The Natural Energy Laboratory of Hawaii

1986 annual report

THE NATURAL ENERGY LABORATORY OF HAWAII

1986 ANNUAL REPORT

To:

The Honorable George R. Ariyoshi
Governor of Hawaii

The Honorable Richard S. H. Wong
President of the Senate

The Honorable Henry H. Peters
Speaker of the House of Representatives

Aerial view of NELH facilities looking north. Cyanotech microalgae ponds in foreground.

Board of Directors

1985-1986

John P. Craven
Director, Law of the Sea Institute, University of Hawaii at Manoa and Marine Affairs Advisor, State of Hawaii

Jack R. Davidson*
Director, University of Hawaii Sea Grant College Program

Philip Helfrich*
Director, Hawaii Institute of Marine Biology, University of Hawaii at Manoa

Kent M. Keith
Director, Department of Planning and Economic Development, and State Energy Resources Coordinator, State of Hawaii

Alan Konishi*
Director, Department of Research and Development, County of Hawaii

Gregory Mooers
Deputy Managing Director, County of Hawaii

Susumu Ono
Chairperson and Member, Board of Land and Natural Resources, State of Hawaii

Patrick K. Takahashi
Professor of Civil Engineering and Director of the Hawaii Natural Energy Institute, University of Hawaii at Manoa

Dennis M. Yamamoto*
Director, Department of Research and Development, County of Hawaii

*Served part of the year

Contents

Governor-Elect John Waihee learns about abalone larvae from NELH Public Relations Officer Kelen Dunford and George Lockwood of Hawaiian Abalone Farms.

Preface

The Natural Energy Laboratory of Hawaii (NELH) has continued to expand in Fiscal Year 1986.

The NELH Kona Seacoast Laboratory remains unique in its ability to supply large volumes of warm surface and cold deep seawater. The seawater supply systems have again functioned throughout the year.

Recognizing the expanded investment at NELH and the facility's dependence on a single source of cold seawater, the 1986 State Legislature appropriated $1,000,000 for the design and installation of an emergency backup pipeline at NELH. Design is underway for installation of an 18-inch diameter pipeline as soon as possible.

The closed-cycle OTEC biofouling and corrosion experiments supported by the U.S. Department of Energy (DOE) at NELH have continued under the supervision of Argonne National Laboratory (ANL). ALCAN International, Ltd., a major aluminum producer, has begun a large experiment at NELH to test the efficiency of various alloys and fabrication techniques for OTEC heat exchangers. Their system collects biofouling and corrosion data automatically and then transmits them by telephone modem to the ALCAN laboratory in Kingston, Ontario. This project represents a major new industrial partner in the development of OTEC.

The open-cycle OTEC experiments begun in 1983 with U.S. Department of Energy (DOE) support through the Solar Energy Research Institute (SERI) have produced encouraging results indicating that the heat and mass transfer in open cycle seawater systems approximates that predicted from previous experiments with fresh water. A major new Heat and Mass Transfer Scoping Test Apparatus for further testing has now been designed, and construction will begin in December 1986.

Several aquaculture experiments have demonstrated exciting possibilities for using the deep cold water at NELH. Hawaiian Abalone Farm's 21-acre commercial demonstration module for abalone production continues to expand, and entrees incorporating Kona-grown abalone are popular at local restaurants. Cyanotech Corporation's microalgae production facility at NELH is now shipping both *Spirulina* and beta carotene. Another firm is planning to initiate lobster culturing and growout operations at NELH this fall. Several research projects also investigated the culturing of nori, giant clams, and oysters at the laboratory. The ongoing OTEC agriculture project is now growing asparagus and some varieties of lettuce irrigated with the cold fresh water which condenses on pipes carrying cold seawater.

The NELH water quality laboratory continues to produce unique and exciting data on the characteristics of the water being pumped. This year has seen the completion of a major renovation and expansion of the water chemistry facilities which now permits both continued monitoring of the incoming water streams and improved service to the growing cadre of laboratory clients.

Also in 1986, NELH began active management of the Hawaii Geothermal Project (HGP) and the Noi'i O Puna (Puna Geothermal Research Center). The HGP geothermal well "Abbott" (HGP-A) continues to produce reliable electricity, at a level of 2.0 to 2.4 megawatts. Several Community Geothermal Technology Program projects are testing nonelectrical uses for the geothermal resource—including papaya and lumber drying, glass making, palm seed germination, and cloth dyeing at the research center. In November, the DOE formally transferred the physical facilities at the site to the state.

As a direct result of the successful research and development at NELH, and at the suggestion of the NELH Board, the High Technology Development Corporation (HTDC) has begun development of the Hawaii Ocean Science and Technology Park (HOST Park) on state land adjacent to NELH. This park will provide sites where successful NELH research projects can pursue commercial-scale development. The groundbreaking for the park was held in

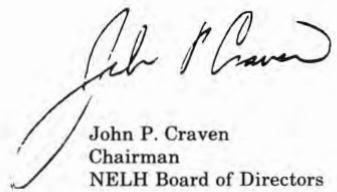
Governor Ariyoshi and Mayor Carpenter at the HOST Park groundbreaking, November 1986.

November 1986, and construction is beginning on the installation of roads, electricity, freshwater and basic infrastructure.

In January 1986, the Department of Energy proposed that it contribute to an expansion of the State's planned HOST Park project so that a multipurpose pipeline for energy and aquaculture could be constructed. Negotiations toward this end are completed, and a new 40-inch diameter cold water pipe will be installed to meet the needs of the Hawaii Ocean Science and Technology Park and expanded Department of Energy OTEC research at NELH.

A new section has been added to this year's annual report which summarizes the progress NELH has made in terms of economic development. Capital investment at the Kona facility now totals $16 million which has been provided in nearly equal thirds by Federal, State and private sources. On-site employment now totals 45, of which 35 are private sector generated. Over the past year, NELH housed 19 projects at the Kona facility which brings the total number of projects conducted to 33. The NELH Puna facility housed 7 projects.

In summary, this fiscal year has again been a very productive and successful one. The pressure of expansion is great, and sound planning and continued support are required if we are to maximize the opportunities before us. The future promises an exciting and continued expansion of research, development, demonstration and commercialization activities at NELH.



