1991
Annual
Report

NATURAL ENERGY LABORATORY of HAWAII AUTHORITY

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MESSAGE FROM THE CHAIRMAN

Keahole Point, including the lab, and the cluster of pre-commercial and commercial aquaculture enterprises, is one of the most fascinating places in the islands. The array of commercial products and the even greater spread of new products and applications of the uses of deep, cold sea water under development are exciting in the potential they hold for brisk economic growth.

The five commercial companies continue to supply Hawaii and other markets with products noted to be cultured in the "pure deep sea water from Keahole Point." One of these companies – Cyanotech – ships their primary product, Spirulina, as far away as Germany. The availability of the deep sea water resource gives all of the companies located at Keahole Point the advantage of freedom from the concerns of possible toxic contamination which has become prevalent in the fisheries of the world. Ethanol production and Freon recycling using the intense sunlight and cold sea water in distillation processes have proven technically feasible during this past year. Agreements for the initiation of two new major non-aquaculture research projects have been concluded. Scientists from the University of Kiel in Germany will be assessing new technology for the electrolytic production of hydrogen, and the concurrent extraction of uranium from sea water. University of Hawaii physicists will be preparing for the installation of an array of detectors moored to the deep ocean floor just offshore that act as a telescope for capturing the passage of the mysterious sub-atomic particles, muons and neutrinos. As they pass through ocean water, a faint glow of Cherenkov radiation signals the detectors and the data is transmitted back to NELHA along a specially designed cable passing under the surf zone through a slanted bored hole drilled for this purpose.

Because of continued permitting difficulties, the commercial geothermal plant located adjacent to our Puna Research Center has been delayed. Until that plan is in operation,

there is no feasible way for the HGP-A well to flow and provide the heat needed for non-electrical use projects. In the interim, the site has been utilized for research in downhole heat exchangers and as a staging area for the scientific observation holes' analyses.

These and other projects have given us a worldwide reputation as a location for innovative research and commercial applications of our natural resources. We intend to exploit this position to draw global interest in the site's high technology research and commercial potential notwithstanding the slowdown in investments that looms ahead in 1992.

We believe that our overall goal of diversified economic development gives us the opportunity to help establish the future of the State in a way that will be beneficial to the people while protecting the beautiful environment of this island and its waters. The Authority has taken a large commitment of time, money and people – we intend to reward this commitment with the best possible return on the investment.

C. Barry Raleigh
Chairman of the Board

MESSAGE FROM THE EXECUTIVE DIRECTOR

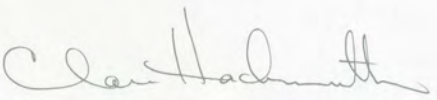
As a newly established entity, the Natural Energy Laboratory of Hawaii Authority was challenged with continuing the success of NELH and HOST Park while combining the two organizations into a world class facility for diversified economic development at Keahole Point. Our past year's achievements in reaching this goal as described in this report reflect the variety of projects currently in operation. The array of research, demonstration and commercial projects using the available unique resources continues to expand as the possibilities become known throughout the world.

NELHA is an excellent example of the State's efforts to diversify the economy and foster the development of ocean related technologies including renewable energy and aquaculture. The synergism between the Authority and the tenants provide an atmosphere of exciting potential, as we work together to advance each new entrepreneurial venture toward commercial success and applaud the exciting results of research activities.

Today we are aggressively seeking new projects for NELHA that take full advantage of the facilities natural resources, technical base, and select group of talented scientists, technicians, and administrators. We will continue to operate our internationally recognized facility at Keahole Point in an environmentally conscious manner as our tenants explore innovative uses of the deep sea water and the intense sunlight. We are looking forward to the re-establishment of projects employing the non-electrical use of the

geothermal resource at the NELHA Puna site. The potential for these projects was just being recognized when the power plant was shut down. Other sources of geothermal heat are currently being considered.

The number of projects which are presently requesting approval promises a very busy future. We welcome the challenge and look forward to the success of all of our tenants – their success is our success.



Clare Hachmuth
Executive Director

OUR ASSETS

SERVICES

1. NELHA services are tailored to fit each tenant. From clerical support to rental of trucks or cranes, generators or aquaculture tanks. Also provided for tenant protection is an eight-acre fenced compound for research and development projects and security guard service off hours and holidays.

2. Our support facility consists of over 4,000 square feet of laboratory space, outdoor wet laboratory, conference room, library, restrooms, shops and an industrial warehouse.

3. The administration building offers cost effective high technology communication systems.

4. Postal services are provided for tenants' convenience.

5. Ocean Water Systems (see chart below)

RESOURCES

The Natural Energy Laboratory of Hawaii Authority is uniquely suited to play the lead role in developing high technology and alternate energy business opportunities for the State of Hawaii.

1. Site Conditions

Planned subdivision including a full range of infrastructure: access roads, potable water, electric power, ocean water, intake and distribution pipes, pumping stations, disposal systems, groundwater quality monitoring wells and a planned return ocean water pipes.

2. Ocean – Environment

Steep ocean bottom gradient makes possible the tapping of deep, cold waters at depths ranging from 50 feet to 2,200 feet. This ocean water is of significant purity and has a high nutrient content.

Pipeline Description	Surface Sea Water	Deep Sea Water
12-inch diameter	1,200 GPM	1,000 GPM
18-inch diameter		3,000 GPM
40-inch diameter		13,300 GPM
28-inch diameter	9,600 GPM	
24-inch diameter	4,000 GPM	

3. Location of NELHA

a. NELHA is adjacent to a major airport and within a relatively short distance from a deep harbor.

b. Established cultural and business links to Asia and other Pacific countries.

Left: Solar desalination experiment

c. Broad base population with bilingual abilities.

d. Central Pacific location and unique time-zoned position.

e. Commercial lease rates equal to or substantially less than spaces in approximate region.

4. Electrical System

The NELHA electrical system includes underground lines, distribution equipment, duct lines and roadway lighting.

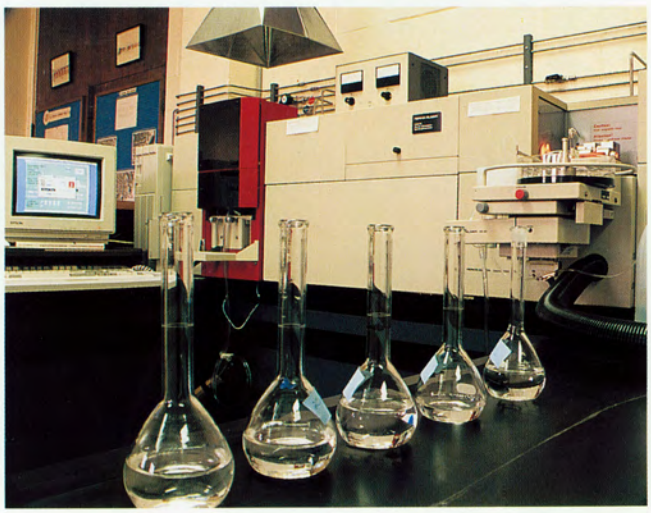
EXPERTISE

1. Water Quality Laboratory

The NELHA Water Quality Laboratory is staffed with professional chemists, bacteriologists, and trained technicians. The commitment to excellence by each staff person, combined with a wide array of state of the art analytical technologies, generates data of maximum quality. The laboratory has become a bench mark in the environmental water quality analysis industry and is now being used by other state agencies for both analytical chemistry and bacterial assays.

