# The Natural Energy Laboratory of Hawaii Annual Report 1977

ADDRESS

The Research Corporation of
the University of Hawaii
1110 University Avenue
Room 402
Honolulu, Hawaii 96826

(808) 955-6344

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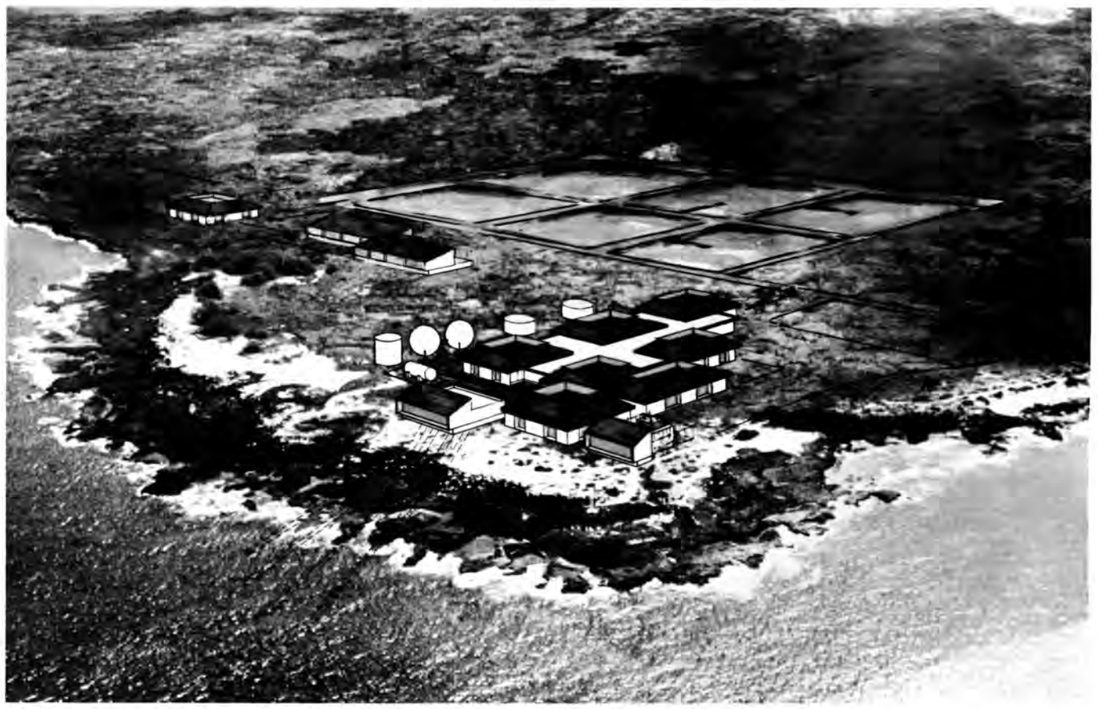
# Introduction

The State of Hawaii is generously endowed with a variety and abundance of natural energy resources: geothermal, solar radiation, steady winds, ocean waves and ocean temperature differential.

The state has recognized these advantages and has moved aggressively to develop its natural energy resources. The 1972 state legislature, well in advance of major concern regarding an energy crisis, allocated funds to initiate investigations into the development of geothermal power. These investigations are continuing with increased support from the National Science Foundation, the Department of Energy, the State of Hawaii and the County of Hawaii.

In 1974, the legislature enacted many energy-related bills, one of which established a Natural Energy Laboratory of Hawaii. The bill provided for planning funds which were matched on a dollar-for-dollar basis by the County of Hawaii.

This report covers development of the laboratory since that time, as well as some of the background factors that complement work in energy research and brief descriptions of research projects related to the laboratory.



Surface sea water pumping facility.



## THE NATURAL ENERGY LABORATORY

With the creation of the Natural Energy Laboratory of Hawaii accomplished, the first task at hand was selection of a site which met all the criteria necessary for the laboratory's successful operation.

Some of the most important of these were the nearby availability of cold, deep ocean water, a warm ocean surface layer not subject to strong seasonal cooling, high annual solar radiation, accessibility to logistical support including major airports, harbors and highways, and adequate quantities of undeveloped land.

The site, selected in 1975, was at Ke-ahole Point, on 320 acres of state-owned land adjacent to the Ke-ahole Airport on the Kona Coast of the Island of Hawaii.

Since that time, federal, state and county permits allowing experimental programs and Ocean Thermal Energy Conversion (OTEC) development have been obtained. In addition, a master plan was completed and approved in January, 1976, along with an Environmental Impact Statement, which won final approval in December, 1976.

To simplify future research use and facilities development at the Ke-ahole site, laboratory officials have petitioned, along with the State Department of Transportation, to have the present "conservation" zoning changed to an "urban" classification. Approval is expected early in 1978.

The ocean adjacent to the site is zoned "Conservation" as are all inshore waters in Hawaii. However, the development of ocean energy and mariculture projects requires a continued monitoring of the ocean environment. In addition, there are needs to pump water from the ocean to the shore and to lay cables from shore-side recorders to ocean monitoring systems.

Thus in November 1976 action was started to establish an "Ocean Research and Baseline Data Collection Area" immediately adjacent to the NELH site and extending out into the ocean. This area designated by the permit is 1,000 feet wide and extends one mile seaward (to the 450-fathom depth contour). The purpose of this research area is to allow the collection of all needed basic research data and the laying of cables, pipelines, and anchored buoys for the purpose of furthering the ocean research mandate of the Laboratory. Under this permit, pipelines, cables, and all other facilities would be removed upon completion of the individual projects. Currently the research area is being used to collect basic research data on currents, temperature structure, water density stratification, biological and chemical analysis, ocean bottom geology, biofouling, corrosion and other information.

Interim facilities at the site are a diesel generating plant to supply power for the research projects and a small office and project monitoring laboratory. These are portable and will be replaced by permanent facilities as the laboratory develops.

Initial permanent capital improvements will include a surfaced access road from the highway to the research site, a water supply line, interim sewage disposal facilities and a 300 KV electric power supply line. Adequate telephone and data processing service will be installed, along with an enclosed service support area and a graded test area. The state has authorized $750,000 to cover costs related to these improvements.

Facilities to be added in a second increment are a service building with shop and test space, covered storage, offices and security guard space. A test building with office, laboratory, support shops and covered test equipment space will be erected in the test and research area. When deep cold water and warm surface water supply pipelines are completed, plans call for construction of a water terminal to make both cold and warm water available to support OTEC and aquaculture test and evaluation projects.

# State Resources

The diverse and broad base of the scientific community in the state of Hawaii is a definite asset to any new program development. The main campus of the University of Hawaii, located a few minutes from Waikiki and from downtown Honolulu, houses the Hawaii Institute of Geophysics which has 53 active researchers. The Department of Oceanography has 22 faculty members and researchers on its staff. In addition, the Department of Ocean Engineering has 9 active staff, and the Department of Meteorology has 11. The Hawaii Institute of Marine Biology, another research institute of the University of Hawaii, is located in Kaneohe Bay on the north coast of Oahu and employs 31 on its research staff. The University of Hawaii maintains two active research ships, the KANA KEOKI, a 156-foot vessel, and the MOANA WAVE, a 174-foot ship.

The federal government supports a number of marine scientific establishments in the state of Hawaii. These include the University of Hawaii Sea Grant College Program which supports 30 principal investigators plus staff, the U.S. Naval Ocean Systems Center employing approximately 40 scientists and specializing in research and development in the areas of marine biology and undersea technology, the Joint Institute for Marine and Atmospheric Research with 9 scientists and the Honolulu Laboratory of the U.S. National Marine Fisheries Service employing 18 scientists.