John P. Craven
Chairman
NELH Board of Directors

Abbreviations

ANL	Argonne National Laboratory
AST	American Society for Testing and Materials
BLNR	Board of Land and Natural Resources, State of Hawaii
CGTP	Community Geothermal Technology Program
CIP	Capital Improvement Projects (State of Hawaii)
CWP	Cold water pipe
DOE	U.S. Department of Energy
DOT	Department of Transportation, State of Hawaii
DPED	Department of Planning and Economic Development, State of Hawaii
DUMAND	Deep Underwater Muon and Neutrino Detection Project
EES	Energy Extension Service
EIS	Environmental Impact Statement
ERDA	Energy Research & Development Administration (Preceded DOE)
FRP	Fiberglass-reinforced plastic
gpm	Gallons per minute
HAF	Hawaiian Abalone Farms
HD&C	Hawaiian Dredging & Construction Co.
HECO	Hawaiian Electric Company
HELCO	Hawaii Electric Light Company, Hilo
HGP-A	Hawaii Geothermal Project-Well "A"
HIG	Hawaii Institute of Geophysics, UHM
HIMB	Hawaii Institute of Marine Biology, UHM
HNEI	Hawaii Natural Energy Institute at UHM
HOST	Hawaii Ocean Science and Technology Park
HTDC	High Technology Development Corporation (State of Hawaii)
JHU/APL	Johns Hopkins University, Applied Physics Laboratory
LMSC	Lockheed Missiles and Space Company, Inc.
MAC	Marine Affairs Coordinator, State of Hawaii
NELH	Natural Energy Laboratory of Hawaii
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NSF	National Science Foundation
OTEC	Ocean Thermal Energy Conversion
PGF	Puna Geothermal Facility
PGRC	Puna Geothermal Research Center (Noi'i O Puna)
PGV	Puna Geothermal Venture
RCUH	Research Corporation of the University of Hawaii
RDA	R & D Associates, Marina del Rey, California
SERI	Solar Energy Research Institute
TPC	Thermal Power Corporation
UHM	University of Hawaii at Manoa
UHSG	University of Hawaii Sea Grant Program

Introduction

This report summarizes the Fiscal Year 1986 activities at the Natural Energy Laboratory of Hawaii.

NELH was created in 1974 by the Hawaii State Legislature as a facility for research, development and demonstration of natural energy resources and other compatible scientific and technological investigations. NELH's Kona Seacoast Test Facility is located on 322 acres of state-owned land at Keahole Point, adjacent to Keahole airport on the Kona coast of the Island of Hawaii. This site was chosen because of the nearby availability of cold, deep ocean water; a warm ocean surface layer not subject to strong seasonal cooling; high annual solar insolation; accessibility to logistical support through airports, harbors, and highways; and the presence of adjacent, suitable undeveloped land. Keahole Point uniquely meets all of these criteria.

In late 1985, NELH expanded its management responsibilities to include the Puna Geothermal Facility located in the Puna District near Hilo on the Big Island of Hawaii. The PGF is comprised of the HGP-A geothermal well, power plant and the Noi'i O Puna geothermal research center. The HGP-A geothermal well produces about 80,000 pounds per hour of mixed steam/liquid flow. The power plant generates an average power between 2.0 and 2.5 megawatts. Noi'i O Puna geothermal research center is comprised of 2000 square feet of laboratory space and 1400 square feet of test pad area which is available for geothermal related research and demonstration projects.

NELH also maintains a Honolulu Office which is responsible for the overall management and administration of both facilities. Marketing, facilities use agreements and subleases are handled through this office, as is coordination with government-related activities, planning, and regulatory permitting agencies.

NELH is governed by a managing Board of Directors consisting of the Marine Affairs Advisor, the Director of Planning and Economic Development of the State of Hawaii, the Chairperson of the Board of Land and Natural Resources, two officers or employees of the University of Hawaii appointed by the President of the University, and two County officials appointed by the Mayor of Hawaii.

The Board is responsible for managing and maintaining NELH properties, reviewing and approving proposals from prospective users, and planning and coordinating the development of NELH facilities. While NELH personnel may provide technical assistance, the primary function of NELH is to make facilities and resources available to researchers, inventors and entrepreneurs for the research, development and pilot testing of innovative new technologies and businesses. Legislation passed in May 1984 permits on-site commercialization of successful research and development projects.

NELH engages the services of the Research Corporation of the University of Hawaii (RCUH) to provide administrative services. Plans call for the NELH eventually to become self-supporting through collection of users' fees.

NELH welcomes proposals from both the public and private sectors. With the approval of the Board, users may arrange to share existing facilities or construct their own. The Kona Seacoast Test Facility welcomes new projects which utilize or are related to the natural ocean and solar resources available at the site. The Puna Geothermal Facility welcomes new projects related to the geothermal resource and its by-products. The appendices contain the NELH Policy on Project Acceptance and a summary of publications resulting from research projects conducted at NELH. Inquiries concerning NELH should be addressed to the Executive Director at 220 South King Street, Suite 1280, Honolulu, Hawaii 96813.

Institutional Developments

Funding

State fiscal support of NELH continued at approximately constant levels throughout Fiscal Year 1986. Federal DOE support has continued for the OTEC biofouling and corrosion and open-cycle experiments, with funding through the Solar Energy Research Institute (SERI) and technical guidance from Argonne National Laboratory (ANL). User fees from aquaculture projects have begun to contribute to the operating budget. We anticipate that the proportion of support from smaller projects will continue to grow as NELH operations expand.

Staff Changes

Mr. Cullen Tendick, our electronics engineeer who had worked at NELH since the first research activities began in 1976, left this year to move to the mainland. His replacement, Aarne Haas, comes to Hawaii from Portland, Oregon bringing many years of engineering and management experience gained with companies in the Northwest. He is also a licensed electrical engineer in Hawaii.

NELH has hired Carla Hannaford, a college teacher with a broad background in biology, chemistry and geology to work part-time in the water quality laboratory and to maintain the NELH library.

The NELH groundskeeper, Daniel Lehfeldt, was hired by the Cyanotech Corporation. The laboratory has been fortunate to replace him with Wendall (Kimo) Shuckert, who is doing a superb job of maintaining and improving our facilities.

The core staff of the laboratory at Keahole Point now consists of eleven and one-half positions, including eight personnel able to provide direct project technical support.

Bud Placek, Cullen Tendick and Ajay Bhargava work on heat transfer instrumentation.

Aerial view of the Puna Geothermal Facility.

Puna Geothermal Facility

The Puna Geothermal Facility consists of a geothermal well, power plant and research facility located on a four-acre site in the Puna District near Hilo on the Big Island of Hawaii.

NELH assumed responsibility for the project in 1985, and in November 1986 the Department of Energy formally transferred facility title to the NELH Board. Jan C. War, Operations Manager of the Kona facility, has been made manager of the Puna Geothermal Facility.

The overall development plan for the facility is similar to that of NELH at Keahole Point. The Puna Geothermal Facility will provide for research, development, and commercialization of alternate uses of geothermal resources and for development of new technologies and businesses at the site.

HOST Park

The High Technology Development Corporation, formed by the Hawaii State Legislature in 1983, began planning in November 1984 for the Hawaii Ocean Science and Technology (HOST) park to be developed on 547 acres of state-owned land adjacent to NELH. This facility will provide space and infrastructure for the large-scale commercialization of projects which have performed successful research and pilot-scale development at the laboratory.

