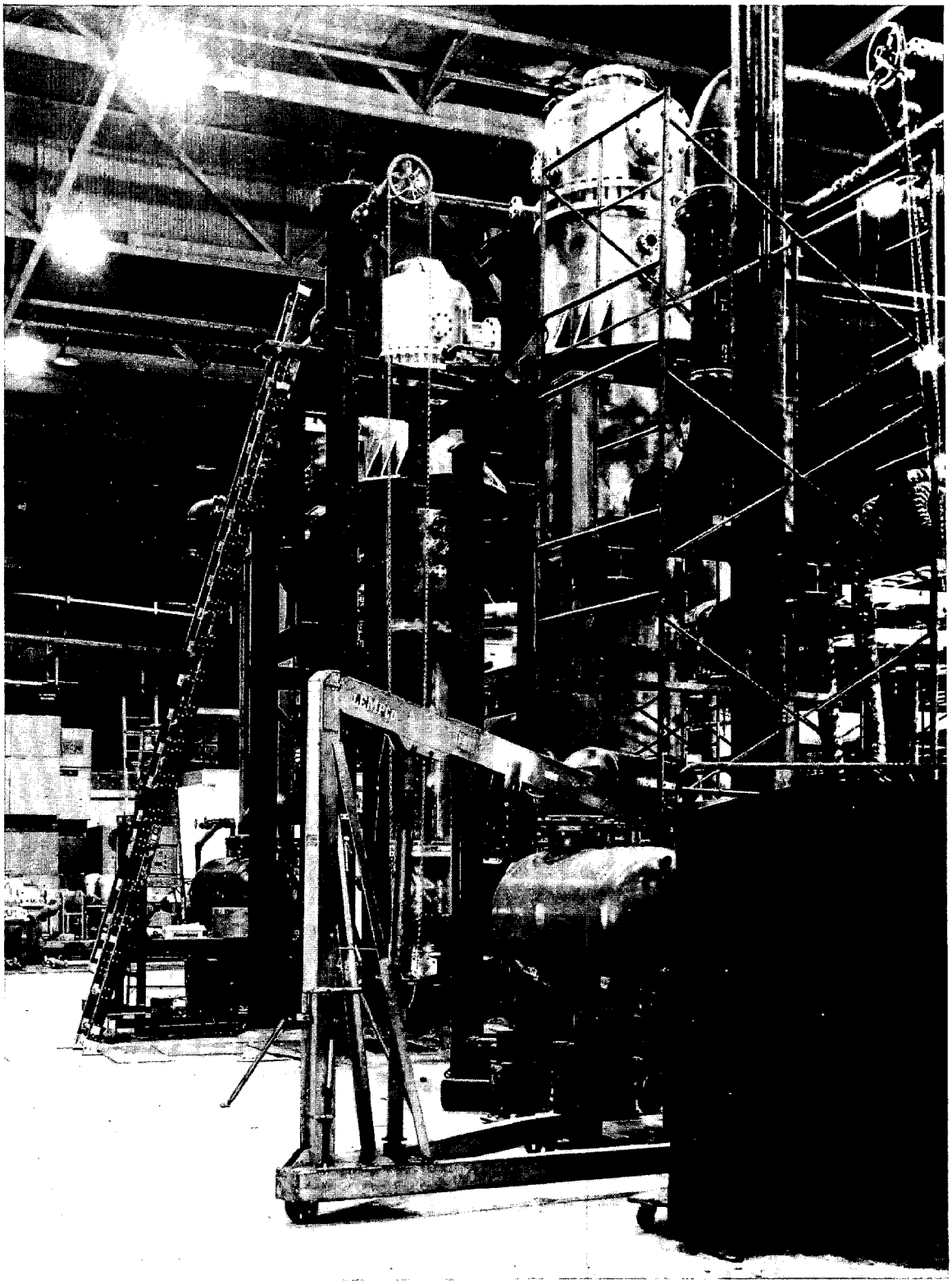

Figure 4. Carnegie-Mellon University Heat Exchangers Installed at the Argonne Core Test Facility (Evaporator-left; Condenser-right)

ENGINEERING TEST AND EVALUATION

Conceptual designs for the various OTEC–1 subsystems have also been developed during 1977. Several methods of deploying the cold water pipe are currently under review and analysis. A solicitation has been released for the OTEC–1 engineering test facility.

An existing platform is to be modified to serve as an engineering test facility (OTEC–1) for significant scaled experiments at sea. Current plans call for five heat exchanger configurations to be tested on the OTEC–1: two shell-and-tube and three plate type units. These experiments will be provided through the power system development contracts by December 1979. Several materials for heat exchangers and cleaning approaches will be explored. A six-foot cold water pipe and warm water piping system will supply enough water to provide a total testing capability of 1 MWe (enough to operate the total equivalent of 10,000 heat exchanger tubes). By 1983, it will be possible to determine long-term cleaning characteristics, corrosion effects, performance, and materials degradation for a wide number of candidate designs.

The initial results from this facility could be used for selection of the units for the modular experiments. Modular experiments of sufficient size to demonstrate overall feasibility of full-scale units and to be utilized directly in an application mode are being considered. These experiments will include: two distinct platform candidates with significantly different economics, operations, and risks; two distinct types of heat exchangers with different cleaning, material, and surface enhancement approaches; several cold water pipe materials and deployment concepts; and two distinct mission possibilities.

Seawater systems and ocean platform sizes with total carrying capacity of about 10 MWe are contemplated as being required to verify OTEC feasibility. Unit power modules of about 10 MWe size are being considered. The design of these power plants modules will be provided through the power system development contracts. Contractor teams will be asked to propose complete OTEC plants. Competitions for these procurements are planned for early 1979.

Multiple design awards for each platform approach are anticipated. Single contractors for integration and construction will be selected after the design competition.

ADVANCED RESEARCH AND TECHNOLOGY (AR&T)

AR&T efforts have been directed primarily toward power cycles, materials, heat transfer enhancement surfaces, working fluids, and open and hybrid cycles. These efforts have produced viable concepts that will lead to further analyses and tests. The biofouling, corrosion, and cleaning activity is an important part of the AR&T effort.

Alternate heat exchanger configurations have been proposed: Shell-and-tube (horizontal tube/thin film, horizontal tube/nucleate boiling, and vertical falling film), and panel concepts. Initial single or multi-tube laboratory tests are being conducted to determine the heat transfer performance of single tube features (surface enhancement, grooves, flutes, inserts, etc.). Early results from single tube tests and core test units (1 MWt) indicate that it is possible to achieve clean overall heat exchanger coefficients two to three times those attainable with standard smooth-tube technology. Economic tradeoffs are being developed on the basis of these technologies. Factors that reduce costs in the fabrication of shell-and-tube heat exchangers have been identified. The industrial base needed to supply the materials required to fabricate OTEC power plants and OTEC industrial complexes is also being assessed.

Biofouling rate and cleaning experiments have provided results which indicate that several cleaning approaches can be used to keep biofouling resistance coefficients to less than 0.0003 (or a heat transfer coefficient of at least 3300 BTU/hr ft² °F). Aluminum alloy tubes are being qualified as candidates for OTEC exchangers by performing tests employing flowing seawater and constant removal of biofouling.

Several attractive plate heat exchanger approaches have been defined. Components based on plate heat exchanger technologies will be fabricated and tested.

Core testing of 1 MWt units will be performed by the fall of 1978 on three shell-and-tube and four plate heat exchanger configurations to determine the overall heat transfer performance. Complicating performance phenomena, such as uneven flow over the face of a large heat exchanger, will be evaluated by hydraulic modeling studies. On the basis of heat exchanger bench tests, cleaning studies, and hydraulic modeling studies, data will be accumulated for a programmatic decision point in early FY 1978. However, other major uncertainties still exist, such as the cost of manufacturing large heat exchangers, geometric effects on local flow conditions, and biofouling and corrosion in large assemblies.

Single and multi-tube testing is being performed by several contractors. To date, experimental heat transfer rates higher than those for standard commercial heat exchangers have been achieved with modified designs. The Accelerated Core Test Facility (ACTF) constructed at Argonne National Laboratory in 1977 (see Figure 3) will permit the testing of subscale (1 MWt) heat exchangers. Figure 4 shows the Carnegie-Mellon University heat exchangers (evaporator and condenser) installed at the ACTF.

Alternative power system cycles are being further investigated. The open steam cycle, resulting in the reduction of biofouling problems and the production of fresh water as a by-product, has been recognized for many

years. The hybrid ammonia-steam cycle offers many of the same advantages as the open steam cycle. Since that latter is a somewhat newer concept, it has not yet been the subject of extensive study. An engineering power system study of both the open and hybrid cycles is being conducted to produce a system design and comparative costs for each option.

Current research related to heat transfer on the working fluid side includes: (1) comparative investigation of the mechanisms of nucleation and evaporation under thin-film flow conditions and (2) comparative investigations of evaporation and condensation for fluted (or Gregorig) enhanced surfaces. For water-side heat transfer, information is being obtained on surface augmentations. boundary layer disruption, and secondary flow generation. In addition, hydraulic studies are underway to determine internal fluid distribution, seawater corrosion, and convenient design algorithms.

Biofouling on the seawater side of the heat transfer surfaces represents a key technology issue. Permitting the growth of organisms or the deposition of inorganic material on the heat exchanger surfaces will interfere with their heat transfer properties and result in performance degradation. Maintenance requirements must be defined for compatibility with operational duty cycle requirements.

Biofouling and corrosion studies, laboratory tests, and ocean surveys of potential sites will continue through 1980. These efforts will provide early information to support: technologies developed in 1977 and 1978; major heat exchanger decisions; and overall program decisions.

The initial phase of the biofouling program is designed to determine biofouling and corrosion rates for ocean regions considered as likely OTEC sites and to evaluate candidate countermeasures for a range of heat exchanger materials. The separate effects of biofouling and corrosion will be quantified. Mechanical, chemical, and other avoidance or control methods will be included. Special instrumentation will be used at various locations to test biofouling potential and candidate control procedures. Biofouling measurements in the ocean were initiated at sites off Hawaii and Saint Croix, Virgin Islands, and will be extended to other sites in the Caribbean, the Gulf of Mexico, and in the Gulf Stream (Florida Current). Data collection devices such as the data buoy shown in Figure 5, are being used in this effort.

By the end of 1978, information will be available regarding biofouling rates as a function of local conditions, heat exchanger configurations, materials, and internal flow conditions. In addition, biofouling countermeasures will be defined to support the heat exchanger concept selection schedule for late 1979.

Plans For Implementation of a Test Program

Ongoing and completed efforts have already allowed a significant number of decisions to be made concerning OTEC, in general, and the OTEC-1 Early Ocean Test Platform, in particular. Overall program priorities were then established in support of these decisions:

- The closed-cycle system will be the immediate thrust of the development program directed toward an early demonstration plant.
- Open-steam and hybrid ammonia-steam cycles will remain under active investigation.
- Ammonia has been selected as the working fluid in the first generation of OTEC plants. Other working fluids will be considered.
- Large components will be tested at 1 MWe (40 MW_t) in an ocean-going test facility (OTEC-1) in a marine environment, including five candidate shell-and-tube and plate heat exchanger designs.
- Several conventional heat exchanger cleaning methods will be tested on OTEC–1.
- A land-based facility will be used to test sub-scale (1 MW_t) heat exchanger concepts.
- Initial siting assessments regarding environmental and thermal resource aspects are being completed.

The success of the OTEC program requires concurrent developments in two major areas: power cycle development and ocean engineering. Although other technological activities are critical to program success, the two areas cited are essentially the technological driving factors of the program. Figure 6 shows the plan for a simplified OTEC system development schedule, and the interrelationships between power cycle engineering and ocean engineering.

The research and development and program activties during FY 1977 have yielded results that have exceeded the projected goals and expectations. The major issues regarding deployment of OTEC systems have been clarified or resolved as indicated in Table 2. OTEC will provide data on system configurations of up to 1 MWe size in ocean environment. Since the objective of the OTEC program is to stimulate the development of a commercially and economically acceptable OTEC system, fully integrated OTEC systems of sufficient size must be demonstrated in potential market applications to provide the necessary operational performance and cost data. Such operational experience in direct applications and in a commercial environment is essential before potential users will adopt OTEC as a viable alternative.

The modular experiments of about 10 MWe are, therefore, being planned as part of an integrated program strategy to provide necessary operational experience. As-

sociated seawater systems and ocean platform sizes of 10 MeW are contemplated. These power plant modules will be provided from the power system development efforts, and will incorporate the results of 1 MWe scale module tests conducted on OTEC–1. Results of ongoing parallel R&D efforts on various subsystems will also be incorporated in the power module design.

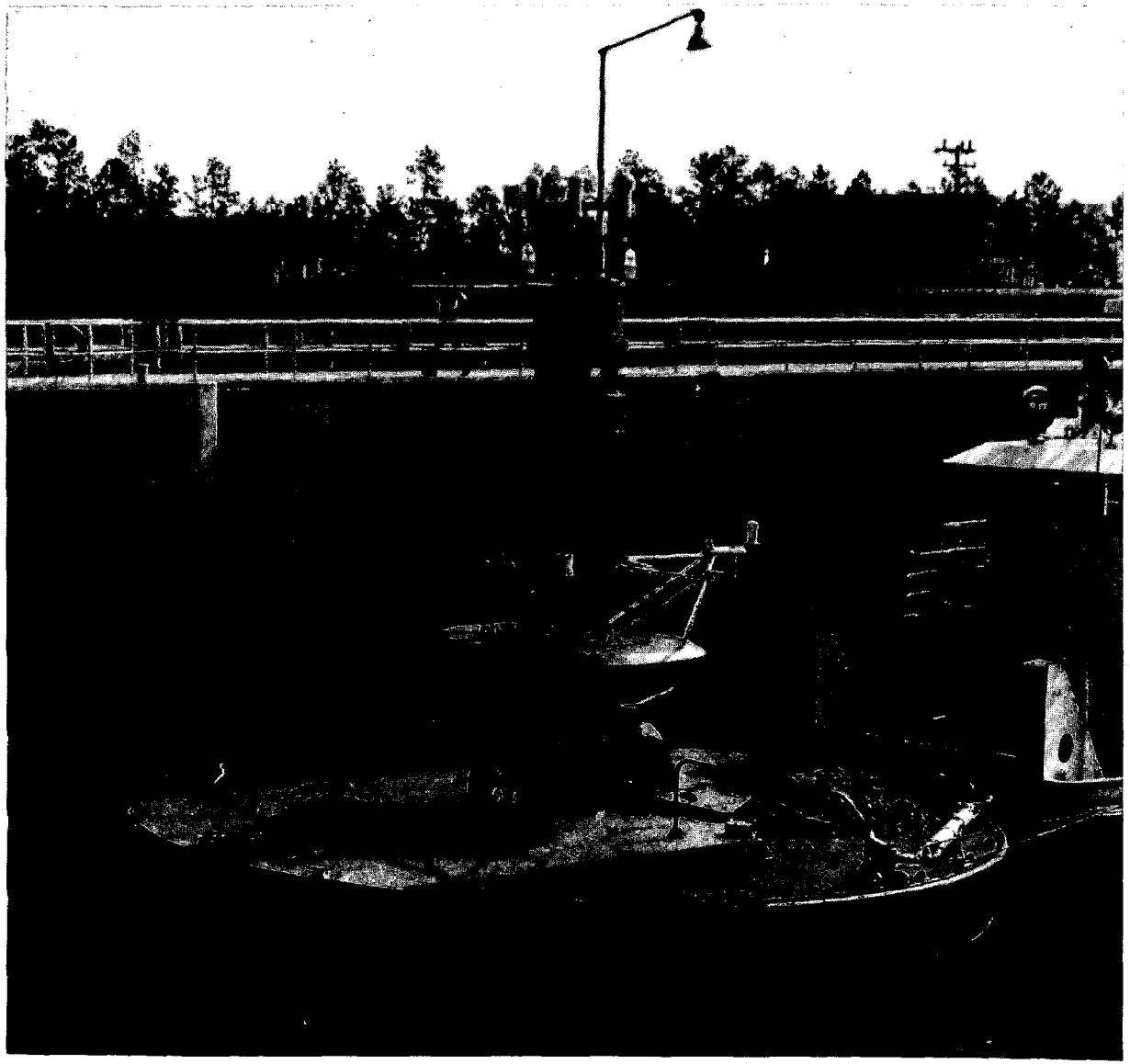

Figure 5. OTEC Data Buoy

OTEC SYSTEMS DEVELOPMENT

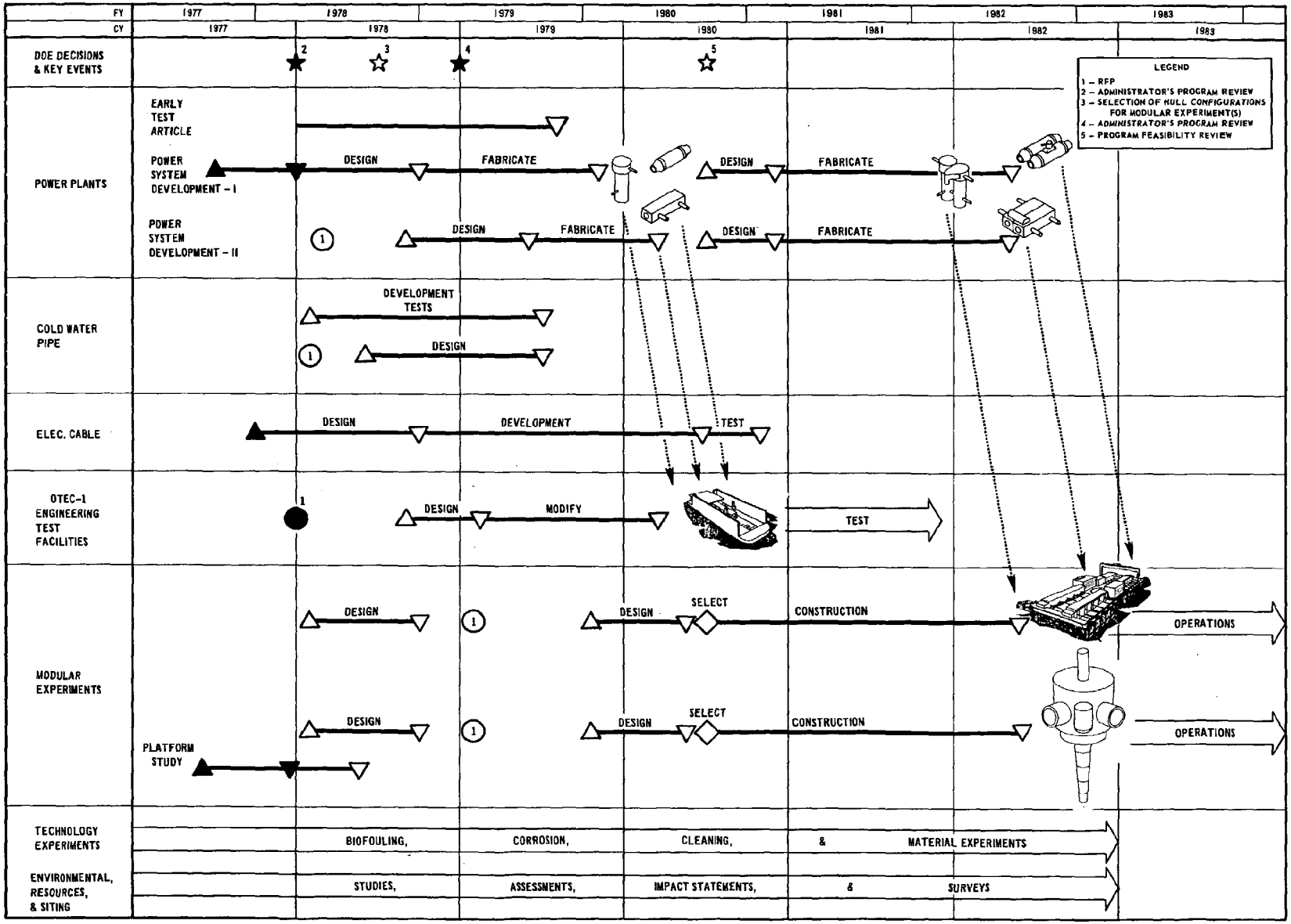

Figure 6.

Organizational and Functional Responsibilities

Although the overall program management of the OTEC program is vested in the Department of Energy, the OTEC community includes many other Federal agencies, as well as university and industry contractors. Contract support to OTEC may be categorized into three major groups: program support, research and development, and architectural and engineering contractors.

Other Federal Agencies

Several Federal agencies are currently contributing to the OTEC program. In addition to other components of the Department of Energy and its predecessor agency, the Energy Research and Development Administration, support is being received from:

- The National Science Foundation
- The Maritime Administration, U.S. Department of Commerce
- The National Oceanic and Atmospheric Administration, U.S. Department of Commerce
- The Naval Facilities Engineering Command, United States Navy.

National Laboratories Support

U.S. Government-owned national laboratories run by private contractors are also contributing to the OTEC program. Their specific functions are more fully described in the "Fiscal Year 1977 Project Summaries" section of this publication.

Academic Support

Numerious academic institutions are conducting research and analysis programs in support of one or more of the elements of the OTEC program. These are decribed specifically in project summary sheets found in the "Fiscal Year 1977 Project Summaries" section of this publication.

Program Funding

GENERAL

Program funding is informally divided into two major categories reflecting the organizational structure of the OTEC program. One category supports the thrust of Engineering Development, Component Testing, Pilot Plant, Demonstration Plant and Commercialization based on the ammonia-vapor, closed-cycle system, with a hull or platform configuration most suited to accommodate these components. Supporting research is directed toward optimum performance of an OTEC plant using the aforementioned power cycle. The second grouping of projects addresses a wide range of technical alternatives in the power cycle, platform configuration, and systems and configurations for second generation plants.The second generation plants are those that will survive commercial competition from conventional power sources that may be expected to come on line during the 21st century.

FUNDING BY PROGRAM ELEMENTS

Table 4 presents a summary of funding by the major program elements. The bulk of the funding was concentrated in the definition planning program element in which a large number of technical alternatives were examined and evaluated. In 1975, the decision was made to proceed with the development of the ammonia-vapor, closed-cycle system. Once this decision was made, the power cycle became the pacing item, and advanced research and technology addressed the two categories of activity described in the previous paragraph. The increasing significance of engineering development, and subsequently of engineering test and development, is reflected in funding for these program elements in the period FY 1977 and beyond.

The services and goods utilized in the OTEC research and development program are being obtained from various sectors of society, including industry, universities, and Government. The percentages of FY 1977 OTEC funding distribution to prime contractors is as follows:

Industry	51.1%
National Laboratories	28.3%
Other Government Agencies	13.7%
Universities	6.3%
Other	0.6%

Table 4. Program Element Funding (Budget Authority) ($ in Millions)

Program Element	Prior Years	FY 76[1]	FY 77
Program Development	0.1	2.1	2.1
Definition Planning	2.5	2.7	1.2
Systems Studies	...	0.3	3.4
Engineering Test and Evaluation	...	...	3.3
Advanced Research & Technology	1.4	3.5	4.5
TOTAL	4.0	8.6	14.5

[1] Includes Transition Quarter

FISCAL YEAR 1977 SUMMARY TABLES

Table 5

FY 1977 SUMMARY TABLES

Program Element

PROGRAM SUPPORT

● *Program Sub-Element*

SUPPORT SERVICES

Organization	*Title*	*Projected Contribution*
Argonne National Laboratory	Program Management Support: Oceanographic and Climatic Impacts	Management support is provided to ERDA (DOE) on all hydrodynamical modelling efforts for OTEC.
U.S. Naval Facilities Engineering Command (NAVFAC)	Technical Management of OTEC Ocean Engineering Program Activity	a. Program management assistance and consultation for assistance in the OTEC program planning, preparation, and evaluation of program solicitations. b. Participation in overall program evaluation, and coordination with other agencies providing support to the DOE in other technology aspects of OTEC development. c. Management and technical coordination of facility access required for utilization of Navy test and fabrication facilities in support of the OTEC program, d. Technical evaluation of system, component, and technology development proposals. e. Monitoring and evaluation of DOE contractor work specifically assigned to NAVFAC for technical direction. f. Transfer of Navy technology to ERDA contractors, and participation in program technical reviews and workshops. g. Technical direction, monitoring, and evaluation of specific research and development projects by DOE or Navy contractors as assigned. h. Coordination, monitoring, and evaluation of assigned DOE-funded research and development projects to be accomplished in-house by Navy organizations and laboratories.
Gilbert Associates, Inc.	Architectural and Engineering Services in Support of the OTEC Program	Architect-engineering support services for a variety of OTEC design, engineering, and programmatic tasks.
National Oceanic and Atmospheric Administration (NOAA)	Ocean Engineering Program Support	Ocean engineering support to ERDA (DOE) in: a. Program planning and approval, b. Implementation of major OTEC activities, c. Participation in annual program reviews, d. Evaluation of program resources, and e. Determination of procurement policy.

Table 5 (cont.)

FY 1977 SUMMARY TABLES

Program Element

PROGRAM SUPPORT

● *Program Sub-Element*

SUPPORT SERVICES—(Cont.)

Organization	*Title*	*Projected Contribution*
Battelle Pacific Northwest Laboratories	Biofouling and Corrosion Studies for OTEC	Subcontract and manage studies to define, measure, and establish countermeasures for OTEC biofouling and corrosion problems.
Lawrence Berkeley Laboratory	Program Management Support: Biological and Ecological Effects of a 100 MWe OTEC Plant	Provision of program management support to DOE on all biological/ecological effects of OTEC studies.

Table 6

FY 1977 SUMMARY TABLES

Program Element

PROGRAM SUPPORT

• *Program Sub-Element*

OTEC WORKSHOP ORGANIZATION

Organization	*Title*	*Projected Contribution*
Society of Naval Architects and Marine Engineers (SNAME)	Spring Meeting on Energy Research in the Oceans at San Francisco, CA (May 1977)	Thirty four papers were presented in the following major areas: (1) Marine transportation (machinery), (2) Offshore fixed platforms, (3) Ocean Thermal Energy Conversion, (4) Offshore mobile platforms, (5) Liquified Natural Gas (transportation and terminals), and (6) Marine transportation (naval architecture).
University of New Orleans	Fourth Annual Ocean Thermal Energy Conference (March 1977)	The conference's proceedings consisted of contributed papers, discussions and working groups summaries, conclusions, and recommendations.
University of Miami Clean Energy Institute	Fifth Ocean Thermal Energy Conversion (OTEC) Conference (Feb. 1978)	A continuing opportunity to present and discuss the latest research results pertinent to the conversion of ocean thermal energy. Subjects covered will include: heat exchangers, modeling and optimization, ocean engineering, biofouling and corrosion, total system design, environmental impact, and economic and legal aspects.