There are located within the state of Hawaii several large steel fabrication facilities and the best concrete precast yards in the United States. In addition to commercial ship-repair facilities, there is a major naval shipyard with four graving (dry) docks. One of these is 325 feet by 1,100 feet and is located outside the shipyard security area, allowing access by commercial civilian employees without a security clearance.

Because of its desirable living conditions, Hawaii has unusually high unemployment of skilled workers who could be attracted to an ocean-energy program. In addition, the Island of Hawaii, site of the NELH, is phasing out its traditional dependence on agriculture and is looking for new programs that would provide desirable employmen for its residents. Traditionally the large majority o the professional and labor employees on the Island of Hawaii are native to that island. Because of the presence of family ties and personal desire to remain on that island, the labor force on Hawaii is considered to be one of the most reliable and stable in the United States.

## THE ISLAND OF HAWAII

The island of Hawaii is known as the Big Island. Its land area of 4,038 square miles is almost twice that of all the other islands combined. With its large land mass the Big Island has attracted many agricultural ventures in the past. Of the earl ventures, cattle ranching and sugar production have survived as leaders of the island's modern agriculture industry.

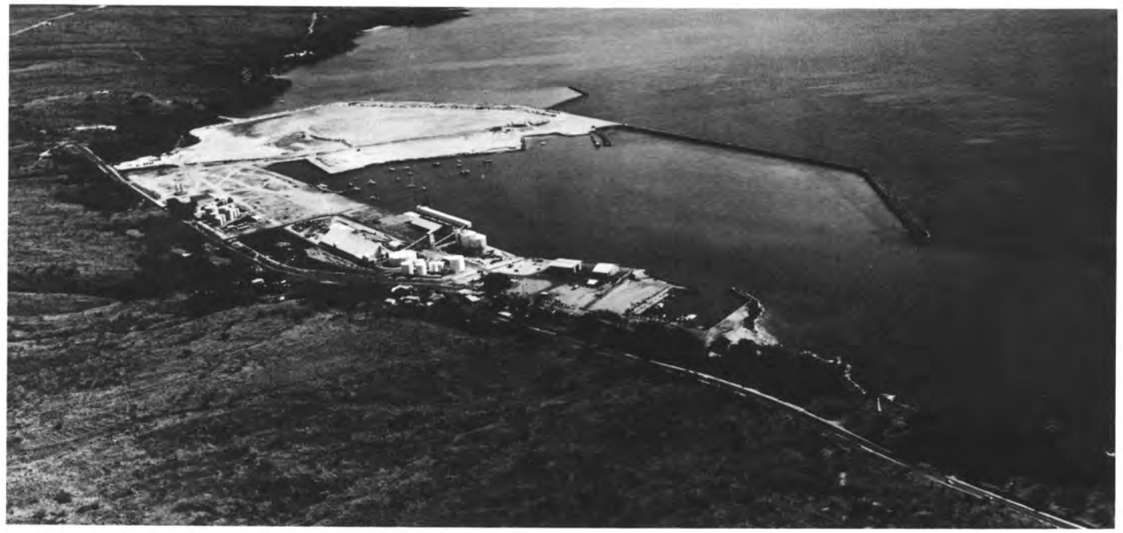
Since about 1965, increased tourism provided the impetus to promote tourist-related industry. In 1967 direct flights were initiated between Hilo and the west coast, and in 1971 the State completed construction of the first phase of a new inter-islan airport at the Ke-ahole Point area. The next phase of construction includes plans for expansion to overseas standards in order to better serve the growing needs of the west or Kona coast of the Big Island. At the present time there are approximately 16 daily flights connecting the mainland through Honolulu to Ke-ahole airport. With the present flight schedules it is possible to leave New York at midmorning and arrive at Kailua-Kona in time for dinner.

At the end of 1974 there were more than 3,000 hotel units in the Kailua-Kona area with a resident population in excess of 6,000. This population is primarily engaged in tourist-related activities either directly in the hotel-restaurant business or indirectly in construction and service industries. Aside from tourism the preferred new industry on the Big Island, as in the state as a whole, is research and development. The summit area of Mauna Kea on the Big Island is rated one of the best accessible sites in the world for astronomical observation. At the present time there is a facility operated by the University of Hawaii featuring an 88-inch mirror built for NASA, as well as several smaller instruments. Construction is presently underway for the installation of the world's fourth largest telescope in a joint venture by France, Canada, and the University of Hawaii at an estimated cost of $18 million.

The Cloud Physics Observatory is located on the Hilo Campus of the University of Hawaii. Administered by the Hawaii Institute of Geophysics, the Observatory is conducting research programs in cloud physics and atmospheric conditions.

The west coast of the Big Island offers excellent potential for ocean-related research. Research vessels can easily moor at the deepwater port at Kawaihae. There is also a small marine biological research laboratory administered by the University of Hawaii, located at Kawaihae. Small-boat facilities are available at Honokohau just three miles south of Ke-ahole Point.

University of Hawaii research vessels at Snug Harbor facility.



*Above:* Kawaihae Deep Draft Harbor. *Below:* Honokohau Small Boat Harbor.



## TRANSPORTATION

Air transportation to Honolulu from the mainland United States is available from any major airport. Excluding charter flights and foreign airlines, there are approximately 28 daily scheduled landings at Honolulu International Airport from the mainland. In addition, there are a few daily flights directly to Hilo on the island of Hawaii.

The Big Island has two major all-weather airports, one located on the east side at Hilo and the other near the town of Kailua-Kona at Ke-ahole Point. There is a third secondary airport located about 30 miles north of Ke-ahole near the town of Waimea. The four local airlines serving the Big Island presently have 23 daily arrivals at Hilo, 22 at Ke-ahole (5 of which stop at Waimea); flight time from Honolulu to Ke-ahole averages 30 minutes by the jets currently in use.

Surface shipping is provided by barge from Honolulu. The scheduling provides for three trips per week into the port of Hilo and two per week into Kawaihae Harbor north of Kona. In addition there are direct shipping routes from the mainland to Hilo.

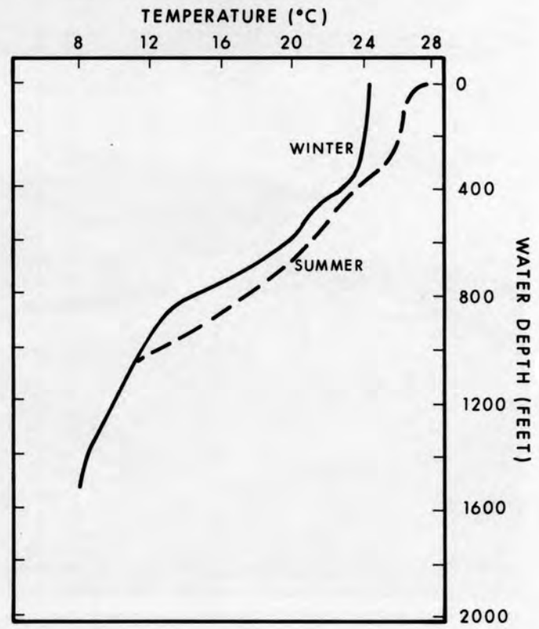
The port of Kawaihae, located 23 miles northeast of Ke-ahole Point, is a commercial deep water harbor. It is about 150 sea miles southeast of Honolulu and 2, 051 sea miles from San Francisco. This harbor is protected to a great extent against northeasterly storms by the Kohala Mountains and against southerly storms by a promontory to the south. The harbor is partially exposed to waves approaching from the northwest direction, but these are not usually severe due to the sheltering offered by the other islands lying in that direction. This port, now dredged to an average depth of 40 feet, has adequate facilities for any vessels used in oceanographic research or deep water pipeline installation. Smaller vessels may be moored at the small boat harbor at Honokohau located just three miles south of Ke-ahole Point.