Initial infrastructure under construction for the HOST park includes improvements to the NELH road and utilities corridor, grading associated access roads and installation of a seawater supply system. The seawater supply system has been expanded to include a larger pipeline and additional pumps and delivery pipes for upcoming DOE OTEC research at NELH.

An Environmental Impact Statement for the HOST Park and the planned expansion of NELH was prepared in 1985. This EIS, along with related updates of existing NELH permits, will help to ensure the orderly development of both facilities. NELH has also contracted the preparation of an updated master plan to serve for the coming years of site development.

Kona Facility Developments and Status

All hands at work on the installation of a Hawaiian Abalone Farms deep seawater pipeline, August 1986.

Coldwater Supply System

NELH remains the only facility in the United States, and possibly the world, supplying a continuous flow of cold deep seawater. At year's end, the three pumps in the pumping system continue to operate well. Continuous flow was maintained throughout the year, except for a 62-hour interruption when the pipe separated in the nearshore zone following a prolonged period of large waves in late February. As of June 30, 1986, coldwater experiments have run for 1521 days.

New Coldwater Pipelines

In 1986, the Hawaii State Legislature recognized the importance of redundancy for NELH's unique coldwater pipeline and appropriated funds for design and installation of an emergency backup pipeline. An 18-inch diameter polyethylene pipeline has been designed for installation about 2000 ft (600 m) south of the existing intake at Keahole Point.

The February 1986 flow interruption also highlighted the need for a redesign of the nearshore routing and anchoring system of the existing 12-inch diameter pipeline. Designs for these system improvements are complete and contract award is expected early in 1987.

Hawaiian Abalone Farms (HAF) has begun installing pipelines and pumping systems at NELH. Initial deployment of a mile-long 15-inch diameter pipe in August 1985 was only partially successful. HAF has received NELH approval to install two 15-inch diameter coldwater pipes at Keahole Point.

HOST Park and DOE have combined their original plans to install separate pipelines into an expanded construction program incorporating larger diameter pipes. Plans call for installation of a 40-inch coldwater and 28-inch warm water pipeline with onshore pump station. These pipelines and pumps are scheduled for installation in 1987 and will be located immediately adjacent to NELH's existing 12-inch pipelines.

The system will provide approximately 6800 gpm of cold water to the HOST Park and 6500 gpm cold water and 9600 gpm warm water to NELH for use by DOE for OTEC research.

Water Quality Laboratory Improvements

The NELH water quality laboratory has been completely renovated and upgraded during the past fiscal year. A $160,000 State CIP appropriation has permitted renovation of existing laboratory space, construction of a new external "wet lab" and the purchase of needed new laboratory equipment. Both the renovated interior laboratory and the new wet lab are being used by NELH staff and by various projects.

Aquaculture tanks in front of the new "Wet Lab" building.

Electrical Distribution System Improvements

Designs are complete for an important upgrade of the NELH emergency electrical system. The three existing 125 kw diesel generators will be connected to start in parallel, providing a total capacity of 375 kw. In addition, a new load bank will allow off-line testing and adjustment of the system without affecting normal operations.

Cold Seawater Air Conditioning of Laboratory Building

Proposals to utilize the cold seawater to air condition lab buildings have been pending for several years. Using DOE alternate energy demonstation funds through the Energy Division of DPED, a design has been completed for air conditioning the laboratory building by using a heat exchanger connected into the existing chilled water system. This project should serve as an example of another potential use of the cold deep seawater.

Abalone Commercial Production Module Facilities

Hawaiian Abalone Farms has continued expansion of their commerical demonstration module on 21.3 acres of open land adjacent to the NELH laboratory compound. Facilities include two one-million-gallon kelp tanks and several acres of shade cloth structure which cover abalone growout tanks. The first of four 4-acre kelp ponds has been excavated, and two cold seawater pipelines are under construction.

Microalgae Culture Facilities

Cyanotech Corporation has progressed rapidly since they began construction of their first commercial production ponds for microalgae growout in January of 1985. Over the past year they have begun beta carotene production in two new raceways. These are in addition to the four raceways already in use for *Spirulina* production. The company is now constructing 10 new ponds which utilize all of their 15-acre lease. The process building at the site has been expanded, and now includes processing facilities for both beta carotene and *Spirulina*, as well as adjacent offices and workshops.

Visitor Program Improvements

Our visitor information program, funded largely by the Federal Energy Extension Service through the State Department of Planning and Economic Development, has continued to expand and improve this year. In addition to conducting regular public tours for individuals and groups, our public relations officer also coordinates preparation of instructional aids and makes many informational presentations on laboratory activities to community groups and schools around the island. Over 2800 people visited the laboratory last year.

Kona Facility Capabilities

As of June 30, 1986, NELH had these operational support capabilities:

Warm Seawater Supply

- 1600 gpm
- 24°C to 28°C

Cold Seawater Supply

- 1100 gpm (three 600 gpm pumps)
- Expandable to 1300 gpm
- 7.5°C to 10.5°C (constant, depends on total flow)

Water Chemistry Laboratory

Measurements:

- Flow
- Temperature
- Salinity
- Suspended Solids
- pH and Alkalinity
- Nutrients
- Dissolved Oxygen
- Biochemical Oxygen Demand (BOD)
- Residual Chlorine
- Analytical Weights

Equipment:

- Balances and Scales
- Microscopes
- Particle Counter
- Auto-analyzer
- Salinometers
- Amperometric Titrators
- pH Meters
- Sampling Nets, Bottles, Etc.
- Fume Hood
- Glassware

Technician Support

- Mechanical
- Electronic/Instrumentation/Electrical
- Laboratory
- Diving

Facilities

- Laboratory Space (in and outdoor)
- Warehouse Space
- Office Space
- Shops: Electronics, Machine
- Large Vacuum Pumps and Open-cycle Experimental Chambers
- Aquaculture Tanks (all plumbed with warm and cold seawater):
  - 10 ea. 600 gal. fiberglass tanks
  - 5 ea. 1000 gal. plastic-lined steel tanks
  - 10 ea. 3 cu.m. (800 gal.) rectangular tanks, each divided into 1 cu.m. sections
  - various tanks, larval basins and growout baskets
- A 20 ft x 50 ft Inflatable Building
- Offshore Research Corridor
- 24 ft Workboat with Trailer
- 3 Automatically-started 125 kw Diesel Generators for Facility Backup
- Electrical Distribution Panels for Experimental Areas
- 2 Trailer-mounted 10 kw Generators for Field Work
- Trailer-mounted 100 kw 440V Three-phase Generator
- 7.5 ton Pettibone 4-wheel Drive Hydraulic Crane
- 3 Trailer-mounted Compressors: one 375 cfm and two 600 cfm
- 2 PDP/11-23 Computers for On-line Heat Transfer Processing
- IBM-PC, IBM-PC/XT and Epson Equity II Microcomputers (with 2 graphics printers, letter quality printer, 2 color monitors, modem, data logger interfaces; and word processing, spreadsheet, communications and high-level language software)