Table 7

FY 1977 SUMMARY TABLES

Program Element

DEFINITION PLANNING

• *Program Sub-Element*

TEST PROGRAM REQUIREMENTS

Organization	*Title*	*Projected Contribution*
Lockheed Missiles and Space Co., Inc.	Test Facilities Requirements Definition	Alternative, non site-specific OTEC facilities and ocean platform requirements for an integrated OTEC test program.
TRW, Inc.	Test Facilities Requirements Definition	Alternative, non site-specific OTEC facilities and ocean platform requirements for an integrated OTEC test program and ocean test facilities.

Table 8

FY 1977 SUMMARY TABLES

Program Element

DEFINITION PLANNING

- *Program Sub-Element*

MISSION ANALYSIS

Organization	*Title*	*Projected Contribution*
Aerospace Corporation	Mission Analysis and Support for OTEC Systems	To study OTEC energy utilization alternatives, markets and market penetrations, and to develop a system costing model.
General Electric Company/TEMPO	OTEC Mission Analysis Study	Identify key OTEC missions and applications, including markets and market penetrations
Columbia University	Marine Pastures: A By-Product of Large (100 Megawatts or Larger) Floating Ocean Thermal Gradient Exchange Technology	Technical and economic feasibility of open-ocean mariculture.
Stone & Webster Engineering Corporation	Southeast Regional Assessment Study	An appraisal by electric utilities of the market for solar energy products in the Southeast United States, including Puerto Rico.

Table 9

FY 1977 SUMMARY TABLES

Program Element

DEFINITION PLANNING

• *Program Sub-Element*

THERMAL RESOURCE ASSESSMENT AND SITING STUDIES

Organization	*Title*	*Projected Contribution*
Ocean Data Systems, Inc.	Ocean Thermal Structure Analysis	An ocean thermal resource assessment and data base for the environmental assessment and siting of the OTEC demonstration plant.
Woods Hole Oceanographic Institution	Oceanographic Data for OTEC Design	Discrete site selection criteria based on OTEC design, a plan and schedule for matching the ocean data base to design, construct, and test, and a plan for acquiring requisite oceanographic data.
Bretschneider Consultants	Design Current and Wave Criteria for Potential OTEC Sites	Provide data on design current and wave criteria for potential OTEC sites.
Research Triangle Institute	Sea Surface Satellite Thermal Data	An analytical tool for synoptic assessment of thermal resource variations at sites of probable OTEC locations via Infra-Red (IR) satellite imagery.
Florida Institute of Technology	A Study of the Geographical Distribution of the OTEC Resource in the Florida Current	An analysis of the geographical distribution of the OTEC resource off the Florida coast.
Florida Solar Energy Center	Ocean Thermal Energy Conversion Resource Assessment Workshop	Selected researchers described data acquisition and reported on projects in support of OTEC siting as well as environmental, resource, and technological assessments.
NOAA Environmental Data Service	Oceanographic Data Base for OTEC	Provide as complete a statement as possible of required oceanographic data.
NOAA Atlantic Oceanographic and Meteorological Lab	Ocean Currents and Thermal Observations	Provide detailed observational data of principal OTEC sites using OTEC specified oceanographic data.

Table 10

FY 1977 SUMMARY TABLES

Program Element

DEFINITION PLANNING

● *Program Sub-Element*

ENVIRONMENTAL

Organization	*Title*	*Projected Contribution*
Hydronautics, Inc.	Experimental Study of Flow Problems Related to Ocean Thermal Energy Conversion (OTEC)	Experimentally investigate the external flow problems unique to OTEC.
Ocean Data Systems, Inc.	Ocean Climatic Impacts Model Reviews	Review of the modeling efforts of the Naval Research Laboratory, Hydronautics, and the Massachusetts Institute of Technology on flow problems and fluid mechanics.
Massachusetts Institute of Technology	External Fluid Mechanics of Ocean Thermal Power Plants	The simulation of the OTEC operation under schematic oceanographic and plant design conditions.
Naval Ocean Research and Development Activity (NORDA)	Theoretical Fluid Dynamical Studies of Resource Availability and Environmental Impact of Ocean Thermal Energy Conversion (OTEC)	Studies of: (1) the near-field flow computations, that is adaption of existing turbulent wake computer programs, production runs for different design parameters and oceanic data parameters, (2) the far-field effects of a single power plant, development of 1-D and 2-D ocean models, determination of optimal power plant size, and areal requirements, (3) the oceanic impact of large-scale operation, model temperature, salinity profiles, their time response for various ocean basins, and estimated power production potentials, and (4) the air-sea coupling, such as weather-induced thermocline modifications and recovery and regional sea breeze modification by sea-surface temperature changes.
Interstate Electronic Corporation	Environmental Impact Assessment of Ocean Test Platforms for OTEC	Environmental Impact Assessment of the 1 MWe (EOTP-1) and 5 MWe (ETOP-5) OTEC floating test facilities.
Lockheed Center for Marine Research	Marine Biota Impact Assessment for OTEC	Establishment of a data base on exposure of marine biota to OTEC discharges for preparation of environmental impact assessments.

Table 11

FY 1977 SUMMARY TABLES

Program Element

DEFINITION PLANNING

- *Program Sub-Element*

LEGAL AND INSTITUTIONAL STUDIES

Organization	*Title*	*Projected Contribution*
Southern California, University of	Evaluation of Incentives for the Development of Ocean Thermal Gradient Exchange Technology	An investigation of the commercialization of new energy technologies and to analyze the potential public policy incentives for accelerating to rate of commercialization of these technologies.
American Society of International Law	Ocean Thermal Energy Conversion: Legal Considerations	Identification of subjects of needed inquiry within five major areas: (1) Rights to emplace and maintain installations, (2) Rights to capture and remove the resource, (3) Sources and content of legal standards governing emplacement and operation; questions of responsibility and liability for the consequences of operation; and the juridical status of operators and installations.
American Socity of International Law	R&D in OTEC Institutional and Legal Matters	Data input regarding institutional and legal requirements for OTEC development and demonstration.
Tefft, Kelly and Motley, Inc.	R&D in Institutional and Legal Matters	Data input regarding institutional and legal requirements for OTEC development and demonstration.

Table 12

FY 1977 SUMMARY TABLES

Program Element

ENGINEERING DEVELOPMENT

● *Program Sub-Element*

POWER SYSTEM

Organization	*Title*	*Projected Contribution*
TRW, Inc.	OTEC Power System Development	A preliminary design for the full-sized (25 MWe nominal), closed-cycle ammonia power system module for 100 MWe OTEC demonstration plant.
Lockheed Missiles and Space Co., Inc.	OTEC Power System Development	A preliminary design for the full-sized (25 MWe nominal), closed-cycle ammonia power system module for the 100 MWe OTEC demonstration plant.
Westinghouse Electric Corporation	OTEC Power System Development	A preliminary design for the full-sized (25 MWe nominal), closed-cyle ammonia power system module for the 100 MWe OTEC demonstration plant.
Lockheed Missiles & Space Co., Inc.	OTEC Tube and Shell Heat Exchanger Producibility Study	Definition of the requirements; development of materials information, including the use of concrete, prerequisite to the conceptual and preliminary design of a shell and tube heat exchanger.
Colorado School of Mines	An Evaluation of Open-cycle Thermocline Power Systems	Conduct a feasibility and costing study of any open cycle system that may be competitive with the closed cycle concept.
Westinghouse Electric Corporation	OTEC 100 MWe Alternate Power System Study	A conceptual power system design for the open-cycle power system addressing all major components and including sufficient information to allow hardware cost estimates to be made.

Table 13

FY 1977 SUMMARY TABLES

Program Element

ENGINEERING DEVELOPMENT

• *Program Sub-Element*

OCEAN SYSTEMS

Organization	*Title*	*Projected Contribution*
Johns Hopkins University Applied Physics Laboratory	Preliminary Engineering Design of a Modular Experiment	A preliminary engineering design of an Ocean Thermal Energy Conversion (OTEC) pilot plant.
Rosenblatt, M., & Son, Inc.	OTEC Platform Configuration and Integration	The conceptual design of an operational, integrated OTEC commercial plant system.
Lockheed Missiles and Space Company, Inc.	OTEC Platform Configuration and Integration	A conceptual design of two leading integrated OTEC system candidates will be developed. Each conceptual candidate system will be accomplished by a demonstration system plan and cost schedule estimate for implementing the hardware application at sea.
Gibbs & Cox, Inc.	OTEC Platform Configuration and Integration	Evaluation of six candidate hullforms as candidates for the OTEC commercial plant.

Table 14

FY 1977 SUMMARY TABLES

Program Element

ENGINEERING DEVELOPMENT

● *Program Sub-Element*

ENERGY UTILIZATION

Organization	*Title*	*Projected Contribution*
Institute of Gas Technology	An Optimization Study of Ocean Thermal Energy Delivery Systems Based on Chemical Carriers	Provide an engineering and economic analysis of chemical energy-carrier alternatives for transportation of energy from large-scale floating OTEC power plants to wholesale energy markets.
Institute of Gas Technology	Alternative Energy Transmission Systems from OTEC Plants	Evaluate the feasibility and generate conceptual designs of two concepts for transporating ocean thermal energy to shore.
Pirelli Cable Systems, Inc.	Bottom Segment Design for Underwater Cable Power Transmission System	Develop designs for the bottom segment of the underwater electric power transmission cable system (Phase 1).
Simplex Wire and Cable Co.	Riser Segment Design of Underwater Electric Power Transmission Cable System	Develop the designs for the riser segment of the underwater electric power transmission cable system (Phase 1).

Table 15

FY 1977 SUMMARY TABLES

Program Element

ENGINEERING TEST AND EVALUATION

• *Program Sub-Element*

1MWe (40MWt) EARLY OCEAN TEST PLATFORM

Organization	*Title*	*Projected Contribution*
Gilbert Associates, Incorporated	OTEC-1 Studies and Cold Water Pipe Activity	Provide systems integration and engineering support for the development of OTEC-1.
Lockheed Missiles and Space Company	Maintenance of Redwood City Facility and OTEC Equipment	Maintain and support the Hughes Mining Barge at the Redwood City Facility.
TRW, Inc.	1MWe Heat Exchangers for Ocean Thermal Energy Conversion	Design, fabricate, and deliver a seawater/ammonia evaporator and condenser for the OTEC-1 MWe heat exchanger system.
W. M. Howerton	Naval Architect and Ocean Engineering Services	Provide naval architect and ocean engineering services in support of the OTEC Program and Hughes Mining Barge.
Morris Guralnick Associates	HMB Conversion Preliminary Design Tasks	Provide preliminary design drawings and studies relating to the Hughes Mining Barge conversion to OTEC-1.
Morris Guralnick Associates	Dredge Base Support Flotation and Stability Analysis	Analyze the stability characteristics of the Hughes Mining Barge dredge base.
U.S. Navy	Dredge Base Removal and HMB Support Services	Remove the dredge base from the Hughes Mining Barge.
Interstate Electronics Corporation	Marine Engineering Support Services	Provide marine engineering and support services related to the Hughes Mining Barge and associated spare equipment.
American Patrol Services	Security of the Redwood Facility and the Hughes Mining Barge	Provide guard services for the Redwood City Facility.
U.S. Naval Construction Battalion Center	Support for the Refit and Mobilization of the HMB	Provide technical and administrative support for the mobilization of the HMB into the Early Ocean Test Platform.
U.S. Navy	HMB Modification/Fabrication	Plan and provide all in-house and contract services for rework of the HMB.

Table 16

FY 1977 SUMMARY TABLES

Program Element

ENGINEERING TEST AND EVALUATION

- *Program Sub-Element*

MODULAR EXPERIMENTS

Organization	*Title*	*Projected Contribution*
Gilbert Associates, Incorporated	Modular Experiment Studies	Provide system integration and engineering studies to determine the appropriate configurations for Modular Experiments.
Gilbert Associates, Incorporated	Siting Studies for Modular Experiments and Commercial OTEC Plants	Develop site data to identify the most satisfactory area for deploying the OTEC plant.

Table 17

FY 1977 SUMMARY TABLES

Program Element

ADVANCED RESEARCH AND TECHNOLOGY

• *Program Sub-Element*

BIOFOULING, CORROSION, MATERIALS

Organization	*Title*	*Projected Contribution*
Aluminum Company of America	Catalog Information on the Performance of Aluminum in Seawater	Compile and critically evaluate existing data on the corrosion of aluminum alloys in seawater.
University of Delaware	Factors Affecting Pitting and Crevice Corrosion of Aluminum Alloys for Seawater Heat Exchanger Tubing	Study factors likely to affect the corrosion of aluminum alloys.
Lehigh University	Reinforced Concrete Constitutive Relations	Predict the constitutive (stress-strain) relations for reinforced concrete under general load conditions including hydrostatic pressure.
Sigma Research, Inc.	Compatibility Studies for the System Water-Ammonia-Titanium as Related to Ocean Thermal Energy Conversion	Identify the SCC tendency of titanium under a range of ammonia environments.
U.S. Naval Construction Battalion Center	Antifouling Marine Concrete	Develop a long-lasting, structurally strong, and environmentally safe antifouling marine concrete.
University of Miami School of Marine and Atmospheric Sciences	Preparation of Catalogue of Oceanographic Data Parameters for Potential OTEC Sites	A catalogue of available oceanographic data from areas of potential OTEC siting, and to identify gaps in the data base.
Applied Equipment Company	Fabricate/Manufacturing/ Engineering of OTEC Biofouling Devices	Manufacture 13 biofouling measurement devices and develop fabrication techniques for quantity production of these devices in the future.
Carnegie-Mellon University	A Study of Fouling and Corrosion Problems in a Solar Sea Power Plant.	Identify the effects of biofouling and corrosion on heat transfer surfaces at a potential OTEC site.
University of Hawaii	OTEC Heat Exchanger Biofouling Experiment	Observe the biofouling rates in water typical of a tropical ocean site having APL heat exchanger water flow conditions.
Hydronautics, Inc.	Investigation of OTEC Heat Exchanger Cleaning Methods	Conduct a critical state-of-the-art study of mechanical and chemical cleaning of low-temperature marine heat exchangers.
Lockheed Missiles and Space Company, Inc.	Develop an Apparatus for Use in Measuring the Effects of Biofouling on the Performance of Heat Transfer Surfaces Exposed to Ocean Environments	Design, manufacture, and proof test an apparatus intended for use in establishing the severity of the biofouling problem and its effect on heat transfer, measuring the effectiveness of potential biofouling countermeasures, and obtaining accurate heat transfer data under a wide variety of operating conditions.

Table 17 (cont.)

FY 1977 SUMMARY TABLES

Program Element

ADVANCED RESEARCH AND TECHNOLOGY

• *Program Sub-Element*

BIOFOULING, CORROSION, MATERIALS—Cont.)

Organization	*Title*	*Projected Contribution*
National Oceanic and Atmospheric Administration National Space Technology Labs	OTEC Studies in the Gulf of Mexico on Biofouling and Corrosion	Use a large discus-buoy hull equipped with a power source, test hardware, water quality indicator system, and data management and telecommunications system to obtain open ocean heat transfer, biofouling, and corrosion data from the Gulf of Mexico.
U.S. Naval Air Development Center	Measure the Effects of Biofouling and Corrosion on the Performance of Heat Transfer Surfaces Exposed in the Ocean Near St. Croix in the U.S. Virgin Islands	Conduct biofouling studies to determine the effects of water velocity, time, rate of fouling, preliminary corrosion rate on aluminum at this location, and specific oceanographic characteristics of the surface water used in the experiments.
U.S. Naval Construction Battalion Center Civil Engineering Lab	A Critcal Review of the Design Factors Influencing Biofouling and Corrosion of OTEC Surfaces	Research available literature to acquire a background on the effects for both fouling and corrosion, critically evaluate the data, and evaluate how optimal use of design can be employed in OTEC systems to avoid fouling and corrosion problems.
U.S. Naval Postgraduate School	The Nature of Primary Organic Films in the Marine Environment and Their Significance for Ocean Thermal Energy Conversion (OTEC) Surfaces	Review critical state-of-the-art literature of marine biofouling to establish what is known of primary film formation and identify research needed to fill technological gaps.
U.S. Navy, The David W. Taylor Naval Ship Research and Development Center	Methods for the Prevention and Control of Corrosion and Biofouling on Floating Platforms and Nonheat Exchanger Surfaces Exposed to Seawater for OTEC Power Plants	Identify and evaluate the technological feasibility, cost effectiveness, and environmental compatibility of different methods for the prevention and control of corrosion and marine biofouling on all seawater-exposed material surfaces (excluding heat exchangers) of OTEC power plants.
U.S. Navy, The David W. Taylor Naval Ship Research and Development Center	Mechanical Cleaning of OTEC Heat Exchanger Tubes	Delineate problems associated with the removal of soft fouling on OTEC heat exchanger tubes.
University of Miami Rosenstiel School of Marine Science	A Study to Define the Tolerable Ranges of Balance Between Dissolved CO_2 and Carbonates in Seawater that Would Avoid Deposits of Calcareous Scales on Heat Transfer Surfaces within the Temperature Range of OTEC Heat Exchangers	Establish the ranges of balance between CO_2 and carbonates, nucleation sites, effect of Mg^{++} and other ions in seawater, etc., which can cause depostion of calcareous films on OTEC heat transfer surfaces.

Table 17 (cont.)

FY 1977 SUMMARY TABLES

Program Element

ADVANCED RESEARCH AND TECHNOLOGY

● *Program Sub-Element*

Organization	*Title*	*Projected Contribution*
Native American Manufacturing, Inc.	Manufacture of OTEC Biofouling Devices	Manufacture ten biofouling measurement devices.
Oak Ridge National Laboratory	Heat Exchanger Joinability Study	Provide a technology review regarding joinability state-of-the-art as it relates to OTEC heat exchangers.

Table 18

FY 1977 SUMMARY TABLES

Program Element

ADVANCED RESEARCH AND TECHNOLOGY

• *Program Sub-Element*

HEAT EXCHANGERS

Organization	*Title*	*Projected Contribution*
Carnegie-Mellon University	Concurrent Studies of Enhanced Heat Transfer and Materials for Ocean Thermal Exchangers	Investigate the feasibility of vertical shell-and-tube exchangers.
Geoscience Ltd.	Water Heat Transfer and Ammonia Nucleate Boiling Studies.	Investigate several different means of enhancing the heat transfer coefficient of water flowing through round tubes, promoting nucleation of ammonia vaporizing over submerged horizontal tubes, and for studing the thin film evaporation of ammonia over horizontal tubes.
Johns Hopkins University Applied Physics Laboratory	Analytical Study of Two-phase Flow Heat Exchangers for OTEC Systems	Analyze the practicality and expected performance of the JHU-SPL concept for two-phase flow heat exchangers.
Oklahoma State University	Heat Exchanger System Evaluation for the OTEC Program	Identify areas of heat transfer technology, develop procedures to ensure that systems analysts are supplied with pertinent heat exchanger design and operational parameters; and perform quick-look analysis and evaluation on any variation in heat exchanger system configuration.
Oak Ridge National Laboratory	Heat Transfer Enhancement for OTEC Systems.	Explore the means for enhancing the boiling and condensing performance of heat exchangers.
Union Carbide Corporation	Heat Exchangers for Ocean Thermal Power Plants	Investigate the thermal hydraulic performance of the heat exchanger with special emphasis on the evaporator.
Oregon State University	Heat Exchanger Development for OTEC Plants	Provide engineering services in the planning and continued updating of the OTEC heat exchanger development program.
DSS Engineers, Inc.	Development of Plastic Heat Exchangers for OTEC	Provide an in-depth review of polymeric materials and material composites that have been proposed for the plastic heat exchanger.
Argonne National Laboratory	OTEC Heat Exchanger Development Program	Determine and evaluate the performance of several types of evaporators and condensers being considered for OTEC plants.
California, Berkeley, University of	Performance Improvement for OTEC Systems	Conduct a literature search on the current state-of-the-art of helix-enhanced (spirolator) water (brine) side heat transfer inside heat exchanger tubing
University of Massachusetts	A Continued Evaluation of Compact Heat Exchangers for OTEC Applications	Provide analytical design of plate-fin heat exchangers and designs for a heater exchanger program.
Sea Solar Power, Inc.	Compact Heat-Exchanger Design for OTEC	Evaluation of the possible applicability of existing designs to OTEC requirements. Development of OTEC plate-fin core test unit design.

Table 19

FY 1977 SUMMARY TABLES

Program Element

ADVANCED RESEARCH AND TECHNOLOGY

● *Program Sub-Element*

POWER SYSTEMS

Organization	*Title*	*Projected Contribution*
University of Oklahoma	Use of Mixtures as Working Fluids in OTEC Cycles	Upgrade previously developed OTEC mixture cycle simulation, develop an optimization program for OTEC mixture cycle design, correlate the thermodynamic properties of ammonia-water mixtures, and simulate the OTEC ammonia cycle with varying amounts of water in ammonia.
University of California, Los Angeles	Design of a Facility for Laboratory Experiments on a Mist-flow Thermal Energy Process	Analyze and design the experimental "mist-flow lift-tube" including engineering drawings and specifications, as required to proceed with the construction and procurement of the equipment.
Carnegie-Mellon University	Foam Sea Solar Power Plant	Study a modification which would offer increased efficiency of an open cycle solar sea power plant.
R&D Associates	Mist-flow Ocean Thermal Energy Process	Investigate a specific mechanism for thermally lifting the warm surface water to drive a hydraulic turbine.

Table 20

FY 1977 SUMMARY TABLES

Program Element

ADVANCED RESEARCH AND TECHNOLOGY

• *Program Sub-Element*

OCEAN ENGINEERING

Organization	*Title*	*Projected Contribution*
Sea Solar Power, Inc.	Design of a Cold Water Pipe for Ocean Thermal Power Plants	Produced a report describing the preliminary analysis of design conditions for a long cold water supply pipe.
U.S.N. Construction Battalion Center	Design, Fabrication, and Installation of Large Diameter Submerged Concrete Structures	Study the design, fabrication, and installation of large-diameter submerged concerte structures
Westinghouse Electric Corporation	Deep Water Pipe and Mooring Design Study	Evaluate a cold water pipe, pump, and plant mooring concepts to determine the overall evluation of the OTEC concept.
Westinghouse Electric Corporation	Seawater Pumps and Platform Stationkeeping	Analyze a cold water pump preliminary design, evaluate a warm water pump, and analyze platform stationkeeping.
Tuned Sphere International	Tuned Sphere Stable Platform for OTEC Power Plants	Prepare a geometric description of the tuned sphere concept of OTEC for output sizes of 100, 500, and 1000 MWe that are satisfactory for calculation of hydrodynamic forces.
Civil Engineering Laboratory	Development of Anchor Systems for OTEC Power Plants	Extend the state-of-the-art in deep sea anchor systems to satisfy the anchor-design requirements of large floating OTEC power plants.
Oregon State University	Biological and Hydrodynamic Influences on the Screens on OTEC Intake Systems	Provide continuous supplies of clean, cold, and warm water to an OTEC plant by excluding debris and marine plants and animals.
Hydronautics, Inc.	Studies of Seaway Responses of OTEC Platform/Cold Water Pipe Configuration Effects of Pipe Elasticity and Model Tests	Evaluate seakeeping, junction loads, cold water pipe bending moments, and stationkeeping thrust requirements.
Science Applications, Inc.	Empirical Hydrodynamics Studies to Produce Parameters for Determining the Drag and Lift Forces on a Cylinder in Supercritical Flow Regimes for OTEC	Determination of definitive and valid values of drag coefficients, lift coefficients, and Strouhal numbers for long rigid cylinders in uniform flows at Reynolds numbers ranging from 10^6 to 10^7. The second phase produced a developmental experimental design dealing with methods and apparatus for the acquisition of similar data in a Reynolds number range from 10^7 to 10^8.

Table 20 (cont.)

FY 1977 SUMMARY TABLES

Program Element

ADVANCED RESEARCH AND TECHNOLOGY

● *Program Sub-Element*

OCEAN ENGINEERING—(Cont.)

Organization	*Title*	*Projected Contribution*
Hydronautics, Inc.	Structural Analysis and Design Studies of OTEC Cold Water Pipe	Documents a methodology for OTEC cold water pipe structral analysis.
U.S. Naval Postgraduate School	Dynamic Response of Moored OTEC Plants to Ocean Waves	Provides computer programs describing the interaction of ocean waves with floating structures; estimates dynamic response resulting from the wave/structure interaction.

Fiscal Year 1977—Project Summaries

I. PROGRAM SUPPORT

Support Services
OTEC Workshop Organization

PROGRAM SUPPORT
Support Services

CONTRACTOR
Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60499

CONTRACT NO.
ANL 189–49553

PERIOD OF PERFORMANCE
December 31, 1976—September 30, 1977

PRINCIPAL INVESTIGATOR
Wyman Harrison (312) 972-3784

FISCAL YEAR 1977 FUNDING
$60,000 (ERAB funds)

TITLE
Program Management Support: Oceanographic and Climatic Impacts

SUMMARY

Management support was provided to ERDA on all hydrodynamical efforts for OTEC. The status and direction of ERDA contracts E(49–26) 1005, E(49–18) 2348, and E(11–1) 2909 were assessed and their results integrated into the overall OTEC framework. Existing and proposed projects were evaluated. Contact was maintained with the project contractors. In addition to the hydrodynamic modeling literature, draft reports to ERDA from the contractors were reviewed. Recommendations have been made on the improvement of the physical data base for model verification.

Bibliography Reference No. 220

PROGRAM SUPPORT
Support Services

CONTRACTOR	INTERAGENCY AGREEMENT
U.S. Naval Facilities Engineering Command (NAVFAC) 200 Stovall Street Alexandria, VA 22332	E(49–26)–1000
	PERIOD OF PERFORMANCE February 24, 1975 to September 30, 1977
PRINCIPAL INVESTIGATOR James H. Osborn (202) 325-0505	FISCAL YEAR 1977 FUNDING $394,800

TITLE

Technical Management of OTEC Ocean Engineering Program Activity

SUMMARY

The object of this project was to perform the following services for ERDA:

a. Program management assistance and consultation for assistance in the OTEC program planning, preparation, and evaluation of program solicitations.
b. Participation in overall program evaluation, and coordination with other agencies providing support to ERDA in other technology aspects of OTEC development.
c. Management and technical coordination of facility access required for utilization of Navy test and fabrication facilities in support of the OTEC Program.
d. Technical evaluation of system, component, and technology development proposals.
e. Monitoring and evaluation of ERDA contractor work specifically assigned to NAVFAC for technical direction.
f. Transfer of Navy technology to ERDA contractors, and participation in program technical reviews and workshops.
g. Technical direction, monitoring and evaluation of specific research and development projects by ERDA or Navy contractors as assigned.
h. Coordination, monitoring and evaluation of assigned ERDA-funded research and development projects to be accomplished in-house by Navy organizations and laboratories.