2. Scientific support is provided in the fields of ocean and atmosphere environmental monitoring and ocean energy applications.

3. Technical support is provided by a Hawaii-licensed engineer, electricians, mechanics and divers.



Right: Atomic Absorption Spectrophotometer at the Water Quality lab

Opposite page: Keahole Point shoreline

This year's annual report is slightly longer than usual. The Natural Energy Laboratory of Hawaii Authority (NELHA) proceeded through a reorganization process that was painstaking and habit-breaking.

The year had an energy that was all its own. The expectations of a new order shouldered up against the old. There were weeks of such profusion. And there were moments in triumph that froze in time as we struggled to absorb the change.

Healing took place too – less controlled but no less significantly.

This is the year of resolution, the time we look forward and backward at the same time. For our part, we will view this year in only one way: as full of hope and promise, a time when everything is possible.

The Staff of NELHA

YEARLY HIGHLIGHTS

ADMINISTRATIVE

The Administrative Section provides administrative support, personnel assistance, internal management, fiscal services, contract-management, permit processing and marketing functions. This office also coordinates and implements procedures with the Department of Accounting and General Services, the Department of Land and Natural Resources, Department of Transportation, Budget and Finance, the Legislature, and all County and Federal agencies.

Eleanor Mirikitani
Administration Manager

ACCOMPLISHMENTS 1990-1991

Permits

- U.S. Army Corps of Engineer 18-inch warm water pipeline
- SMA Permit approval for Construction of pipeline
- Geothermal Well Modification
- Shoreline Certification
- Application to reconsolidate and subdivide
- Environmental Project Review

Contract-Management

- Completed and executed 45 outside services contracts
- Completed drafts of five subleases

Personnel

- Established 31 new positions
- Processed 2,132 personnel transactions
- Filled 28 positions
- Updated departmental organizational charts
- Created and drafted Personnel Handbook for employees
- Drafted Administrative Rules

Fiscal

- Closed RCUH operating funds and accounts
- Completed transfer to State by on line BSR
- Establishment of in house petty cash controls
- Establishment of purchasing procedures
- Implementation of special fund receipts and disbursements
- Implementation of tenant collection controls

Marketing

- Continued profile marketing campaign for NELHA's services and investment opportunities

Right: NELHA's Administration building

- Publication of various articles and newsletters
- Presentations and speeches
- Participation in Ocean Expo 90, Pacific Science Congress, County Farm Fairs and the Kona Coffee Festival
- Continued weekly guided and VIP tours
- Assisted in Career Day Programs with the high schools

ENGINEERING

The Engineering Section has the responsibility of supervision and performance of planning, design, construction, inspection of the facilities, structures and equipment.

John Sullivan
Engineering Manager

ACCOMPLISHMENTS 1990-1991

Administration

- Conducted cost analysis of sea water systems operation
- Automated the engineering section with Computer Aided Design and Drafting (CADD) system

Capital Expansion Projects

Planned and designed the following capital improvement projects:
- Eight-inch fresh water line extension
- 28-foot x 40-foot storage building for pipe fittings
- Sea water air conditioning for Administration Building
- Gas system for Water Quality Laboratory
- Preliminary plans for new laboratory building
- Completed the conceptual engineering for surface sea water distribution system and pipeline/utility access corridor for new surface sea water and deep sea water intake and pumping

Electrical Power Projects

- Expanded the electrical power distribution system by installation of six new meters and upgraded service to three tenants in the compound expansion area
- Upgraded 12-inch deep sea water power cables from the Water Quality Laboratory to the 12-inch off shore pipelines
- Rebuilt and modified 10-kw generator
- Assisted tenants in all aspects electrical and electronic systems including: panel and

Right: Pumping station

Opposite page: Constructing a disposal trench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transformer work, pumps and controls, emergency generator, system load balancing, installation of circuits and circuit breakers
• Implemented and expanded the telephone system
• Upgraded the existing computer applications

OPERATIONS AND MAINTENANCE

The Operations and Maintenance Section is responsible for all of the fresh and sea water systems, fixed and mobile equipment, maintenance of the facility, security, roadway, parking lot, inventory, and all offshore maintenance including dive operations. The equipment provided to the tenants as part of the services range from 15-ton 4WD hydraulic cranes, diesel generators, compressors, large vacuum pumps, to passenger vans, trucks and dive boats.

Jan War
Operations Manager

ACCOMPLISHMENTS 1990-1991

Water Systems

• Refurbish compound and deep sea water and surface sea water manifolds
• Refurbish 16-foot fish tanks with new liners and plumbing
• Replace 28-inch surface sea water intake with fiberglass
• Install 28-inch x 24-inch deep sea water crossover
• Install 9,000 feet of 4-inch PVC pipe for temporary fresh water lines

Buildings, Facilities and Grounds

• Hired three security/utility workers
• Hired a maintenance mechanic
• Installed sea water air conditioning system for Administration building
• Reworked all shop areas, installed secured tool gauge area
• Refurbished all electrical distribution panels
• Built a new expansion for water chemistry laboratory
• Refurbished compound fencing
• Enclosed conference and office space
• Installed shelving, storage racks in mezzanine
• Repainted and carpeted all first floor office and hallways
• Excavated and fenced two mariculture disposal trenches

Right: Divers maintaining submerged pipeline

Opposite page: Above ground sea water distribution pipes

• Cleaned entire coastline and beach recreation area
• Assisted tenants in landscaping their premises
• Constructed 1,120 square foot storage building in new boneyard

Vehicles and Equipment

• Purchased Caterpillar 446 backhoe with hydraulic ram
• Purchased 125 CFM portable air compressor
• Purchased new shop tools and assorted support equipment
• Purchased Ford LTD Station Wagon
• Registered all vehicles with State plates and emblems
• Refurbished boats and outboard motors
• Overhauled and refurbished three hydraulic cranes

Puna Geothermal Facility

• Refurbished entire compound fencing
• Dismantled remaining power plant structures and equipment
• Installed new siding and roofing for research center
• Cleaned entire compound
• Fenced old silica settling pond
• Filled and graded discarded silica pond
• Rebuilt potable water system for research center
• Reworked and logged HGP-A well casing to 3,000 feet