Vehicles

- 2 Fork Lifts
- 3 Trucks
- Electric Utility Vehicle
- Station Wagon

Communications

- Private VHF System with all Vehicles, Boat and Handheld Units
- NEC 1648 Phone System with 6 CO Lines and 16 Extensions
- Computer-based Modem for Electronic Mail Communications

Environmental Monitoring

- Wind, Temperature, Rainfall
- Solar Insolation
- 3 Multichannel Data Loggers

Permits in Place

- Approved Offshore Research Corridor
- Conservation District Use Permit for Coastal and Submerged Land
- Special Management Area Use Permit for Coastal Lands
- DOT Harbors Division Shore Waters Construction Permit
- Environmental Impact Statement/Environmental Assessment for the Whole Facility
- NPDES Discharge Permit for Seawater Effluents
- United States Army Corps of Engineers Permits
- Federal Aviation Administration Permits

Public Information

- Tours Available
- Public Lectures
- Brochures and Information Packets

Security

- Fenced Research Compound
- Guard Service Off-hours and Holidays

Table I: Summary of Research Projects at the NELH Kona Seacoast Facility

Project Name	Objective	Sponsor Institution(s)	Funding Source(s)	Investigator(s)	Dates	Results	Status 1/87
Buoy Fouling and Corrosion Studies	Study fouling and corrosion of OTEC heat exchanger materials.	UHM, HNEI, JHU / APL	HNEI, DOE, NSF / ERDA, UHSG, MAC	J. Larsen-Basse F. Munchmeyer	76-79	Biofouling became significant after an initial incubation period of several weeks.	Completed
Mini-OTEC	Demonstrate net power production from OTEC.	DPED, LMSC, Dillingham Corp.	State of Hawaii, various companies	E. Grabbe	1/79-12/79	First successful production of net power from OTEC. Generated more than 10 kw net on a floating platform moored in the NELH Offshore Research Corridor.	Completed
Argonne Test Project	Heat transfer monitoring and biofouling control Microfouling studies Corrosion studies Macrofouling studies Water quality analyses	UHM / ANL UHM / ANL UHM / ANL UHM / ANL NELH / ANL	DOE / DPED DOE funding via SERI since 7 / 83	J. Larsen-Basse L.R. Berger E.A. Kay T. Daniel	7/81 - present	1. Biofouling in warm surface water repeatably reduces heat transfer to unacceptable level within 20 days. 2. Only 70 ppb chlorine applied for 1 hr / day controls the biofouling. 3. No reduction in heat transfer (i.e., biofouling) has occurred over 4 years of continuous cold water flow. 4. Aluminum alloys do not show pitting corrosion in surface water, but do in deep water.	Continuing
Simplex Corrosion	Measure corrosion of samples installed on offshore buoy.	UHM	Simplex Wire & Cable Co.	J. Larsen-Basse	7/81 - 3/82	Measured corrosion on several alloys installed on offshore buoy.	Completed
UH Atmospheric Corrosion Project	Monitor and analyze corrosion of samples in NELH marine atmosphere.	HNEI	UH Foundation	J. Larsen-Basse	7/81 - 3/83	Collected corrosion data on several aluminum alloys.	Completed
OTEC Aquaculture Fish	Investigate parameters of growing salmon and trout in deep cold water.	HIMB	UHSG, MAC, DPED	A. Fast	1/82-11/84	1. Grew more that 1/2 lb. fish per gallon deep water. 2. Found optimum temperatures, photoperiods and flow rates. 3. Studied smoltification parameters. 4. Spawned trout successfully in seawater.	Completed
OTEC Aquaculture Macroalgae	Demonstrate culture of nori (*Porphyra tenera*) and ogo (*Gracilaria spp.*).	HIMB	UHSG, MAC, DPED	F. Mencher R. Spencer	1/82-3/83	1. High nori growth rates (35% mass increase per day) initially and 40-60 gm /m^3/ day in high density (2-3 kg /m^3) tanks. 2. Optimum photoperiods and temperatures were determined.	Completed
Abalone Culture	Investigate feasibility of commercial abalone culture in Hawaii.	Monterey Abalone Farms	Monterey Abalone Farms	G. Lockwood	2/82 - present	1. Abalone and kelp (*Macrocystis*) to feed them can be grown in the deep cold water. 2. The high nutrient content of the deep water results in high protein in kelp. 3. The lack of pathogens in the deep water permits its use without filtration. 4. A commercial development module has been initiated.	Continuing
OTEC Chlorination	Study the effects of low level chlorination on the marine food chain.	UHM	HNEI	F.J. Sansone	6/82-6/83	1. Chlorine kinetics in tropical seawater differ markedly from results with other seawater. 2. Reaction of the chlorine with the water takes much longer than in temperate water. 3. Only trace levels of halogenated organics are produced in chlorinated NELH water.	Completed
Maine Lobster Culture	Validate Hawaii as site for northern lobster (*Homarus americanus*) culture.	Sanders Associates, Inc.	Sanders Associates, DPED	M. Thays	9/82-10/83	1. Maine lobster grow well in the Sanders culture system using temperature control obtained by mixing surface and deep water. 2. Present economics indicated this culture would be unprofitable.	Completed
Cable Corrosion	Investigate corrosion of candidate materials for deep sea cables.	Parson's Hawaii	DOE / HECO	J. Larsen-Basse	1/83 - present	Various candidate cable materials show expected corrosion in seawater.	Continuing
ASTM Corrosion	Monitor corrosion of metals in the ocean offshore of Keahole Point.	ASTM	NELH	J. Larsen-Basse	6/83-6/89	First samples submitted to ASTM.	Continuing
Alcoa Corrosion	Study the corrosion of various aluminum alloys in flowing seawater.	Alcoa	Alcoa	B. Liebert	1/83-1/85	Analysis of proprietary samples completed. Effects of brushing in warm and cold water were studied.	Completed
Open-cycle OTEC							
Heat and Mass Transfer Research	Study efficiency of spout evaporators and condensers by measuring heat and mass transfer in seawater system.	UHM / HNEI	SERI / DOE	J. Larsen-Basse	6/83 - present	1. Seawater results are similar to those with fresh water in Colorado. 2. Spout evaporators and condensers promise high efficiency for OC-OTEC.	Continuing
Gas Desorption Research	Use a packed column to study composition of dissolved gases in seawater at various temperatures and pressures.	UHM / Look Laboratory	SERI / DOE	H-J. Krock	6/83-6/84	1. Dissolved gas compositions confirm predictions. 2. The "height of transfer units" which measure the power required to remove dissolved gases are about 50% less with NELH seawater than predicted from fresh water data.	Continuing (*now combined with heat and mass transfer study*)
Mist-lift Process	Demonstrate operation of the mist-lift cycle with seawater.	R & D Associates, Marina del Rey, CA.	SERI / DOE	S.L. Ridgway	6/83-12/83	1. Mist generator works well without clogging. 2. Vapor-mist coupling approximates predictions—up to 100 m of lift may be available from 20° C.	On Hold
CWP / AST Phase III	Deploy and monitor 1/3 scale FRP CWP down slope off Keahole Point.	HD&C / NOAA	NOAA / DOE	I. Sandison	4/83-5/85	Deployment successful. Data collection completed.	Completed
OTEC Agriculture	Grow strawberries in freshwater condensing on pipes carrying cold seawater.	UHM	UHSG	S. Siegel, M. Vitousek	1/84-6/84	Strawberries and various vegetables grow well. Seasonal cycling can be controlled by water flow rate.	On Hold
Microalgae Culture	Develop commercial microalgae culture techniques in seawater.	Cyanotech Corporation	Cyanotech Corporation	G. Cysewski	7/84 - present	*Spirulina* grows well in seawater. Commercial production begun.	Continuing
Macroalgae Study	Study growth of macroalgae in surface and deep water.	UHM	HNEI	F. Mackenzie, C. Agegian	1/85-6/85	Macroalgae efficiently utilize high deep water nutrient concentrations..	Completed
Giant Clam Culture	Study effects of Hawaiian environment on giant clam growth.	Marine Animal Associates / Waikiki Aquarium	Private	M. Dailey	8/85-8/86	Preliminary: Clams grow well in Hawaii.	On Hold
Nori Culture	Develop commercial nori culture techniques for Hawaii.	Aquaculture Concepts	Private	S. Katase	8/85 - present	Preliminary: Nori spores will germinate and grow in NELH seawater.	Beginning
ALCAN OTEC	Investigate corrosion behavior of various alloys and heat exchanger configurations.	ALCAN International	ALCAN	D. Goad	3/86 - present	Apparatus erected; experiments in progress.	Operating
Opihi Culture	Investigate and demonstrate growth of opihi (Hawaiian limpets).	W.H. Magruder	Private	W.H. Magruder	10/86 - present	Preliminary: Opihi reproduce and grow well in sprays of the deep water.	Operating
Macroalgae Investigation	Investigate potential of macroalgae for removing excess nutrients from seawater return.	UH Dept. Tropical Agriculture	HNEI ADP	D. Robichaux	5/86-1/87	Preliminary: Algae can remove most of the excess nutrients from water flowing past them.	Completed