## THE OCEAN

**Physical Characteristics.** Deep oceanic water is as close to shore off Ke-ahole Point as anywhere in the world. Consequently, conditions typical of the open ocean can be found within a mile from the shore.

The vertical profiles of temperature and nutrients show that cold, nutrient-rich deep water is available within 4,000 feet of the shoreline. The illustration shows two profiles as they occurred off Ke-ahole Point in the spring of 1972. Water with a temperature less than 10°C (50°F) is found at 1,200-foot depth decreasing to nearly 5°C at about 2,500 feet. Although the surface mixed layer of

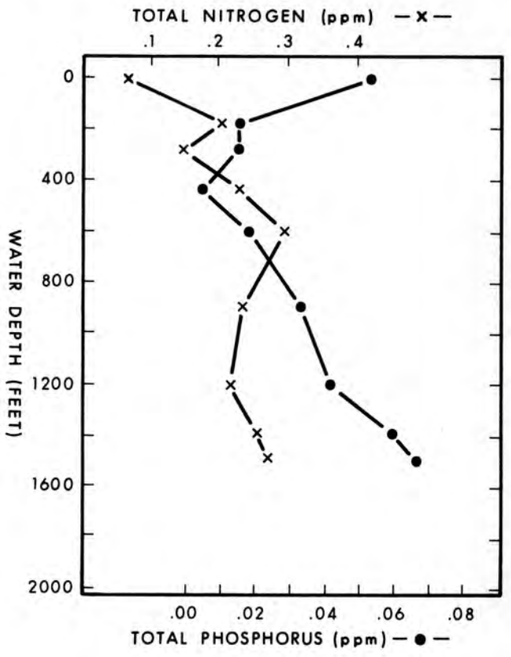
**Thermocline Offshore Ke-ahole Point**



water undergoes seasonal changes in thickness and temperature, the water properties below about 500 feet tend to remain the same throughout the year, with temperature decreasing with depth, and nutrient concentrations increasing. At Ke-ahole Point, water less than 11°C may be obtained within one-half mile of the shoreline.

The surface layer (mixed layer) responds to the seasonal changes in circulation, mixing, and incident radiation (insolation). The general pattern is that the mixed layer is deeper (350 ft.) and colder (25°C) in the spring; shallower (200 ft.) and warmer (28°C) in the summer. There are small diurnal changes and some variation within a month

**Nutrient Content Offshore Ke-ahole Point**



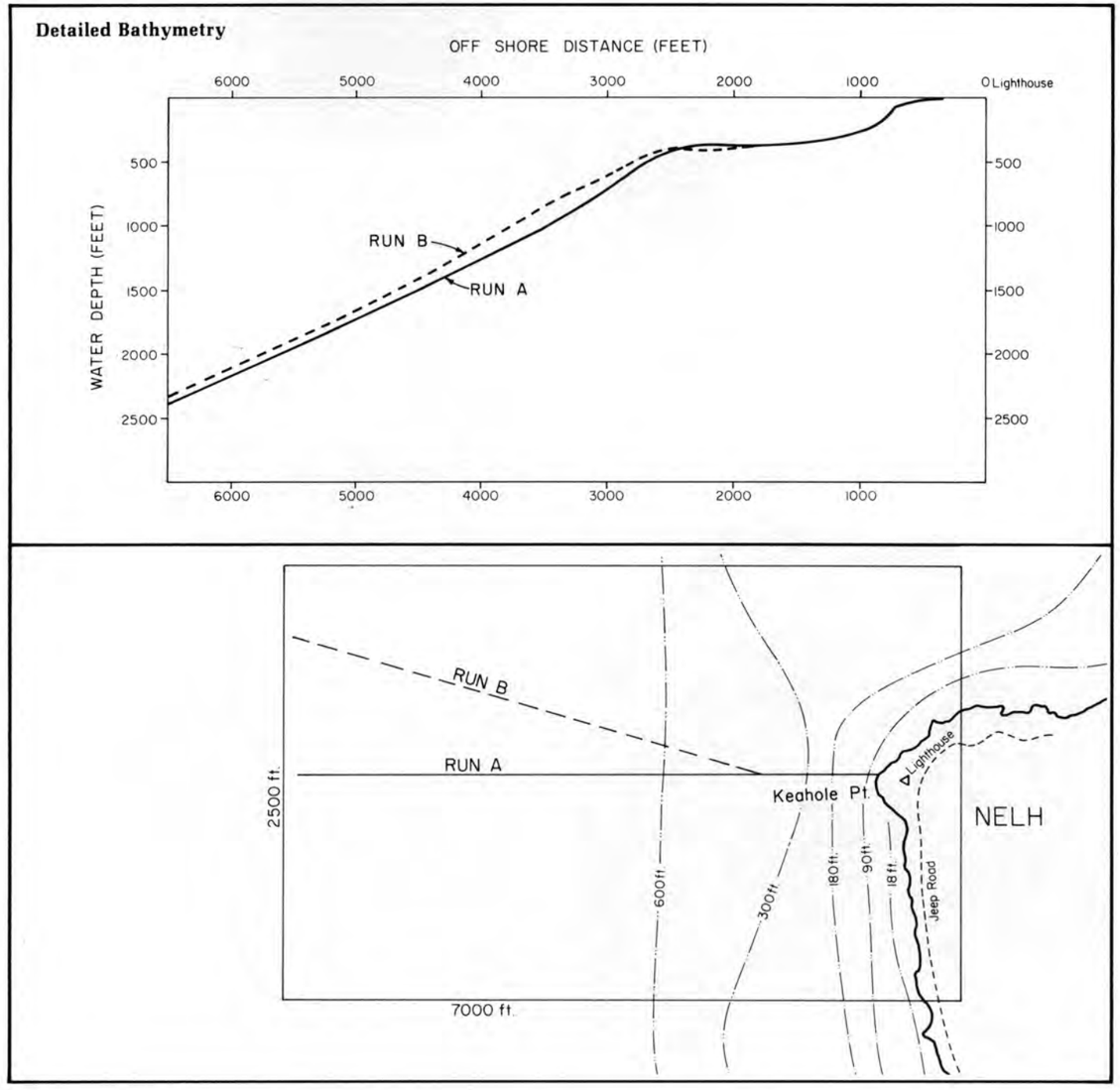

(±1/2°C). Annual average differences among succeeding years do not exceed ±1-1/2°C. These variations depend on actual conditions, but they do represent expected maximum values and variations.

**Ocean Currents.** Observations in the offshore Ke-ahole area have indicated that the currents are a combination of tidal and geostrophic with a modal value offshore of one-half to three-quarters of a knot. The northeasterly tending drift is dominant in the area, indicating an overall net transport in that direction. More recent observations taken during the fall of 1977 have indicated a nearshore-to-offshore structural difference in the currents. These measurements revealed that the nearshore surface and near bottom flow tended to be toward the south-southeast, following the contours, out to about 4,000 feet offshore. Further offshore the dominant flow was in the opposite direction—toward the north-northwest. Maximum surface current speeds were observed from 2.1 knots nearshore to 0.7 knots offshore. Near bottom flows were in the 0.2 - 0.5 knots range.

**Bathymetry and Bottom Conditions.** The bathymetry offshore Ke-ahole is characterized generally by a very steep slope to depths of 6,000 feet. However, detailed bathymetry has not been available until recently. In the summer of 1977 the State of Hawaii funded a study to provide this detailed information as a preliminary site-selection survey for a deepwater pipeline. A number of precision depth records were run from the westernmost portion of the NELH Ke-ahole site (just seaward of the U.S. Coast Guard lighthouse) to a depth of about 3,000 feet. The result of one of these profiles is given in the illustration.