SCIENTIFIC AND TECHNICAL

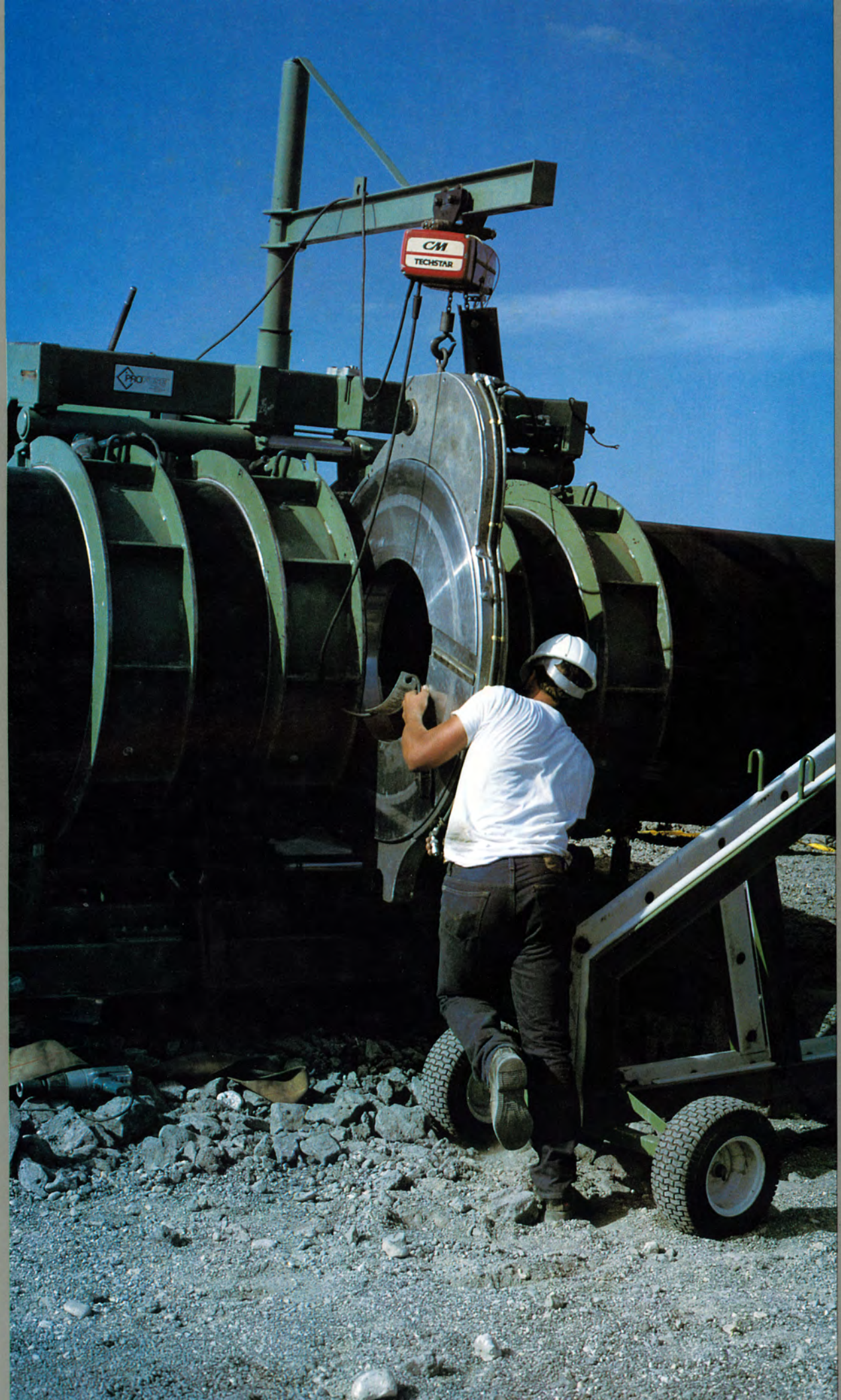
This section's program is responsible for sample collection, analysis, data recording, and testing of sea water, ground water, and anchialine pond waters, as well as monitoring benthic and midwater biota in the ocean and the anchialine ponds. It also monitors other environmental variables which may affect our water resources. Regulatory requirements from other State programs including the Department of Land and Natural Resources, Office of Environmental Quality Control, State Department of Health and County agencies are complied with and reported on.

Tom Daniel
Scientific/Technical Program Manager

ACCOMPLISHMENTS 1990-1991

• Hired and trained a chemist
• Completed the Water Quality Laboratory Expansion
• Installed a Perkin Elmer 5100Z Atomic Absorption Analyzer
• Acquired and completed contracts with the State Department of Health Blue Waters Program by providing analytical chemistry services
• Initiated biota monitoring program for the Comprehensive Environmental Monitoring Program (CEMP)
• Completed the CEMP quarterly reports and annual report
• Installed a total organic carbon (TOC) analyzer and established TOC as a routine analysis

Opposite page: Fusing polyethylene pipe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PROJECTS

OTEC-RELATED RESEARCH PROJECTS

CLOSED-CYCLE OTEC:

Alcan International Heat Exchanger Research

Since April of 1986, ALCAN Aluminium, Ltd. of Canada has performed research at NELHA investigating the possible use of aluminum in the large heat exchangers required for power generation using the relatively small temperature difference between the ocean's deep cold water and the warm tropical surface water. Warm and cold sea water flow through several multitube heat exchanger elements which are monitored for heat transfer and corrosion. ALCAN personnel control system parameters and operate the data collection system by telephone modem from their Kingston, Ontario, Canada laboratory.

In the process of designing a pilot plant to be constructed at Keahole Point, ALCAN and their partners from Marconi Division of the General Electric Company (GEC) of Great Britain, recognized that great cost savings could be achieved by replacing the conventional shell-and-tube heat exchanger design with modern "roll-bonded" technology. Subsequent testing and design work have indicated that this technique will work well and that it will reduce the cost of the heat exchangers, formerly about 1/3 the overall cost of an OTEC plant, by 80%.

ALCAN/GEC, working in a consortium with Hawaiian-based companies, now plan to demonstrate this new technology by constructing an initial module of a generating facility using existing sea water supplies at NELHA. Present plans call for this plant to be on-line in 1992. The consortium views this as the first step in the construction of a one-half megawatt pilot plant at Keahole Point. The one-half megawatt plant will use new sea water pipelines to 3,000 foot (1,000 meter) depth to provide the colder water required to make the power generation more efficient.

OPEN-CYCLE OTEC:

Net Power Producing Experiment (NPPE)

Since 1987, the U.S. Department of Energy has been sponsoring the Pacific International Center for High Technology Research (PICHTR) in "open-cycle" OTEC investigations. Experiments using HMTSTA (Heat and Mass Transfer Scoping Test Apparatus) to obtain data in support of the open-cycle OTEC evaporator and condenser design were completed in 1989. These data have now been incorporated, with the assistance of the Solar Energy Research Institute (SERI), into the design of the NPPE. The developers intend to have the 210-kw gross power OTEC plant on-line and producing 40-kw net output (after subtracting sea water pumping and other parasitic energy costs) by the last quarter of 1992.

OTHER ENERGY-RELATED PROJECTS

Horizontal Directional Drilling Demonstration

Horizontal Directional Drilling Demonstration was established by the 1990 Hawaii State Legislature which appropriated $2.5 million for drilling exploratory holes. This demonstration is testing the feasibility of using horizontal drilling and reaming technique for tunneling through the coastline to provide conduits for sea water and other utilities.