Kona Research Activities

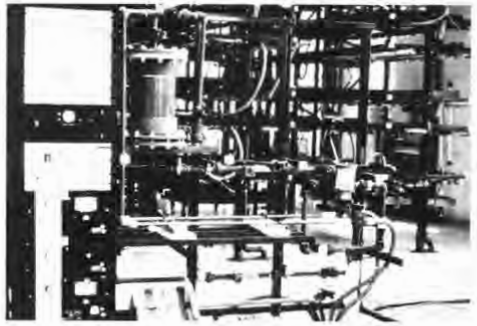
Table I summarizes the research activities at the NELH Kona Facility.

OTEC Research

The ongoing biofouling and corrosion research initiated in 1981 by Argonne National Laboratory (ANL) has continued this year with DOE support through both ANL and the Solar Energy Research Institute (SERI) under the technical direction of Dr. Jorn Larsen-Basse of UHM. The open-cycle OTEC research initiated last year by SERI and Dr. Larsen-Basse has also continued. Considerable effort has gone into planning for the construction of major new open-cycle experimental facilities.

Closed-cycle OTEC

Heat Transfer, Biofouling and Corrosion — These experiments use 1-inch diameter piping loops in the laboratory, each of which contains a



Equipment racks for biofouling and corrosion experiments.

heat transfer monitor and through which seawater flows continuously at 4.5 ft/sec or 6 ft/sec. Throughout FY 1986, the main system ran near its design capacity of 12 warm water and 6 coldwater loops. An independent system contains three additional loops for a SERI-sponsored study of nonchemical biofouling control. One of these loops, operated by researchers from HNEI, has an ultraviolet fouling control apparatus; one contains an ultrasonic control experiment run by the Applied Physics Lab of The Johns Hopkins University (JHU/APL); and the third serves as a control. These three loops are controlled by a second PDP-11/32 computer using software similar to the main system.

Warm Water — Warm seawater has flowed through 12 experimental loops throughout FY 1986. In addition to the 7 loops run since July 1981, 5 loops started in 1984 also contain heat transfer monitors and samples designed to test different alloys and new heat exchanger enhancements. Both spirally-fluted ("korodense"-enhanced) and rectangular cross-section ("Trane"-type) tubes are being tested. Two of the HTMs have been combined into one loop to determine variations in the biofouling control provided by chlorine as it passes through the system. The five years of data obtained in these experiments will establish a baseline on biofouling and corrosion in tropical surface seawater. A new apparatus is being designed to test surface water biofouling and corrosion in mist generators needed for mist-lift OTEC systems.

Biofouling Countermeasures — Continued experimentation in FY 1986 has further confirmed the efficacy of intermittently-applied low chlorine levels for effective biofouling control. Only 70 parts per billion (ppb) of residual chlorine applied for one hour per day appears to almost completely control the biofouling of tubes made from several candidate heat exchanger materials. In addition, the same low intermittent chlorination schedule can remove established biofouling films. Similar behavior has been found for rectangular cross-section and spirally-fluted tubes used in enhanced heat exchanger designs. These results, combined with the improved understanding of the chemical dynamics of chlorine in tropical water obtained from chlorination studies, indicate that chlorine can control OTEC biofouling without adverse environmental effects.

Coldwater Results — Coldwater flow continued in FY 1986 for research on biofouling and corrosion. The data generally corroborated the previously obtained results: no biofouling and significant pitting corrosion of most aluminum alloys in the cold water. These results continue to indicate that biofouling will not be a serious problem in OTEC condensers and that care will be required in the selection of aluminum alloys which resist corrosion on the coldwater side. Testing of both rectangular cross-section and spirally-fluted tubes also continued in the cold water.