The bottom slope from about the 450-foot depth contour to the 3,000-foot depth was between 25° and 30°. This steep slope was also investigated visually to a depth of 1,400 feet using the STAR II submersible in order to determine the

**Detailed Bathymetry**



characteristics of bottom material and roughness. The bottom of the major slope region was generally hard basalt covered by a thin layer of sand. The bottom slope was smooth, with a few rock outcroppings and channels occurring at the 450-foot depth where the major slope begins. Very little benthic life and no precious corals were observed.

**The Biota.** Visual and quantitative surveys have been made of the larger invertebrates, the species composition of corals and echinoderms, and reef physiography. The overall species composition was similar to that of other areas of the Kona coast. Differences noted at the various study areas around the Point were attributed to changes in exposure, depth, and substrate factors. These differences were predictable and serve as indicators of environmental variation.

One hundred twenty species of reef fishes were recorded within the four study regions at Ke-ahole Point. The fishes range in size from less than one inch to over six feet. An equally wide range of feeding types, activity patterns, body colors and shapes characterized the Ke-ahole fish fauna. A comparison of Ke-ahole with West Hawaii fish assemblages at other stations indicates no significant difference.

The micromollusk assemblages represent sensitive indicators of a variety of environmental parameters in benthic marine communities. Those studied at Ke-ahole Point indicate an absence of eutrophic, silty-sand, and anaerobic conditions, and of freshwater intrusions. Thus the indicators imply active currents, well mixed oxygenated water, and no significant amount of freshwater inflow.

Surgeon Fish, 100 feet depth, off Ke-ahole Point.

## WINDS AND SKY

The Ke-ahole area is located on the southwestern or Kona (lit. leeward) side of the island of Hawaii. Because of the relatively large land mass of this island, diurnal onshore-offshore breezes are observed. They are not significant on any of the other Hawaiian Islands. The daytime onshore breeze causes clouds to build up against Mt. Hualalai at altitudes between 2,500 and 4,000 feet. Along the coastline, however, the sky is relatively cloud-free most of the year. During 1972, only 22 days with significant amounts of cloud cover were reported from the Ke-ahole Airport. Rainfall, which is correlated with cloud cover, is also low for this area. Predominant wind speeds are between 8 and 10 knots principally from the southwest sector. Occasional winter storms which approach the islands from the southwest can cause rough surf conditions and locally heavy rain for brief periods.



# NELH-Related Ocean Studies

## 1972-76

**Report on Aquaculture and Ocean Energy Systems for the County of Hawaii**

*Investigators: Prof. Kaare R. Gunderson, Dr. Robert Q. Palmer, UH. Agency ($): County of Hawaii ($5,000)/State of Hawaii ($5,000). Year: July 1971-December 1972.*

A state/county-supported survey of coastal areas on the island of Hawaii has resulted in the selection of Ke-ahole Point as potentially the most suitable site for an ocean thermal energy pilot plant and a pilot plant aquaculture station. Factors which were considered included:

- Bathymetry and horizontal distance to deep water
- Suitability of adjacent coastal land for laboratory and for production plants
- Ownership of land and likely availability
- Stability of climatic conditions with maximum of yearly sunshine hours
- Closeness to transportation and lodging centers.

Of eight sites considered, Ke-ahole Point was found by far the most suitable. This state-owned land consists of more than 240 acres of fairly level, lava-covered coast land between the new Ke-ahole Airport and the shoreline. A depth of 700 meters is reached 1.6 km offshore at this location. Several commercial flights daily connect Ke-ahole with Honolulu and Hilo within 45 minutes flight time. Kailua town, with hotels, service facilities, and a harbor, is located three miles south on the sunny, low-precipitation Kona Coast. The coastal waters on this leeward side of the island are fairly calm and offer maximum stability during installation of deep-water pipes and pumps.

**Project Support for Natural Energy Laboratory of Hawaii**

*Investigators: James H. Jones, NELH; John P. Craven, Marine Programs, MAC; William Coops, Research Corporation of the University of Hawaii. Agency ($): County of Hawaii ($50,000), State of Hawaii ($108,000). Year: 1975-76.*

This project was established to assist the University of Hawaii, the State of Hawaii, and such other institutions as may be required, in preparing proposals for submission to federal agencies or any other out-of-state sources as may be concerned with the development of natural energy. These proposals are concerned primarily with the establishment of a land- or sea-based ocean thermal energy conversion test system and the establishment of complementary energy options as they may become appropriate. This project also assists in conducting analytical studies required to supply information for these proposals and past contract award studies as may be required for the successful initiation of these projects.

This project also prepares the terms and conditions under which the Natural Energy Laboratory at Ke-ahole Point, Hawaii may be proposed as a site for the conduct of natural energy projects by other corporations, institutions, or entities seeking to do research, development, or demonstration for the federal government or other institutions or entities which sponsor natural energy research.

**A Pilot Engineering Study on OTEC**

*Investigators: Theodore T. Lee, UH, Ocean Engineering. Agency ($): HNEI ($6,686). Year: 1975 (Continued to 1976 at $12,000).*

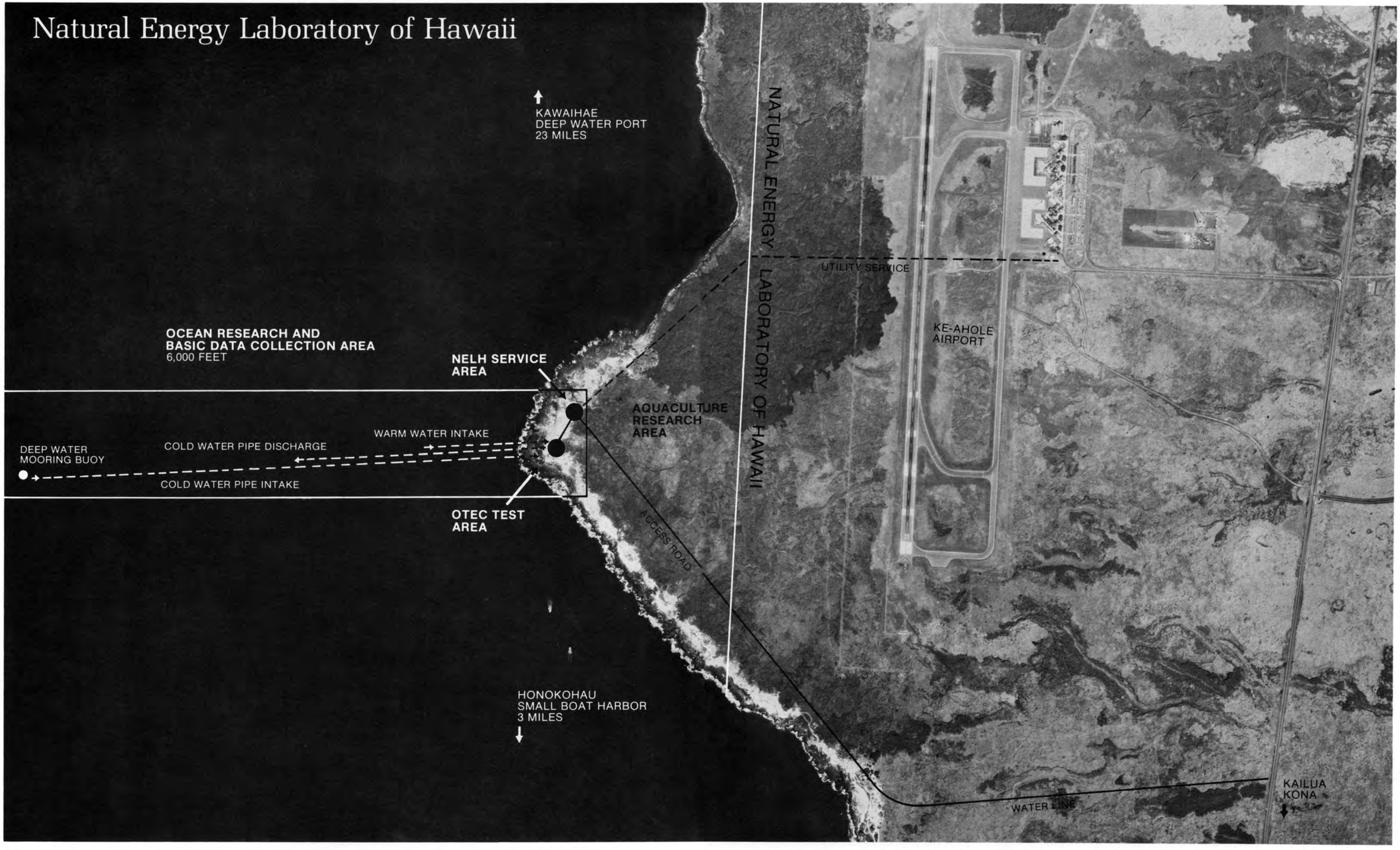
The materials and equipment for the OTEC working model have been procured with the help of funds from other sources, and fabrication was completed by the end of February. The model is to be used for determining the dynamic response of the platform-pipe-mooring system, hydrodynamic aspects, and thermal diffusion under the combined action of wind, waves, and currents. Supporting analytical studies have also been initiated.