NELHA working with the Hawaii Institute of Geophysics at the University of Hawaii at Manoa, has contracted with a horizontal drilling company out of Olathe, Kansas to perform this exploratory program. The demonstration will begin in August of 1991 and expects to drill

Left: 40-inch pipeline deployment

several pilot holes from sites on shore to offshore destinations at diver depths of about 60-70 feet (18-21 meters). At least one of the holes will be reamed to a larger diameter. One of the interesting research parts of the program will analyze the work of a remote vehicle which can take over diver roles when the drill breakout point is at deeper depth. The demonstration will also produce cost data to clarify how this technology competes with traditional methods of deployment in Hawaii. The geological situation at NELHA is considered to be a "worst case" scenario. Success here should prove that similar shafts can be drilled in any ground formation.

Solar Desalination for Milolii

An innovative project recently completed at NELHA by the Hawaii County Economic Opportunity Council has developed a solar powered desalination system for the isolated community of Milolii. The prototype constructed at NELHA generated 10-20 gallons per hour of clean fresh water by blowing air past a spray of sea water heated in a solar collector. Fresh water then condenses from the hot saturated air as it flows past condensers cooled by incoming water. The pumps and air fans for the apparatus are powered by photovoltaics, thus providing a "low-tech" solar powered desalination system which will soon be in operation in Milolii.

Sogi International

On a grant from the DBED, Sogi International has completed construction on its solar powered 1,000 gallon ethanol still for production of vehicle fuel. The sun provides the heat and the cold water improves the condensation efficiency, resulting in a significant energy savings. Ethanol can be used in vehicles by making a slight modification, and it burns much cleaner than gasoline. Sogi International produced its first 60 gallons of ethanol in October 1990. They have successfully designed and begun testing a 100% ethanol powered vehicle with programmable electronic fuel injection. The company hopes to sell 10% of the vehicle fuel in Hawaii within the next 10 years.

Thermal Recovery Systems

Formed to develop the concept of a freon recycling system, the project utilizes the abundant sunlight at NELHA to power a solar still which cleans the impurities of used or "dirty" freon from air conditioners. The solar still boils the "dirty" freon, recovered from commercial air conditioners after years of use, and then uses the cold sea water to condense the purified freon for resale. The resultant product is equivalent in purity to that originally obtained from the manufacturer and is being resold to hotels and other air conditioning users.

Cold Water Air Conditioning

Cool air, produced by the cold sea water flowing through heat exchangers, is maintained throughout NELHA buildings. The Water Quality Laboratory has taken advantage of this resource since 1986, and the Administration building was converted to a similar system in 1991. The staff of NELHA performed the needed conversion of the building by recycling material from previous projects performed at NELHA. The cold sea water used in this system is returned to a pipeline designated for aquaculture. This process offers significant cost savings over standard electrical air conditioners and may prove to be valuable for future hotel developments in Hawaii and elsewhere.

Environmental Measurements

NELHA remains an official National Weather Service Observation station, reporting daily readings of temperature and rainfall. Since January 1985, a data logger system has provided continuous measurements of many environmental variables. Hourly averages of direct and diffuse insolation, air temperature and humidity, surface and deep sea water temperatures, wind vector

speed and direction as well as daily averages, maxima and minima of all these variables, and daily total rainfall are recorded on tape cassettes. These data are processed to produce summary charts and tables for distribution to interested researchers and potential NELHA users.

SEA WATER UTILIZATION PROJECTS

Ever since NELH was founded in 1974, it has been recognized that some of the potential by-products of OTEC may be economically significant. The initial 12-inch deep sea water pipeline was installed by the State of Hawaii using aquaculture capital improvement funds. Some early projects were sponsored by the University of Hawaii Sea Grant College Program to investigate the growing of nori (the seaweed used for wrapping sushi) in the cold sea water. Many private companies have since done research on growing various organisms, and several of them are now in various stages of commercial development.

The cold sea water has three properties which make it desirable for aquaculture:

• ***Cold temperature:*** Since the sea water is colder than required for growing any of the species studied, it can be used to maintain or change the water temperature in the culture systems economically and reliably by regulating the water flow rate or by mixing deep sea water with surface sea water.

• ***Nutrients:*** The deep sea water has high concentrations of dissolved inorganic nutrients (nitrates, phosphates and silicates). The low concentrations of these nutrients in surface waters limit plant growth in tropical oceans. Deep-water nutrients contribute to the successful growth of nori, kelp, diatoms and other algae in deep-water culture systems.

• ***Purity:*** Since the deep sea water comes from below the photic zone and has been out of contact with the surface for centuries, it contains few living plants and very low levels of bacteria. This has proven useful in culturing larvae of various marine mollusks which are particularly susceptible to the pathogens usually present in surface waters. The virtual absence of competing viable plant cells also facilitates the growth of pure algae cultures.

Right: The Cyanotech facility

COMMERCIAL PROJECTS

Cyanotech

Cyanotech Corporation from Woodinville, Washington, in 1984 began experimentation and facility construction of a micro-algae farm. In 1990, they consolidated all company operations on land leased from NELHA. Cyanotech Corporation produces high value products from microalgae. The company currently produces two product lines: 1) Spirulina, used in the nutrition industry as protein and vitamin source and 2) phycobiliproteins, high value fluorescent pigments, used in the medical diagnostic industry.

Cyanotech now sells bulk Spirulina Pacifica™ to customers throughout the world. The most important development over the last year was the formation of a marketing subsidiary, Nutrex Inc. and the introduction of the company's own Spirulina consumer product, Spirulina Pacifica Gold Label™ tablets. Cyanotech now controls all aspects of Spirulina production from pond culture to tablet production and bottling at its NELHA facility.

Cyanotech is currently conducting research on developing two new phycobiliproteins for the medical diagnostic industry. These are potentially very high priced products selling for as much as $70,000 per gram. In 1992, Cyanotech hopes to begin a project which will allow completion of development work on beta-carotene production followed by commercial distribution of its beta-carotene product, Konatene™.

Dewani Lauro Marine Products

This company proposed to raise various edible seaweeds at a commercial facility located at NELHA. Final approval of their plans was granted in March 1990.

Hawaiian Sun-Dried Fish

Hawaiian Sun-Dried Fish began in 1988, with a local company and the assistance of the DBED's Energy Division. The company designed a series of lightweight aluminum-framed solar drying units for use at the NELHA facility. Taking advantage of the ideal weather conditions, electric energy requirements were eliminated and the product dried in a shorter time period than traditional oven methods.

Hawaiian Sun-Dried Fish has grown from producing 25 lbs. a week to approximately 150 lbs. per week. The company has experimented with several different species of fish as well as marinating sauces and has recently researched methods for drying several fruits.