Coupon Analysis — Dr. Jorn Larsen-Basse's study of the corrosion of candidate heat exchanger materials has continued to indicate that aluminum will work well in warm surface water, but only alloy 5052 shows acceptably low corrosion in the cold deep water. Dr. L. Ralph Berger's continued analysis of the biofouling films has produced spectacular electron micrographs of the fouling organisms and shown how they grow on the corrosion layers. Some skeletal forms appear to remain on the surfaces even after removal of all heat transfer resistance by chlorination. Dr. Bruce Liebert, Associate Professor of Mechanical Engineering at UHM, will continue the corrosion analysis experiments while Dr. Larsen-Basse is on leave in 1986-87.

ALCAN Aluminium, Ltd. — Aluminium of Canada has installed the apparatus for a large-scale test of aluminum heat exchanger elements. Several multitube heat exchangers of various alloys now have warm and cold seawater flowing through them in the laboratory for continuous monitoring of heat transfer and corrosion with 6 ft/sec (2 m/sec) flow. NELH has installed new seawater supply lines for this project. The experiment has been designed to eliminate the need for costly booster pumps used to maintain the required flow in earlier systems. Argonne National Laboratory is supporting this research by making the heat transfer instrumentation available to ALCAN. Reseachers at ALCAN's British laboratory outside London designed and built the experiment, which has been designed so that both data and experiment control information are transmitted automatically over the telephone. System components were constructed in the UK and in New Jersey. The system is controlled via telephone modem from ALCAN's Kingston Ontario laboratory, and it has been operating continuously since April 1986.

Macrofouling Studies — The study of corrosion and macrofouling under slow-flow conditions, has continued throughout FY 1986. Three warm water and three coldwater troughs carry seawater at about 1 ft/sec (0.3 m/sec) past samples which are extracted periodically for both biofouling and corrosion analyses. Dr. E. Alison Kay of the UHM Zoology Department is responsible for the macrofouling analyses. Dr. Larsen-Basse has combined these corrosion studies with those of the Deep Sea Cable Corrosion study (p. 19).

Kinetics of Chlorine in Seawater — Dr. Francis J. Sansone's research at UHM using NELH seawater samples has led to some understanding of the kinetics and fate of chlorine in tropical seawater. Results indicate that potential environmental impacts of chlorination at an OTEC plant would be minimal because of the low levels required and because of the lack of significant production of the halogenated organics found when other seawaters are chlorinated.

Open-cycle OTEC

Heat and Mass Transfer and Gas Sorption Kinetics — These studies continued experimentation at NELH on the properties and efficiencies of spout evaporators and condensers and on the dissovled gas contents of both the warm and cold seawater. Heat and mass transfer data collected under Dr. Larsen-Basse's direction by researchers from UHM and SERI have continued to replicate the results obtained earlier at SERI with fresh water. These results indicate the potential for very high efficiencies in spout evaporators and condensers. At year's end, plans are nearing completion for a major new experimental apparatus using larger tanks and more sophisticated instrumentation to continue these experiments.

In 1984 and 1985, experiments performed at NELH by researchers from SERI and Look Laboratory of Ocean Engineering showed that much less energy is required to extract the dissolved gases from seawater than had previously been known to be required to perform the same process with fresh water. Look Lab Director Dr. Hans-Jurgen Krock and graduate student Manfred Zapka constructed and installed

a seawater deaeration device which further demonstrated the ease of removal of dissolved gases from both warm surface and cold deep seawater. These tests indicate that the parasitic losses required for gas removal from open-cycle systems will be significantly less than had been assumed in previous studies.

Coldwater Aquaculture Research

Potential economic benefits from aquacultural by-products which might be grown in the coldwater discharge from an operating OTEC plant have prompted the development of facilities for research into coldwater aquaculture. These include the unique NELH cold seawater supply system and several types of tanks and other equipment for growing various species of plants and animals. These facilities have attracted a number of research projects from both the private and public sectors investigating the potential utilization of the deep cold water. Significant potential appears to exist for commercialization of several species of aquatic plants and animals, utilizing the properties of low temperature, high nutrient content and lack of pathogens that are found in the deep cold water.

For example, the deep cold water being pumped at NELH is uniquely suited for aquaculture of many marine animals. The purity of the water permits successful growout of even sensitive larval stages without expensive water purification processes. The high levels of dissolved inorganic nutrients in the deep water provide rapid growth rates in the various algae which serve as food for the animals. The deep water is always colder than needed, so temperature can be inexpensively maintained throughout complex systems by controlling the coldwater flow to balance heat gained from the Hawaiian climate.

A publication now in preparation will summarize the results of all of the coldwater aquaculture research at NELH, including the previous projects which investigated growth of salmon, trout, nori (seaweed) and Maine lobster. That report will include an analysis of the economics of raising the various species, both independently and in conjunction with an OTEC power plant.

Abalone — In May 1984, Hawaiian Abalone Farms signed a long-term sublease for 21.3 acres of land at NELH and began development of a commercial demonstration module of an abalone production facility. The formal groundbreaking for this facility in June 1984 culminated more than two years of research at NELH which had indicated the suitability of the deep cold water for abalone culture. They have built two large 1-million gallon tanks for initial growout of kelp to be fed to the abalone and installed several acres of abalone growing tanks covered by shadecloth.

HAF has completed excavation of the first of four 4-acre kelp ponds which will be lined and filled with about 20 million gallons each of cold deep water for kelp production. HAF has begun installation of their own deep seawater pipelines and pumping sytems.

Microalgae — Cyanotech Corporation broke ground in January 1985 for a facility designed to grow microalgae at Keahole Point. After a formal

Cyanotech Corporation's microalgae raceways.

dedication of their completed facility in July of the same year, they began shipping *Spirulina*, a microalga popular as a health food, to mainland health food wholesalers. In FY 1986 they have expanded production of *Spirulina* and begun production of *Dunaliella*, a microalga rich in beta carotene which is a vitamin A precursor widely used in pharmaceutical preparations. Cyanotech has begun shipping large quantities of their new product—a powder containing about 7.5% beta carotene. The company is now completing development of their 15-acre parcel

approximately 1/2 mile from the main laboratory compound. They are preparing to begin production of another microalga containing high concentrations of EPA, the active ingredient in fish oil which prevents the buildup of cholesterol in fatty tissues.

Giant Clams — Murray D. Dailey of California State University, Long Beach has conducted a project in cooperation with the Waikiki Aquarium investigating the feasibility of culturing giant clams (*Tridacna spp*) in Hawaii.

Giant clam tanks.

Since August 1985, about 2000 specimens brought from Palau have grown in raceways constructed at NELH. The experiments show how the growth rate of these animals in captivity is affected by several parameters such as the temperature, nutrient content and flow rate of the water, the incident light spectrum and the specimen spacing. These experiments have now been transferred to California, but some specimens remain in tanks at NELH for our public information program. Dr. Dailey plans further research at NELH in 1987 to investigate the spawning behavior of mature clams, some of which may span 60 inches.