**The Oceanic Institute's OTEC Ocean Structure Scale Model Project**

*Investigator: Joe A. Hanson, Oceanic Institute. Agency ($): SG (111,594)/UH ($9,724)/OI ($4,907). Year: 1975-76.*

The term "OTEC Ocean Structure" is used here to encompass not only the platform, but also the water pipes and the station-keeping mechanism, whether it be mooring or dynamic positioning. These three components are so closely coupled hydrodynamically that they must be treated as one system in order to avoid a possibility of catastrophic seakeeping behavior in early floating OTEC installations. The concern is that this is a new species of ocean engineering

# Natural Energy Laboratory of Hawaii



problem, and this concern stems from the following observations:

1. The contained watermass of the structure is a very large proportion of the total mass.

2. This water mass is in motion andl is hydrodynamically coupled to the structure to a greater or lesser extent depending on the design employed. It was concluded that some preliminary scale model tests would help confirm or deny these suspicions. The work is now well underway and will be completed by July 1976.

**Ocean Energy Related Wave Studies**

*Investigator: Robert Grace, UH, Civil and Ocean Engineering. Agency ($): 1975: MAC ($10,000)/SG ($37,000), 1976: MAC ($10,000)/SG ($39,000).*

The studies concern three aspects of local wave conditions:

1. Hawaii wave climate and wave predictions;

2. Wave-induced sub-surface water motions; and

3. Effects of wave forces on pipelines. pipelines.

While all three aspects have many important applications, it is the third one that is especially vital to future ocean energy projects, as many different methods and ideas of tapping ocean energy, or using the ocean in connection with energy-generation (for cooling, especially) require that pipelines be laid through shallow, near-shore surf zones. A point of interest in connection with this project is that the Australian Bureau of Meteorology is cooperating with this project by sending reports of waves and swells they observe that appear to be heading toward Hawaii.

**Corrosion and Fouling Renewal**

*Investigator: Jorn Larsen-Basse, UH, Mechanical Engineering. Agency ($): HNEI ($7,598). Year: 1976.*

A simple and efficient test method for stress corrosion cracking was developed and checked out in the laboratory. A small specimen rack has been constructed and emplaced in the ocean at a water depth of 20 feet near the shore at Ke-ahole Point. The rack holds an initial set of specimens for study of general corrosion. An additional set of general corrosion specimens has been placed in a lava tube where there is considerable water motion and heavy aeration of the water. It was expected to recover the specimens in mid-February for initial studies of corrosion rate and fouling removal. A second set of specimens will be emplaced at a later time.

**Operational Sea State and Design Wave Criteria for Ocean Thermal Energy Conversion Projects**

*Investigator: C.L. Bretschneider, UH, Ocean Engineering. Agency ($): ERDA ($36,000). Year: 1976.*

This project is to acquire environmental data on winds, waves, and currents for specified areas. The specific zones of interest include the Atlantic, Pacific, and Gulf Coasts of the Continental United States, the Hawaiian Islands, and all other oceanic areas (including the Indian Ocean) situated between 20° North and 20° South latitudes. These locations have primarily to do with potential selections of ocean thermal energy conversion (OTEC) project sites.

**Fouling and Corrosion in OTEC Heat Exchangers**

*Investigators: J. Fetkovich, Carnegie-Mellon University; F. Munchmeyer, UH, Mechanical Engineering. Agency ($): NSF/ERDA ($114,000) Year: 1976*

One of the most essential elements in demonstrating the economic feasibility of OTEC is to establish that scaling, biofouling, and corrosion can be held in check for the life of the plant without adding excessively to the capital or operating costs. Studies of fouling and corrosion must be done in the ocean under conditions approximating those expected to exist in practice. Test apparatus, consisting of heat exchanger tubes operating under various conditions of water flow velocity and utilizing different antifouling methods, is to be operated submerged in the ocean at Ke-ahole Point.

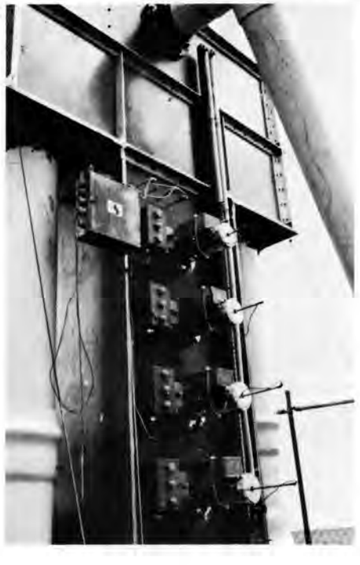
The tests will be done under conditions simulating those in the evaporator where, because of the higher temperature and greater abundance of sea life and dissolved oxygen in the surface waters, fouling and corrosion are expected to be most severe.

**An Evaluation of Oceanographic and Socio-Economic Aspects of a Nearshore Ocean Thermal Energy Conversion Pilot Plant in Sub-Tropical Hawaiian Waters**

*Investigators: Karl H. Bathen, with R. M. Kamins, D. Kornreich, J.E.T. Moncour, UH. Agency ($): NSF/RANN/ERDA ($48,000). Year: 1975*

This study was particularly concerned with local bathymetry to





*Above:* Fetkovich biofouling devise being loaded on boat.
*Left:* Applied Physics Laboratory, OTEC, heat exchanger test section.

the 2,000-foot depth, nearshore and offshore thermal density stratification to 1,500 feet, nutrient concentrations in the water column, local nearshore benthic biota, plankton community composition and productivity, seasonal circulation patterns around Ke-ahole Point, local wave and swell conditions, and the local meteorological conditions at Ke-ahole throughout the year. The concluding part of the oceanographic work involved an evaluation of the potential environmental impact a 10-MW pilot plant located at or just off Ke-ahole Point would have on the local, characteristically subtropical waters.

The three-part socio-economic program was concerned with examining the legal aspects of a nearshore OTEC plant. The applicable law, federal interests, legislative experience, and site conditions were considered.