Ocean Farms of Hawaii

Ocean Farms of Hawaii has conducted proprietary cold water aquaculture experiments at NELHA since 1982 and began operating as a commercial demonstration module in 1983. They are the largest tenant, leasing 21 acres, since their $20 million expansion in 1987. The aquaculture farm raises red abalone, sea urchin, giant kelp, king and silver salmon and oysters. The sea urchins, still in the development stage, are raised for the *uni* (the roe of the sea urchin, a valuable component of sushi). Abalone, oysters and salmon from Ocean Farms of Hawaii are being sold throughout Hawaii in restaurants and hotels.

Royal Hawaiian Sea Farms

Royal Hawaiian Sea Farms was begun in 1985 by a former researcher from a Sea Grant-sponsored project to grow nori. The rapidly growing company is now producing four varieties of Ogo (Gracilaria), Nori (Porphyra) and Ele Ele (Enteromorpha). The nutritious products sold by Royal Hawaiian Sea Farms can be purchased fresh year round in grocery stores or seafood markets in Hawaii and California.

Seatech Contracting Inc.

Seatech Contracting Inc. was founded in 1988 on Oahu. A field office was set up in 1989 at NELHA. The company's emphasis is on marine construction and commercial diving, specifically

associated with underwater piping or pumping systems. Seatech assisted in surveying, construction, deployment, inspection and repair of the pipelines that have been installed at Keahole Point and provided services for the companies at NELHA and the surrounding area. They recently completed offshore bottom surveying for the Slant Drilling project and plan to continue their assistance in that project as it progresses.

Uwajima Fisheries/Yonezawa Suisan,

Uwajima Fisheries/Yonezawa Suisan, a Japanese-based firm, began production of a type of flounder known in Japan as *Hirame* in 1988. The company developed technology to grow these sensitive fish through experimentation in the NELHA compound. They have developed a building, extensive raceways, pumping and plumbing systems on a one-acre site along the NELHA access road.

The company has selected and is maintaining broodstock for maturation and spawning of Hirame on site, but they presently transport fertilized eggs from Japan. They produce all live food organisms for larval fish, and pelleted feed for large fish, using a mixer and extruder on site.

Uwajima Fisheries is currently marketing 1.5 to 2.0 lb. Hirame locally to Honolulu distributors. Plans for future expansion include additional acreage.

RESEARCH PROJECTS

Aquaculture Enterprises

Aquaculture Enterprises began its project at NELHA in 1988 to develop a methodology for the culture of Atlantic lobster. Breeding projects, including hybridization and backcrosses, have been conducted with the American lobster, *Homarus americanus* and the European lobster, *Homarus gammarus*. Aquaculture Enterprises produces its own pelletized lobster food and has been experimenting with various components to improve health, growth and reproductive conditions.

A 12,000 square foot "greenhouse" expansion has been completed recently and is preparing for the first shipment of Maine Lobsters from New England for holding and resale. They are planning to use this method of introducing their company to the market while the Hawaii-reared lobster reach commercial production levels. Aquaculture Enterprises also plans for major expansion to 20 acres in the near future.

D/S Ventures

This project continues to test the possibility of culturing namako (edible sea cucumbers). Previous projects on Guam and elsewhere in the Pacific have been unsuccessful in achieving full larval development of these organisms. These researchers are testing whether the temperature control available, using the cold deep sea water, will allow implementation of all the growth stages in a culture system. The Kona businessmen who started the venture eventually hope to market live namako throughout the world.

Hawaii Cultured Pearls

Hawaii Cultured Pearls is culturing various species of pearl oysters in suitable mixtures of the warm and cold sea water supplied at NELHA. This project plans to expand soon to a commercial operation.

Hawaii Seafood Growers

Hawaii Seafood Growers began their research, in 1988 to grow land-based mahi or dolphin fish. The project was initially funded by NORAQUA, an aquaculture venture of a large Norwegian construction company. After NORAQUA terminated their aquaculture operations, several of the personnel formed Hawaii Seafood Growers and purchased the rights to the technology. They expanded the experimental operations and test marketed the product in Hawaii. They completed their research in the second quarter of 1991.

PUNA GEOTHERMAL FACILITY

Background

The Puna Geothermal Facility (PGF) consists of a geothermal well, a three-megawatt electric power plant, and a research facility located on four acres in the Kilauea East Rift Zone of the Puna District, 25 miles south of Hilo on the Big Island of Hawaii. The HGP-A geothermal well was started in December 1975, completed in April 1976, and successfully flashed steam in July 1976. In June of 1978 a contract was signed with the DOE for development and construction of a geothermal power plant. Following completion of the plant and several months of trials, commercial operation commenced in early 1982 and terminated in December 1989.

The HGP-A geothermal well produced about 80,000 pounds per hour of mixed steam/liquid flow and the power plant generated an average net power of between 2.0 and 2.5 megawatts. Noi'i O Puna Geothermal Research Center contains 2,000 square feet of laboratory space, 1,400 square feet of test pad and 25,000 square feet of compound area which is available for geothermal-related research and demonstration projections.

Specifications

The depth of the well is 6,450 feet (1,966 meters) and has one of world's hottest bottom hole temperatures at 676 F (358 C). The well produced 80,000 lbs/hr of mixed phase fluid (57% liquid and 43% steam) at a wellhead pressure of 175 psia and a surface temperature of 365 F (186 C).

Management

NELH assumed management responsibility for the facility in December 1985, and in November 1986 the federal DOE formally transferred title to NELH.

The Puna Geothermal Facility will continue to provide for by-product development through support of research projects which utilize geothermal heat. Negotiations are continuing with a nearby private geothermal power plant to provide fresh water which has been heated by geothermal brine. The HGP-A well will be available for monitoring of the area's geothermal resource. Like its sister facility in Kona, PGF encourages the further commercialization of successful research projects.

GEOTHERMAL R&D PROJECTS

Downhole Coaxial Heat Exchanger

The Downhole Coaxial Heat Exchanger (DCHE) project was initiated as a joint PICHTR and Japanese collaboration to investigate the commercial viability of the DCHE technology. This technology provides a method for transfer of the heat in the well to the surface by circulating fluid in a closed system. After seven days of continuous operation, the temperature of the outlet water was stable at a 13.5 degrees Celsius increase over the temperature of the inlet water. This data supports the theory.

Scientific Observation Hole Program

The Scientific Observation Hole Program (SOH) conducts site analysis of core and fluid samples recovered from observation holes. The objectives of this effort are to provide data that will be used in the assessment of Hawaii's geothermal resource base and in the development of identified geothermal reservoirs for electrical power production.

PAST RESEARCH HIGHLIGHTS

NELHA FACILITY

Mini-OTEC Demonstration
1/79 to 12/79
FUNDING SOURCE - State of Hawaii

Demonstrated net power production from closed-cycle OTEC. Generated > 10-kw net electricity on a floating platform moored in the NELH Offshore Research Corridor.

Argonne Test Project
7/81 to 9/87
FUNDING SOURCE - DOE/DPED, DOE funding via SERI since 7/83

Studied heat transfer monitoring, biofouling control (micro and macro) of closed-cycle OTEC, researched corrosion of candidate heat exchanger materials and analyzed incoming sea water. Found biofouling in warm sea water repeatedly reduces heat transfer to unacceptable level within 20 days. Chlorine levels as low as 70 parts per billion for one hour per day found to control the problem. Aluminum alloys show pitting corrosion in cold sea water, but not in the warm sea water.