Nori seaweed — The success of an earlier UH Sea Grant-sponsored research project on the growth of nori (*Porphyra sp.*), a valuable edible seaweed has led Steven A. Katase to form a company which has begun development of a pilot-scale nori production farm at NELH. With funding from a Phase I U.S. Department of Agriculture Small Business Innovation Research (SBIR) grant, and in cooperation with one of the largest Japanese nori processors, they have conducted pilot-scale growout and nursery tests since August 1985. The company plans

Nori seaweed growout and nursery tanks adjacent to the giant clam growout tanks.

commercial expansion outside the laboratory compound in the near future.

Opihi — Bill Magruder has begun a research project at NELH to develop techniques for growout of opihi (Hawaiian limpets) on lava rock sprinkled with seawater. A facility constructed in the NELH compound has several species of the Hawaiian delicacy growing under diverse test conditions.

Coldwater Agriculture Research

Following successful 1984 tests growing strawberries using the cold freshwater which condenses on pipes carrying cold seawater, Dr. Vitousek of UHM has grown several varieties of

Coldwater agriculture research—strawberry beds in center, lettuce in raised beds at right.

Troughs used to investigate algal removal of excess nutrients from returning seawater.

lettuce and asparagus. By controlling the cold seawater flow and thus the plant root temperatures, economically valuable plants are being forced to mature when the seasonal fluctuations in their prices maximize in the local market. Some mainland investors have expressed interest in commercializing this technique for producing off-season vegetables. Although the cold seawater requirements are still being investigated, it appears that several acres could be irrigated using the condensate formed on the coldwater effluent from a medium-sized OTEC plant.

Water Analysis

Analysis of the unique four-year computerized data set of water quality parameters measured at the laboratory has led to recognition of significantly larger variability in the deep water than had been anticipated. NELH plans to continue weekly sampling and updating of the computer data base for use by researchers at NELH and throughout the scientific community. In addition to providing baseline data to experiments at NELH, those analyses also monitor used seawater to maintain NELH compliance with regulatory requirements and environmental and health permits.

Concentrated Sampling Experiments — An important experiment conducted in April 1986 has helped to clarify the nature of the variability of the various water quality parameters measured in NELH's weekly water sampling program. With coordination from the UH Environmental Center, several UHM researchers conducted concentrated sampling experiments over a six-week period to measure changes in nutrients, phytoplankton, zooplankton, trace metals, etc. in both the surface and deep water supplies.

Phytoplankton Study — NELH is also participating in a large experiment sponsored by the Office of Naval Research under the direction of Dr. John Heinbokel from Johns Hopkins University. They are investigating the variability and dynamics of certain phytoplankton (diatom) populations in an effort to understand why the biomass of these primary producers is significantly higher in the ocean than would be predicted from known nutrient concentrations. NELH staff take three sets of samples weekly and one 24-hour set of samples monthly. These will be analyzed by Dr. Heinbokel, along with samples from several other sites around the world.

Nutrient Removal from Returning Seawater — David Robichaux and Jaw-Kai Wang of the UHM Department of Agricultural Engineering have constructed an apparatus and performed a series of experiments at NELH to investigate the efficiency of various algae in removing or "stripping" the excess nutrients from the mixed warm and cold effluent seawater. Initial results from the four 32-foot long raceways indicate that, with suitable waves for mixing, more than 90% of the excess nutrients can be removed in that relatively short distance by suitable growth of a variety of algae. These results appear to support the efficacy of a trench seawater return system which has been proposed for NELH and HOST Park expansion. Further research is being proposed to determine the relative value of various potential harvestable algae candidates.

Other Research

Environmental Measurements

NELH remains an official National Weather Service observation station, reporting daily observations 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 solar insolation, air temperature and humidity, surface and deep water temperatures, and wind vector speed and direction, as well as daily averages and maxima and minima of all these variables and daily total rainfall are recorded on tape cassettes which are processed to produce charts and tables for distribution to HNEI for incorporation into the state-wide sensor network and to other interested researchers.

Deep Sea Cable Corrosion

This project sponsored by DOE with Hawaiian Electric Company and Parsons Hawaii has contracted with Dr. Larsen-Basse of UHM to monitor corrosion of several candidate materials proposed for jacketing the deep sea cables required for inter-island power transmission.

Measurements of the electric potential changes on samples installed in troughs which have warm and cold water flows of about 1 ft/sec (30 cm/sec) yield estimates of expected corrosion rates in the ocean. The troughs used for this experiment also serve as test vessels for the macrofouling analyses conducted by Dr. E. Alison Kay in conjunction with the OTEC research program. A new phase of this project is beginning at year's end with the expected arrival of new samples of proposed cable designs for installation offshore of Keahole Point.

Alcoa Corrosion Project

Aluminum Company of America sponsored Dr. Bruce Liebert of UHM Mechanical Engineering to conduct a three-year project to measure corrosion of proprietary aluminum alloys in rapidly flowing seawater (6 ft/sec). Coupons of several alloys, some brushed periodically, were sampled on a regular basis and analyzed for corrosion. The program ended in January 1986.

ASTM Corrosion Tests

NELH is participating in a five-year international inter-laboratory research program on the global variability of the corrosivity of seawater. ASTM has supplied a rack holding samples of steel, aluminum and copper-nickel which NELH personnel have deployed near the coldwater pipe offshore of Keahole Point. Specimens are collected at regular intervals and sent for analysis and comparison with similar samples deployed elsewhere. This research has been coordinated by Dr. Larsen-Basse of UHM.

Puna Facility Developments and Status

The Puna Geothermal Facility consists of a geothermal resource well, a three megawatt electric power plant and a research facility located on four acres in 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 Apirl 1976 and successfully flashed steam in July 1976. The depth of the well is 6450 feet (1966 meters) and has one of the world's hottest bottom hole temperatures at 676 deg. F (358 deg. C). The well produces approximately 80,000 lbs/hr of a mixed phase fluid (57% liquid and 43% steam) at a wellhead pressure of 175 psia and a surface temperature of 365 deg. F (186 deg. C).

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. The steam from the separator drives the turbine generator which produces 2500 kw of electricity. The plant uses 200 kw and delivers 2300 kw to the Hawaii Electric Light Company (HELCO) grid system for transmission to its customers. Exhaust steam goes to a condenser where it is converted back to a liquid by water from a cooling tower. Maintaining the environment was a major consideration in the plant design, therefore hydrogen sulfide and other noncondensible gases are extracted from the main condenser and burned in an incinerator. Burning hydrogen sulfide produces sulfur dioxide gas which is quenched and absorbed by water. The sulfur gases from the incinerator are finally neutralized in an abatement scrubber with caustic soda. A comprehensive environmental program is being carried out to monitor the air quality as well as the noise level from the facility. After the steam and water mixture exits the well and goes through the separator, the water travels through a pipe to drainage ponds where it percolates back into the earth.