Bibliography Reference No. 217, 222

PROGRAM SUPPORT
Support Services

CONTRACTOR	CONTRACT NO.
Gilbert Associates, Inc. P.O. Box 1498 Reading, PA 19603	EY–76–C–02–2847
	PERIOD OF PERFORMANCE January 1, 1976 to December 31, 1977
PRINCIPAL INVESTIGATOR John van Summern (202) 331-0252	FISCAL YEAR 1977 FUNDING $772,872*

TITLE

Architectural and Engineering Services in Support of the OTEC Program

SUMMARY

This project provides architect-engineering support services for a variety of OTEC design, engineering, and programmatic tasks. This work is carried out on a program-wide basis and includes such activities as technical review of proposals, projects and reports, systems analysis, conceptual design development, test program development, and integration.

These five tasks relate to the above mentioned activities and cover a contract period of two years. Plans and procedures that coordinate program activities and ensure the best utilization of OTEC program resources were emphasized during the initial effort. Development of recommendations relating to all phases of design, construction, fabrication, and test of OTEC facilities were emphasized during the second year. Major subcontractors used on this project are identified below.

SUBCONTRACTORS:

Frederic R. Harris, Inc.
Ichthyological Associates, Inc.
Mechanics Research, Inc.
M. Rosenblatt and Son, Inc.
Santa Fe International, Inc.
Tetra Tech, Inc.

* The total 1977 funding to Gilbert Associates was $1,850,000.

Bibliography Reference No. 2

PROGRAM SUPPORT
Support Services

CONTRACTOR	CONTRACT NO.
Office of Ocean Engineering National Oceanic and Atmospheric Administration (NOAA) 6010 Executive Bldg. Rockville, MD 20852	EG–77–A–29–1978
	PERIOD OF PERFORMANCE April 19, 1977 to December 19, 1977
PRINCIPAL INVESTIGATOR Joseph Vadus (301) 443–8385	FISCAL YEAR 1977 FUNDING $91,500
TITLE Ocean Engineering Program Support	

SUMMARY

The contractor provided ocean engineering support to ERDA in the following areas:

a. Program planning and approval.
b. Implementation of major OTEC activities.
c. Participation in annual program reviews.
d. Contract monitoring.
e. Determination of procurement policy.

Bibliography Reference No. 218

PROGRAM SUPPORT
Support Services

CONTRACTOR	CONTRACT NO.
Battelle Pacific Northwest Laboratories Battelle Boulevard, P.O. Box 999 Richland, WA 99352	AT (45–1)–1830
	PERIOD OF PERFORMANCE December 19, 1975 to September 30, 1977
PRINCIPAL INVESTIGATOR Lyle D. Perrigo (509) 946-2113	FISCAL YEAR 1977 FUNDING $399,000*

TITLE
Biofouling and Corrosion Studies for OTEC

SUMMARY

Battelle subcontracted and managed a series of studies with the objective of defining, measuring, preventing, alleviating, and controlling biofouling and corrosion problems associated with Ocean Thermal Energy Conversion (OTEC) systems. This effort included the participation by the contractor, in conjunction with DOE Headquarters, in planning study objectives, milestones, and coordination with related areas of OTEC development, especially heat exchangers. The subcontracted studies include laboratory and ocean measurements and the instrumentation thereof. In the area of prevention, studies were conducted on materials, surface properties and coatings, electro-chemical techniques, and environmental alteration. Alleviation techniques for controlling biofouling once it has occurred were investigated, including mechanical and chemical methods.

Battelle organized a symposium held October 10–12, 1977 in Seattle, WA. Papers were presented on the importance of coping with OTEC biofouling and corrosion problems, results of completed OTEC relevant biofouling and corrosion projects, descriptions of projects currently underway or anticipated, and ideas or concepts for future OTEC biofouling and corrosion research. A proceedings of that symposium is being prepared.

Battelle also provided an assessment of the CMU data reduction program for evaluating heat transfer measurements and designed a backup date reduction capability for the OTEC biofouling and corrosion program.

* Does not include transfer of funds by Battelle to the following subcontractors:

1.	Native American Manufacturing, Inc.	$ 18,750
2.	Applied Equipment, Inc.	$ 27,433
		18,875
3.	Alcoa, Inc. Alcoa Research Center	$ 4,338
4.	Carnegie-Mellon University, Subcontracted with the University of Hawaii	$396,361
5.	Dow Chemical Company	$ 72,323
6.	University of Miami	$ 91,153
7.	University of Delaware (amount shown includes 1976 funding)	$101,193
8.	Hydronautics, Inc.	$ 11,534
9.	NOAA/National Data Buoy Office	$448,000
10.	Naval Ship R&D Center	$210,000
11.	Battelle Pacific Northwest Laboratories	$ 10,000
12.	Battelle Pacific Northwest Laboratories	$ 15,000

Bibliography Reference No. 190

PROGRAM SUPPORT
Support Services

CONTRACTOR	CONTRACT NO.
Lawrence Berkeley Laboratory Berkeley, CA 94720	LBL 189 No. 475–C
	PERIOD OF PERFORMANCE May 19, 1977 to September 30, 1977
PRINCIPAL INVESTIGATOR Pat Wilde (415) 843-2740	FISCAL YEAR 1977 FUNDING $30,000 (ERAB Funds)

TITLE

Program Management Support: Biological and Ecological Effects of a 100 MWe OTEC Plant

SUMMARY

The objective of this effort was to provide program management support to DOE on all biological/ecological effects of OTEC studies.

The project implemented the following approaches:

a. Assessing the present status and continually reviewing experience with the bio-ecological effects of large ocean engineering systems which are relevant to OTEC.
b. Evaluating and integrating pertinent knowledge from completed and on-going projects.
c. Eliciting bio-ecological concerns from OTEC contractors.
d. Summarizing above points, identifying gaps in the knowledge, and recommending specific topics for further study.
e. Assisting headquarters in the preparation of RFP's, then evaluating and integrating the products of the RFP's into the bio-ecologic program.
f. Disseminating information such as reports and ensuring that appropriate OTEC groups are well-informed and have appropriate bio-ecologic data.
g. Recommending ameliorating strategies during pre-100 MWe tests.
h. Documenting bio-ecologic studies in proper form for eventual use in EA's.

Bibliography Reference No. 213

PROGRAM SUPPORT
OTEC Workshop Organization

CONTRACTOR	GRANT NO.
Society of Naval Architects and Marine Engineers (SNAME) Suite 1369, One World Trade Center New York, NY 10048	EG–77–G–10–0025
	PERIOD OF PERFORMANCE October 30, 1976 to October 31, 1977
PRINCIPAL INVESTIGATOR A.J. Haskell (212) 432–0310	FISCAL YEAR 1977 FUNDING $ 5,000

TITLE

Spring Meeting on Energy Research in the Oceans at San Francisco, California, May 25 to 27, 1977

SUMMARY

The theme of this meeting, "Energy Research in the Oceans," is a timely topic of major international significance. Thirty-four papers were presented covering the following major areas:

a. Marine transportation (machinery).
b. Offshore fixed platforms.
c. Ocean Thermal Energy Conversion.
d. Offshore mobile platforms.
e. Marine transportation (naval architecture).
f. Liquified Natural Gas (transportation and terminals).

In addition to SNAME members from the United States and abroad, engineers from cooperating professional societies (the American Society of Civil Engineers, the Institute of Electrical and Electronic Engineers, and the Marine Technology Society) participated.

Bibliography Reference No. 212

PROGRAM SUPPORT
OTEC Workshop Organization

CONTRACTOR	CONTRACT NO.
University of New Orleans New Orleans, LA 70122	EG–77–G–05–5376
	PERIOD OF PERFORMANCE February 1, 1977 to July 31, 1977
PRINCIPAL INVESTIGATOR David Mayer (504) 283–0331	FISCAL YEAR 1977 FUNDING $ 33,000

TITLE

Fourth Annual Ocean Thermal Energy Conference

SUMMARY

A conference on OTEC was conducted by the contractor in New Orleans, LA, on March 21 through 23, 1977. The conference proceedings were edited by the contractor and published in September 1977.

The proceedings consisted of contributed papers, discussions and summaries of conclusions, and recommendations of working groups.

Bibliography Reference No. 204

PROGRAM SUPPORT
OTEC Workshop Organization

CONTRACTOR	CONTRACT NO.
Clean Energy Research Institute University of Miami P.O. Box 248294 Coral Gables, FL 33124	EG–77–G–05–5550
	PERIOD OF PERFORMANCE June 28, 1977 to June 27, 1978
PRINCIPAL INVESTIGATOR T. Nejat Veziroglu (305) 284–2404	FISCAL YEAR 1977 FUNDING $ 11,000

TITLE

Fifth Ocean Thermal Energy Conversion (OTEC) Conference (Miami Beach, Fl., Feb. 20–22, 1978)

SUMMARY

The objective of this workshop, to be held in Miami Beach, FL, February 20–22, 1978, is to provide a public opportunity to present and discuss the latest research results pertinent to the conversion of ocean thermal energy. Subjects covered will include:

a. Heat exchangers.
b. Modeling and optimization.
c. Ocean engineering.
d. Biofouling and corrosion.
e. Total system design.
f. Environmental impact.
g. Economic and legal aspects.

A proceedings of the workshop will be compiled and published.

Bibliography Reference No. None

II. DEFINITION PLANNING

Test Program Requirements
Mission Analysis
Thermal Resource Assessment & Siting Studies
Environmental
Legal and Institutional Studies

DEFINITION PLANNING
Test Program Requirements

CONTRACTOR	CONTRACT NO.
Lockheed Missiles and Space Co., Inc. P.O. Box 504 Sunnyvale, CA 94088	EY–76–C–03–1156
	PERIOD OF PERFORMANCE December 10, 1975 to January 17, 1977
PRINCIPAL INVESTIGATOR Lloyd C. Trimble (408) 742–5035	FISCAL YEAR 1977 FUNDING $0

TITLE
Test Facilities Requirements Definition

SUMMARY

This study developed alternative non site-specific OTEC facilities and ocean platform requirements for an integrated OTEC test program that may include land and ocean test facilities. Alternative OTEC systems and equipment which must be developed and tested were defined and analyzed. The study included development of cost, schedule, and performance data for each of the alternative OTEC test facility requirements, and the performance of tradeoff analyses relative to these factors. The study results were documented in sufficient detail to enable DOE to identify and examine all data considered, and to perform an independent evaluation of and selection between the alternatives.

Specific land sites and ocean test platforms were not considered in this study. The key objective of the study was to provide and consider a spectrum of possible OTEC test facility requirements, both ocean-based and land-based, and to perform cost benefit-timing tradeoff analyses for those options.

The project established system and component testing requirements by reviewing, updating, and utilizing existing conceptualized and analyzed alternative system test configurations. From those configurations, testing plans were prepared. Conceptualized testing requirements for advanced research and technology and energy utilization were prepared. Test facilities support requirements, associated costs, and overall test facilities requirements (including space and resource requirements, scheduling, and cost) were established.

Subcontractors:

Bechtel Corporation
Stanford Research Institute

Bibliography Reference No. 74–78

DEFINITION PLANNING
Test Program Requirements

CONTRACTOR	CONTRACT NO.
TRW Inc., DSSG Building 81, Room 1538 1 Space Park Redondo Beach, CA 90278	E(04–3)–1158
	PERIOD OF PERFORMANCE December 16, 1975 to January 15, 1977
PRINCIPAL INVESTIGATOR Robert H. Douglass (213) 535–2246	FISCAL YEAR 1977 FUNDING $0

TITLE

Test Facilities Requirements Definition

SUMMARY

This study developed alternative, non site-specific OTEC facilities and ocean platform requirements for an integrated OTEC test program that may include land and ocean test facilities. Alternative OTEC systems and equipment which must be developed and tested were defined and analyzed. The study included development of cost, schedule, and performance data for each of the alternative OTEC test facility requirements, and the performance of tradeoff analyses relative to these factors. The study results were documented in sufficient detail to enable DOE to identify and examine all data considered, and to perform an independent evaluation of and selection between the alternatives.

Specific land sites and ocean test platforms were not considered in this study. The key objective of the study was to provide and consider a spectrum of possible OTEC test facility requirements, both ocean-based and land-based, and to perform cost-benefit-timing tradeoff analyses for those options.

The project established system and component requirements, by reviewing, updating and utilizing existing conceptual baseline design studies as the primary information source, and conceptualized and analyzed alternative system test configurations. From those configurations, testing plans were prepared. Conceptualized testing requirements for advanced research and technology and energy utilization were prepared. Test facilities support requirements, associated costs, and overall test facilities requirements, (including space and resource requirements, scheduling, and cost) were established.

Subcontractor:

Global Marine Development, Inc.

Bibliography Reference No. 79–81

DEFINITION PLANNING

Mission Analysis

CONTRACTOR Aerospace Corporation P.O. Box 92957 Los Angeles, CA 90009	CONTRACT NO. EC–76–C–03–1101, PA–9
	PERIOD OF PERFORMANCE May 1, 1976 to June 1, 1978
PRINCIPAL INVESTIGATOR George C. McKoy (213) 648–6406	FISCAL YEAR 1977 FUNDING $100,000
TITLE Mission Analysis and Support for OTEC Systems	

SUMMARY

Objective of this procurement is to provide mission analysis and support for OTEC. Activities include tasks in area definition and siting analysis, energy utilization alternatives, and marketability. The emphasis in FY 1977 was to document and upgrade the system costing model known as OTECOST.

Bibliography Reference No. 8

DEFINITION PLANNING
Mission Analysis

CONTRACTOR	CONTRACT NO.
General Electric Company/TEMPO 777 Fourteenth Street, N.W. Washington, DC 20005	EX-76-C-01-2421
	PERIOD OF PERFORMANCE May 15, 1976 to February 28, 1978
PRINCIPAL INVESTIGATOR Edward J. Tschupp (202) 637-1507	FISCAL YEAR 1977 FUNDING $169,000

TITLE
OTEC Mission Analysis Study

SUMMARY

This study provides a mission analysis of OTEC which supports governmental, institutional, and industrial decision-making with respect to the utilization of the ocean's thermal energy resources on a regional scale. An assessment of the potential for large-scale utilization of ocean thermal energy for various applications was provided. The major tasks were:

a. Identification of high priority missions.
b. Development of implementation for high priority mission applications.
c. Development of an OTEC system deployment plan.
d. Legal, institutional, and political analysis.
e. Definition of the consequence of implementation of an OTEC system.

Bibliography Reference No. 11, 12, 181

DEFINITION PLANNING
Mission Analysis

CONTRACTOR	CONTRACT NO.
Columbia University Lamont-Doherty Geological Observatory Palisades, NY 10964	AT(11-1)-2581
	PERIOD OF PERFORMANCE February 1, 1975 to January 31, 1976
PRINCIPAL INVESTIGATOR Oswald A. Roels* (512) 794-6757	FISCAL YEAR 1977 FUNDING $0

TITLE

Marine Pastures: A By-Product of Large (100 Megawatts or Larger) Floating Ocean Thermal Power Plants

SUMMARY

The economic feasibility of large, floating ocean thermal power plants will depend upon both the costs of power production and the value of possible by-products. The question of technical and economic feasibility of one adjunct process, that of open-ocean mariculture, was approached through this study of how to utilize the nutrient-rich, cold-water effluents of OTEC power plants for that application.

The project examined this possibility through four approaches:

1) Physical/Chemical—The fate of deep water discharge at the surface was determined experimentally, including its mixing rate with surface water and the vertical and horizontal migration of the resulting mixture of surface water and deepsea water.
2) Primary Production—The indigenous phytoplankton species best suited for this open-ocean mariculture were determined, based upon measurements of comparative growth rates in differing mixtures of deep and surface water, efficiency of nutrient utilization and nutritional value for the second level.
3) Secondary Producers—Various species of shellfish (oysters, clams, and scallops) were grown in raft and case cultures suspended in the open sea. Simultaneous small-scale growth tests were conducted in shallow water near shore, using the same species of phytoplankton and shellfish. That water was enriched with a continuous flow of water from a depth of 870 meters.
4) Scale-Up—An engineering and economic feasibility study was conducted, based upon the earlier results, to determine the possibility of producing commercially valuable filter-feeding shell-fish.

* Dr. Roels is now the Director of the Port Aransas Marine Laboratory, Marine Science Institute, University of Texas, Port Aransas, Texas 78373.

Bibliography Reference No. 82-84

DEFINITION PLANNING
Mission Analysis

CONTRACTOR	CONTRACT NO.
Stone & Webster Engineering Corporation 245 Summer Street, P.O. Box 2325 Boston, MA 02107	EG-77-C-06-1018
	PERIOD OF PERFORMANCE September 1977 to January 1979
PRINCIPAL INVESTIGATOR Donald Guild (617) 973-2501	FISCAL YEAR 1977 FUNDING $120,000 from OTEC Account

TITLE
Southeast Regional Assessment Study

SUMMARY

The objective of this study is to provide an assessment of the potential of the various solar energy technologies for providing significant solar-electric and other forms of central and dispersed solar energy to the southeastern United States. The Southeast region is defined to include Alabama, Delaware, Florida, Georgia, Maryland, Mississippi, North Carolina, South Carolina, Tennessee, Virginia, and the Commonwealth of Puerto Rico. (Several of these states and Puerto Rico are likely to be primary recipients of OTEC power cables.)The study is designed to develop a siting and resources data base and analytical models that will be used to project the potential applications and market penetrations for solar energy options. It will commence by formulating technology characterizations of those options. User's future needs will be projected, along with analyzing and defining how users can integrate and utilize these potential new energy sources. A description and evaluation of deployment opportunities for each solar energy option will be established. Governmental, institutional, legislative, environmental, and socioeconomic factors will be evaluated by potential users, who will help define user-requirements for successful implementation of solar energy in this region. A Consumer Interest Advisory Panel and a State Government Advisory Panel will act as reviewers as the study proceeds.

Subcontractors:

Baltimore Gas and Electric Company
Coca-Cola Company
Duke Power Company
Florida Power Corporation
Florida Power & Light Company
Florida Solar Energy Center
Georgia Institute of Technology
Institute of Gas Technology
Jacksonville Electric Authority
Jefferson Mills, Inc.
Savannah Electric and Power Company
Southern Company
Tampa Electric Company
Tennessee Valley Authority
Puerto Rico Water Resources Authority

Bibliography Reference No. None

DEFINITION PLANNING

Thermal Resource Assessment and Siting Studies

CONTRACTOR

Ocean Data Systems, Inc.
6000 Executive Blvd.
Rockville, MD 20852

CONTRACT NO.

EG-77-C-01-4028*
EG-77-C-01-4028 (Change Order)**

PERIOD OF PERFORMANCE

February 23, 1977 to November 23, 1977

PRINCIPAL INVESTIGATOR

Paul Wolff (408) 649-1133

FISCAL YEAR 1977 FUNDING

$ 77,438 (OTEC Funds)*
$ 29,937 (ERAB Funds)**

TITLE

Site Specific Thermal Data* and Ocean Thermal Structure Analysis**

SUMMARY

The first phase of this two-part contract involved site specific thermal data. The objectives were to (1) define the ocean thermal structure at four specific locations, with resolution of 1 °C, 10 m in depth, and 1 Km horizontal distance, and (2) conduct monthly archival data assessments. The historical data file was updated, and preliminary and final data summaries were prepared.

The second part of this contract involved ocean thermal structure analysis. The objective of this phase was to provide a more useful ocean thermal resource assessment and data base for the environmental assessment and siting of the 100 MWe OTEC demonstration plant. The approach was to (1) add Key West, FL data to the previous thermal data study, (2) develop most-probable temperature sounding and associated standard deviations for each 1° square in the Gulf of Mexico, and near Hawaii and Puerto Rico as identified by DOE, (3) produce summary tables of temperature characteristics by 1° square, and (4) prepare a final report.

Bibliography Reference No. 213

DEFINITION PLANNING
Thermal Resource Assessment and Siting Studies

CONTRACTOR Woods Hole Oceanographic Institution Woods Hole, MA 02543	CONTRACT NO. EG–77–S–02–4293
	PERIOD OF PERFORMANCE April 1, 1977 to April 1, 1978
PRINCIPAL INVESTIGATOR James W. Mavor, Jr. (617) 548–1400	FISCAL YEAR 1977 FUNDING $136,370
TITLE Oceanographic Data for OTEC Design	

SUMMARY

The objective of this effort is to provide: discrete site selection criteria based on OTEC design; a plan and schedule for matching the ocean data base to design, construction and test requirements; and a plan for acquiring requisite oceanographic data.

This will be accomplished by: determining present OTEC design specifications using DOE direction and completed studies; determining available ocean data base for sites specified by DOE; reviewing and interpreting data bases for applicability to OTEC; developing a plan/schedule for matching data bases to design and integrate into the OTEC subsystems plan and schedule; determining what additional data are required; and develop a plan to acquire the data.

Bibliography Reference No. 103, 183, 185, 213

DEFINITION PLANNING
Thermal Resource Assessment and Siting Studies

CONTRACTOR	CONTRACT NO.
Bretschneider Consultants 2600 Pualani Way Honolulu, HI 96815	EG–77–X–01–2849
	PERIOD OF PERFORMANCE June 8, 1977 to July 8, 1977
PRINCIPAL INVESTIGATOR Charles Bretschneider (808) 948–8110	FISCAL YEAR 1977 FUNDING $ 9,980

TITLE

Design Current and Wave Criteria for Potential OTEC Sites

SUMMARY

The objective of this study was to provide data on design current and wave criteria for potential OTEC plant sites.

The data was accumulated by studying surface and profile currents and looking at the height, period, and spectra for southern swells around Hawaii. Also investigated were the spectra for two sea states and the hurrican parameters at all potential sites.

The data is being used to provide engineering design and potential environmental impact information for the 1 MWe OTEC test platform and its cold water pipe.

Bibliography Reference No. 88, 89, 93–96, 213

DEFINITION PLANNING

Thermal Resource Assessment and Siting Studies

CONTRACTOR	CONTRACT NO.
Research Triangle Institute Research Triangle Park, NC 27709	EG-77-C-05-5441
	PERIOD OF PERFORMANCE June 7, 1977 to June 7, 1978
PRINCIPAL INVESTIGATOR Fred M. Vukovich (919) 541-6000	FISCAL YEAR 1977 FUNDING $ 93,439

TITLE

Sea Surface Satellite Thermal Data

SUMMARY

The objective of this effort is to provide an analytical tool for synoptic assessment of thermal resource variations at sites of probable OTEC locations via infra-red (IR) satellite imagery.

The work includes:

a. Determining OTEC thermal resource data requirements by the review of existing system and subsystems specifications.
b. Assessing the state of practice in thermal IR imagery via satellite and comparing it to OTEC requirements.
c. Developing methodology for acquiring relevant data and applying it to OTEC resource assessment.
d. Preparing schemes for OTEC operational usage of IR data.
e. Analyzing existing IR data and including it in OTEC data summaries/atlas(es)

Bibliography Reference No. 213

DEFINITION PLANNING

Thermal Resource Assessment and Siting Studies

CONTRACTOR	CONTRACT NO.
Florida Institute of Technology Department of Oceanography and Ocean Engineering Melbourne, FL 32901	EG–77–G–05–5518
	PERIOD OF PERFORMANCE June 1, 1977 to March 31, 1978
PRINCIPAL INVESTIGATOR Ross McCluney (305) 723–3701	FISCAL YEAR 1977 FUNDING $ 9,995

TITLE

A Study of the Geographical Distribution of the OTEC Resource in the Florida Current

SUMMARY

The objective of this study is to perform an analysis of the geographical distribution of the OTEC resource in the Florida current.

The study will be accomplished through data acquisition and organization, development of an interpolation model, calculation and mapping of trend surfaces, and a thermocline analysis of maps.

Bibliography Reference No. None

DEFINITION PLANNING

Thermal Resource Assessment and Siting Studies

CONTRACTOR	CONTRACT NO.
Florida Solar Energy Center 300 State Road 501 Cape Canaveral, FL 32920	EG-77-G-05-5547
	PERIOD OF PERFORMANCE June 16, 1977 to September 30, 1977
PRINCIPAL INVESTIGATOR W. R. McCluney (305) 723-3701	FISCAL YEAR 1977 FUNDING $ 9,879

TITLE

Ocean Thermal Energy Conversion Resource Assessment Workshop

SUMMARY

The contractor organized this workshop which was held to discuss OTEC data acquisition and siting requirements, and environmental, resource, and technical assessments.

The organizers invited knowledgeable oceanographic researchers familiar with the ocean data base at site of interest to DOE/OTEC, convened the workshop, and integrated the papers presented by the researchers into a proceedings.

Bibliography Reference No. 213

DEFINITION PLANNING

Thermal Resource Assessment and Siting Studies

CONTRACTOR

National Oceanic and Atmospheric Administration
Environmental Data Service
National Oceanographic Data Center
300 Whitehaven Street, N.W.
Washington, D.C. 20235

INTERAGENCY AGREEMENT

EX-76-A-29-1041
Task Order T017

PERIOD OF PERFORMANCE

April 1, 1977–October 1, 1977

PRINCIPAL INVESTIGATOR

James Churgin (202) 634-7500

FISCAL YEAR 1977 FUNDING

$ 44,800 (ERAB Funds)

TITLE

Oceanographic Data Base for OTEC

SUMMARY

The objective of this effort was to provide as complete a statement as possible of required oceanographic data from existing and updated archives.

The work was accomplished by determining OTEC system and subsystem specifications in terms of required oceanographic data, establishing a common formula for displaying the data, and preparing the necessary atlas(es).

Work for each OTEC area of interest included identification of available historical oceanographic and meteorological data, identification of those areas where data are scarce or lacking altogether, construction of a test oceanographic data base, and provision of data and data services to DOE and OTEC contractors.

Bibliography Reference No. 213

DEFINITION PLANNING

Thermal Resource Assessment and Siting Studies

CONTRACTOR National Oceanic and Atmospheric Administration Atlantic Oceanographic & Meteorological Laboratories Miami, FL 33149	INTERAGENCY AGREEMENT EX–76–A–29–1041 Task Order T018 PERIOD OF PERFORMANCE April 4, 1977–July 4, 1978
PRINCIPAL INVESTIGATOR Dr. Robert Molinari (305) 361–3361 X322	FISCAL YEAR 1977 FUNDING $250,000 (ERAB Funds)

TITLE

Ocean Currents and Thermal Observation

SUMMARY

This project is to provide necessary details of observational data over a 15-month period at sites of principal economic interest using requirements for oceanographic data as specified for OTEC. The approach will include the aspects of data as required for engineering design, as required for environmental issues, and as input to numerical models. After all previous archival data resources have been studied, a measurement program will be developed for critical data and sites as specified by DOE. An at-sea observation program of currents and temperatures will result in a report of the data acquired and an analysis of this data to meet OTEC requirements.