OTEC Aquaculture: Trout and Salmon
1/82 to 11/84
FUNDING SOURCE - UHSG, MAC, DPED

Investigation in growing salmon and trout yielded > 0.5 lb. fish per gallon of deep cold sea water. It identified optimum temperatures, photoperiods and flow rates, and studied smoltification parameters for salmon. First to spawn trout successfully.

OTEC Chlorination
6/82 to 6/83
FUNDING SOURCE - HNEI

Researched the effects of low level chlorination on the marine food chain. Found that in tropical sea water chlorine kinetics differ markedly from other sea water, the reaction of the chlorine takes much longer than in temperate water, and only trace levels of halogenated organics are produced in chlorinated NELH sea water.

ALCOA Corrosion
1/83 to 1/85
FUNDING SOURCE - Alcoa

Studied the effects of corrosion in flowing sea water and the effects of brushing in warm and cold sea water on various aluminum alloys.

Heat and Mass Transfer Research
6/83 to 12/90
FUNDING SOURCE - SERI/DOE, PICHTR

Efficiency of spout evaporators and condenser in a sea water system are similar to those with fresh water in Colorado tests. They promise high efficiency, however, for open-cycle OTEC.

Gas Desorption Research
6/83 to 6/84
FUNDING SOURCE - SERI/DOE

Used a packed column to study composition of dissolved gases in sea water at various temperatures and pressures. The "height of transfer units" which measure the power required to remove dissolved gases are about 50% less with NELH sea water than predicted from fresh water data.

Mist-Lift Process
6/83 to 12/83
FUNDING SOURCE - SERI/DOE

Mist generator with sea water works well without clogging, and the vapor-mist coupling may provide up to 100-meters of lift from 20 degrees Celsius.

CWP/AST Phase III
4/83 to 5/85
FUNDING SOURCE - NOAA/DOE

Deployed and monitored a 1/3 scale Fiberglass-reinforced-plastic (frp) cold-water pipeline down a slope off Keahole Point. Data was collected on forces on the pipe and its foundation under varying environmental conditions.

OTEC Agriculture
1/84 to 6/84
FUNDING SOURCE - UHSG

Grew strawberries and various vegetables with fresh water condensing on pipes carrying cold sea water. Seasonal cycling can also be achieved by controlling water flow rate.

Giant Clam Culture
8/85 to 8/86
FUNDING SOURCE - Marine Animal Association, Waikiki Aquarium

Studied the effects of Hawaiian environment on giant clam growth.

Opihi Culture
10/86 to 1/89
FUNDING SOURCE - W.H. Magruder

Investigation and demonstration of opihi (Hawaiian limpets) growth. Opihi reproduced and grew well in sprays of deep sea water.

Macroalgae Investigation
5/86 to 1/87
FUNDING SOURCE - HNEI, ADP

Investigated the use of macroalgae to remove most of the excess nutrients from return sea water at NELH. Algae mats were found to be effective.

Phytoplankton Study
9/86 to 9/87
FUNDING SOURCE - Office of Naval Research
Studied the occurrence of a symbiotic cyanobacterium in the cells of certain diatom population in surface sea water.

Algal CO_2 Uptake
7/88 to 12/89
FUNDING SOURCE - EPRI
Studied the use of algae to remove carbon dioxide from fossil fuel gases. Hoped to develop ways to optimize algal CO_2 uptake.

Polyculture Experiment
11/88 to 1990
FUNDING SOURCE - Sea Farms of Hawaii
Demonstration and testing of a patent concept for a tank farm design. Allows for harvesting of multiple level tanks and to increase production density.

Microalgae Testing
5/90 to 1990
FUNDING SOURCE - Microbio Resources
Testing the growth of proprietary strains of *Dunaliella* and *Haematococcus* microalgae. To gather productivity data for these strains under the light and temperature regime at NELH.

PUNA GEOTHERMAL FACILITY

Bottom Heating System
4/86 to 4/88
FUNDING SOURCE - DOE, Private Donations
Utilizing the geothermal waste heat seed propagation and plant growth was significantly accelerated with heated soil. Commercial potential high.

Green Papaya Powder Drying
4/86 to 10/88
FUNDING SOURCE - DOE, Private Donations
Experimental dryer worked well with all types of fruits and the cost savings using the geothermal waste heat makes commercial potential high.

Lumber Drying
4/86 to 1/88
FUNDING SOURCE - DOE, Private Donations
Developed methods and drying schedules for local hardwoods. Drying was possible within four to five weeks.

Cloth Dyeing by Geothermal Steam
4/86 to 11/87
FUNDING SOURCE - DOE, Private Donations
Utilized flash brine to dye silks and experimented with local dye sources. Hawaiian steam produces brilliant colors and sets dyes fast in Japanese silk.

Hawaiian Glass Making
4/86 to 10/87
FUNDING SOURCE - DOE, Private Donations
Made glass from silica produced as a by-product from HGP-A well. Formula developed produced excellent art glass and was distributed to UHM and artists statewide.

Atmospheric Corrosion
12/86 to 4/87
FUNDING SOURCE - UHM
Identified corrosiveness of geothermal environment for better material selection. HGP-A corrosion is uniquely determined by physiochemical conditions of site environment. Corrosion rate accelerated by presence of hydrogen sulfide, chloride and sulfate ions at site.

Media Steam Sterilization and Drying
3/88 to 12/89
FUNDING SOURCE - DOE, Private Donations
Utilized the brine/steam to produce a growing medium for plant growth. Pasteurized potting mix comprised mostly of lava cinder and shredded coconut husks would be used as alternative to imported sterile soil from mainland.

Electrodeposition of Minerals
3/88 to 12/89
FUNDING SOURCE - DOE, Private Donations
Researched the use of liquid brine samples to produce mineral deposits via electrolysis. Sufficient trace minerals of calcium deposit on test specimens were found by this method.

Silica Bronze Casting
3/88 to 7/89
FUNDING SOURCE - DOE, Private Donations
Research developed techniques to separate, dry and wash silica from geothermal brine for use as a refractory material in bronze casting.