**A Further Evaluation of the Oceanographic Conditions Found off Ke-ahole Point, Hawaii, and the Environmental Impact of Nearshore Tropical Energy Conversion Plants on Subtropical Hawaiian Waters.**

*Investigator: Karl H. Bathen UH, Ocean Engineering. Agency ($): DPED ($10,000). Year: 1976.*

This is an extension of a previous project providing further definition of existing oceanographic conditions off Ke-ahole Point and the environmental impact resulting from conducting nearshore tests for both a 100- and 240-megawatt OTEC floating power plant off the Point. Field efforts were completed to compare the 1975

*Left:* Issacs Wave Energy Pump being implanted on the ocean.
*Above:* The Issacs Wave Energy Pump.



summer thermal vertical structure and the profile of nearshore currents down to the 550m (1,800-foot) depth to 1974 observations.

## 1976-1977

**Environmental Survey Benthic Ecosystem at Ke-ahole Point**

*Investigators: James H. Jones, NELH, and R.S. Nolan, Ocean Research Consulting and Analysis, Ltd., E. Alison Kay, UH. Agency ($): DPED ($25,625).*

This study was designed to provide a portrait of the coral reef community adjacent to the Natural Energy Laboratory of the State of Hawaii, which is located at Ke-ahole Point, Island of Hawaii. It represents an effort to provide baseline information in anticipation of a Natural Energy Laboratory artificial upwelling test facility. This study advances a first step toward an integrated, comprehensive description of a coral reef ecosystem; and it provides a unique vignette of the corals, macro-invertebrates, fishes, micromolluscs, and reef substrate that constitute an undisturbed Hawaiian reef. Four regions were selected, based on the OTEC outfall and plume predictions. Region 1 was designated a control area and was situated on reefs upstream (in the southern sector) of the lab site. Region 2 was located near the proposed outfall, while Regions 3 and 4 were located down current.

**The Isaacs Wave Energy Pump: Tests off the Coast of Kaneohe Bay, Oahu, Hawaii, November 1976 to March 1977.**

*Investigators: James H. Jones, NELH; Gerald L. Wick and David Castel, Scripps Institution of Oceanography, Institute of Marine Resources, University of California, San Diego. Agency ($): DPED ($45,000).*

The purpose of this study was to bring to Hawaii for testing a modified version of this device that had already been successfully tested off southern California. The Hawaii tests provided performance information in a tradewind regime where the wave energy distribution is different and usually more consistent and greater than it is off California. The float was about 8 feet in diameter on the top and was shaped as a body of revolution having exponential sides. The float supported a cluster of three flexible polyethylene pipes, each 300 feet long with a diameter of 1.4 inches, 1.4 inches, and 2 inches respectively. On the buoy deck the pipes fed accumulator tanks, which fed water through a nozzle to a Pelton wheel coupled to an electric generator. A telemetry system monitoring pertinent information transmitted data to a shore station on command. The results indicated that one- to three-foot seas produced a continuous jet flow to a height of about 20 feet. A sea-state with three- to four-foot waves, 6-second period (power density of about 4100 watts/foot) produced 225 watts of power through the buoy generator. With proper scaling and careful construction, this device could produce significant energy and could be designed to bring nutrient-rich water from the 10,000-foot depth to the surface for an open-ocean mariculture system.

**OTEC Mariculture/Algal Project**

*Investigators: James H. Jones, NELH; M.S. Doty, UH. Agency ($): DPED ($10,000)*

This project is intended to identify seaweed algae that can economically be grown in the State of Hawaii. The first step was to determine the basic ecological and physiological responses of three of the most common seaweeds found in Hawaii: *Sargassum, Eucheuma,* and *Gracilana.* The first two genera are the best choices for the bioconversion of sunlight to a gas such as methane or alcohol. Four factors influencing fertility were identified: light, water motion, temperature, and water quality. The total fertility is a complicated function of all four of these factors. The primary thrust of this program has been to compare methods of measuring growth by standard respirometric methods and by weight change and how these methods can best be used to predict the success of a commercial algae production pond using OTEC waste water.

## DOE/ERDA BIOFOULING AND CORROSION CONTRACTS

**Fouling and Corrosion in OTEC Heat Exchangers**

*Investigators: J. Fetkovich, Carnegie-Mellon University; F. Munchmeyer, UH, Mechanical Engineering. Agency ($): NSF/ERDA ($246,000). Year: 1976.*

APL test section under test at NELH surface sea water pumping facility.

One of the essential elements in demonstrating the economic feasibility of OTEC is to establish that biofouling and corrosion can be held in check for the life of the plant without adding excessively to the capital or operating costs. Studies of fouling and corrosion must be done in the ocean under conditions approximating those expected to exist in practice. Test apparatus, consisting of heat exchanger tubes operating under various conditions of water flow velocity and utilizing different materials and antifouling methods, is operated submerged in the ocean at Ke-ahole Point.

The first ocean data for the ERDA biofouling and corrosion program were obtained in the waters off Ke-ahole Point during the summer of 1976. These data gave the first known indications of the rate at which heat exchange, between ocean and an OTEC power loop, will degrade. The indications are favorable; the rate of degradation is believed to be low enough to yield favorable technical and economic predictions.

The second set of data for this ERDA program was obtained between February and July 1977. The experiments were designed to confirm the 1976 results and also to inquire into heat exchange tube cleaning. Experiments of this nature are subject to a large number of uncertainties; however, the 1977 effort did confirm the 1976 results, adding credibility to the OTEC concept. The cleaning data were also encouraging, but only one experiment was conducted.

**OTEC Heat Exchanger Biofouling Experiment**

*Investigators: James H. Jones, NELH, Peter P. Pandolfini, Applied Physics Laboratory, Johns Hopkins University. Agency ($): Sea Grant ($53,591), MAC ($15,000).*

This contract deals with the investigation of the effects of biological fouling on the outside of APL OTEC heat exchanger elements, as tropical ocean water flows continuously through the test sectior The Applied Physics Laboratory designed and built the test section and the experimental measuring equipment; NELH provided a test sit uncontaminated tropical seawater typical of an OTEC environment, an NELH operates and conducts the tes in cooperation with APL. The tests, which began in June 1977, measured the water-side heat transfer coefficient as a function of time at th flow rate of 3 fps under both light ar dark conditions. The initial results o these tests indicate that the fouling coefficient built up to average values near 0.0005 in 6 weeks. These result are consistent with other experimental data taken independent of this project at the NELH site.

**NELH Uncontaminated Surface Seawater Supply System**

*Investigator: James H. Jones, NELH. Agency ($): DPED ($65,000)*

The initial impetus for this system was to supply water for the APL-OTEC heat exchanger biofouling experiment. However, the need for a large volume, reliable water supply system became clear as the OTEC program began to encourage experiments designed to obtain data on heat exchanger corrosion and biofouling with OTEC-type surface water. A system was designed consisting of two 12-inch PVC pipelines running from a depth of 10 feet below sea level to the pumping facility 270 feet inland. The seaward end of the pipes is protected by a seven-ton steel structure secured to the basalt cliff. Two high-capacity suction pumps can provide a total of over 3,000 gpm of seawater continuously.