Bibliography Reference No. 213, 214

DEFINITION PLANNING
Environmental

CONTRACTOR	CONTRACT NO.
Hydronautics, Inc. 7210 Pindell School Road Laurel, MD 20810	EX–76–C–01–2348 (Change Order)
	PERIOD OF PERFORMANCE June 30, 1977 to December 30, 1977
PRINCIPAL INVESTIGATOR T. R. Sundaram (301) 776–7454	FISCAL YEAR 1977 FUNDING $ 48,000 (ERAB Funds)

TITLE

Experimental Study of Flow Problems Related to Ocean Thermal Energy Conversion (OTEC)

SUMMARY

The principal objective of this work is to investigate experimentally the external flow problems unique to OTEC with major emphasis on avoiding the recirculation problem. The work will define the conditions for recirculation by conducting:

a. Recirculation experiments for different geometrical configurations.
b. Experiments on the combined effects of current and stratification.
c. Limited experiments in a 6-foot cube to verify and complement MIT's flow field schematization.

Bibliography Reference No. 205, 221

DEFINITION PLANNING
Environmental

CONTRACTOR	CONTRACT NO.
Ocean Data Systems, Inc. 6000 Executive Blvd. Rockville, MD 20852	EG-77-X-01-1807
	PERIOD OF PERFORMANCE February 28, 1977 to March 28, 1977
PRINCIPAL INVESTIGATOR Paul Wolff (408) 649-1133	FISCAL YEAR 1977 FUNDING $ 4,952 (ERAB Funds)

TITLE

Ocean Climatic Impacts Model Reviews

SUMMARY

The objective of this effort was to review the modeling efforts under contracts E(49-26)1005, E(49-18)2348, E(11-1) 2909 of the Naval Research Laboratory, Hydronautics, and the Massachusetts Institute of Technology on flow problems and fluid mechanics. The approach was to state the problems in realistic terms, examine the methods used, evaluate assumptions used, and state the applicability of the results to OTEC.

The deliverables were: (1) a draft analysis, critique, and report of the published results of the above contracts, and (2) a final analysis and report.

Bibliography Reference No. 213

DEFINITION PLANNING
Environmental

CONTRACTOR	CONTRACT NO.
Massachusetts Institute of Technology 77 Massachusetts Avenue Cambridge, MA 02139	EY-76-S-02-2909
	PERIOD OF PERFORMANCE January 1, 1976 to June 30, 1977
PRINCIPAL INVESTIGATOR Gerhard H. Jirka* (607) 256-3438	FISCAL YEAR 1977 FUNDING $ 79,933

TITLE

External Fluid Mechanics of Ocean Thermal Power Plants

SUMMARY

This research program on external fluid mechanics consisted of experimentation and mathematical modeling. The experimental program was aimed at the simulation of the OTEC operation under schematic oceanographic and plant design conditions. The effect of the governing parameters on recirculation was investigated in a series of experiments conducted in a laboratory basin. The data collected in the testing program served for verification and calibration of mathematical (analytical or numerical) models of OTEC operation.

Several major accomplishments resulted from this research program:

(1) Detailed experimental data sets of the flow and temperature fields of OTEC plans operating under different design and ambient conditions have been established. The data was used in the development of design formulas for the prevention of recirculation and is available for perusal by other OTEC research contractors.

(2) The potential for OTEC recirculation is governed by the interaction of the jet discharge and a double sink flow (one sink being the evaporator onflow, the other being the jet entrainment). These processes occur within two to three mixed layer depths from the OTEC plant. The recirculation potential appears to be largely independent of jet discharge geometry and of small ambient current speeds (up to 0.10 m/s).

(3) An analytical model, in conjunction with experimental data, provides a design formula for the prevention of recirculation at OTEC plants of the mixed discharge design, i.e., the condenser and evaporator flows are discharged jointly or close to each other at the approximate level of the ocean thermocline.

(4) A standard 100 MW OTEC plant with the mixed mode design under typical OTEC candidate site conditions appears to be able to operate without near field recirculation.

* Now at the Department of Environmental Engineering, Cornell University, Ithaca, New York 14853

Bibliography Reference No. 97, 98

DEFINITION PLANNING
Environmental

CONTRACTOR	INTERAGENCY AGREEMENT
Naval Ocean Research and Development Activity (NORDA) Bay St. Louis, Mississippi 39520	E(49–26)–1005
	PERIOD OF PERFORMANCE August 15, 1977 to February 15, 1978
PRINCIPAL INVESTIGATOR Steve A. Piacsek (601) 688–4835	FISCAL YEAR 1977 FUNDING $ 59,000 (ERAB Funds)

TITLE

Theoretical Fluid Dynamical Studies of Resource Availability and Environmental Impact of Ocean Thermal Energy Coversion (OTEC)

SUMMARY

This work completes the analysis (by fluid dynamical computer modeling) of local and far-field environmental impacts associated with OTEC operations. These include possible thermal, dynamic, and climatic impacts. The completion of this work provides a basis for additional investigation of the biological/ecological effects of OTEC.

Subcontractors:

Science Applications, Inc.
Jaycor, Inc.

Bibliography Reference No. 101, 102, 209, 225, 226

DEFINITION PLANNING
Environmental

CONTRACTOR	CONTRACT NO.
Interstate Electronics Corporation 707 E. Vermont Avenue P.O. Box 3117 Anaheim, CA 92803	EG–77–C–06–1033
	PERIOD OF PERFORMANCE September 1, 1977 to June 1, 1978
PRINCIPAL INVESTIGATOR S.T. Kelly (714) 772–2811	FISCAL YEAR 1977 FUNDING $ 53,551 (ERAB Funds)

TITLE

Environmental Impact Assessment of Ocean Test Platforms for OTEC

SUMMARY

The objective of this project is to prepare environmental impact assessments of the 1 MWe and 5 MWe OTEC floating test facilities. This is being accomplished by:

a. Reviewing existing system and subsystem specifications with the DOE/OTEC Program Manager and the designated contractor.
b. Identifying environmental issues and drawing up an OTEC environmental development plan.
c. Assessing data requirements and availability and setting priorities on data acquisition.
d. Recommending, as required, the development of an Environmental Impact Statement (EIS).
e. Suggesting possible design modifications to mitigate unresolvable impacts.

Bibliography Reference No. None

DEFINITION PLANNING
Environmental

CONTRACTOR	CONTRACT NO.
Lockheed Center for Marine Research 6350 Yarrow Drive Carlsbad, CA 92008	EG–77–C–06–1032
	PERIOD OF PERFORMANCE September 15, 1977 to September 15, 1978
PRINCIPAL INVESTIGATOR Scott Robinson (714) 438–1253	FISCAL YEAR 1977 FUNDING $ 84,925 (ERAB Funds)

TITLE

Marine Biota Impact Assessment for OTEC

SUMMARY

The objective of this project is to establish a data base on exposure of marine biota to OTEC discharges for preparation of environmental impact assessments. Consideration is being given to both closed- and open-cycle discharges. The approach being implemented is as follows:

(1) Laboratory and/or in situ experiments are being designed to assess the effect of exposure to OTEC physical and chemical conditions on ocean flora and fauna, such as corrosion products, screening, and biocides.

(2) A plan is being developed for subjecting specific species common to one or more OTEC candidate sites to chemical and physical environmental changes, simulating those anticipated during passage through heat exchangers or in passing through the outflow of the plant. This plan specifies that: (a) the observed effects will be analyzed and extrapolated to estimate total impacts of OTEC commercial-size plant operation, (b) assessment will be made of the ecological effects of chemical releases from OTEC plants, (c) assessment will be made of the ecological impact of toxic effects of metallic ion releases from OTEC plants (i.e., corrosion products), and (d) assessment will be made of the effect on marine life of screening systems located at OTEC intake structures.

Bibliography Reference No. None

DEFINITION PLANNING
Legal and Institutional Studies

CONTRACTOR	NSF Grant ATR-7518279
University of Southern California University Park Los Angeles, CA 90007	PERIOD OF PERFORMANCE July 1, 1975 to December 31, 1976
PRINCIPAL INVESTIGATOR Jack M. Nilles (213) 741-7464	FISCAL YEAR 1977 FUNDING $0

TITLE

Evaluation of Incentives for the Development of Ocean Thermal Gradient Exchange Technology

SUMMARY

The objectives of the program were to investigate the present environment for commercialization of new energy technologies and to analyze the potential public policy incentives for accelerating the rate of commercialization of these technologies. OTEC was used as the basis for developing the policy analysis framework. The research involved: (1) analysis of the present extent of technological innovation and the criteria for new technology acceptance in public utilities and in representative ocean energy industrial complexes for both U.S. and foreign markets; (2) modeling of the relative economic competitiveness of OTEC in comparison to nuclear and coal energy alternatives for markets studied under both existing and postulated incentive conditions; (3) examination of the number and extent of indirect effects (benefits and disadvantages to the public) accruing from successful development of OTEC technologies as they might relate to providing motivation for public policy actions; and (4) examination of specific legal, institutional, administrative, tax, and economic incentives and disincentives appropriate or potentially applicable to OTEC technology.

The net result of these investigations and analyses led the USC team to the general conclusion that, provided that OTEC technology is demonstrated to be feasible at the costs claimed by various organizations engaged in OTEC R&D, OTEC plants can become economically competitive with coal-fired energy plants in the 1990's and with nuclear plants shortly after the turn of the century under existing conditions and trends. If appropriate incentives are applied, or if costs of conventional energy plants escalate, the date of initial economic compentitiveness could be shortened by as much as 20 years. Estimates of dollar costs to the public for providing these incentives were broken down into those appropriate for the R&D, prototype, demonstration, construction, and operation phases.

Bibliography Reference No. 40, 175

DEFINITION PLANNING
Legal and Institutional Studies

CONTRACTOR	CONTRACT NO.
American Society of International Law 2223 Massachusetts Avenue, N.W. Washington, DC 20008	E(49–26)–1039
	PERIOD OF PERFORMANCE Feb., 1975 to July, 1976
PRINCIPAL INVESTIGATOR Robert E. Stein (202) 265–4313	FISCAL YEAR 1977 FUNDING $0

TITLE

Ocean Thermal Energy Conversion: Legal Considerations

SUMMARY

This study identified subjects of needed inquiry within five major areas:

a. Rights to emplace and maintain installations.
b. Rights to capture and remove the resource.
c. Sources and content of legal standards governing emplacement and operation.
d. Questions of responsibility and liability for the consequences of operation.
e. The juridical status of operators and installations.

The project examined each of these areas in light of several key variable factors, including the features of the system in place, the environmental consequences of its operation, the likely locations and operators of installations, and the impact of the developing international law of the sea.

An interdisciplinary panel was established to pursue these inquiries in the context of evolving technology for ocean thermal conversion. Its findings were communicated to investigators concerned with other aspects of the technology at a public workshop.

Bibliography Reference No. 9, 10, 176

DEFINITION PLANNING
Legal and Institutional Studies

CONTRACTOR	CONTRACT NO.
American Society of International Law 2223 Massachusetts Avenue, N.W. Washington, D.C. 20008	EG-77-C-01-4118
	PERIOD OF PERFORMANCE September 29, 1977 to April 29, 1978
PRINCIPAL INVESTIGATOR J. L. Hargrove (202) 265-4313	FISCAL YEAR 1977 FUNDING $ 32,000

TITLE
R&D in OTEC Institutional and Legal Matters

SUMMARY

The objective of this project is to perform a research and development effort to provide data inputs regarding institutional and legal requirements for OTEC development and demonstration. (This project is complemented by a related coordinated study being performed by Tefft, Kelly and Motley, Inc.) This contractor is clarifying the international OTEC legal position under existing law, and studying what improvements to this situation would be desirable.

Bibliography Reference No. None

DEFINITION PLANNING
Legal and Institutional Studies

CONTRACTOR	CONTRACT NO.
Tefft, Kelly and Motley, Inc. 1225 Connecticut Avenue, N.W. Washington, D.C. 20036	EG-77-C-01-4119
	PERIOD OF PERFORMANCE September 22, 1977 to April 21, 1978
PRINCIPAL INVESTIGATOR R. Clark Tefft (202) 659-2650	FISCAL YEAR 1977 FUNDING $ 46,000

TITLE
R&D in OTEC Institutional and Legal Matters

SUMMARY

The objective of this project is to perform a research and development effort to provide data inputs regarding institutional and legal requirements for OTEC development and demonstration. (This project is complemented by a related coordinated study being performed by the American Society of International Law.) This contractor is clarifying the domestic OTEC legal position under existing law, and studying what improvements to this situation would be desirable.

Bibliography Reference No. None

III. ENGINEERING DEVELOPMENT

Power Systems
Ocean Systems
Energy Utilization

ENGINEERING DEVELOPMENT
Power System

CONTRACTOR	CONTRACT NO.
TRW, Inc. Systems and Energy Group 1 Space Park Redondo Beach, CA 90278	EG-77-C-03-1570
	PERIOD OF PERFORMANCE August 1, 1977 to October 31, 1978
PRINCIPAL INVESTIGATOR William Tallon (213) 536-2347	FISCAL YEAR 1977 FUNDING $270,546

TITLE
OTEC Power System Development (Phase I)

SUMMARY

The objective of the first phase of this project is to develop a preliminary design for the full-sized (25 MWe nominal), closed-cycle ammonia power system module for 100 MWe OTEC Demonstration Plant. This project will incorporate heat exchangers (evaporator and condenser) utilizing advanced high performance heat transfer techniques.
Included in this effort is the conceptual and preliminary design of the following:

a. The 25 MWe power system module.
b. A scaled (5 MWe nominal) proof-of-concept power system.
c. The 1 MWe heat exchangers (evaporator and condensers) representative of the 25 MWe design, for early test and design verification.

Subcontractors:

Union Carbide Corp., Linde Division
Carnegie-Mellon University
C.F. Braun & Co.
Marston Excelsior Ltd.

Bibliography Reference No. None

ENGINEERING DEVELOPMENT
Power System

CONTRACTOR	CONTRACT NO.
Lockheed Missiles and Space Co., Inc. P.O. Box 504 Sunnyvale, CA 94088	EG–77–C–03–1568
	PERIOD OF PERFORMANCE August 1, 1977 to October 31, 1978
PRINCIPAL INVESTIGATOR Lloyd C. Trimble (408) 742–5035	FISCAL YEAR 1977 FUNDING $403,697

TITLE
OTEC Power System Development (Phase I)

SUMMARY

The object of the first phase of this project is to develop a preliminary design for the full-sized (25 MWe nominal), closed-cycle ammonia power system module for the 100 MWe OTEC Demonstration Plant. This project will incorporate heat exchangers (evaporation and condenser) utilizing state-of-the-art heat transfer techniques.

Included in this effort is the conceptual and preliminary design of the following:

a. The 25 MWe power system module.
b. A scaled (5 MWe nominal) proof-of-concept power system.
c. The 1 MWe heat exchangers (evaporator and condensers) representative of the 25 MWe design, for early test and design verification.

Subcontractors:

Bechtel Corp.
Foster Wheeler Energy Corp.
Lockheed Shipbuilding and Construction Co.
Lockheed Electronic Co.

Bibliography Reference No. None

ENGINEERING DEVELOPMENT

Power System

CONTRACTOR	CONTRACT NO.
Westinghouse Electric Corporation Steam Turbine Division Lester, PA 19113	EG-77-C-03-1569
	PERIOD OF PERFORMANCE August 1, 1977 to October 31, 1978
PRINCIPAL INVESTIGATOR Eugene Barsness (215) 595-3124	FISCAL YEAR 1977 FUNDING $925,757

TITLE
OTEC Power System Development (Phase I)

SUMMARY

The objective of the first phase of this project is to develop a preliminary design for the full-sized (25 MWe nominal), closed-cycle ammonia power system module for the 100 MWe OTEC Demonstration Plant. This project will incorporate heat exchangers (evaporator and condenser) utilizing state-of-the-art heat transfer techniques.

Included in this effort is the conceptual and preliminary design of the following:

a. The 25 MWe power system module.
b. A scaled (5 MWe nominal) proof-of-concept power system.
c. The 1 MWe heat exchangers (evaporator and condensors) representative of the 25 MWe design, for early test and design vertification.

Subcontractors:

Union Carbide Corp., Linde Division
Carnegie-Mellon University
Middle South Services, Inc.
Gibbs & Hill, Inc.

Bibliography Reference No. None

ENGINEERING DEVELOPMENT

Power System

CONTRACTOR	CONTRACT NO.
Lockheed Missiles & Space Co., Inc. P.O. Box 504 Sunnyvale, CA 94088	EG–77–C–03–1291
	PERIOD OF PERFORMANCE June 28, 1976 to December 23, 1976
PRINCIPAL INVESTIGATOR Lloyd C. Trimble (408) 742–5035	FISCAL YEAR 1977 FUNDING $ 0

TITLE

OTEC Tube and Shell Heat Exchanger Producibility Study

SUMMARY

This project was a study of shell and tube heat exchangers for an Ocean Thermal Energy Conversion (OTEC) plant. Its purpose was to define requirements and develop material information, including the use of concrete, prerequisite to the conceptual and preliminary design of a shell and tube heat exchanger. This study developed design requirements and prepared design concepts. Structural loads during operations were defined and considered. A construction analysis was made based upon its concepts through contracts and and discussions with three or more large scale heat exchanger manufacturers. Also, design requirements were established for a maintenance and repair philosophy for its designs. The results of the study are available to interested parties

Subcontractors:

Bechtel Corporation
T.Y. Lin International
Wyatt Industries
Aluminum Company of America
Yuba Heat Transfer Corporation
University of Denver

Bibliography Reference No. 185

ENGINEERING DEVELOPMENT

Power System

CONTRACTOR	CONTRACT NO.
Colorado School of Mines Engineering Physics Department Golden, CO 80401	E(29-2)-3723
	PERIOD OF PERFORMANCE June 1, 1976 to December 31, 1977
PRINCIPAL INVESTIGATOR Frank Mathews (303) 279-0300	FISCAL YEAR 1977 FUNDING $13,213

TITLE

An Evaluation of Open-cycle Thermocline Power Systems

SUMMARY

The purpose of this project was to conduct a feasibility and costing study of any open-cycle system that may be competitive with the closed-cycle concept. In this project the feasibility of using an open-cycle system for the production of electric power from ocean thermocline was determined. This was accomplished by: developing performance and cost relations in parametric form for the thermocline; developing a performance/costing program arriving at minimum cost per rated kWe output for system component combinations in the 1 to 100 megawatt range; developing preliminary engineering designs for the most cost-effective of the open-cycle systems considered; estimating installed capital and operating costs for the most cost-effective system; and determining cost estimates for electric energy.

Subcontractors:

Westinghouse Eelectric Corp.; Barber-Nichols Engineering Co.

Bibliography Reference No. 202

ENGINEERING DEVELOPMENT
Power System

CONTRACTOR	CONTRACT NO.
Westinghouse Electric Corp. Steam Turbine Division Box 9175 Philadelphia, PA 19119	EG–77–C–03–1473
	PERIOD OF PERFORMANCE June 01, 1977 to March 01, 1978
PRINCIPAL INVESTIGATOR C. Sciubba (215) 595–2861	FISCAL YEAR 1977 FUNDING $100,000

TITLE
OTEC 100 MWe Alternate Power System Study

SUMMARY

The objective of this contract is to develop a conceptual power system design for the open-cycle power system addressing all major components and including sufficient information to allow hardware cost estimates to be made. Also, the contractor will develop a conceptual power system design based on the hybrid (water vapor/ammonia) cycle.

Bibliography Reference No. None

ENGINEERING DEVELOPMENT
Ocean Systems

CONTRACTOR
Johns Hopkins University
Applied Physics Laboratory
Laurel, MD 20810
VIA: Naval Sea Systems Command
Arlington, VA 20360

INTERAGENCY AGREEMENTS
EG-77-A-29-1076 Amend #1
MARAD 400-79011

PERIOD OF PERFORMANCE
June 15, 1977 to September 30, 1978

PRINCIPAL INVESTIGATOR
Jim George (301) 953-7100, ext. 7412

FISCAL YEAR 1977 FUNDING
ERDA—$130,000
MARAD—$200,000

TITLE
Preliminary Engineering Design of a Modular Experiment

SUMMARY

This project is for a preliminary engineering design of an Ocean Thermal Energy Conversion (OTEC) pilot plant. The concept for heat exchangers that employ large diameter, multipass aluminum tubes with the ammonia working fluid inside the tubes was developed by APL with ERDA funding. With MARAD-funded support, APL conducted an analysis of the maritime and construction aspects of OTEC plant ships for deployment in tropical oceans to produce ammonia or other energy-intensive products.

As a follow-on study, this DOE- and MARAD-funded project will result in the preliminary design of 5 MWe concrete barge type vessel with sufficient plans and specifications to solicit a price proposal from interested shipbuilders.

Bibliography Reference No. None

ENGINEERING DEVELOPMENT
Ocean Systems

CONTRACTOR	CONTRACT NO.
Rosenblatt, M., & Son, Inc. 350 Broadway New York, NY 10013	EG–77–C–01–4065
	PERIOD OF PERFORMANCE July 18, 1977 to May 13, 1978
PRINCIPAL INVESTIGATOR N. Basar (212) 431–6900	FISCAL YEAR 1977 FUNDING $366,778

TITLE

OTEC Platform Configuration and Integration

SUMMARY

This project is for the conceptual design of an operational, integrated OTEC commercial plant system. A set of specific evaluation criteria is being prepared to evaluate six candidate generic hull shapes to develop systems requirements for commercial application integration with site-related requirements. Of six generic hull shapes, the two most satisfactory hull configurations that emerge from the evaluation will be integrated with the OTEC ocean systems and the power system.

The nine specific studies in this project are:

a. Data assembly and synthesis.
b. Systems requirements and analysis with an evaluation plan.
c. Technology review.
d. Systems integration and evaluation.
e. Conceptual design.
f. Development plan for demonstration unit.
g. Cost and time schedule.
h. Site sensitivity.
i. Facilities and equipment.

Subcontractors:

Burns & Roe, Inc.
Columbia Research Corp.

Bibliography Reference No. None

ENGINEERING DEVELOPMENT
Ocean Systems

CONTRACTOR	CONTRACT NO.
Lockheed Missiles and Space Company, Inc. P.O. Box 504 Sunnyvale, CA 94088	EG–77–C–01–4063
	PERIOD OF PERFORMANCE July 18, 1977 to May 13, 1978
PRINCIPAL INVESTIGATOR R. L. Waid (408) 742–5000	FISCAL YEAR 1977 FUNDING $435,424
TITLE OTEC Platform Configuration and Integration	

SUMMARY

The contractor is investigating candidate hull concepts, position control concepts, and seawater system concepts which have application to OTEC commercial plants. There are currently six candidate hull concepts and three possible sites being considered for OTEC plants. A conceptual design of the two leading integrated OTEC system candidates will be developed. Each conceptual candidate system will be accomplished by a demonstration system plan and cost schedule estimate for implementing the hardware application at sea.

The study consists of the following technical goals:

a. Data assembly and synthesis.
b. Systems and requirements analysis with an evaluation plan.
c. Technology review.
d. Systems integration and evaluation.
e. Conceptual design.
f. Facilities and equipment.
g. Development plan for demonstration unit.
h. Cost and time schedule.
i. Site sensitivity.

Subcontractors:

Earl and Wright
Morris Guralnick Associates, Inc.
Hydronautics, Inc.
Bechtel Corp.
T.Y. Lin International
Tuned Sphere International, Inc.

Bibliography Reference No. None

ENGINEERING DEVELOPMENT
Ocean Systems

CONTRACTOR	CONTRACT NO.
Gibbs & Cox, Inc. 40 Rector Street New York, NY 10006	EG-77-C-01-4064
	PRINCIPAL INVESTIGATOR P. H. Hadley, Jr. (212) 487-2800
PERIOD OF PERFORMANCE July 18, 1977 to May 14, 1978	FISCAL YEAR 1977 FUNDING $316,900

TITLE
OTEC Platform Configuration and Integration

SUMMARY

The purpose at this project is to evaluate six candidate hullforms as candidates for the OTEC commercial plant. The hullforms are being systematically evaluated to rank them in order to perference considering the factors of cost, schedule, and risk. Conceptual designs of two of these plants will then be conducted and a plan for development of a demonstration plant will be prepared.

This study consists of the following technical goals:

a. Data assembly and synethesis.
b. Systems evaluation and requirements.
c. Plan evaluation.
d. Technology review.
e. Systems integration evaluation.
f. Conceptual design.
g. Facilities and equipment.
h. Cost and schedules.
i. Site sensitivity.

Subcontractors:

Santa Fe International
Giannotti and Buck Associates
Alan C. McClure Associates, Inc.

Bibliography Reference No. None

ENGINEERING DEVELOPMENT
Energy Utilization

CONTRACTOR	CONTRACT NO.
Institute of Gas Technology Energy Systems Analysis 3424 S. State Street ITT Center Chicago, IL 60616	NSF AER–75–00033
	PERIOD OF PERFORMANCE May 1, 1975 to May 15, 1976
PRINCIPAL INVESTIGATOR Derek P. Gregory (312) 567–3893	FISCAL YEAR 1977 FUNDING $ 0

TITLE

An optimization Study of Ocean Thermal Energy Delivery Systems Based on Chemical Carriers

SUMMARY

This study provided an engineering and economic analysis of chemical energy-carrier alternatives for transportation of energy from large-scale floating OTEC power plants to wholesale energy markets. The chemical energy carriers analyzed in this study were hydrogen (both as a gas and as a liquid) and ammonia, since both are marketable fuels for industrial, commercial, and residential applications. The project focused on the following:

a. Chemical energy production.
b. Assessment of present chemical energy transmission technologies for hydrogen and ammonia.
c. Projection for technological advancements in delivery system elements including cost goals for improving energy utilization efficiency, investment costs, and unit operations costs for the various elements.
d. Synthesis of b. and c.
e. Evaluation of land-based terminal facilities.
f. Reconversion of chemical energy to electricity and onshore fertilizer production.
g. Determination of the sensitivity of the systems to variations in operating parameters.
h. Recommendations regarding future R&D.