FINANCIAL STATEMENT 7.90 – 6.91

OPERATING FUNDS	STATE	FEES	TOTAL
Kona Facility			
• Operational Support	$1,528,800		
• Project Funding			
· OTEC Experiments			
· Aquaculture Projects		264,639	
· Other Projects		71,281	
· Department of Health Contract		39,652	
Kona Subtotal:	*$ 1,528,800*	*375,572*	*1,904,372*
Puna Geothermal Facility			
• Operational Support	$ 144,200		
• Project Funding			
· CGTP			
· Equipment Sales		550,000	
Puna Subtotal	*144,200*	*550,000*	*694,200*
TOTAL OPERATING BUDGET:	**$ 1,673,000**	**925,572**	**2,598,572**

CAPITAL IMPROVEMENT FUNDS	STATE	FEES	TOTAL
Kona Facility			
• Infrastructure Upgrades	$ 276,000		
• Pipeline Electrical	41,000		
• Equipment Replacement	25,000		
• New Projects & Expansions		695,000	
Kona Subtotal:	*342,000*	*695,000*	*1,037,000*
TOTAL CAPITAL IMPROVEMENT:			**$ 1,037,000**

APPENDIX A

PUBLICATIONS RESULTING FROM RESEARCH AT NELHA - KONA

Berger, Leslie Ralph and Joyce A. Berger, "Countermeasures to Microbiofouling in Simulated Ocean Thermal Energy Conversion Heat Exchangers with Surface and Deep Ocean Waters in Hawaii," *Applied & Environmental Microbiology*, June 1986, p. 1186-98.

Brewer, Wm. A., Jack P. Huizingh and Jane E. Sexton, "Hawaii's OTEC Park Triggers High-Tech Aquaculture Development," *Info-Fish Marketing Digest*, NO 1/85, p. 18-21.

Daniel, T.H., "Ongoing Experiments at the Natural Energy Laboratory of Hawaii, Keahole Point," presented at the 7th Big Island Science Conference, UH Hilo, April 1983.

Daniel, T.H., "OTEC and Cold Water Aquaculture Research at the Natural Energy Laboratory of Hawaii," *Proc. of the Pacific Conf. on Marine Technology - PACON 84*, Marine Technology Soc., April 1984, p. MRM2/47-52.

Daniel, T.H., "Aquaculture Using Cold OTEC Water," *Oceans 85 Conference Record*, Marine Technology Soc., Nov. 12-14, 1985, San Diego, Ca., p. 1284-89.

Daniel, T.H., "Operational Experience with the Cold Water Pipe at the Natural Energy Laboratory of Hawaii," *Oceans 86 Conference Record*, Marine Technology Soc., Washington, D.C., Sept. 23-25, 1986, p. 185-90.

Daniel, T.H., "Ocean Thermal Energy Conversion and the Natural Energy Laboratory of Hawaii," in Fast, A.W. and K.Y. Tanoue, eds., *OTEC Aquaculture in Hawaii*, UH Seagrant, November 1988, p. 5-48.

Daniel, T.H., "New Seawater Delivery Systems at the Natural Energy Laboratory of Hawaii," *Solar Engineering*, A.H. Fanney and K.O. Lund, eds., Am. Soc. of Mech. Engrs., Book No. H00467-1989, April 1989, p. 323-330.

Fast, Arlo W. and Karen Y. Tanoue, eds., *OTEC Aquaculture in Hawaii*, UNIHI-SEAGRANT-MR-89-01, UH Seagrant College Program, Honolulu, November 1988, p. 178.

Fitzpatrick, N.P., V. Hron, E. Hay and F.A. Johnson, "Alcan's Ocean Thermal Energy (OTEC) Program," presented at: 9th Miami International Congress on Energy & Environment, December 11-13, 1989, p. 11-13.

Grau, E. Gordon, Arlo W. Fast, Richard S. Nishioka, Howard A. Bern, David K. Barclay and Steven A. Katase, "Variations in Thyroid Hormone Levels and in Performance in the Seawater Challenge Test Accompanying Development in Coho Salmon Raised in Hawaii," presented at Intrntl. Smoltification Workshop, Sponsored by E.O.C., Stirling, Scotland, July 3-6, 1984, published in *Aquaculture*, 1985.

Hallanger, L.W., "Capabilities and Potential of the OTEC Seacoast Test Facility," presented at the 8th Ocean Energy Conference, Washington, D.C., June 1981.

Halloran, R., "Tapping Ocean's Cold for Crops and Energy," *N.Y. Times*, May 22, 1990, p. C4.

Hawaii Public Television KHET, "Kona Cold: It's the Water," 1/2 hour videotape in Series: Facets of Science, Filmed July 1989, Broadcast Feb. 1990.

Johnson, F.A., "A 250-KW Closed Cycle Land Based Ocean Thermal Energy Plant," presented at International Conference on Ocean Energy Recovery, Hawaii Natural Energy Institute, Honolulu, Nov. 1989, p. 5.

Kearney, T.J., "Analysis and Formation Mechanisms of N- Halomethylamines: Application to Seawater Chlorination," M.S. Thesis in Oceanography, UHM, August 1983.

Kearney, T.J. and F.J. Sansone, "Analysis and Formation Mechanisms of Mixed N-Halogenated Methylamines," presented at the Fifth Conf. on Water Chlorination, Williamsburg, Va., June 3-8, 1984, in *Water Chlorination: Environmental Impact and Health Effects*, Vol. 5, R.L. Jolley, et al. (eds), 1985.

Krock, H.-J. and M.J. Zapka, "Gas Evolution in Open Cycle OTEC," *Proceedings of 5th Symposium on Offshore Mechanics and Arctic Engineering*, Tokyo, Japan, April, 1986, p. 612-17.

Larsen-Basse, J., "Corrosion of Some Aluminum Alloys in Cold and Warm OTEC Waters," presented at Corrosion 83, Paper No. 66, NACE, April 1983.

Larsen-Basse, J., "Effect of Biofouling and Countermeasures on Heat Transfer in Surface and Deep Ocean Hawaiian Waters – Early Results from the Seacoast Test Facility," presented at ASME/JSME Thermal Engineering Joint Conference, Honolulu, March 1983, Volume 2, p. 285-289.

Larsen-Basse, J. and T.H. Daniel, "OTEC Heat Transfer Experiments at Keahole Point, Hawaii, 1982-1983," presented at Oceans 83, San Francisco, Ca., August 1983.

Larsen-Basse, Jorn and Sanjeev Jain, "Aluminum Alloys as Potential O.T.E.C. Heat Exchanger Materials," *Oceans 86 Conference Record*, Marine Technology Soc., Washington, D.C., Sept. 1986, p. 191-195.

Larsen-Basse, Jorn, Sanjeev Jain, Joyce A. Berger and Leslie R. Berger, "Effect of Marine Microbiofouling and Countermeasures on Corrosion of Some Aluminum Alloys Under OTEC Heat Exchanger Conditions," *Proceedings: Corrosion 87* Paper #346, NACE, San Francisco, March 1987.

Larsen-Basse, J., N. Sonwalkar and A. Seki, "Preliminary Seawater Experiments with Open Cycle O.T.E.C. Spout Evaporation," *Oceans 86 Conference Record*, Marine Technology Soc., Washignton, D.C., Sept. 1986, p. 202-6.

Lee, C.K.B. and S.L. Ridgway, "Vapor/Droplet Coupling and the Mist Flow (OTEC) Cycle," *J. Solar Energy Engrng.*, v. 105, May 1983, p. 181-6.

Link, H., "Operational Experience of the OC-OTEC Experiments at NELH," SERI/TP-253-3480, Solar Energy Research Institute, February 1989, p. 9.