**Consolidated Oceanographic and Meteorological Data for Four North Pacific OTEC Sites**

*Investigator: Karl Bathen et al., UH, Ocean Engineering. Agency ($): State of Hawaii ($4,500).*

This report was prepared in answer to a request from NELH to review historical data and compare oceanographic conditions at potential OTEC sites in the eastern, central, and western tropical Pacific Ocean. The goal of this data review was to determine for each of four sites 5° lat. x 10° long., the characteristic annual limits and potential extreme conditions of local meteorology, $\Delta T$ over the 0- to 3,000-foot depth, initial profiles of salinity and local circulation, sea state, bathymetry, tides, and biota. A rough ranking of these four sites giving equal weight to each one of the eight criteria is: Southern Hawaiian Islands (upper left-hand corner of rectangle is 20°N, 160°W); Western Tropical Pacific (20°N, 140°E); Central Tropical Pacific (5°N, 165°W); and last, Eastern Tropical Pacific (15°N, 100°W).

**Site Selection Bathymetry Survey, Ke-ahole Point, Hawaii for Deepwater OTEC Pipeline**

*Investigator: Edward K. Noda, UH, J.K.K. Look Laboratory. Agency ($): DPED ($35,000).*

This field survey filled the need for detailed, precise information about the bathymetry offshore the NELH Ke-ahole site. Specifically this survey determined bottom conditions which would have a major impact on the design and construction of a deepwater pipeline. Such questions as the existence of small canyons, cliffs, abrupt changes in slope, and the position of an optimum corridor were carefully investigated.

High accuracy positioning data are required to provide this information from a surface vessel survey. An Electronic Positioning System providing instantaneous readouts with an accuracy of ±3 meters was utilized. A shallow-water, high-frequency surface-fathometer was used to depths of 70 meters, with a lower-frequency, towed-fathometer used from 70 meters to 900 meters depth. Detailed results are available from the NELH office.

Four submersible dives to 370 meters were made along the most probable track. These dives included visual observations and photographic recording of the bottom conditions and biota.

**Field Observations of Ocean Currents, Temperature Profiles, and Surface Plankton off Ke-ahole Point, Hawaii**

*Investigator: Karl Bathen, UH, Ocean Engineering. Agency ($): State of Hawaii ($2,400).*

Ocean currents in the near-surface waters (30-ft. and 51-ft. depths), benthic waters (900-ft., 2,000-ft., and 2,200-ft. depths), ocean temperatures both in the near-surface and benthic waters, plus plankton biota and productivity were observed over a one-month period between mid-September and mid-October 1977 off Ke-ahole Point, Hawaii. The stations chosen are located in the area off this coast that has been considered a prime candidate site for continuing OTEC studies. A total of 529.4 hours of current-meter data, at sampling intervals varying between 14 seconds and 3-3/4 minutes, plus several hours of biological samplings was completed. The intent of the work was to describe the flow characteristics off Ke-ahole Point, as it occurs simultaneously in the near-surface and benthic depths and from the near-shore (300 feet from shore) to offshore (6,030 feet from shore) waters. In contrast to the near-surface flows, the benthic currents were weaker, maximum flows over four stations ranging from 0.3 to 0.5 knots. *In situ* recordings of water temperature, both inshore, near-surface, and offshore benthic, showed that temperatures in the near-surface waters varied the most diurnally (to 0.7°C). Primary productivity rates were extremely low; the vertical distribution to carbon fixation rates suggests a photic zone depth of *ca* 90m below which rates show a strong truncation. The vertical distribution of productivity indices shows an exponential decline with depth. The similarity of this pattern with that of light attenuation, the overall low values commensurate with low light levels, and the similarity of the decay

constants (-0.03) for both productivity indices and light attenuation indicate that light availability was exerting a strong influence on the phytoplankton dynamics at the time of this investigation.

## CONTINUING STUDIES 1978-ON

**Operational Support for Natural Energy Laboratory of Hawaii**

*Investigator: William Coops, RCUH. Agency ($): Hawaii State Energy Resources Coordinator ($92,000).*

This support is to provide the following three functions for the NELH: administration, grant solicitation, and laboratory operations. The administration is continued under the auspices of the RCUH. The operations include the cost of maintaining and operating facilities at the Kona field office, communications, and authorized support in project co-ventures. The NELH grant solicitation is continued as a joint HNEI/NELH effort with the NELH Board of Directors exercising final authority.

**OTEC Heat Exchanger Biofouling Experiment**

*Investigators: Paul Yuen, James H. Jones, HNEI; Peter P. Pandolfini, Applied Physics Laboratory, Johns Hopkins University. Agency ($): Sea Grant ($52,477); DPED ($32,874).*

The basic objects of this study remain the same: the identification of marine life causing biofouling on the water side of APL/OTEC heat exchangers and a measurement of the loss of heat transfer as it affects the overall efficiency of the heat exchangers. However, the methods have been modified as a result of data obtained during the past year. The time period for each measurement in the series has been extended from three weeks to—in some cases—as long as four months. In addition, techniques for *in situ* cleaning of the water side during full-flow conditions and during no flow are being investigated.

**Fouling and Corrosion in OTEC Heat Exchangers**

*Investigator: F. Munchmeyer, UH, Department of Mechanical Engineering. Agency ($): DOE ($294,000).*

A third set of experiments was started in December of 1977 using alternate heat exchanger tube materials and seeking significantly more data on heat exchanger cleaning. Biological quality of tube deposits and corrosion of heat exchanger materials are being analyzed and reported on in addition to the heat transfer loss data for the new materials.