Bibliography Reference No. 162–164

ENGINEERING DEVELOPMENT
Energy Utilization

CONTRACTOR	CONTRACT NO.
Institute of Gas Technology (IGT) 3424 State Street Chicago, IL 60616	ERDA E(49–18)–2426
	PERIOD OF PERFORMANCE June 28, 1976 to July 15, 1977
PRINCIPAL INVESTIGATOR Nicholas Biederman (312) 567–3930	FISCAL YEAR 1977 FUNDING $ 0

TITLE
Alternative Energy Transmission Systems from OTEC Plants

SUMMARY

The study evaluated the feasability and the generated conceptual designs of two concepts for transporting ocean thermal energy to shore. One concept dealt with an onboard electrical system to produce high temperature heat. In addition, a thermal storage medium would be used to store and ship this energy which subsequently would be used for electric generation at the shore facility. The other concept would take hydrogen, produced by water electrolysis, and react it with carbon dioxide aboard the OTEC platform to produce carbonaceous fuels and other "high energy" fuels. Two alternatives exist as the source of this carbon dioxide: a back-haul scheme that would bring carbon dioxide from an onshore source to the OTEC platform, and the use of carbon dioxide that is dissolved in the cold seawater used by the OTEC plant.

Methane, methanol, and conventional light fuels of the gasoline family were considered for synthesis at the OTEC plant. The possibility of producing high-energy fuels such as hydrazine onboard the OTEC plant were analyzed. Other high-energy fuels reviewed included unsymmetrical dimethylhydrazine (UDMH); 1, 7–octadiyne; and tetrahydrodicyclopentadienes. Two other methods of moving OTEC-derived energy using "electrochemical bridges" were also evaluated.

This study was conducted to allow a uniform comparison of these alternatives with the results of the previous OTEC analysis conducted by IGT.

Bibliography Reference No. 165, 180

ENGINEERING DEVELOPMENT
Energy Utilization

CONTRACTOR	CONTRACT NO.
Pirelli Cable Systems, Inc. 245 Park Avenue New York, NY 10017	EG-77-C-05-5360
	PERIOD OF PERFORMANCE September 6, 1977 to September 6, 1978
PRINCIPAL INVESTIGATOR Giulio Viola (212) 661-5820	FISCAL YEAR 1977 FUNDING $70,000

TITLE

Bottom Segment Design for Underwater Cable Power Transmission System

SUMMARY

This project involves the development of designs for the bottom segment of an OTEC underwater electric power transmission cable system (Phase 1). The work includes the following tasks:

a. Delineate the conditions, circumstances, and environment to which the system is subjected during installation, operation, maintenance and repair.
b. Assess the suitability of each candidate system in each situation defined in a. including any potential environmental impact.
c. Development preliminary specifications.
d. Perform a reliability analysis of the combined generator/transmission system.
e. Perform a cost analysis.

Bibliography Reference No. None

ENGINEERING DEVELOPMENT
Energy Utilization

CONTRACTOR	CONTRACT NO.
Simplex Wire and Cable Co. P.O. Box 479 Portsmouth, NH 03801	EG–77–C–05–5359
	PERIOD OF PERFORMANCE September 28, 1977 to September 28, 1978
PRINCIPAL INVESTIGATOR Charles Pieroni (603) 436–6100	FISCAL YEAR 1977 FUNDING $130,000

TITLE

Riser Segment Design of Underwater Electric Power Transmission Cable System

SUMMARY

This project is developing the designs for the riser segment of the underwater electric power transmission cable system (Phase 1). The system includes the submarine connector, connections to the submarine connector and the plant, and the integral cable suspension system. The work includes the following tasks:

a. Delineate the conditions, circumstances, and environment to which this system is subjected during installation, operation, maintenance, and repair.
b. Assess the suitability of each candidate cable system in each of the situations defined in task "a," including any environmental impact.
c. Develop preliminary specifications.
d. Develop the submarine connector and the plant termination designs to make with the riser cable design.
e. Perform a reliability analysis of the combined system.
f. Perform a cost analysis.

Bibliography Reference No. None

IV. ENGINEERING TEST AND EVALUATION

1 MWe Early Ocean Test Platform
Modular Experiments

ENGINEERING TEST AND EVALUATION
1 MWe Early Ocean Test Platform

CONTRACTOR	CONTRACT NO.
Gilbert Associates, Inc. P.O Box 1498 Reading, PA 19603	EY–76–C–02–2847
	PERIOD OF PERFORMANCE January 1, 1977 to October 1, 1977
PRINCIPAL INVESTIGATOR John van Summern (202) 331–0252	FISCAL YEAR 1977 FUNDING $440,132*
TITLE OTEC–1 Studies and Cold Water Pipe Activity	

SUMMARY

This project provided systems integration and engineering support for the development of the OTEC–1. System guidance and technical direction have been provided in the development of the RFP package for OTEC–1 heat exchangers. Design studies were made for the OTEC–1 power subsystems resulting in a set of design criteria. OTEC–1 system objectives were formulated, mission profiles developed, and mission test objectives developed.

Subcontractors:

a. Mechanics Research, Inc.: Cost feasibility of converting HMB–1 to OTEC 1.
b. M. Rosenblatt & Son, Inc.: OTEC–1 system requirements cold water pipe deployment and retrieval time line estimates, cold water systems design reviews, and review of OTEC–1 preliminary drawings.
c. Santa Fe International: OTEC–1 prelimnary conversion cost estimate.
d. Tetra Tech, Inc.: Review of cold water pipe dynamic models.
e. Frederic R. Harris, Inc.: Sea water system design criteria, siting studies, analyses, and criteria development; cold water pipe dynamic modeling; and survey of state-of-the-art mooring techniques and dynamic positioning.

* The total 1977 funding for Gilbert Associates, Inc. was $1,850,000.

Bibliography Reference No. 1, 3, 4, 5

ENGINEERING TEST AND EVALUATION
1 MWe Early Ocean Test Platform

CONTRACTOR Lockheed Missiles and Space Co. P.O. Box 504 Sunnyvale, CA 94088	CONTRACT NO. EY–76–C–03–1248 PERIOD OF PERFORMANCE April 1, 1976 to October 21, 1977
PRINCIPAL INVESTIGATOR W. D. Orr (408) 942–5000	FISCAL YEAR 1977 FUNDING $45,000

TITLE
Maintenance of Redwood City Facility and OTEC Eqiupment

SUMMARY

This contract provided for the maintenance of the Redwood City Facility, where the Hughes Mining Barge (HMB) was berthed prior to its being moved to Hunters Point Shipyard. In addition, Lockheed Company provided for maintenance, security, and support related to the HMB equipment and spares located at Redwood City, California.

Bibliography Reference No. None

ENGINEERING TEST AND EVALUATION
1 MWe Early Ocean Test Platform

CONTRACTOR	CONTRACT NO.
TRW, Inc. Systems and Energy Group 1 Space Park Redondo Beach, CA 90278	EG–77–C–03–1361
	PERIOD OF PERFORMANCE May 16, 1977 to March 31, 1979
PRINCIPAL INVESTIGATOR Dr. J. E. Snyder (213) 536–3410	FISCAL YEAR 1977 FUNDING $308,110

TITLE

1 MWe Heat Exchangers for Ocean Thermal Energy Conversion

SUMMARY

The objective of this project is to design, fabricate, and deliver one seawater/ammonia evaporator and one condenser for the Ocean Thermal Energy Conversion (OTEC) 1 MW electric equivalent heat exchanger system to be installed on the Early Ocean Test Platform (OTEC–1).

This system will be used to validate OTEC heat exchanger performance in the ocean environment. The ocean tests will provide data on overall heat transfer coefficients, biofouling, and operational feasibility in order to further the technology required for the development of larger, more efficient OTEC power systems.

The contract work is divided into four sequential phases as follows:

a. Phase I: Conceptual and Preliminary Design.
b. Phase II: Detailed Design.
c. Phase III: Fabrication, Test, and Inspection.
d. Phase IV: Installation and Initial Operation.

Subcontractors:

Southwestern Engineering Co.
C. F. Braun & Company
Union Carbide Corp., Linde Division

Bibliography Reference No. None

ENGINEERING TEST AND EVALUATION
1 MWe Early Ocean Test Platform

CONTRACTOR	CONTRACT NO.
W. M. Howerton 2311 Carroll Lane Escondido, CA 92025	EX–77–X–03–0063
	PERIOD OF PERFORMANCE January 29, 1977 to December 31, 1977
PRINCIPAL INVESTIGATOR W. M. Howerton (415) 273–7946	FISCAL YEAR 1977 FUNDING $44,250
TITLE Naval Architect and Ocean Engineering Services	

SUMMARY

The objective of this contract was to provide naval architect and ocean engineering services. Additionally, the contractor was to support the OTEC Program and Hughes Mining Barge Conversion activities at the DOE's San Francisco Operations Office.

Bibliography Reference No. None

ENGINEERING TEST AND EVALUATION
1 MWe Early Ocean Test Platform

CONTRACTOR Morris Guralnick Associates 550 Kearny Street San Francisco, CA 94108	CONTRACT NO. EG–77–C–03–1434
	PERIOD OF PERFORMANCE March 14, 1977 to November 15, 1977
PRINCIPAL INVESTIGATOR N. Harris (415) 362–1092	FISCAL YEAR 1977 FUNDING $363,884
TITLE HMB Conversion Preliminary Design Tasks	

SUMMARY

The objective of this contract was to provide certain preliminary design drawings and studies related to the Hughes Mining Barge (HMB) conversion to OTEC–1. This work was performed in support of the procurement of a System Integration Contractor to design, fabricate, deploy, support, and operate the OTEC–1 Platform.

The results of this effort are being included as a reference information data package and will be available to potential OTEC–1 system integration contractor bidders.

Subcontractors:

Southwest Research Institute
J. R. Paulling

Bibliography Reference No. None

ENGINEERING TEST AND EVALUATION
1 MWe Early Ocean Test Platform

CONTRACTOR	CONTRACT NO.
Morris Guralnick Associates 550 Kearny Street San Francisco, CA 94108	EG–77–C–03–1388
	PERIOD OF PERFORMANCE March 1, 1977 to July 1, 1977
PRINCIPAL INVESTIGATOR Norman Harris (415) 362–1092	FISCAL YEAR 1977 FUNDING $9,200

TITLE
Dredge Base Support Flotation and Stability Analysis

SUMMARY

This work involved analysis of the stability characteristics of the Hughes Mining Barge (HMB) dredge base using flotation devices to remove it from the HMB well deck while flooded. Also, a removal rigging system was designed.

Bibliography Reference No. None

ENGINEERING TEST AND EVALUATION
1 MWe Early Ocean Test Platform

CONTRACTOR U.S. Navy Superintendent of Shipbuilding, Conversion, and Repair San Francisco, CA 94135	CONTRACT NO. EG–77–03–1376 PERIOD OF PERFORMANCE December 15, 1976 to December 30, 1977
PRINCIPAL INVESTIGATOR Lt. Commander R. B. Bubeck (415) 641–3003	FISCAL YEAR 1977 FUNDING $850,000
TITLE Dredge Base Removal and HMB Support Services	

SUMMARY

This interagency agreement provides for the removal of dredge base from the Hughes Mining Barge (HMB). It also provides for certain repairs, maintenance and support services related to the HMB including temporary berthing and security.

Bibliography Reference No. None

ENGINEERING TEST AND EVALUATION
1 MWe Early Ocean Test Platform

CONTRACTOR Interstate Electronics P.O. Box 3117 Anaheim, CA 92803	CONTRACT NO. EG–77–C–03–1369
	PERIOD OF PERFORMANCE December 15, 1976 to August 31, 1977
PRINCIPAL INVESTIGATOR Sam Kelly (714) 772–2811	FISCAL YEAR 1977 FUNDING $107,259
TITLE Marine Engineering Support Services	

SUMMARY

The objective of this activity was to provide marine engineering and support services related to the Hughes Mining Barge (HMB) and associated spare equipment. Activities included reviewing assessing, advising and supporting operations on HMB equipment and spare parts, HMB drydocking, dredge base removal, equipment maintenance and facility security.

Bibliography Reference No. None

ENGINEERING TEST AND EVALUATION
1 MWe Early Ocean Test Platform

CONTRACTOR	CONTRACT NO.
American Patrol Services 8105 Edgewater Oakland, CA 94621	EG–77–C–03–1298
	PERIOD OF PERFORMANCE April 1, 1976 to December 31, 1976
PRINCIPAL INVESTIGATOR Jack L. Mann (415) 568–6818	FISCAL YEAR 1977 FUNDING $22,500

TITLE

Security of the Redwood Facility and the Hughes Mining Barge

SUMMARY

This work is to provide guard services for the Redwood City facility and the Hughes Mining Barge.

Bibliography Reference No. None

ENGINEERING TEST AND EVALUATION
1 MWe Early Ocean Test Platform

CONTRACTOR U.S. Naval Construction Battalion Center Civil Engineering Laboratory Port Hueneme, CA 93403	INTERAGENCY AGREEMENT EX–77–A–29–1070 PERIOD OF PERFORMANCE December 1, 1976 to September 30, 1977
PRINCIPAL INVESTIGATOR L. W. Babby (805) 982–5336	FISCAL YEAR 1977 FUNDING $50,000
TITLE Support for the Refit and Mobilization of the HMB	

SUMMARY

The objective of this contract was to provide technical and administrative support for the mobilization of the Hughes Mining Barge into the Early Ocean Test Platform (OTEC–1).

Bibliography Reference No. None

ENGINEERING TEST AND EVALUATION
1 MWe Early Ocean Test Platform

CONTRACTOR U.S. Navy Superintendent of Shipbuilding, Conversion, and Repair San Francisco, CA 94135	INTERAGENCY AGREEMENT EG-77-A-03-1376 PERIOD OF PERFORMANCE December 15, 1976 to September 30, 1978
PRINCIPAL INVESTIGATOR Lt. Commander R. B. Bubeck (415) 641-3003	FISCAL YEAR 1977 FUNDING $850,000
TITLE HMB Modification/Fabrication	

SUMMARY

The object of this work is to plan and provide all in-house and contract services for rework of the Hughes Mining Barge and other Ocean Thermal Energy Conversion (OTEC) related systems in accordance with requirements to be provided by DOE. The specific work to be performed is to be provided by separate Task Orders written under this agreement. This work may include, but it not limited to, design, specification and drawing effort, procurement services, contract administration, quality assurance, and inspection.

Subcontractor:

Triple A Shipyard, Inc.

Bibliography Reference No. 4

ENGINEERING TEST AND EVALUATION
Modular Experiments

CONTRACTOR	CONTRACT NO.
Gilbert Associates, Inc. P.O. Box 1498 Reading, PA 19603	EY–76–C–02–2847
	PERIOD OF PERFORMANCE August 15, 1977 to December 31, 1977
PRINCIPAL INVESTIGATOR John van Summern (202) 331–0252	FISCAL YEAR 1977 FUNDING $475,814*

TITLE
Modular Experiment Studies

SUMMARY

This project was to provide the system integration and engineering studies to determine the feasibility of:

a. Bulk carrier converted to an appropriate configuration with an integral 15-ft. diameter cold water pipe and a 30-ft diameter cold water pipe.
b. An existing ship converted to an appropriate configuration with a detached cold water pipe of 15-ft. or 30-ft. diameter.
c. A spar buoy with a 15-ft. and 30-ft. diameter cold water pipe.
d. A concrete barge with an integral 30-ft. diameter cold water pipe configured for shell-less heat exchangers. The platforms were configured for a 5 MWe power plant module with provisions for an additional 5 MWe power plant module retrofit, and the site conditions at Puerto Rico.

Subcontractors:

a. M. Rosenblatt & Son, Inc.: Bulk carrier utilization studies and configuration recommendations.
b. Santa Fe International: Spar buoy utilization studies and configuration recommendations, and concrete barge construction and cost estimate study.
c. Tetra Tech, Inc.: Design analysis for spar buoy utilization studies in support of Santa Fe International.
d. J. R. Paulling: Cold water pipe dynamic modeling in support of M. Rosenblatt & Son and Johns Hopkins University Applied Physics Laboratory (APL).
e. Hydronautics: Modeling of APL plant ship design with 15-, 30-, and 60-ft. diameter cold water pipes.
f. Doty Associates, Inc.: Preparation of data which depicts parametric costs for each of the major OTEC Platform Configurations.

* The total 1977 funding for Gilbert Associates, Inc. was $1,850,000.

Bibliography Reference No. 216

ENGINEERING TEST AND EVALUATION
Modular Experiments

CONTRACTOR	CONTRACT NO.
Gilbert Associates, Inc. P.O. Box 1498 Reading, PA 19603	EY–76–C–02–2847
	PERIOD OF PERFORMANCE January 1, 1976 to December 31, 1977
PRINCIPAL INVESTIGATOR John van Summern (202) 331–0252	FISCAL YEAR 1977 FUNDING $161,182*

TITLE

Siting Studies for Modular Experiments and Commercial OTEC Plants

SUMMARY

The object of this effort was to develop site data that would assist in identifying the most satisfactory area for deployment of the OTEC plant for base-load electrical generation. Site selection efforts were based on evaluating site data in terms of the possible systems that may be used for the OTEC commercial plant and for earlier test facilities.

Data dealing with the site environment was gathered from archival sources and possibly from site specific measurements in the areas of the ocean near the continental U.S. and its possessions. This data was analyzed and catalogued for use by designers and other OTEC contractors.

Subcontractors:

Frederic R. Harris, Inc.
Tetra Tech, Inc.
Evans-Hamilton, Inc.

* The total 1977 funding for Gilbert Associates, Inc. was $1,850,000.

V. ADVANCED RESEARCH & TECHNOLOGY

Biofouling, Corrosion, Materials
Heat Exchangers
Power Systems
Ocean Engineering

ADVANCED RESEARCH AND TECHNOLOGY
Biofouling, Corrosion, Materials

CONTRACTOR	CONTRACT NO.
Aluminum Company of America Alcoa Laboratories Alcoa Center, PA 15069	Battelle PNL AT (45-1)-1830
	PERIOD OF PERFORMANCE September 30, 1976 to April 19, 1977
PRINCIPAL INVESTIGATOR Robert A. Bonewitz (412) 339-6651	FISCAL YEAR 1977 FUNDING $34,975

TITLE

Catalog Information on the Performance of Aluminum in Seawater

SUMMARY

The objective of this project was to compile and critically evaluate existing data on the corrosion of aluminum alloys in seawater as applicable to OTEC conditions, and to prepare a catalog for use by the OTEC Program Office.

Bibliography Reference No. 108, 196, 197

ADVANCED RESEARCH AND TECHNOLOGY
Biofouling, Corrosion, Materials

CONTRACTOR	CONTRACT NO.
University of Delaware College of Marine Studies Lewes, DE 19958	EY–76–S–02–2957
	PERIOD OF PERFORMANCE June 15, 1976 to June 14, 1978
PRINCIPAL INVESTIGATOR Stephen C. Dexter (302) 738–2841	FISCAL YEAR 1977 FUNDING $48,693

TITLE

Factors Affecting Pitting and Crevice Corrosion of Aluminum Alloys for Seawater Heat Exchanger Tubing

SUMMARY

The objective of this project is to study the factors likely to affect the corrosion of aluminum alloys in OTEC systems. The scope of these investigations include laboratory measurements on the effects of:

a. Dissolved oxygen from 0.5 to 7 ppm.
b. pH from 7.0 to 8.4.
c. The combined effects of pH and DO.
d. Mild abrasion and velocity on the seawater corrosion of aluminum alloy 5052 and 99.99% aluminum.

It has been found that decreasing the dissolved oxygen concentration of unpolluted natural seawater from air saturation to 0.5 ppm does not decrease the length of time for pit initiation on either 99.99 percent aluminum or on alloy 5052. Neither does it increase the rate of pit growth of alloy 5052 as was previously believed. Decreasing the pH from 8.2 to 7.6, however, decreases the induction time for pit and crevice initiation, and increases the rate of pit and crevice growth on alloy 5052 in natural seawater. Pit and crevice growth rates are determined by measuring the current density of the aluminum electrode surface when under cathodic polarization either by a potentiostat or in a suitable galvanic cell.

Subcontractors:

Woods Hole Oceanographic Institution

Bibliography Reference No. 195–198

ADVANCED RESEARCH AND TECHNOLOGY
Biofouling, Corrosion, Materials

CONTRACTOR	CONTRACT NO.
Lehigh University Dept. of Civil Engineering Bethlehem, PA 18015	E(11–1)2682
	PERIOD OF PERFORMANCE May 1, 1975 to July 31, 1976
PRINCIPAL INVESTIGATOR Wai-Fah Chen* (317) 494–5733	FISCAL YEAR 1977 FUNDING $ 0

TITLE
Reinforced Concrete Constitutive Relations

SUMMARY

Previous to this contract, the investigators had conducted research which enabled them to predict the constitutive (stress-strain) relations for concrete under general load conditions, including hydrostatic pressure. This project extended that research to cover reinforced concrete. Hydrostatic pressure at the ocean depths occupied by structural components of ocean thermal power plants is several atmospheres; hence, the behavior of materials such as concrete under such conditions could be substantially different from that normally experienced in an air environment.

A computer program was developed in the form of a subroutine for incorporation into existing finite element analysis programs. This program can be made available to structural analysts. The constitutive relations developed are of a general nature in that the effects of hydrostatic pressure may be either included or neglected in defining the materials response. Thus, they are applicable both for the analysis of submerged ocean structures and on land for underground structures.

* Now located at the Department of Civil Engineering, Purdue University, W. Lafayette, Indiana, 47907.

Bibliography Reference No. 109–113

ADVANCED RESEARCH AND TECHNOLOGY
Biofouling, Corrosion, Materials

CONTRACTOR Sigma Research, Inc. 2952 George Washington Way Richland, WA 99352	CONTRACT NO. EY–77–C–06–2446
	PERIOD OF PERFORMANCE September 30, 1976 to September 29, 1977
PRINCIPAL INVESTIGATOR Elric W. Saaski (509) 946–0663	FISCAL YEAR 1977 FUNDING $51,665

TITLE

Compatibility Studies for the System Water-Ammonia-Titanium as Related to Ocean Thermal Energy Conversion

SUMMARY

Because of an excellent performance record in marine environments, titanium is under consideration as the primary structural material for the evaporator and condenser components of the OTEC power plant concept. Stress Corrosion Cracking (SCC) is a subtle phenomenon, and its potential influence on titanium under conceivable OTEC working conditions is not well known.

The objective of this project was to identify the SCC tendency of titanium under a range of ammonia environments conceivably pertinent to OTEC heat exchangers using ammonia as the working fluid. Test environments included anhydrous ammonia with and without oxygen presence, corresponding to atmospheric exposure and ammonia plus distilled water contamination at various levels. The test procedure used the slow straining technique at a strain rate of 1×10^{-6} sec^{-1}. Test temperature was 25 ± 5 °C. Rod specimens of 0.125 in. diameter were used.

Various criteria, including percent elongation at fracture; percent reduction of area at fracture; electrode potential as a function of plastic strain; and microscopic evidence of SCC were used to assess the SCC susceptibility of titanium under the relevant OTEC environments.

Subcontractor:

Electrochemical Technology Corporation

Bibliography Reference No. 198

ADVANCED RESEARCH AND TECHNOLOGY

Biofouling, Corrosion, Materials

CONTRACTOR	CONTRACT NO.
U.S. Naval Construction Battalion Center Civil Engineering Laboratory Port Hueneme, CA 93043	I.A.A EG–77–A–29–1104 Battelle
	PERIOD OF PERFORMANCE July 12, 1976 to September 30, 1978
PRINCIPAL INVESTIGATOR H. P. Vind (805) 982–5000	FISCAL YEAR 1977 FUNDING $100,000

TITLE

Antifouling Marine Concrete

SUMMARY

Since antifouling paints have life spans of about two years, they are not useful for preventing fouling on massive concrete structures in the ocean, such as those proposed for OTEC plants. For prolonged protection, a reservoir of antifouling chemicals is needed that is larger than can be stored in a thin layer of paint. For concrete structures, it may be possible to incorporate a sufficient quantity of an antifouling agent in the concrete itself to provide many years of antifouling protection.

The objective of this study is to develop a long-lasting, structurally strong, and environmentally safe antifouling marine concrete. It is intended that the concrete be used for lining the inner surface of the seawater intake ducts and forming the basic floating structure of an OTEC plant.

Antifouling marine concrete will be made from portland cement, river sand, special admixtures, water, and expanded shale aggregate that is impregnated with antifouling chemicals. Studies will be conducted to determine compressive strength; antifouling persistency in the ocean and Port Hueneme (where biofouling accumulates on the surface) and at a tropical exposure site (where pholads could bore into unprotected shale concrete); diffusion rates of antifouling chemicals from the concrete; the concentration of antifouling chemicals needed at the concrete surface to prevent biofouling and boring; corrosion rates of steel reinforcing rods in the concrete; and forces required to shear specimens of antifouling concrete from the surface to which they are bonded.

Bibliography Reference No. None

ADVANCED RESEARCH AND TECHNOLOGY
Biofouling, Corrosion, Materials

CONTRACTOR	CONTRACT NO.
University of Miami School of Marine & Atmospheric Sciences 10 Rickenbacker Causeway Miami, FL 33149	Battelle B–31928–A–E
	PERIOD OF PERFORMANCE June 15, 1976 to October 31, 1977
PRINCIPAL INVESTIGATOR H. Lee Craig (305) 350–7472	FISCAL YEAR 1977 FUNDING $ 0

TITLE

Preparation of Catalogue of Oceanographic Data Parameters for Potential OTEC Sites

SUMMARY

Thin biological and/or corrosion films may result in significant degradation of OTEC heat exchanger performance. Additionally, corrosion and biofouling will cause degradation of other OTEC surfaces and materials of construction. Oceanographic variables can significantly affect the rates of growth of biofouling organisms and rates of corrosion at OTEC sites.

The goal of this project was to assemble, critically review, and catalogue available oceanographic data from areas of potential OTEC siting. Additionally, gaps in the data base were identified and recommendations made for future research. Data were obtained for the Gulf of Mexico, near Puerto Rico and the Virgin Islands, the Gulf Stream, Hawaii, and Guam. Oceanographic variables to be catalogued included surface currents, current profiles, turbidity, salinity, surface temperature, temperature profiles, dissolved carbon dioxide, pH, Eh, trace metals, and nutrient levels/microbial cell counts.

Bibliography Reference No. 194

ADVANCED RESEARCH AND TECHNOLOGY

Biofouling, Corrosion, Materials

CONTRACTOR	CONTRACT NO.
Applied Equipment Company 15048 Celano Blvd. Van Nuys, CA	EY–76–C–06–1830 Special Agreement B–54345–A Battelle
	PERIOD OF PERFORMANCE June 1977 to September 1977
PRINCIPAL INVESTIGATOR A. D. Walker (213) 989–3410	FISCAL YEAR 1977 FUNDING $17,500+$27,800

TITLE

Fabricate/Manufacturing Engineering of OTEC Biofouling Devices

SUMMARY

This contract was directed toward the manufacture of 13 biofouling measurement devices and the development of fabrication techniques for quantity production of these devices in the future. The devices being manufactured by the Applied Equipment Company were delivered to the NOAA Data Buoy Office (NDBO) for use on a large discus buoy which was deployed in the Gulf of Mexico in the fall of 1977; to the University of Hawaii for use at Keahole Point; and to other contractors to satisfy program requirements.