Mencher, F.M., R.B. Spencer, J.W. Woessner, S.A. Katase and D.K. Barclay, "Growth of Nori (Porphyra tenera) in an Experimental OTEC-Aquaculture System in Hawaii," *J. World Maricul. Soc.*, 14:458-470, 1983.

Miller, J.N. and J.F. Walters, "Zooplankton Populations and Water Chemistry from a Shallow (4.3m) and Deep (600m) Pumped Water Discharge, Keahole, Hawaii," UH Environmental Center, August 1983.

Panchal, C.B., H.S. Stevens, L.E. Genens, D.L. Hillis, J. Larsen - Basse, S. Zaidi and T.H. Daniel, "Biofouling and Corrosion Studies at the Seacoast Test Facility in Hawaii," Proc. MTS-IEEE Oceans 84 Conf., Washington, D.C., September 1984.

Penney, T.R. and D. Bharathan, "Power from the Sea," *Scientific American*, Jan. 1987, p. 86-92.

Penney, T.R. and T.H. Daniel, "Energy from the Ocean: A Resource for the Future," in *Science and the Future: 1989 Yearbook*, Encyclopaedia Britannica, 1988, p. 98-111.

Pitzer, P., "The Ocean Source," *Spirit of Aloha*, Aloha Airlines, August 1989.

Prakash, A., J. Craven, N. Fitzpatrick, and E. Hay, "Recent Advances in Ocean Thermal Energy Conversion (OTEC) Technology and OTEC-Based Aquaculture," Presented at Carribean conference, August 1989, p. 5.

Ridgway, S.L., "Projected Capital Costs of a Mist Lift OTEC Power Plant," Presented at ASME Winter Meeting, New Orleans, December 1984.

Sansone, F.J. and T.J. Kearney, "Unusual Chlorine Kinetics of Tropical Seawater, and the Potential Environmental Effects," Proc. of the Pacific Cong. on Marine Technology – PACON 84, Marine Technology Soc., Honolulu, April 1984, p. MRM2/35-39.

Sansone, F.J. and T.J. Kearney, "Chlorination Kinetics of Surface and Deep Tropical Seawater", presented at the Fifth Conf. on Water Chlorination, Williamsburg, Va., June 5, 1984. Published in *Water Chlorination: Environmental Impact and Health Effects*, Vol. 5, R.L. Jolley, et al. (eds.), 1985.

Sansone, F.J., S.V. Smith, J.M. Price, T.W. Walsh, T.H. Daniel and C.C. Andrews, "Long-term Variation in Seawater Composition at the Base of the Thermocline," *Nature*, v. 332, No. 6166, p. 714-717, April 21, 1988.

Seki, Arthur, Byron Auker, Roger Fujioka, Peter Ono and Patrick Takahashi, "OTEC Heat Exchanger Biofouling Control by Ultraviolet Irradiation," *Oceans 86 Conference Record*, Marine Technology Soc., Washington, D.C., Sept. 1986, p. 232-37.

Smith S.V., et al., "Time Series Measurements of Nutrients in Deep Seawater," *PACON 86 Proceedings*, Marine Technology Soc., Honolulu, April 1986.

U.S. Dept. of Energy, "The Potential of Renewable Energy: An Interlaboratory White Paper," SERI/TP-250-3674, March 1990, OTEC: Appendix D, p. D1-D12.

APPENDIX B

PUBLICATIONS RESULTING FROM RESEARCH AT THE PUNA RESEARCH FACILITY

Baughman, E. C., "HGP-A Single Stage Direct Flash Geothermal Power Plant Overhaul Assessment Part II," August 1983.

Baughman, E.C., "Two-Day Shutdown of March 20 and 21, 1984," interoffice correspondence, April 27, 1984.

DeCarlo, E.H., and C. Ronay, "Separation of Silica from Scale Geothermal Fluids by Adsorptive Bubble Technique," submitted to *Separation Science*, 1986.

Hawaiian Electric Light Company, Inc., "Chemistry, Scale and Performance of the Hawaii Geothermal Project-A Plant," Electric Power Research Institute Report No. AP-4342, December 1985.

Kroopnik, P., R.W. Buddemeier, D. Thomas, L.S. Lau and D. Bills, "Hydrology and Geochemistry of a Hawaiian Geothermal System, HGP-A," Hawaii Institute of Geophysics Technical Report No. 78-6, 1978.

Morrow, J.W., D.M. Thomas and H.D. Burkard, "Ambient H2S Monitoring in the Vicinity of Hawaii's first Geothermal Power Plant," presented at the 81st Annual Meeting at the Association Dedicated to Air Pollution Control and Hazardous Waste Management, June 19-24, 1988.

Mottle, M.J., and H.D. Holland, "Chemical Exchange During Hydrothermal Alternation of Basalt by Saltwater - I. Experimental Results for Major and Minor Components of Sea Water," 1978.

Mottle, M.J., H.D. Holland and R.F. Corr, "Chemical Exchange during Hydrothermal Alternation of Basalt by Seawater - II. Experimental Results for Fe, Mn and Sulfur Species," 1979.

Nuti, P., "Crevice Corrosion Evaluation of Some Stainless Steel Alloys in Tropical Surface and Deep Ocean Seawaters," M.S. Thesis, Department of Mechanical Engineering, University of Hawaii at Manoa, May 1987.

Nuti, P., K.M. Htun and J. Larsen-Basse, "Crevice Corrosion from Some Stainless Steels in Hawaiian Surface and Deep Ocean Seawaters," Abstract presented at International Conference on Fatigue, Corrosion Cracking, Fracture Mechanics and Failure Analysis, Salt Lake City, December 1985.

Rogers Engineering Co., Inc., "HGP-A Wellhead Generator, Proof of Feasibility Project, 3 MW Wellhead Generator," Plant Data Manual, Vol. I, 1981.

Seki, A., B. Chen, P. Takahashi and J. Woodruff, "Noi'i O Puna: Geothermal Research in Hawaii," Proceedings of the Eleventh Annual Workshop on Geothermal Reservoir Engineering, Stanford University Press, Stanford, 1986.

Seki, A., B. Chen, P. Takahashi and J. Woodruff, 1985, "Noi'i O Puna: Geothermal Research in Hawaii," Proceedings of the Seventh New Zealand Geothermal Workshop, University of Auckland Geothermal Institute in conjunction with Centre for Continuing Education, Auckland, 1985.

Thomas, D.M., "Status Summary of the HGP-A Generator Facility," 1985.

Thomas, D.M., "A Geothermal Model of the Kilauea East Rift Zone," U.S.G.S. Prof. Paper 1350, Ch. 56, p. 1507-25, 1987.

Thomas, D.M., "Hydrothermal Systems in Hawaii," in G.S.A. *Decade of North American Geology Volume: The Eastern Pacific Ocean and Hawaii*, 1987.

Thomas, D.M., "Geothermal Resources in Hawaii," *Geothermics*, 1987.

Thomas, D.M., "Geothermal Resources in Hawaii," (map), *Geothermics*, 1987.