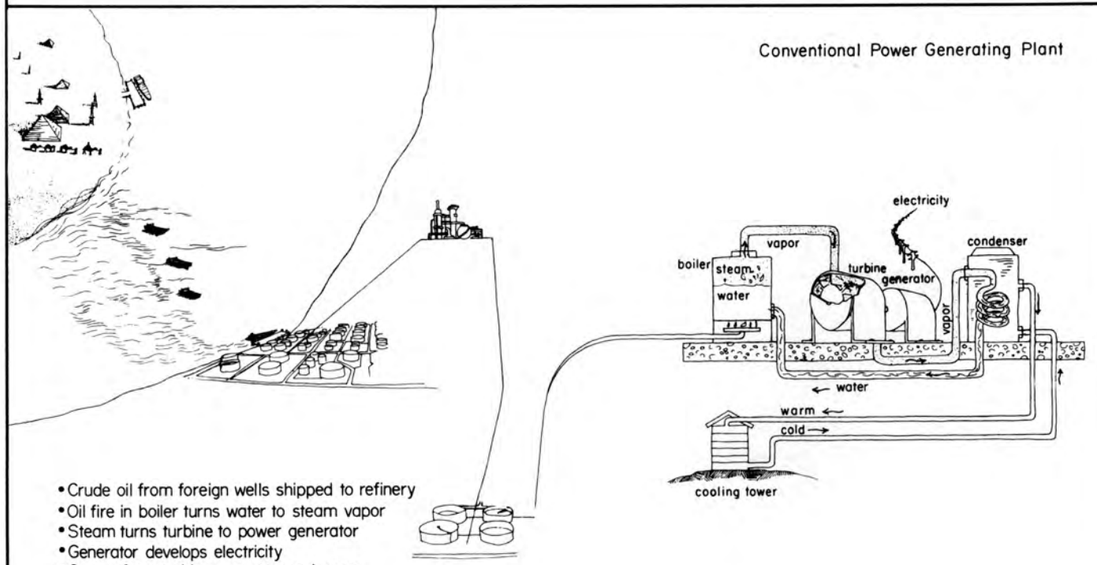
# Budget Summary/1972-1978

## OCEAN ENERGY RESEARCH PROJECTS AND DEVELOPMENTAL FUNDS EXPENDED IN HAWAII

| Project | Year | County of Hawaii | State | Federal | |
|---|---|---|---|---|---|
| Site Selection | 1972 | $ 5,000 | $ 5,000 | | |
| NELH Development | 1974 | 50,000 | 50,000 | | |
| OTEC Floating Structure | 1975 | | 9,725 | $ 111,594 | SG |
| Ocean Environment | 1975 | | | 58,000 | ERDA |
| Ocean Environment | 1975 | | 10,000 | | |
| NELH Development | 1975 | | 58,000 | | |
| Ocean Environment | 1975 | | 20,000 | 76,000 | SG |
| Ocean Environment | 1975 | | | 36,000 | ERDA |
| Pilot Study | 1976 | | 6,686 | 100,000 | ERDA |
| OTEC Fouling and Corrosion | 1976 | | | 100,000 | ERDA |
| OTEC Fouling and Corrosion | 1976 | | 7,598 | | |
| NELH Ocean Survey | 1976 | | 25,625 | | |
| Wave Energy | 1976 | | 45,000 | | |
| Ocean Biomass | 1977 | | 10,000 | | |
| OTEC Fouling and Corrosion | 1977 | | | 246,000 | ERDA |
| OTEC Fouling and Corrosion | 1977 | | 45,000 | 53,591 | SG |
| NELH Site Development | 1977 | | 65,000 | | |
| Ocean Environment | 1977 | | 4,500 | | |
| NELH Ocean Survey | 1977 | | 35,000 | | |
| NELH Ocean Survey | 1977 | | 12,400 | | |
| OTEC Fouling and Corrosion | 1978 | | 32,874 | 52,477 | SG |
| OTEC Fouling and Corrosion | 1978 | | | 294,000 | DOE |
| **Total** | | **$55,000** | **$442,408** | **$1,017,662** | |

SG Sea Grant
ERDA Energy Research and Development Agency, became DOE in 1978
DOE Department of Energy

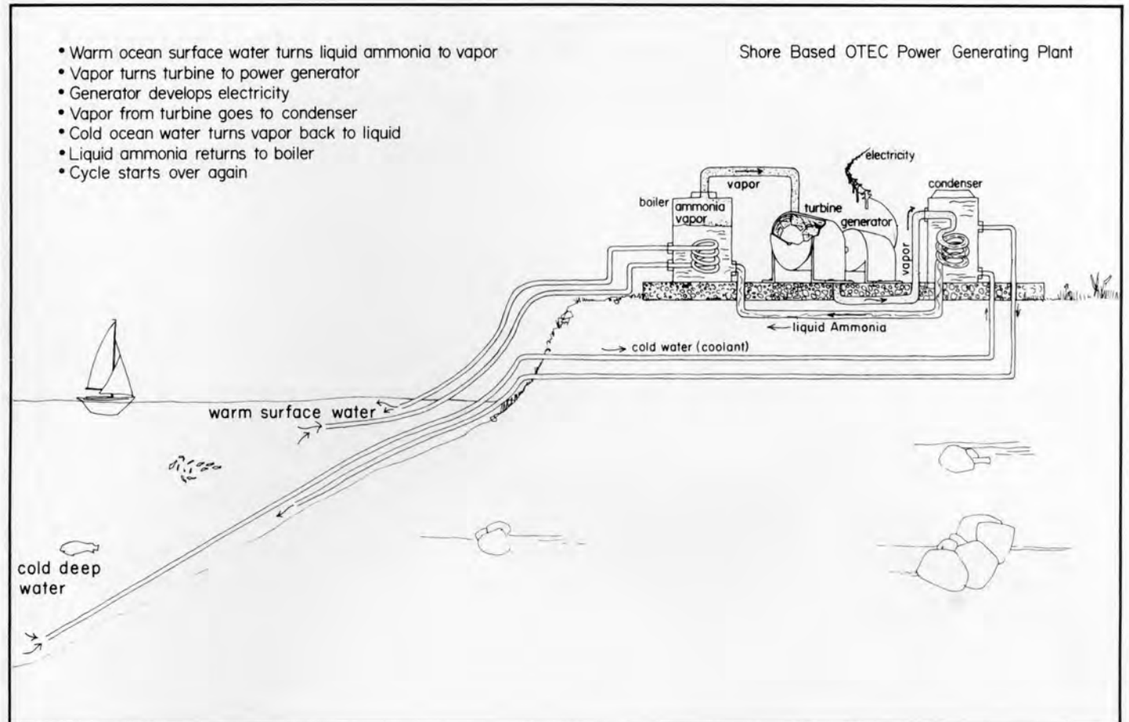
# What is Ocean Thermal Energy Conversion (OTEC)?

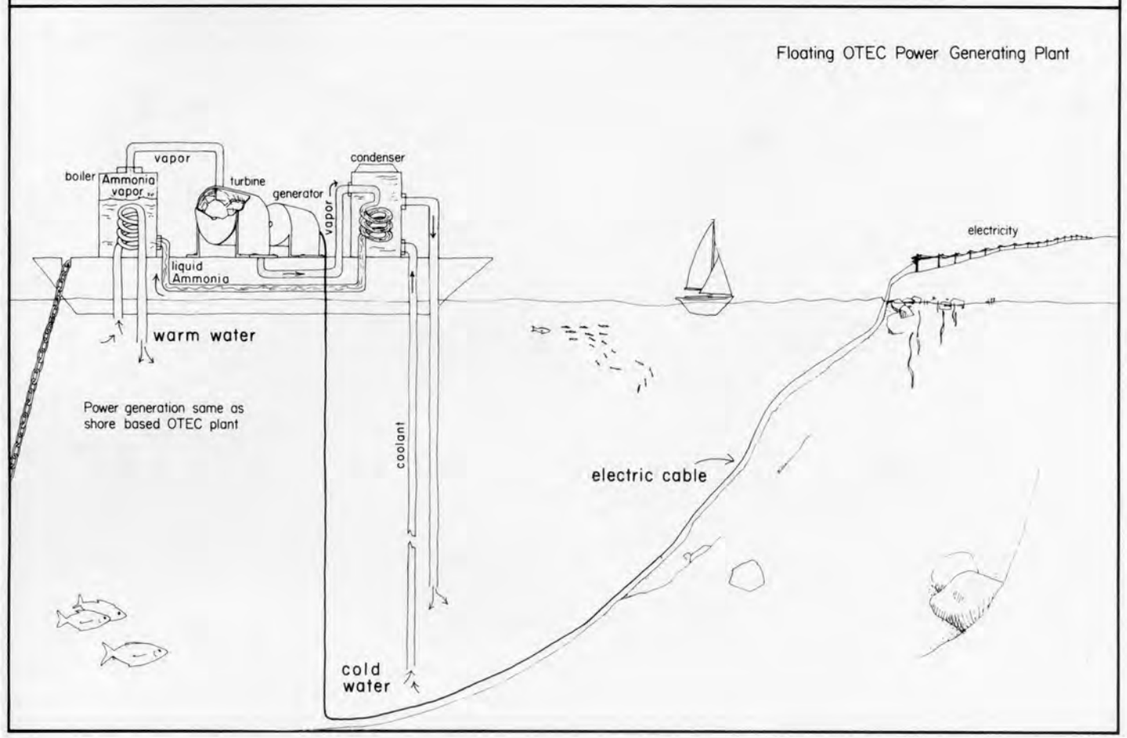



- Crude oil from foreign wells shipped to refinery
- Oil fire in boiler turns water to steam vapor
- Steam turns turbine to power generator
- Generator develops electricity
- Steam from turbine goes to condenser
- Cold condenser turns steam vapor back to vapor
- Water from condenser returns to boiler
- Cycle starts over again



- Warm ocean surface water turns liquid ammonia to vapor
- Vapor turns turbine to power generator
- Generator develops electricity
- Vapor from turbine goes to condenser
- Cold ocean water turns vapor back to liquid
- Liquid ammonia returns to boiler
- Cycle starts over again



# Proposed Plan for Mini OTEC