The manufacturing engineering portion of this project was aimed at providing the necessary procedures for quantity production of the biofouling measurement device that was developed at Carnegie-Mellon University (CMU). Earlier efforts at CMU had been proof-of-principle studies to show the validity of the concept.

Bibliography Reference No. None

ADVANCED RESEARCH AND TECHNOLOGY
Biofouling, Corrosion, Materials

CONTRACTOR	CONTRACT NO.
Carnegie-Mellon University Schenley Park Pittsburgh, PA 15213	EY–76–S–02–4041
	PERIOD OF PERFORMANCE May 15, 1975 to August 31, 1977
PRINCIPAL INVESTIGATOR John G. Fetkovich (412) 612–2600 ext. 484	FISCAL YEAR 1977 FUNDING $252,000

TITLE

A Study of Fouling and Corrosion Problems in a Solar Sea Power Plant

SUMMARY

The purpose of this project was to identify the effects of biofouling and corrosion on heat transfer surfaces at a potential OTEC site. The objectives were to install and proof test biofouling measuring devices in the sea at Keahole Point, Hawaii. In addition, the following tasks were accomplished:

a. Tests were conducted.
b. The proof testing of the biofouling monitoring devices for remote and subsurface operation and experimental methods was completed.
c. A comprehensive report after proof testing, describing the design in detail, was compiled.
d. The devices and auxiliary equipment were constructed, tested, and made operational.
e. Studies of fouling rates on various types of heat exchanger materials were carried out.
f. Other organizations were assisted using the devices in their construction, operation, and installation at various alternate OTEC sites.

A program of laboratory research was carried out at Carnegie-Mellon University, including studies of the corrosion properties of heat exchanger tubing materials and techniques of laminar flow injection of chlorine and heavy-metal ions into the heat exchanger flow stream.

Instrumentation was developed in the laboratory for installation in the ocean environment off Keahole Point, Hawaii.

Subcontractor:

University of Hawaii

Bibliography Reference No. 170, 171, 172, 193

ADVANCED RESEARCH AND TECHNOLOGY

Biofouling, Corrosion, Materials

CONTRACTOR	CONTRACT NO.
University of Hawaii 2565 The Mall Honolulu, HI 96822	NOAA Office of Sea Grant 04–5–158–44026
	PERIOD OF PERFORMANCE May 20, 1976 to December 31, 1976
PRINCIPAL INVESTIGATOR James H. Jones (808) 948–8745	FISCAL YEAR 1977 FUNDING $ 0

TITLE

OTEC Heat Exchanger Biofouling Experiment

SUMMARY

This study observed the biofouling rates in water typical of of a tropical ocean site having APL heat exchanger water flow conditions. It measured the waterside heat transfer coefficients under hydrodynamic conditions duplicating those of the APL heat exchanger (V_w=3 to 7 ft/sec) as a function of fouling time and after cleaning with a high pressure waterjet system. Observations were made on the effect of biofouling of a different tube arrangement (pitch/ratio). A determination was made of the magnitude of microbial fouling of the heat exchangers by direct microscopic examination of materials accumulating on the pipe surface, by photographic recording of the material, by survey of the types of bacterial forms of culture techniques, and by quantification of microbial fouling organisms.

Subcontractor:

Applied Physics Laboratory of Johns Hopkins University

ADVANCED RESEARCH AND TECHNOLOGY
Biofouling, Corrosion, Materials

CONTRACTOR	CONTRACT NO.
Hydronautics, Inc. 7210 Pindell School Road Laurel, MD 20810	Battelle PNL AT (45–1)–1830
	PERIOD OF PERFORMANCE July 19, 1976 to April 15, 1977
PRINCIPAL INVESTIGATOR A.F. Conn (301) 776–7454	FISCAL YEAR 1977 FUNDING $ 9,000

TITLE
Investigation of OTEC Heat Exchanger Cleaning Methods

SUMMARY

Because of the low thermodynamic efficiencies inherent in OTEC operation, primary biological fouling films must be avoided or periodically removed from heat transfer surfaces to maintain optimal operation. For the same reason, calcareous and similar inorganic deposition must be controlled. This project conducted a critical state-of-the-art study of mechanical and chemical cleaning of low-temperature marine heat exchangers. Additionally, it related the results to the cleaning of OTEC heat exchangers, developed conceptual methods for cleaning OTEC heat exchangers, and completed two reports covering the results of these efforts.

Bibliography Reference No. 192

ADVANCED RESEARCH AND TECHNOLOGY
Biofouling, Corrosion, Materials

CONTRACTOR
Lockheed Missiles and Space Company, Inc.
Ocean Systems
P.O. Box 504
Sunnyvale, CA 94088

CONTRACT NO.
Battelle B–07471–A–E

PERIOD OF PERFORMANCE
April 1, 1977 to December 20, 1977

PRINCIPAL INVESTIGATOR
Joseph F. Rynewicz (408) 742–4052

FISCAL YEAR 1977 FUNDING
$620,620

TITLE
Develop an Apparatus for Use in Measuring the Effects of Biofouling on the Performance of Heat Transfer Surfaces Exposed to Ocean Environments

SUMMARY

The overall thermal resistance across heat exchanger surfaces is likely to increase substantially in the presence of very thin films of biofouling and related corrosion. Little information is available on biofouling in ocean environments suitable for operation of OTEC power plants. Additional information is needed on the nature and behavior of biofouling organisms under conditions closely simulating the actual operating conditions for OTEC heat exchangers.

The objectives of this project were to design, manufacture, and proof test an apparatus that was intended for use in (1) establishing the severity of the biofouling problem and its effect on heat transfer, (2) measuring the effectiveness of potential biofouling countermeasures, and (3) obtaining accurate heat transfer data under a wide variety of operating conditions. The apparatus has both heating and cooling capability, and is adjustable to allow for simulating seawater-to-wall temperature gradients in the range anticipated for both OTEC evaporators and condensers.

The work plan developed at the start of the contract was to design the apparatus by July 1977. The first task of completing the design was accomplished on schedule. There will be a report for each of the three major tasks. The design report was submitted on July 22, 1977.

Subcontractor:

Heat Transfer Research Incorporated

Bibliography Reference No. None

ADVANCED RESEARCH AND TECHNOLOGY
Biofouling, Corrosion, Materials

CONTRACTOR	INTERAGENCY AGREEMENT
National Oceanic and Atmospheric Administration National Space Technology Labs Bay St. Louis, MS 39520	EG–77–A–06–1055
	PERIOD OF PERFORMANCE May 1, 1977 to October 31, 1977
PRINCIPAL INVESTIGATOR William T. Sheppard (601) 688–2822	FISCAL YEAR 1977 FUNDING $448,000

TITLE

OTEC Studies in the Gulf of Mexico on Biofouling and Corrosion

SUMMARY

Heat exchangers in ocean environments are susceptible to fouling by organic and inorganic substances in seawater. Thin biological or corrosion film on heat transfer surfaces could cause intolerable increases in heat transfer resistance in OTEC heat exchangers. Quantitative information on biofouling and inorganic precipitates is currently not available for ocean environments where OTEC power plants will be operated.

Data on effects of biofouling and corrosion of OTEC heat transfer surfaces must be obtained under conditions simulating actual OTEC operation. Data should encompass a wide range of circumstances since the severity of biofouling is likely to vary with season, geographic location, and power plant operating conditions.

The goals of this project were to use a large discus buoy hull equipped with a power source, test hardware, water quality indicator system, and data management and telecommunications system to obtain open ocean heat transfer, biofouling, and corrosion data from the Gulf of Mexico.

Subcontractor:

Magnavox Government Industrial Electronics Co.
Southwest Research Institute
U.S.N. Ocean Research and Development Activities (NORDA)
U.S.N. Oceanographic Office
University of Miami

Bibliography Reference No. 209

ADVANCED RESEARCH AND TECHNOLOGY
Biofouling, Corrosion, Materials

CONTRACTOR U.S. Naval Air Development Center Warminster, PA 18974	CONTRACT NO. INTERAGENCY AGREEMENT EG-77-A-29-1101
	PERIOD OF PERFORMANCE June 1, 1977 to October 1, 1977
PRINCIPAL INVESTIGATOR Jules Hirschman (305) 463-1211 Tracor Marine, Inc.	FISCAL YEAR 1977 FUNDING $145,000

TITLE

Measure the Effects of Biofouling and Corrosion on the Performance of Heat Transfer Surfaces Exposed in the Ocean Near St. Croix in the U.S. Virgin Islands

SUMMARY

Biofouling studies were conducted to determine the effects of the water velocity, time, rate of fouling, preliminary corrosion rate on aluminum at this location, and specific oceanographic characteristics of the surface water used in the experiments. This short-term study was an effort to obtain information of the biofouling potential of the ocean in this oceanographic region, a potential OTEC site. The devices developed at Carnegie-Mellon University were used as the experimental instruments, and two of these devices operated with water velocities of 3 ft/sec and 6 ft/sec flowing in the tubes.

Subcontractor:

Tracor Marine, Inc.
University of Miami

Bibliography Reference No. None

ADVANCED RESEARCH AND TECHNOLOGY
Biofouling, Corrosion, Materials

CONTRACTOR	INTERAGENCY AGREEMENT
U.S. Naval Construction Battalion Center Civil Engineering Lab. (CEL) Port Hueneme, CA 93043	Battelle PNL AT (45–1)–1830
	PERIOD OF PERFORMANCE July 12, 1976 to July 5, 1977
PRINCIPAL INVESTIGATOR James F. Jenkins (805) 982–4797	FISCAL YEAR 1977 FUNDING $ 35,000

TITLE

A Critical Reveiew of the Design Factors Influencing Biofouling and Corrosion of OTEC Surfaces

SUMMARY

Equipment and process design factors such as geometry, orientation, layout, velocity, and temperature are known to affect corrosion. Both macro- and micro-fouling may be influenced by some of these same design factors. This study was aimed at accomplishing the following:

a. Researching available literature to acquire a background on these effects for both fouling and corrosion.
b. Critically evaluating these data.
c. Evaluating how optimal use of design can be employed in OTEC systems to avoid fouling and corrosion problems.

Bibliography Reference No. 199

ADVANCED RESEARCH AND TECHNOLOGY
Biofouling, Corrosion, Materials

CONTRACTOR
U.S. Naval Postgraduate School
Department of Oceanography
Monterey, CA 93940

INTERAGENCY AGREEMENT
ERDA–RL–76–9670

PERIOD OF PERFORMANCE
September 30, 1976 to October 1, 1977

PRINCIPAL INVESTIGATOR
Eugene C. Haderlie (408) 464–2632

FISCAL YEAR 1977 FUNDING
$ 9,000

TITLE
The Nature of Primary Organic Films in the Marine Environment and Their Significance for Ocean Thermal Energy Conversion (OTEC) Surfaces

SUMMARY

Marine organisms and organic material form a film on any surface placed in the ocean. The presence of even a thin film of organic material on the seawater side of the OTEC heat exchanger will result in significant degradation of the unit's efficiency.

The development of bacterial slime films on the heat exchanger surfaces of OTEC power plants is likely to be of critical importance in determining if OTEC closed cycle systems are technically and economically viable.

The goal of this project was a critical state-of-the-art literature review of marine biofouling to establish what is known of primary film formation and to identify research needed to fill technological gaps. Biofouling experts throughout the world were contacted for input, and pertinent references including preprints of the 1977 literature were obtained.

The final report surveyed the present state of knowledge concerning the nature and behavior of primary films in the marine environment. Areas where further research is needed were indicated. The report included an extensive bibliography and is available through the Technical Information Center, Oak Ridge, Tennessee.

Bibliography Reference No. 224

ADVANCED RESEARCH AND TECHNOLOGY

Biofouling, Corrosion, Materials

CONTRACTOR	INTERAGENCY AGREEMENT
U.S. Navy The David W. Taylor Naval Ship Research and Development Center Annapolis, MD 21402	ERDA–RL–76–9599
	PERIOD OF PERFORMANCE October 1, 1976 to September 30, 1977
PRINCIPAL INVESTIGATOR Vincent J. Castelli (301) 267–2853	FISCAL YEAR 1977 FUNDING $ 75,000

TITLE

Methods for the Prevention and Control of Corrosion and Biofouling on Floating Platforms and Nonheat Exchanger Surfaces Exposed to Seawater for OTEC Power Plants

SUMMARY

The purpose of this investigation was to identify and evaluate the technological feasibility, cost effectiveness, and environmental compatibility of different methods for the prevention and control of corrosion and marine biofouling on all seawater-exposed material surfaces (excluding heat exchangers) of OTEC power plants.

The major objectives were to accomplish the following:

a. Search and compile a bibliography on fouling and corrosion prevention of OTEC power plants.
b. Determine general types and amounts of fouling that can be expected to be encountered and the dependence on location and the physical and chemical environment.
c. Describe and technically evaluate the most applicable, existing fouling and corrosion prevention techniques for metal, plastic, and concrete piping and surface grooming.
d. Analyze the cost effectiveness and environmental compatibility of techniques for prevention of corrosion and fouling on metal, plastic, and concrete piping and surface grooming.
e. Determine and technically evaluate future techniques for cleaning and preventing corrosion of metal, plastic, and concrete piping and other surfaces in seawater in anticipation of constructing OTEC plants.
f. Complete environmental assessment of the most promising techniques using data from available bioassay experiments and available environmental impact statements of specific systems or chemicals.
g. Make recommendations as to techniques and areas of future research and development which will provide solutions to unusual problems generated by OTEC design.

Bibliography Reference No. 195

ADVANCED RESEARCH AND TECHNOLOGY
Biofouling, Corrosion, Materials

CONTRACTOR	INTERAGENCY AGREEMENT
U.S. Navy The David W. Taylor Ship Research and Development Center Annapolis, MD 21402	ERDA-RL-76-9599
	PERIOD OF PERFORMANCE March 1, 1977 to February 28, 1978
PRINCIPAL INVESTIGATOR Vincent J. Castelli (301) 267-2853	FISCAL YEAR 1977 FUNDING $285,000

TITLE

Mechanical Cleaning of OTEC Heat Exchanger Tubes

SUMMARY

This project is an experimental program to delineate problems associated with the removal of soft fouling on OTEC heat exchanger tubes. Aluminum is presently considered a primary candidate construction material for OTEC heat exchangers due to cost, thermal transport properties, availability, and weight. Several experimental test units are being assembled and tested using existing cleaning techniques. Specific cleaning systems being tested in the program during the early tests are the AMERTAP, M.A.N., and abrasive slurry system. There is also a control which will be allowed to foul for an extended period.

These tests are now underway at the Naval Coastal Systems Laboratory in Panama City, Florida. The test instruments, which are in use elsewhere for determining the rate of biofouling at OTEC sites, are similar to those developed by Carnegie-Mellon University. Future tests will involve additional mechanical cleaning systems, different tube materials, and extended and enhanced surface tubes.

Bibliography Reference No. None

ADVANCED RESEARCH AND TECHNOLOGY
Biofouling, Corrosion, Materials

CONTRACTOR
University of Miami
Rosenstiel School of Marine Science
4600 Rickenbacker Causeway
Miami, FL 33149

CONTRACT NO.
EY–76–C–06–1830
Special Agreement B–07455–A–E

PERIOD OF PERFORMANCE
July 13, 1977 to July 12, 1978

PRINCIPAL INVESTIGATOR
John W. Morse (305) 350–7482

FISCAL YEAR 1977 FUNDING
$ 90,153

TITLE

A Study to Define the Tolerable Ranges of Balance Between Dissolved CO_2 and Carbonates in Seawater that Would Avoid Deposits of Calcareous Scales on Heat Transfer Surfaces within the Temperature Range of OTEC Heat Exchangers

SUMMARY

A possible barrier to heat transfer, other than biofouling films, could be films of calcareous or other inorganic materials that could be deposited from waters in which an unfavorable balance between dissolved carbonates and CO_2 favor such a deposition. It is, therefore, necessary that the tolerable ranges of balance between dissolved CO_2 and carbonates be defined to be able to predict the probability of disposition of calcareous films within the range of temperature (0°C to 30°C) and pressure (surface to 1500 meter head). This would serve as a guide for designing and/or operating OTEC power plants to minimize calcareous film formation problems.

The research effort is being directed toward establishing the ranges of balance between CO_2 and carbonates, nucleation sites, effect of $Mg++$ and other ions in seawater, etc., which can cause deposition of calcareous films on OTEC heat transfer surfaces. Existing information is being assembled on the reactions in seawater between dissolved CO_2 and carbonates and instances where deposition of carbonates could result or has resulted from such reactions. In addition, data related to the deposition of carbonates are included, and on the basis of such, the ranges of dissolved CO_2 and carbonates, temperatures, pressures, ionic substances (Mg^{++}, etc.), within which calcareous films might be expected to form in an OTEC heat exchanger or other OTEC surface exposed to the seawater environment. An experimental program is being conducted to confirm the literature data relative to the potential for deposition of inorganic scale from seawater onto appropriate heat transfer surfaces.

Bibliography Reference No. None

ADVANCED RESEARCH AND TECHNOLOGY
Biofouling, Corrosion, Materials

CONTRACTOR Native American Manufacturing, Inc. 20241—84 Avenue So. Kent, WA 98031	CONTRACT NO. EY–06–C–06–C–06–1830 Special Agreement B–37989–A–H
	PERIOD OF PERFORMANCE September 1977 to November 1977
PRINCIPAL INVESTIGATOR W.W. Armstrong (206) 852–0800	FISCAL YEAR 1977 FUNDING $ 18,800

TITLE
Manufacture of OTEC Biofouling Devices

SUMMARY

This contract was directed toward the manufacture of ten biofouling measurement devices. The ten devices being manufactured by Native American Manufacturing Company were delivered to the OTEC Biofouling and Corrosion Activity Office for use at OTEC biofouling and corrosion experimental sites.

The manufacturing was aimed at providing a quantity of biofouling measurement devices that were developed by Carnegie-Mellon University (CMU). Earlier efforts at CMU have been proof-in-principle studies to show the validity of the concepts.

ADVANCED RESEARCH AND TECHNOLOGY
Biofouling, Corrosion, Materials

CONTRACTOR Oak Ridge National Laboratory (ORNL) P.O. Box Y Oak Ridge, TN 37380	CONTRACT NO. ERDA-W-7405-ENG-26
	PERIOD OF PERFORMANCE April 1, 1977 to December 30, 1977
PRINCIPAL INVESTIGATOR G.M. Slaughter (615) 483-8611	FISCAL YEAR 1977 FUNDING $ 30,000

TITLE
Heat Exchanger Joinability Study

SUMMARY

The objective of this project is to provide a technology review regarding the joinability state-of-the-art as it relates to OTEC heat exchangers. Shell and tube heat exchangers with aluminum, titanium, copper-nickel, and stainless steel tubing are being considered. Plate-fin heat exchangers are also being considered. Joints being considered employ welding, mechanical, brazing, soldering, adhesives, and other methods.

Bibliography Reference No. 215

ADVANCED RESEARCH AND TECHNOLOGY
Heat Exchangers

CONTRACTOR	CONTRACT NO.
Carnegie-Mellon University Dept. of Chemical Engineering Schenley Park Pittsburgh, PA 15213	EY–76–S–02–2641
	PERIOD OF PERFORMANCE April 7, 1975 to October 31, 1977
PRINCIPAL INVESTIGATOR Robert R. Rothfus (412) 578–2227	FISCAL YEAR 1977 FUNDING $226,000

TITLE

Concurrent Studies of Enhanced Heat Transfer and Materials for Ocean Thermal Exchangers

SUMMARY

Experiments at CMU have investigated the feasibility of vertical shell-and-tube exchangers with heat transfer enhanced by fine axial flutes on both the seawater and working fluids sides of the transfer surface. At the same time, analytical models of such exchangers and of the entire power cycle have been developed to predict the steady state and dynamic behavior of the prototype on the basis of the experimental results.

Results indicate that waterside heat fluxes can be doubled by axial flutes at moderate velocities with only a comparable increase of friction. Data on Refrigerant–11 and ammonia show that flutes enhance the heat flux three to five times. Overall heat transfer coefficients on clean, axially-fluted tubes of 600 Btu/(hr)(sq. ft.)(°F) in the condenser and 900 Btu/(hr) (sq. ft.) (°F) in the evaporator appear to be achievable when using ammonia as the working fluid.

Preliminary data indicate that pressure losses in the shell-side vapor can be controlled by manifolding the tube bundle. Means have been developed for applying liquid working fluid to the tubes of the evaporator and experiments indicate favorable head-discharge relationships and no trouble with splashing. Waterside header maldistribution appears to have no significant effect on heat transfer but may lead to additional parasitic power loss.

Tests made to date have largely supported previously untested hypotheses and projections. From the standpoint of heat transfer and fluid mechanics, the vertical shell-and-tube exchanger with extruded aluminum transfer surfaces, using ammonia as the working fluid, remains a viable base point for economic evaluation of full-scale heat exchanger designs.

Subcontractors:

Alcoa Technical Cener
Foster-Wheeler, Corp.

Bibliography Reference No. 114, 115, 171, 187

ADVANCED RESEARCH AND TECHNOLOGY
Heat Exchangers

CONTRACTOR
Geoscience, Ltd.
410 S. Cedros Avenue
Solana Beach, CA 92075

CONTRACT NO.
EG-77-C-03-1094

PERIOD OF PERFORMANCE
May 1, 1975 to December 31, 1977

PRINCIPAL INVESTIGATOR
Cullen M. Sabin (714) 755-9396

FISCAL YEAR 1977 FUNDING
$ 36,000

TITLE
Water Heat Transfer and Ammonia Nucleate Boiling Studies

SUMMARY

The objective of this project was to investigate several means for enhancing the heat transfer coefficient of water flowing through round tubes, for promoting nucleation of ammonia vaporizing over submerged horizontal tubes, and for fundamentally studying the thin film evaporation of ammonia over horizontal tubes.

Results, thus far, have shown that there are a number of useful techniques for enhancing water heat transfer without recourse to generating random turbulence. In addition, at least one of these techniques, a system of wire rings adjacent to the tube wall, can enhance heat transfer significantly (at its optimum Reynolds number) without modifying the pressure loss. The wire ring dimensions can be chosen so that this optimum Reynolds number falls within the Reynolds number range of interest to the OTEC plant. Data also indicate that sand grain-type roughness behaves in this same manner. These highly advantageous characteristics have been verified by analysis and by comparison with several sets of data from other laboratories.

The nucleate boiling tests demonstrated that several surfaces can be made to nucleate readily, and that an easily constructed double screen surface initiates nucleation at temperature differences below 0.2°F. Work was done on the different geometries for waterside enhancements and in establishing the stability of boiling nucleation under multiple startup and long run conditions.

The film evaporation work is directed toward measurement of the heat transfer conductance as a function of recirculation rate, saturation temperature, heat flux, and wetting and surface characteristics.

Bibliography Reference No. 118-121

ADVANCED RESEARCH AND TECHNOLOGY
Heat Exchangers

CONTRACTOR	INTERAGENCY AGREEMENT
Johns Hopkins University Applied Physics Laboratory Laurel, MD 20810 VIA: Naval Sea System Command (NAVSEA) Arlington, VA 20360	E(49–26)–1030; EG–77–A–29–1075, 1076
	PERIOD OF PERFORMANCE June 27, 1975 to March 31, 1978
PRINCIPAL INVESTIGATOR Robert Makofski (301) 953–7100 ext. 7469	FISCAL YEAR 1977 FUNDING $163,000

TITLE

Analytical Study of Two-phase Flow Heat Exchangers for OTEC Systems

SUMMARY

The first phase of this study was a detailed analysis of the practicality and expected performance of the JHU–SPL concept for two-phase flow heat exchangers for an OTEC power plant. In this concept, the working fluid would flow on the inside of large-diameter (3 in. to 9 in.) multipass tubes. The analytical model for the heat exchangers was based upon the latest two-phase flow theory and correlations. Parametric studies for producing heat exchanger designs (for the evaporator and condenser) were used to project minimum annual costs (including amortization and expected operating, maintenance, repair, and replacement costs) over the equipment lifetime. The work included development of a power module design for use within an overall power plant concept incorporating manifolding/assembly/disassembly, as well as the design of an experiment that could provide engineering data on both evaporator and condenser performance.

The second phase includes preliminary experiments on the flow and heat transfer of the two-phase flow heat exchangers using two models. The first, simulating a portion of an evaporator tube, is being used for internal flow experiments to (1) perform an evaluation of potential dry-out problems, (2) validate heat transfer coefficients, and (3) determine pressure losses in return bends. In addition, experiments have been conducted to determine the onset of nucleate boiling in the first pass of the tube.

The second model is being used to determine circumferential distribution of the waterside heat transfer coefficient on one tube in a simulated tube arrangement. It is also to check water pressure drop and to evaluate the degree of water crossflow through the arrangement.

Results to date indicate that dryout problems can be alleviated by tilting the horizontal tube a couple of degrees. Heat transfer measurements on the water and ammonia sides (80 percent liquid) confirm the analytical predictions. Finally, an experimental unit of 1 MWt is being designed which is to be built by TRANE Company for testing at the Argonne National Laboratory Core Test Facility.

Subcontractor:

Trane Manufacturing, Inc.

Bibliography Reference No. 122, 123

ADVANCED RESEARCH AND TECHNOLOGY
Heat Exchangers

CONTRACTOR	CONTRACT NO.
Oklahoma State University School of Chemical Engineering Stillwater, OK 74074	EY–76–S–02–5092
	PERIOD OF PERFORMANCE November 21, 1975 to March 31, 1979
PRINCIPAL INVESTIGATOR Kenneth J. Bell (405) 624–2580	FISCAL YEAR 1977 FUNDING $ 30,410

TITLE

Heat Exchanger System Evaluation for the OTEC Program

SUMMARY

The technical and economic feasibility of the OTEC concept is dependent upon the heat exchangers which dominate the cost, size, configuration and operational reliability of the plant. To update information on OTEC heat exchanger design, and to evaluate new concepts as quickly as possible, this project requires the following tasks:

a. Help maintain the overall schedule for OTEC research, development, and deployment.
b. Identify areas of heat transfer technology in which exchanger system design methods and operating experience exist in large scale process plants and are applicable to ocean thermal power plants.
c. Develop procedures to ensure that system analysts are supplied with pertinent heat exchanger design and operational parameters.
d. Perform "quick-look" analysis and evaluation on any variation in heat exchanger system configuration that seems to show promise for improvements in OTEC plant construction or operation.

Bibliography Reference No. None

ADVANCED RESEARCH AND TECHNOLOGY
Heat Exchangers

CONTRACTOR	CONTRACT NO.
Oak Ridge National Laboratory (ORNL) P.O. Box X Oak Ridge, TN 37830	ERDA W–7405 ENG–26
	PERIOD OF PERFORMANCE December 11, 1975 to September 30, 1977
PRINCIPAL INVESTIGATOR H.W. Hoffman (615) 483–8611 ext. 37715	FISCAL YEAR 1977 FUNDING $107,000

TITLE
Heat Transfer Enhancement for OTEC Systems

SUMMARY

This study explored means for enhancing the boiling and condensing performance of heat exchangers for service in OTEC systems. Emphasis was placed on the study of ammonia condensation on Gregorig surfaces. The initial period of this study included design and assembly of laboratory-scale apparatus for condensing studies with ammonia, determination of concept feasibility through scoping experiments, and design of a more flexible facility for characterization of optimum configurations.

Early results confirmed the advantage of vertical fluted tube condensers over horizontal tubes. Heat transfer coefficients exceeding 5000 Btu/hr-ft^2-°F have been obtained.

In addition, ORNL investigated the feasibility of shell-less vertical tube heat exchangers with axial flutes on the tube side where ammonia evaporation and condensation take place.

This project also provided technical planning input for the OTEC heat exchanger program activity, describing in some detail the organization, manning, and proposed methodology. In addition, ORNL monitored ongoing R&D contracts in various aspects of OTEC heat exchangers and provided consulting services to the various phases of the program. ORNL efforts were specifically directed towards consulting in advanced heat exchanger concepts, reviewing the current state-of-the-art, conducting a literature search, and developing optimization techniques for system evaluation.

Bibliography Reference No. 120, 207

ADVANCED RESEARCH AND TECHNOLOGY
Heat Exchangers

CONTRACTOR	CONTRACT NO.
Union Carbide Corporation Linde Division/Branch 4019451 P.O. Box 44 Tonawanda, NY 14150	EX–76–C–01–2448
	PERIOD OF PERFORMANCE June 30, 1976 to December 31, 1977
PRINCIPAL INVESTIGATOR Frank Notaro (716) 877–1600 ext. 8122	FISCAL YEAR 1977 FUNDING $189,000

TITLE

Heat Exchangers for Ocean Thermal Power Plants

SUMMARY

The purpose of this study was to investigate the thermal hydraulic performance of the heat exchanger, with special emphasis on the evaporator. It was an extension of a previously completed NSF-funded effort. The study assessed the baseline design as proposed by Lockheed and further evaluated the methods for reducing the overall cost of the heat exchanger via enhancement of the heat transfer coefficient.

The study provided performance studies of a flooded evaporator using special enhanced surfaces, heat transfer studies, performance studies of a large spray-film evaporator, experimental demonstration of the thermal hydraulic performance of the heat exchanger, physical design and manufacturing cost determination, prediction of life and reliability of the heat exchanger, and design of two evaporators and one condenser for testing at Argonne National Laboratory.

Experiment on a flooded evaporator tube indicated that enhancement raises the heat transfer rate substantially. Results on spray-film evaporator hydraulics indicated that liquid entrapment of ammonia can be a serious problem in a large tube bundle if the vapor velocity approaches a critical valve.

The contractor has provided a 4 MWt flooded bundle evaporator with specially enhanced surfaces. This unit will be tested at the Argonne National Laboratory Core Test Facility. In addition, a spray film evaporator and a horizontal tube condenser are being built for testing at Argonne.

Bibliography Reference No. 70

ADVANCED RESEARCH AND TECHNOLOGY
Heat Exchangers

CONTRACTOR	CONTRACT NO.
Oregon State University Department of Mechanical Engineering Corvallis, OR 97331	EG–77–C–03–1370
	PERIOD OF PERFORMANCE July 1, 1976 to September 30, 1977
PRINCIPAL INVESTIGATOR James G. Knudsen (503) 754–2354	FISCAL YEAR 1977 FUNDING $ 22,000

TITLE
Heat Exchanger Development for OTEC Plants

SUMMARY

The contractor performed engineering planning and updating for the OTEC heat exchanger development program. In this program, all promising heat exchanger concepts were assessed, and a development plan was implemented for a logical evolution from the conceptual stage to the final testing of prototype heat exchangers. Additional services included assisting in the formulation of background information to incorporate into Requests for Proposals regarding OTEC power-cycle development.

Bibliography Reference No. 114–122

ADVANCED RESEARCH AND TECHNOLOGY
Heat Exchangers

CONTRACTOR	CONTRACT NO.
DSS Engineers, Inc. 7483 Northwest 4th Street Fort Lauderdale, FL 33317	EY–76–C–05–5165
	PERIOD OF PERFORMANCE August 24, 1976 to October 23, 1978
PRINCIPAL INVESTIGATOR Geoffrey K. Hart (305) 792–6660	FISCAL YEAR 1977 FUNDING $ 0

TITLE
Development of Plastic Heat Exchangers for OTEC

SUMMARY

As a continuation of an earlier study, this project provides an in-depth review of polymeric materials and material composites that have been proposed for the plastic heat exchangers. Test apparatus is being designed to achieve accurate and significant tests for predicting durability and performance of plastic heat exchangers in an OTEC environment. Properties to be evaluated are:

a. Long term strength and service life.
b. Thermal conductivity of plastic, incorporating thermally conductive filler materials.
c. Permeability of the heat transfer surface to working fluid and seawater.
d. Antifouling potential of plastics through polymer modification or additive incorporation.

Experiments conducted by DSS indicate that a plastic for OTEC service with ammonia as a working fluid is commercially available. Because of low thermal conductivity of plastic and the difficulty of distributing ammonia liquid in a falling film evaporator, plastic condensers are likely to be practical earlier than evaporators. Based on results of materials tests in ammonia and seawater, a plate-type core test condenser is being designed for testing at Argonne National Laboratory.

Subcontractor:

Florida Atlantic University

Bibliography Reference No. 116–117

ADVANCED RESEARCH AND TECHNOLOGY
Heat Exchangers

CONTRACTOR	CONTRACT NO.
Argonne National Laboratory (ANL) 9700 South Cass Avenue Argonne, IL 60439	W-31-109-ENG-38
	PERIOD OF PERFORMANCE December 7, 1976 to September 30, 1977
PRINCIPAL INVESTIGATOR Norman Sather (312) 972-3732	FISCAL YEAR 1977 FUNDING $1,308,000

TITLE
OTEC Heat Exchanger Development Program

SUMMARY

The objective of the program was to determine and evaluate the performance of several types of evaporators and condensers being considered for OTEC plants. The program included the design and construction of a test facility in which candidate heat exchanger units were tested at typical OTEC operating conditions. Off-design performance of the experimental units was also determined. Analyses of local flow and heat transfer in OTEC evaporators and condensers were made to assist in resolving problems in their design and operation.

During FY 1977, design and construction of the test facility were completed, and preparation of the facility for testing of the first evaporator, a pool boiler, was planned. The construction included procurement and installation of piping, pumps, and a 500-ton refrigeration unit, a steam heater, flow meters and instrumentation for measurement and control of temperature and pressure for water loops to supply up to 4000 gpm of warm water and cold water to the evaporator and condenser under test. The principal activities in the analytical part of the program included review and evaluation of available convective heat transfer models for OTEC heat exchangers and development of improved design methods for evaporators of the pool-boiler and spray-film types. In carrying out the design and construction of the test facility, ANL has had the support of three major subcontractors.

Subcontractor:

Lester B. Knight, Inc. ($81,000)—engineering design support
Globe Engineering Co. ($68,000)—engineering design support
Power Systems, Inc. ($150,000)—construction

Bibliography Reference No. 203

ADVANCED RESEARCH AND TECHNOLOGY
Heat Exchangers

CONTRACTOR	CONTRACT NO.
University of California, Berkeley College of Engineering Office of Research Services Berkeley, CA 94720	EY–76–S–03–0034
	PERIOD OF PERFORMANCE March 1, 1977 to September 30, 1977
PRINCIPAL INVESTIGATOR H.H. Sephton (415) 642–6000	FISCAL YEAR 1977 FUNDING $ 60,000

TITLE
Performance Improvement for OTEC Systems

SUMMARY

The contractor conducted a literature search on the current state-of-the-art of helix-enhanced (spirolator) water (brine) side heat transfer inside heat exchanger tubing. The project proposes to design, build, and test a heat transfer test rig capable of simulating OTEC conditions for conducting experiments with a rotating spiral. In addition, the project aimed to establish the design feasibility and to compare biofouling effects of a reference tube to those with the spiral inserts. Finally, the pressure drops and heat transfer in the water flow with and in the absence of the spiral inserts for both vertical and horizontal tubes was measured.

Bibliography Reference No. 219

ADVANCED RESEARCH AND TECHNOLOGY
Heat Exchangers

CONTRACTOR	CONTRACT NO.
Massachusetts, University of Mechanical Engineering Department Amherst, MA 01003	EG–77–S–02–4238
	PERIOD OF PERFORMANCE April 1, 1977 to March 31, 1978
PRINCIPAL INVESTIGATOR Jon G. McGowan (413) 545–2756	FISCAL YEAR 1977 FUNDING $183,771

TITLE

A Continued Evaluation of Compact Heat Exchangers for OTEC Applications

SUMMARY

The contractor is to provide analytical designs of plate-fin heat exchangers, designs for a heat exchanger test program, and the initiation of an industrial OTEC plate-fin heat exchanger cleanliness/maintenance manufacturing capability.

The contractor is continuing analytical and experimental evaluation of the performance characteristics of compact heat exchangers using ammonia as the working fluid. This work is covering the entire range of OTEC operating conditions presently defined. In addition, the contractor is to evaluate applicable manufacturing process concepts for large plate-fin heat exchangers. Specific emphasis is being placed on the manufacturing processes that project design-to-cost capabilities.

A subcontract was awarded to a manufacturer who is to conduct an in-depth investigation of compact heat exchanger manufacturing, headers, module assembly, and maintenance systems.

Bibliography Reference No. 23, 33, 35–39, 124–126, 129–131

ADVANCED RESEARCH AND TECHNOLOGY
Heat Exchangers

CONTRACTOR	CONTRACT NO.
Sea Solar Power, Inc. 1615 Hillock Lane York, PA 17403	EG–77–C–02–4300
	PERIOD OF PERFORMANCE August 2, 1977 to July 31, 1978
PRINCIPAL INVESTIGATOR J.H. Anderson (717) 741–0884	FISCAL YEAR 1977 FUNDING $144,500

TITLE
Compact Heat Exchanger Design for OTEC

SUMMARY

Manufacturers of compact heat exchangers will be surveyed to evaluate the possible applicability of existing designs to OTEC requirements. A design of an OTEC plate-fin core test unit will be developed. This design must be manufacturable by an existing United States manufacturer. The study will consider the questions of cleaning on the water side, modularization for scale-up, and operation with ammonia on one side and sea water on the other. Conceptual drawings will be prepared, and detailed performance calculations will be obtained for heat transfer, pressure drops, vapor quality, and mechanical stress.

Bibliography Reefrence No. 72, 73

ADVANCED RESEARCH AND TECHNOLOGY

Power Systems

CONTRACTOR
University of Oklahoma
School of Chemical Engineering and Materials Sciences
202 W. Boyd, Room 23
Norman, OK 73069

CONTRACT NO.
E(40–1)–4918

PERIOD OF PERFORMANCE
May 1, 1975 to August 15, 1977

PRINCIPAL INVESTIGATOR
Kenneth E. Starling (405) 325–5811

FISCAL YEAR 1977 FUNDING
$ 0

TITLE
Use of Mixtures as Working Fluids in OTEC Cycles

SUMMARY

The use of mixtures in ocean thermal power cycles was evaluated for hydrocarbon mixtures, ammonia-water mixtures, and possible halocarbon mixtures. The mixtures cycles were compared with baseline pure fluid ocean thermal power cycles using propane, ammonia, and possible halocarbons as working fluids.

This research project included:

a. Upgrading a previously developed OTEC mixture cycle simulation (particularly the condenser design subroutine to include the effects of diffusive mass transfer).
b. Developing an optimization program for OTEC mixture cycle optimized design.
c. Correlating the thermodynamic properties of ammonia-water mixtures for ranges of conditions applicable to OTEC cycles.
d. Simulating the OTEC ammonia cycle with varying amounts of water in the ammonia to provide information on the ammonia-water cycle and to determine the maximum tolerable water concentration for acceptable thermodynamic performance of the cycle.
e. Evaluating alternative cycles using the optimization program developed in this research.

Results indicated that the economic benefit of using a mixture of working fluids is marginal. The ammonia water mixtures have the potential of lowering heat exchanger weight at the expense of reduced turbine efficiency. The overall economic benefit was also investigated.

Bibliography Reference No. 132–135

ADVANCED RESEARCH AND TECHNOLOGY
Power Systems

CONTRACTOR	CONTRACT NO.
University of California Mechanics and Structures Department School of Engineering and Applied Science Los Angeles, CA 90024	EY–76–F–03–0034
	PERIOD OF PERFORMANCE July 15, 1977 to July 15, 1978
PRINCIPAL INVESTIGATOR A.F. Charwat	FISCAL YEAR 1977 FUNDING $ 12,913

TITLE

Design of a Facility for Laboratory Experiments on a Mist-flow Thermal Energy Process

SUMMARY

The project's objective is to analyze and design the experimental "mistflow lift-tube," including engineering drawings and specifications as required to proceed with the construction and procurement of the equipment. The contractor is also to modify, as necessary, and shake down the support equipment, in particular the jet-ejector vacuum system in the UCLA Supersonic Tunnel Lab. During FY 1978, the contractor will carry out the construction of the experimental setup and will conduct experiments on the mist generation and lifting. This project is being conducted in cooperation with the analytical project of R&D Associates.

Bibliography Reference No. 208

ADVANCED RESEARCH AND TECHNOLOGY
Power Systems

CONTRACTOR	CONTRACT NO.
Carnegie-Mellon University Pittsburgh, PA 15213	G–02–77–2701
	PERIOD OF PERFORMANCE July 15, 1977 to July 15, 1978
PRINCIPAL INVESTIGATOR Clarence Zener (412) 578–2538	FISCAL YEAR 1977 FUNDING $ 45,000

TITLE
Foam Sea Solar Power Plant

SUMMARY

An open cycle, solar sea power plant, which operates on the same principle as an air-lift pump with air being replaced by the vapor of the water itself, is being proposed by Beck*. In this program, a modification is being studied which offers promise of increasing the efficiency of such a plant and may make it less costly than a closed-cycle OTEC plant.

The thermal energy stored in ocean water can be converted into potential energy by lifting the warm water from one level to another. The overall objective of this work is to investigate a specific mechanism for thermally lifting the warm surface water to a high enough level so that it can drive a hydraulic turbine as it falls. The lifting approach proposed is to use a foaming agent to provide a stable structure to entrap liquid, warm sea water and to carry this water as the foam travels upward from a high vapor pressure region (warm) to an artificially low-pressure region (cold) created by condensing the vapor at low temperature.

* E.J. Beck, *Science, 189,* 293 (1975)

Bibliography Reference No. 51–55, 211

ADVANCED RESEARCH AND TECHNOLOGY

Power Systems

CONTRACTOR	CONTRACT NO.
R&D Associates P.O. Box 9695 Marina del Rey, CA 90291	EG–77–C–03–1684
	PERIOD OF PERFORMANCE September 1, 1977 to May 31, 1978
PRINCIPAL INVESTIGATOR Stewart L. Ridgway (213) 822–1715	FISCAL YEAR 1977 FUNDING $ 75,497

TITLE

Mist-flow Ocean Thermal Energy Process

SUMMARY

The thermal energy stored in ocean water can be converted into potential energy by lifting the warm water from one level to another. The purpose of this project is to investigate a specific mechanism for thermally lifting the warm surface water to a high enough level so that it can drive a hydraulic turbine as it falls. The approach entails generating a mist of water droplets mixed with water vapor rising from a high pressure at the lower level to a lower pressure region at the top. The entrapped mist may be collected at the top and allowed to fall driving a hydraulic turbine. The components of the power system are to be arranged so that the warm surface water is first allowed to fall and do work on a hydraulic turbo generator and then lifted by the mist lift process. The vapor and mist are condensed in a spray condenser receiving cold, deep ocean water. The cycle requires no separation of the mist from the vapor because the energy is first extracted by allowing the warm water to fall by means of artificially created quasi vacuum at the mist generator located in the bottom. Experimental work on the mist-flow lift concept will be conducted at the University of California, Los Angeles, California, as described in their project summary.

Bibliography Reference No. 208

ADVANCED RESEARCH AND TECHNOLOGY
Ocean Engineering

CONTRACTOR	CONTRACT NO.
Sea Solar Power, Inc. 1616 Hillock Lane York PA 17403	E(11-1)-2691
	PERIOD OF PERFORMANCE May 1, 1975 to February 29, 1976
PRINCIPAL INVESTIGATOR J. Hilbert Anderson (717) 741-0884	FISCAL YEAR 1977 FUNDING $ 0

TITLE

Design of a Cold Water Pipe for Ocean Thermal Power Plants

SUMMARY

This report described the preliminary analysis of design conditions for a 40 ft. diameter, 4000 ft. long cold water supply pipe for a 100 MW sea thermal power plant. The pipe was assumed to be freely suspended from a floating platform. The design was based on a circular row of tubes separated by spacers to form the pipe wall. Internal pressure conditions were calculated for maximum assumed flow rates in the pipe. External pressure distribution was calculated for maximum assumed ocean current velocity. Drag and moment distributions were calculated for the pipe loaded with an assumed current velocity profile and buoyancy distribution. Collapse stability calculations were made for the pipe and for the individual tubes. Tube and spacer interaction stresses were calculated for the combined pressure, bending moment, and tensile loads imposed on the pipe. Preliminary analysis was performed on a flexible pipe support system capable of isolating the pipe from the platform during any sea state likely to be encountered by a sea thermal power plant. It was concluded that the basic design is feasible and justifies more precise analysis.

Bibliography Reference No. 146, 147, 223

ADVANCED RESEARCH AND TECHNOLOGY
Ocean Engineering

CONTRACTOR	CONTRACT NO.
U.S.N. Construction Battalion Center Civil Engineering Laboratory Port Hueneme, CA 93043	ERDA E(949–26)–1023
	PERIOD OF PERFORMANCE June 6, 1975 to March 31, 1977
PRINCIPAL INVESTIGATOR Harvey H. Haynes (805) 982–5578	FISCAL YEAR 1977 FUNDING $ 0

TITLE

Design, Fabrication, and Installation of Large Diameter Submerged Concrete Structures

SUMMARY

This was a feasibility study of the design, fabrication, and installation of large-diameter submerged concrete structures. The state-of-the-art related to these structures was summarized, feasible approaches for fabricating and installing the structures recommended, problem areas enumerated, and research and development areas outlined. The intent of this study was to point out significant problem areas and to assess the feasibility of using large concrete structures for ocean thermal power plants which would provide DOE with some decision criteria on which to focus research and development efforts.

The continuation of this contract was directed toward studying fabrication methods to build massive floating concrete OTEC structures in relatively shallow waters. It was determined that OTEC structures of various configurations and sizes up to 500,000 tons or larger can be constructed in Puget Sound, Washington; OTEC structures of about 150,000 tons (about 100 MWE power plant size) can be built of concrete using existing facilities. Techniques for reducing the draft of structures during construction and towout, such as temporary buoyancy and the use of lightweight concrete, were also discussed.

Bibliography Reference No. 154–157

ADVANCED RESEARCH AND TECHNOLOGY
Ocean Engineering

CONTRACTOR	CONTRACT NO.
Westinghouse Electric Corporation Oceanic Division P.O. Box 1488 Annapolis, MD 21404	E(11–1)–2642
	PERIOD OF PERFORMANCE May 1, 1975 to April 30, 1976
PRINCIPAL INVESTIGATOR Thomas E. Little (301) 765–5446	FISCAL YEAR 1977 FUNDING $ 0

TITLE
Deep Water Pipe and Mooring Design Study

SUMMARY

The main thrust of the study was the preliminary evaluation of cold water pipe, pump, and plant mooring concepts with a view toward judging their effect upon the overall evaluation of the ocean thermal energy conversion concept. The two principal goal criteria were the illumination of the impact of the cold water transport and mooring systems on the overall power plant concepts and delineation of critical development needs.

The selection of the three subsystems (pipe, pump, and mooring) for combined study was based upon their mutual interrelationship and dependence on common environmental and system parameters. The study identified a spectrum of possible design concepts, selected one or more alternatives for further evaluation, and assessed them in terms of such criteria as structural characteristics, feasibility of construction and deployment, operating efficiency implications, serviceability, research and development requirements, and cost. Salient conclusions distilled from the concept analyses and their overall plant-concept-evaluation implications were explored. Alternatives were described and their impacts and interactions as a function of parameters over ranges of interest were shown. Recommendations were made regarding technological directions that should be pursued.

Bibliography Reference No. 158–161

ADVANCED RESEARCH AND TECHNOLOGY
Ocean Engineering

CONTRACTOR Westinghouse Electric Corp. P.O. Box 1488 Annapolis, MD 21404	CONTRACT NO. EY–76–C–02–4071 PERIOD OF PERFORMANCE November 1, 1976 to October 30, 1977
PRINCIPAL INVESTIGATOR T.E. Little (301) 765–5446	FISCAL YEAR 1977 FUNDING $ 0

TITLE
Seawater Pumps and Platform Stationkeeping

SUMMARY

This work involved the following three major tasks:

a. Cold water pump preliminary design.
b. Warm water pump evaluation.
c. Platform stationkeeping.

The cold water pump was analyzed based on operational requirements and designed in accordance with state-of-the-art characteristics. Pump drives and diffuser assembly designs were included in the preliminary design as well as in a cost and performance evaluation.

The warm water pump was evaluated similarly to the cold water pump regarding performance requirements. The cold and warm water pumps were compared to determine if the warm water pump design can be the same as the cold water pump. The impact of the overall OTEC system was assessed as a result of this comparison.

Platform stationkeeping involved the analysis of system requirements in regard to positioning an OTEC plant/platform. The primary considerations were drag loads and environmental effects. Two types of stationkeeping were studied: dynamic positioning and mooring. Dynamic positioning involved analyses of both effluent thrust and auxiliary thrusters. Dynamic positioning and mooring as a combination were also evaluated, and the impact on the overall system regarding cost and performance were assessed.

This project was a continuation of a previously DOE-funded study "Deep Water Pipe and Mooring Design Study" E(11–1)–2692.

Bibliography Reference No. 160

ADVANCED RESEARCH AND TECHNOLOGY
Ocean Engineering

CONTRACTOR	CONTRACT NO.
Tuned Sphere International 1 Pine Street Nashua, NH 03060	EG-77-C-01-4032
	PERIOD OF PERFORMANCE April 26, 1977 to October 25, 1977
PRINCIPAL INVESTIGATOR Charles R. Fink (603) 889-5112	FISCAL YEAR 1977 FUNDING $ 95,976

TITLE

Tuned Sphere Stable Platform for OTEC Power Plants

SUMMARY

The contractor was preparing a geometric description of the tuned sphere concept of OTEC for output sizes of 100, 500, and 1000 MWe that are satisfactory for calculation of hydrodynamic forces. The cold water pipe dimensions were to be 50, 110, and 156 feet diameters respectively, and 3000 feet in length. The project was utilizing the Tuned Sphere International's existing linear seakeeping program to determine the response of the three sizes for wave heights of 20, 40, and 80 feet, and vessel drafts of 0.3, 0.5, and 0.8 times the diameter.

Seakeeping response was compared to that for five other competing candidate hull forms and was found generally superior thereto, with and without cold water pipes.

Subcontractors:

Hydronautics, Inc.
Waller and Associates, Inc.
Oceanic Development, Co.

Bibliography Reference No. 210

ADVANCED RESEARCH AND TECHNOLOGY
Ocean Engineering

CONTRACTOR	CONTRACT NO.
U.S.N. Construction Battalion Center Civil Engineering Laboratory Port Hueneme, CA 93043	ERDA E(49-26)-1017
	PERIOD OF PERFORMANCE May 13, 1975 to March 31, 1977
PRINCIPAL INVESTIGATOR Philip Valent (805) 982-5780	FISCAL YEAR 1977 FUNDING $ 0

TITLE

Development of Anchor Systems for OTEC Power Plants

SUMMARY

This project was aimed at extending the state-of-the-art in deep sea anchor systems to satisfy the anchor-design requirements of large floating OTEC power plants. These new requirements result from the different combination of environmental conditions, water depth, and large power plant size. Performance characteristics of enlarged versions of existing anchors were estimated and innovative anchoring concepts were devised and evaluated. This task was accomplished by utilizing the experience of the U.S. Navy and of private industry, particularly oil companies and drilling contractors. The capability of each anchor was defined for a series of seafloor sites that could be encountered at potential OTEC plant locations. (These site varieties account for the majority of possible seafloors where OTEC is regarded as practicable.)

This parametric study identified the deadweight anchor with base shear keys as the best choice for mooring the OTEC platforms, except for those platforms sited over hard (rock) seafloors. On hard seafloors, the pile group anchor is the more suitable and feasible anchor type.

Installation techniques for these anchor concepts have been developed and their impact on anchor design evaluated. Concepts for controlled lowering of the deadweight anchor are unattractive due to their complexity and cost. A concept for free-fall lowering of the deadweight has been developed and partially evaluated using a 0.15 m (6 in.) diameter scaled model anchor. Complete evaluation of the free-fall lowering concept has been proposed for FY '78.

It is recommended that further development of the pile group anchor under the OTEC program be deferred. Those few potential OTEC sites where anchors would have to be placed on hard (rock) seafloors should be avoided if possible. If such a site must be considered, then an individual pile group anchor design can be undertaken.

Bibliography Reference No. 148–152

ADVANCED RESEARCH AND TECHNOLOGY
Ocean Engineering

CONTRACTOR	CONTRACT NO.
Oregon State University Department of Mechanical Engineering Corvallis, OR 97331	EY-76-S-06-2227
	PERIOD OF PERFORMANCE September 15, 1976 to September 14, 1977
PRINCIPAL INVESTIGATOR John H. Nath (503) 754-2354	FISCAL YEAR 1977 FUNDING $ 0

TITLE

Biological and Hydrodynamic Influences on the Screens of OTEC Intake Systems

SUMMARY

The objective of this project was to provide continuous supplies of clean, cold and warm water to an OTEC plant; therefore, it was necessary to exclude debris and marine plants and animals for the protection of the plant equipment and the ocean environment. However, the exclusion of this material from the plant was to be accomplished with minimal increase in the parasitic hydraulic losses at the intakes.

The basic problem was the lack of information on the biological and hydrodynamic factors that influence the design of the screens at the intake structures. This program proposed to:

a. Gather, assess, and document the available knowledge of the biota of the ocean environment in the regions proposed for OTEC plant siting.
b. Assess and document the hydraulic energy losses, and other costs of candidate screen designs which exclude certain biota.
c. Utilize the results to develop first-order design criteria for the configuration of cold and warm water intake screen.
d. Design an experiment for sampling the biota at depths as deep as possible during second year extension of this study.

The results of this research are applicable to the design of an OTEC plant regardless of the final configuration of the prototype structure.

Bibliography Reference No. 145

ADVANCED RESEARCH AND TECHNOLOGY
Ocean Engineering

CONTRACTOR	CONTRACT NO.
Hydronautics, Inc. 7210 Pindell School Road Laurel, MD 20810	E(11-1)-2681
	PERIOD OF PERFORMANCE May 1, 1975 to December 31, 1977
PRINCIPAL INVESTIGATOR Roderick A. Barr (301) 776-7454	FISCAL YEAR 1977 FUNDING $ 0

TITLE

Studies of Seaway Responses of OTEC Platform/Cold Water Pipe Configuration Effects of Pipe Elasticity and Model Tests

SUMMARY

This project, originally entitled "Evaluation of Platform Designs for Ocean Thermal Power Plants," consisted of an evaluation of seakeeping (motions and accelerations), junction loads, cold water pipe bending moments, and stationkeeping thrust requirements for five generic platform types each with a cold water pipe or riser for ocean thermal power plants. The study was to indicate which platform types appear most attractive.

The study developed a mathematical model of seakeeping response that employed linear wave theory with a Pierson-Maskowitz representative of the sea spectrum for three sea states. It was conducted in a parametric sense with respect to plant output (size), cold water pipe length, diameter and degree of fixity at the hull (the pipe itself was assumed infinitely stiff), and platform heading into oncoming waves.

The platform shapes chosen for investigation were the semisubmersible, ship shape, disc, spar, and submersible.

The continuation study determined in detail the probable effects of coldwater pipe stiffness on OTEC platform design. The study defined the elastic properties of typical pipe designs, developed methods for calculation of platform/pipe dynamics and loads, and used these methods to calculate the dynamic seaway induced motions and loads.

Using this data, two platform/pipe configurations were selected for hydraulic model testing, two models constructed and tested, and the test results compared with predicted responses from the earlier developed mathematical representations.

Bibliography Reference No. 138, 140–144

ADVANCED RESEARCH AND TECHNOLOGY
Ocean Engineering

CONTRACTOR
Science Applications, Inc.
One Continental Plaza, Suite 310
101 Continental Boulevard
El Segundo, CA 90245

CONTRACT NO.
EX-76-C-01-2331 (ERDA)
EG-77-A-19-1092 (NASA)

PERIOD OF PERFORMANCE
June 29, 1976 to December 31, 1977

PRINCIPAL INVESTIGATOR
Duane T. Hove (213) 640-0480

FISCAL YEAR 1977 FUNDING
$ 0

TITLE

Empirical Hydrodynamics Studies to Produce Parameters for Determining the Drag and Lift Forces on a Cylinder in Supercritical Flow Regimes for OTEC

SUMMARY

The first phase of this project was to determine definitive and valid values of drag coefficients, lift coefficients, and Strouhal numbers for long rigid cylinders in uniform flows at Reynolds numbers ranging from 10^6 to 10^7. Data for smooth cylinders and cylinders with surface roughness were to be obtained, as was determination of the effect of low-angle inclination to the flow.

The second phase was to produce a developmental experimental design dealing with methods and apparatus for the acquisition of similar data in a Reynolds number range from 10^7 to 10^8. This was a design project, rather than laboratory work because the experimental difficulties in this regime were considered to introduce much greater project risk than the work over the range 10^6 to 10^7.

Bibliography Reference No. 184

ADVANCED RESEARCH AND TECHNOLOGY
Ocean Engineering

CONTRACTOR	CONTRACT NO.
Hydronautics, Inc. 7210 Pindell School Road Laurel, MD 20810	EY-76-C-01-2424
	PERIOD OF PERFORMANCE May 26, 1976 to January 25, 1977
PRINCIPAL INVESTIGATOR Pin Yu Chang (301) 776-7454	FISCAL YEAR 1977 FUNDING $ 0

TITLE

Structural Analysis and Design Studies of OTEC Cold Water Pipe

SUMMARY

The purpose of this study was to document a methodology for OTEC cold water pipe structural analysis. Differential equations were developed which included factors neglected in simple beam theory, e.g., variable axial force, nonlinearity, variable cross section, shear deflections, and load changes due to local deformations. Instability due to hydroelastic effects was also considered in addition to the effect of fatigue.

Bibliography Reference No. 140, 206

ADVANCED RESEARCH AND TECHNOLOGY
Ocean Engineering

CONTRACTOR	CONTRACT NO.
U.S. Naval Postgraduate School Monterey, CA 93940	E(49–26)–1044
	PERIOD OF PERFORMANCE April 1, 1976 to December 31, 1977
PRINCIPAL INVESTIGATOR Clarence J. Garrison (408) 646–2632	FISCAL YEAR 1977 FUNDING $ 0

TITLE
Dynamic Response of Moored OTEC Plants to Ocean Waves

SUMMARY

This project was a research effort to provide computer programs describing the interaction of ocean waves with large floating structures and to estimate dynamic response resulting from the wave/structure interaction. The work was not directed toward any particular proposed OTEC plant configuration but was general and inclusive of all OTEC candidate designs. This project also addressed problems peculiar to mooring very large structures in ocean waves.

The research was particularly concerned with the development of solutions for determining the seaway response of large symmetrical bodies that do not meet the assumptions of classical strip theory. Numerical procedures that combine some of the features of the finite element method with the Green's function method were adapted to this problem. In addition, the non-linear force which results in slowdrift oscillations was studied, and analytical methods for its evaluation were developed. The work also considered the behavior of the cold-water pipe as it attaches to the OTEC hull structure.

Bibliography Reference No. 71, 182

BIBLIOGRAPHY – PART I

BIBLIOGRAPHY – PART I
OCEAN THERMAL ENERGY CONVERSION

This bibliography contains information pertinent to the projects described in this summary. The information dates back as far as useful references could be obtained and is current through December 1977. Reference entries may include any or all of the following:

1) author's name
2) "title of report" within a larger publication
3) *title of publication*
4) publisher's name and address
5) publication date
6) number of pages in the report or page numbers of report found within a publication
7) (report or publication number/where it may be obtained*/price)

* A listing may contain one of the following abbreviations as to availability. If none are listed, the reports may be available from the author's organizational affiliation.

GPO For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

NTIS For sale by the National Technical Information Service, U.S. Department of Commerce, microfiche copy of each separately bound document can be purchased for $2.25. Reports issued by organizations outside the United States will be sold by NTIS only to purchasers within the United States.

TIC Available from the DOE Technical Information Center, P.O. Box 62, Oak Ridge, Tennessee 37830

NSF On file at the RANN Library, National Science Foundation, 1800 G Street, N.W., Washington, D.C. 20550.

To obtain the *Proceedings, Fourth Annual Conference on OTEC; University of New Oreans, New Orleans, LA; March 22–24, 1977* send $20 in check or money order, payable to the University of New Orleans, to:

Professor George Ioup
Department of Physics
University of New Orleans
New Orleans, LA 70122

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PART II

RELATED RENEWABLE OCEAN ENERGY TECHNOLOGIES: WIND-WAVE ENERGY, OCEAN CURRENT ENERGY, SALINITY GRADIENT ENERGY

PART II

RELATED RENEWABLE OCEAN ENERGY TECHNOLOGIES

Introduction

A relatively small level of effort is being committed to investigating the feasibility of extracting energy from the ocean by technologies other than those which exploit temperature differences at different depths of the ocean. Specifically, the energies of ocean waves and currents and the energy of salinity gradients have been judged to be exploitable in various regions adjacent to (or on) the coasts of the United States.

WHAT MAKES THESE TECHNOLOGIES POSSIBLE?

The energies of waves, ocean currents, and salinity gradients are either totally or in part due to the sun; thus, they are considered to be special forms of solar energy.

The sun causes thermal currents of air which, when also affected by the rotation of the earth, result in winds. These winds cause surface stresses on the ocean waters, resulting in both waves and currents. The sun also evaporates fresh water from salt water and brines, leaving more saline surface ocean waters or salt pans on adjacent coasts.

Wave energy is the most conspicuous of the three energy forms and, as such, attracts the most attention. The rising and falling ocean surface can simultaneously raise and lower large floating objects, such as 10,000-ton ships. This body motion can be converted to electrical energy or to other usable forms by using electro-mechanical, pneumatic or hydraulic systems.

Ocean current energy can be converted into electricity by using large turbogenerators. These generators are powered by undersea "windmills," large ducted turbines, or a series of drogue chutes.

The energy of salinity gradients can be converted by two methods:

(1) The first method utilizes the osmatic pressure between salt water and fresh water, or between brine and fresh water. Since salt lowers the vapor pressure of water, the resulting osmotic pressure between salt water and fresh water is large (usually about 25 atmospheres). The osmotic pressure between brine and fresh water can be up to 250 atmospheres. The separation of solutions of differing salt concentrations by a semipermeable membrane results in the forcing of fresh water through the membrane by the osmotic pressure, thus, pressurizing the more saline solution. The high pressure saline solution can be passed through a hydroturbine to produce electrical energy.

(2) The second technique involves breaking down the salt molecules into sodium ions (Na^+) and chlorine ions (Cl^-) by using ion-selective membranes. These ions travel to opposite sides of a membrane stack, thus charging two electrodes, as in a car battery. An electrical current will then be driven through a load connected between the electrodes.

PRESENT TECHNOLOGICAL STATUS

Each of the related ocean energy technologies is being investigated on a relatively modest scale. It is perhaps equally appropriate to refer to these pursuits as research and development excursions to ensure that the bridge between understanding the science which defines a phenomenon and the technology which allows the exploitation of that knowledge for practical purposes is appreciated. The existence of these energy sources, as well as effective methods to convert them to measurable electrical energy and concepts by which the conversion can be effected, are now known.

Program Activities

Research is being pursued on the following technologies:

- Wind-Wave Energy Conversion.
- Ocean Current Energy Conversion.
- Salinity Gradient Energy Conversion.

WIND-WAVE ENERGY

Status

Promising devices that generate electricity from the motion of ocean waves are being investigated. One is a buoy

which uses the up-and-down motion of waves to build up air and water pressure in a storage tank. The pressurized water then drives a hydroturbine. This wave energy conversion technique is being investigated under a $10,000 DOE contract.

Implementation

Additional understanding and techniques to exploit wave energy phenomena will be encouraged. Close coordination is being maintained with the British wave energy program, where about $5 million is being used for studies of four wave energy conversion technologies.

OCEAN CURRENT ENERGY

Status

A prototype engine to convert ocean currents, tidal currents, and river currents into electricity and other usable forms of mechanical power has produced a measured 300 watts electrical output in approximately a one knot current. These tests demonstrated that a WLEVC engine would develop greater power than that which is predicted mathematically.

Implementation Plan

A new model will be designed and tested for sustained operation with a higher degree of mechanical power conversion efficiency.

SALINITY GRADIENT ENERGY

Status

A workshop was conducted in May, 1976 on Wave and Salinity Gradient Energy Conversion, and five specific studies on salinity gradients are being conducted in FY 1977.

Implementation Plans

Although an infant technology, the utilization of salinity gradients appears very promising. Two unusual concepts for obtaining energy from salt water are being explored by the Department of Energy.

One energy conversion technology is based on the principle of simple osmosis. The second technology is designed to exploit reverse electrodialysis. This second technique uses specially designed membranes which are ion-permeable. Cation-permeable membranes allow positively charged sodium ions to pass through, and anion-permeable membranes allow negatively charged chloride ions to penetrate. A "battery" could be built by stacking these membranes, alternating the two types, and filling the space in between with either fresh water or salt water in an alternating pattern. Both of these approaches will be encouraged since promising results are foreseen. FY 1977 studies concentrated on feasibility, membrane technology, and conceptual design. FY 1978 studies are directed toward improvement of membrane characteristics, preliminary design of both osmotic and reverse electrodialytic energy converters, and definition of legal, political, and environmental aspects of the utilization of this resource.

FISCAL YEAR 1977
SUMMARY TABLES

Table 1

FY 1977 SUMMARY TABLES

Program Element

RELATED OCEAN ENERGY TECHNOLOGIES

● *Program Sub-Element*

WIND-WAVE ENERGY

Organization	*Title*	*Projected Contribution*
University of California, San Diego, Scripps Institution of Oceanography	Ocean Wave Energy Extraction Using the Scripps-FOR Wave Pump	Data obtained from an empirical analysis of the Scripps-FOR wave pump. These data cover the wave spectra outside of the wave spectra that is found beneath the Trade Winds where the experimental data were obtained.

Table 2

FY 1977 SUMMARY TABLES

Program Element

RELATED OCEAN ENERGY TECHNOLOGIES

● *Program Sub-Element*

OCEAN CURRENT ENERGY

Organization	*Title*	*Projected Contribution*
WLVEC Technology Company	Demonstration of the Mechanical Feasibility of the WLVEC Engine	A WLVEC engine which converts ocean currents, tidal currents, and unconstrained fresh water river currents into electricity and other usable mechanical power forms.

Table 3

FY 1977 SUMMARY TABLES

Program Element

RELATED OCEAN ENERGY TECHNOLOGIES

● *Program Sub-Element*

SALINITY GRADIENT ENERGY

Organization	*Title*	*Projected Contribution*
Bend Research, Inc.	Membranes Research for Salinity Gradient Energy Production	Membranes with high permeate flow rates.
Intertechnology Corp.	Technological Problems of Osmo-Hydro Power Systems	A study of membrane problems such as high-pressure creep, polarization, and low-thermal efficiency in conjunction with the osmotic energy conversion of salinity gradient energy.
Intertechnology Corp.	Feasibility and Concept Design of a Pressure-retarded Osmosis Conversion System	An assessment of the economic and technical feasibility of pressure-related osmotic energy conversion. In addition, the resource of salinity gradient energy conversion is being assessed.
Clarkson College of Technology	Technological Potential of Osomotic Energy	An assessment of the technological potential of osmotic energy conversion.

FISCAL YEAR 1977
PROJECT SUMMARIES

RELATED OCEAN ENERGY TECHNOLOGIES
Wind Wave Energy

CONTRACTOR	CONTRACT NO.
California, San Diego, University of Scripps Institution of Oceanography La Jolla, CA 92093	U7700597
	PERIOD OF PERFORMANCE March 1, 1977 to September 1, 1977
PRINCIPAL INVESTIGATOR Gerald L. Wick (714) 452–2869	FISCAL YEAR 1977 FUNDING $ 9,998

TITLE

Ocean Wave Energy Extraction Using the Scripps-FOR Wave Pump

SUMMARY

The objective of this project was to provide data obtained from an empirical analysis of the Scripps-FOR wave pump. These data cover the wave spectra outside of the wave spectra that are found beneath the Trade Winds where the experimental data was obtained. A transfer function for the wave pump was developed based on the Trade Winds data. The analysis included the effects of the one-way valve and the efficiency of the turbo-generator. The analytical data were compared with the experimental data to prove the validity of the analysis. Presentation of these data were in both dimensional form and dimensionless form, the latter to be used for a prototype analysis.

Bibliography Reference No. 1

RELATED OCEAN ENERGY TECHNOLOGIES

Ocean Current Energy

CONTRACTOR	CONTRACT NO.
WLVEC Technology Company 310 South 11th Street Adel, IA 50003	G–05–77–2266
	PERIOD OF PERFORMANCE June 9, 1977 to November 9, 1977
PRINCIPAL INVESTIGATOR Gary Steelman (515) 993–3604	FISCAL YEAR 1977 FUNDING $ 9,990

TITLE

Demonstration of the Mechanical Feasibility of the WLVEC Engine

SUMMARY

The objective of this project was to provide a WLVEC engine which converts ocean currents, tidal currents, and unconstrained fresh water river currents into electricity and other usable mechanical power forms.

A prototype engine produced a measured 300 watts electrical output in approximately a one knot current. This wattage was produced by fifteen, 2-foot diameter working parachutes. These tests demonstrated that a WLVEC engine would develop greater power than the mathematical theory would predict.

A new model has been designed and tested for sustained operation with a higher degree of mechanical power conversion efficiency.

Bibliography Reference No. 2

RELATED OCEAN ENERGY TECHNOLOGIES

Salinity Gradient Energy

CONTRACTOR	CONTRACT NO.
Bend Research, Inc. Bend, OR 97701	EG-77-C-05-5525
	PERIOD OF PERFORMANCE March 1, 1977 to December 30, 1977
PRINCIPAL INVESTIGATOR H. Lonsdale (503) 382-4100	FISCAL YEAR 1977 FUNDING $ 31,176

TITLE

Membranes Research for Salinity Gradient Energy Production

SUMMARY

The energy of salinity gradients can be converted into useful forms by using a semipermeable membrane. The osmotic pressure across the membrane can be used to drive a hydroturbine, thus creating electrical energy. The research effort is devoted to developing membranes with high permeate flow rates.

Bibliography Reference No. 3

RELATED OCEAN ENERGY TECHNOLOGIES
Salinity Gradient Energy

CONTRACTOR	CONTRACT NO.
Intertechnology Corp. 1001 Main Street Warrenton, VA 22181	EG-77-G-01-4066
	PERIOD OF PERFORMANCE September, 1977 to March, 1978
PRINCIPAL INVESTIGATOR Malcom D. Fraser (703) 347-7900	FISCAL YEAR 1977 FUNDING $ 49,933

TITLE
Technological Problem of Osmo-Hydro Power Systems

SUMMARY

Membrane problems such as high-pressure creep, polarization, and low thermal efficiency are being studied in conjunction with the osmotic energy conversion of salinity gradient energy. These problems are analyzed and remedies are then recommended. The overall effects of the remedies on the energy conversion efficiency are also examined.

Bibliography Reference No. None

RELATED OCEAN ENERGY TECHNOLOGIES

Salinity Gradient Energy

CONTRACTOR	CONTRACT NO.
Intertechnology Corp. 1001 Main St. Warrenton, VA 22186	EG–05–77–2859
	PERIOD OF PERFORMANCE July 20, 1977 to January 20, 1978
PRINCIPAL INVESTIGATOR Malcom D. Fraser (703) 347–7900	FISCAL YEAR 1977 FUNDING $ 57,273

TITLE

Feasibility and Concept Design of a Pressure-retarded Osmosis Conversion System

SUMMARY

The purpose of this study is to assess the economic and technical feasibility of pressure-retarded osmotic energy conversion. In addition, the resource of salinity gradient energy conversion is being assessed. A conceptual design of an osmotic power plant is being performed. Salt water/fresh water, brine/salt water, and brine/fresh water systems are being analyzed.

Bibliography Reference No. None

RELATED OCEAN ENERGY TECHNOLOGIES

Salinity Gradient Energy

CONTRACTOR	CONTRACT NO.
Clarkson College of Technology Potsdam, NY	EG–77–S–05–5440
	PERIOD OF PERFORMANCE August 1, 1977 to July 31, 1978
PRINCIPAL INVESTIGATOR H.H.G. Jellinek (315) 268–2394	FISCAL YEAR 1977 FUNDING $ 35,448

TITLE

Technological Potential of Osomotic Energy Conversion

SUMMARY

The purpose of this study is to assess the technological potential of osmotic energy conversion. This is being accomplished by designing, constructing, and testing a scale model of a pressure-retarded osmotic power plant. Several semipermeable membranes are being tested to determine the effect of partial salt passing on flow rate. Measurements of salinity on both sides of the semipermeable membrane will be made to determine the decrease in the salinity gradient with time and position.

Bibliography Reference No. 4

BIBILIOGRAPHY – PART II

BIBILIOGRAPHY – PART II
RELATED OCEAN ENERGY TECHNOLOGIES

1. Isaacs, J., Castel, D. and Wick, G., "Utilization of the Energy of Ocean Waves," *Wave and Salinity Gradient Energy Conversion Workshop Proceedings (May 24–26, 1976).* University of Delaware, Newark, Delaware. ERDA Report C00–2946–1. Contact: Dr. R. G. Dean, Department of Civil Engineering, University of Delaware, Newark, Delaware 19087.
2. Steelman, G. E., "An Invention Designed to Convert Ocean Currents into Useable Power," *Proceedings of the MacArthur Workshop on the Feasibility of Extracting Usable Energy from the Florida Current (February 27-March 1, 1974).* Palm Beach Shores, Florida. Contact: Dr. Harris B. Stewart, Jr., Director, NOAA Atlantic Oceanographic and Meteorological Laboratories, 75 Virginia Beach Dr., Miami, Florida 33149.
3. Lonsdale, H. K., "Current Status of Membrane Technology," *Wave and Salinity Gradient Energy Conversion Workshop Proceedings (May 24–26, 1976).* University of Delaware, Newark, Delaware. ERDA Report No. COO–2946–1. Contact: Dr. R. G. Dean, Department of Civil Engineering, University of Delaware, Newark, Delaware 19081.
4. Jellinek, H.H.G., "I-Osmotic Work Energy Production from Osmosis of Fresh Water/Saline Water Systems; II-Direct Conversion of Chemical Energy into Work; III-Power From Reverse Electrodialysis," *Wave and Salinity Gradient Energy Conversion Workshop Proceedings (May 24–26, 1976).* University of Delaware, Newark, Delaware. ERDA Report No. COO–2946–1. Contact: Dr. R. G. Dean, Department of Civil Engineering, University of Delaware, Newark, Delaware 19081.

ADDITIONAL SELECTED BACKGROUND REFERENCES – PART II

1. Loeb, S., "Production of Energy from Concentrated Brines by Pressure-Retarded Osmosis," *Journal of Membrane Sciences, Vol. 1.* 1976, pp. 49–63.
2. Panicker, N. N., "Power Resource Estimate of Ocean Surface Waves," *Ocean Engineering (A Pergamon Journal) Vol. 3. No. 6.* 1972, pp. 429–440.
3. Richards, A. F., "Extracting Energy from the Oceans: A Review," *Journal of the Marine Technology Society.* Feb.-March 1976, pp. 5–24.
4. Salter, S., Jeffrey, D. and Taylor, J., "The Architecture of Nodding Duck Wave Power Generators," *The Naval Architect.* January 1976, pp. 21–24.
5. Sheets, H.E., "Power Generation from Ocean Currents," *Naval Engineers Journal.* April 1975, pp. 47–56.

ALPHABETICAL INDEX OF CONTRACTORS (PART I)

ALPHABETICAL INDEX OF CONTRACTORS (PART II)

APPENDIX ON UNSOLICITED PROPOSAL REQUIREMENTS

SOLAR recognizes that the unsolicited proposal is a valuable means by which unique or innovative methods or approaches can be made available in developing energy technology. Unsolicited proposals are offered in the hope that SOLAR will enter into a contract with the offeror for researching, developing, or providing services indicated within the proposal. These proposals should not be merely an advance proposal for a specific requirement which would normally be procured by competitive methods.

It is SOLAR's policy to encourage and foster the submission of unsolicited proposals. Since the preparation of an unsolicited proposal represents a substantial investment of time and effort by the offeror, those organizations or individuals who are interested in submitting an unsolicited proposal are encouraged to utilize preliminary proposals to establish if they can relate to SOLAR's needs before expending extensive effort in preparing a detailed unsolicited proposal.

Favorable evaluation of an unsolicited proposal is not, in itself, sufficient justification for SOLAR to enter into contract with the offeror. Generally, any unsolicited proposal that (a) is available to Government without restriction from another source, (b) closely resembles that of a pending competitive solicitation, or (c) is not sufficiently unique to justify acceptance, is unacceptable and must be rejected.

Individuals and organizations may submit unsolicited proposals at any time to SOLAR. Proposals related to solar energy programs may be submitted to:

Office of Unsolicited Proposals
U.S. Department of Energy
Washington, D.C. 20545

Since unsolicited proposals may form the basis for technical evaluation or contract negotiations, each should contain: detailed information on the purpose and objective of the proposed work; an indication of the offeror's background and previous experience; a concise statement of work; information relating to organization, facilities, and qualifications; other pertinent data; and a detailed cost estimate.

Because of the greater degree of interest in solar energy programs and the similarities among many proposed concepts and research and development ideas (which preclude funding them on an unsolicited basis), most projects are supported as a result of solicitations. Solicitation mechanisms used by SOLAR include:

a. *Requests for Proposals.* Requests for Proposals (RFP) are used to contract for a specific scope of work.
b. *Program Research and Development Announcements.* The Program Research and Development Announcements (PRDA) are used to solicit proposals where a specific need is not sufficiently definable to use the traditional RFP process.
c. *Program Opportunity Notices.* The Program Opportunity Notices (PON) are used for technological demonstrations where the objective is the acceleration of commercial application of new energy technologies and systems.

By their very nature, demonstration projects for solar energy technology do not lend themselves to consideration on an unsolicited basis. In addition, innovative

concepts submitted on an unsolicited basis should promise a clear benefit to the solar energy program by offering a potential for improvement in cost or performance over other approaches.

Additional information on proposal preparation may be found in:

a. *Guide for the Submission of Research and Development Proposals by Individuals and Organizations,* available at no cost from DOE, Division of Procurement, Washington, D.C. 20545.
b. *Guide for the Submission of Research Proposals from Educational Institutions,* available at no cost from DOE, Office of University Programs, Washington, D.C. 20545.
c. *Guide for the Preparation of Proposals for Special Projects in Energy Education and Training,* available at no cost from DOE, Office of Public Affairs, Educational Programs Branch, Washington, D.C. 20545.

Procurement regulations containing additional information concerning contracting policy and procedures are available at nominal costs from the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402.

☆ U.S. GOVERNMENT PRINTING OFFICE : 1978 O—261-325

Department of Energy
Washington, D.C. 20545

1978 August 15

Dear Colleague,

Your name appears on the mailing list for the Ocean Thermal Energy Conversion (OTEC) program of the U.S. Department of Energy. Accordingly, enclosed herewith is a copy of the OTEC Program Summary for Fiscal Year 1977.

Please let me know if your address needs correction or if you no longer wish to be included on the OTEC mailing list. In addition to OTEC, the Ocean Systems Branch is developing technology for utilizing other ocean energy resources (waves, currents, and salinity gradients). If you want to receive information from us in any of those specific areas, please communicate which ones. Thank you.

Sincerely,

Robert Cohen
Program Manager
Ocean Systems Branch
Division of Central Solar Technology