NELH assumed management responsibility for the facility in December 1985, and in November 1986 the DOE formally transferred title to the NELH. Jan C. War, Operations Manager of the Kona Facility has been made manager of the facility. The overall development plan for the facility is similar to that of NELH at Keahole Point. The Puna Geothermal Facility will provide for research, development, and commercialization of alternate uses of geothermal resources and for development of new technologies and businesses at the site.

Over the five years which HELCO has been contracted to operate the power facility, the plant has generated 91,400,000 kw hours of electricity. Annually, the plant displaces 39,000 barrels of oil, provides electricity for 2000 homes and has had an availability factor exceeding 95% It has demonstrated that the production of electricity from the geothermal resource in the Kilauea East Rift Zone is technically, environmentally and economically viable.

The power plant has not only provided operational experience and research data on Hawaii's geothermal resource; the sale of electricity also provides sufficient income to cover operating costs and most maintenance expenses.

In order to further commercial development of geothermal energy on the Big Island, NELH has contracted with Puna Geothermal Venture and its active partner, Thermal Power Corporation, to permit TPC to use the HGP-A powerplant and gas abatement system to perform a long-term flow test using fluids from their KS-1A well. This will allow continued production of electricity while the HGP-A well receives a routine overhaul.

In June of 1986, the County of Hawaii received $600,000 in State of Hawaii Capital Improvement Funds for expansion of the Noi'i O Puna Geothermal Research Center. The funds will be used primarily to increase the present building's capacity for additional research projects and to increase the amount of geothermal resources available for experimentation. In addition to the high temperature, high pressure brine originally plumbed to the PGRC, new equipment and hardware will be installed to provide high temperature, low pressure brine; high temperature, low pressure steam; and low pressure, high temperature (210 deg. F) potable water. The addition of these new resources will significantly increase the research potential of the facility.

Table II: Summary of Research Projects at NELH, Puna Facility

Project Name	Objective	Sponsor(s)	Funding Source(s)	Investigator(s)	Dates	Results	Status 6 / 86
Bottom Heating System	Utilize geothermal waste heat to enhance seed propagation and growth.	HNEI, DPED, CGTP	DOE, private donations	James Downing Ken May	4 / 86 to present	Seed propagation and plant growth significantly accelerated with heated soil.	Continuing commercial potential high
Green Papaya Powder Drying	Dry agricultural products using geothermal waste heat.	HNEI, DPED, CGTP	DOE, private donations	Peter Allen David Livingstone	4 / 86 to present	Experimental dryer works well with all types of fruits; cost savings ideal.	Continuing commercial potential high
Lumber Drying	Develop methods and drying schedules for local hardwoods.	HNEI, DPED, CGTP	DOE, private donations	Bill Irwin Denver Leaman	4 / 86 to present	Drying lumber possible within four to five weeks. More data required to develop schedules for other hardwoods.	Continuing
Cloth Dyeing by Geothermal Steam	Utilize flashed brine to dye silks. Experiment with local dye sources.	HNEI, DPED, CGTP	DOE, private donations	Yukie Kimura Dr. Kawagoe	4 / 86 to present	Hawaiian steam produces brilliant colors and sets dyes fast in Japanese silks.	Continuing commercial potential high
Hawaii Glass Making	Make glass from silica produced as a by-product from HGP-A well.	HNEI, DPED, CGTP	DOE, private donations	Norman Miller Bill Irwin	4 / 86 to present	Formula developed which produces excellent art glass. Formula distributed to UHM and artists statewide.	Continuing
Atmospheric Corrosion	Identify corrosiveness of geothermal environment for better material selection.	UHM	UHM	S. Quazi B. Liebert	12 / 86 to 4 / 87	Corrosion at HGP-A is uniquely determined by physiochemical conditions of site environment. Corrosion rate accelerated by presence of hydrogen sulfide, chloride and sulfate ions at site.	Continuing
Fiber Optic Sensor	Develop a technique for measuring chemical properties in operating geothermal wells.	UHM	Lawrence Livermore National Laboratory	A. Seki S. Sharma	9 / 87 (start)	Preliminary lab results indicate that temperatures can be measured with a ruby crystal.	Pending commencement of project
Silica Recovery	Develop a means of recovering silica from geothermal brines.	HIG, NELH	DPED	D. Thomas	4 / 87 to present	None to date.	Continuing

Puna Geothermal Facility Capabilities

High Pressure Brine Supply
- *160 psig at 370 deg. F

Low Pressure Brine Supply
- *15 psig at 250 deg. F

Low Pressure Steam Supply
- *15 psia at 250 deg. F

Hot Potable Water Supply
- *50 psig at 210 deg. F

***Disposal system available for all fluids.**

Brine Chemistry Parameters
- Total Dissolved Solids (TDS): 15,800 mg/L
- pH: 6.6
- Conductivity: 23,000 μmhos/cm

Technical Support
- Mechanical
- Electronic/Instrumentation/Electrical
- Laboratory

Facilities
- Research Laboratory Space (in/out)
- Office Space
- Chemistry Laboratory (lab benches, glassware, balances, fume hood, etc.)
- Mechanical Shop
- Electrical Distribution Panel (70 kva)
  - 480 vac single- and three-phase
  - 240 vac single- and three-phase (30 amp and 50 amp receptacles)
  - 120 vac single phase (20 amp receptacles)
- Instrumentation and Shop (100 psi at 50 cfm) Air Compressors
- Heat Exchangers (shell and tube, air exchangers)
- Surplus Supplies (valves, pipe fittings, temperature/pressure devices, etc.)
- 40 ft x 40 ft Concrete Test Pad
- Trailer-mounted Air Compressor (375 cfm at 100 psi)
- Trailer-mounted 10 kw Electrical Generator
- IBM-PC/XT Computer System and Okidata Printer
- Telephone
- Rest Room
- Potable Water
- Trash Receptacles
- Post Office Box (Pahoa)

Public Information
- Informative Visitors Center
- Public Lectures
- Tours Available on Request

Facility Security
- Full Coverage Off-hours, Holidays

Puna Geothermal Research Activities

Community Geothermal Technology Program Projects

Hawaii has been blessed with one of the highest temperature geothermal resources in the world suitable for conventional electric power production. Many applications of geothermal energy useage, however, are nonelectric. Geothermal energy supplies home heating and hot water requirements for more than two hundred thousand residents in Reykjavik, Iceland. An Oregon dairy uses geothermal heat for milk processing and pasteurization. In Hawaii, direct use of geothermal heat could be applied to agricultural and food processing, materials drying, packaging, refrigeration, health spas, household hot water, and much more.

The HGP-A electrical power plant uses only a portion of the available heat energy produced by the well. The heat value of the untapped "waste heat," if properly developed, could actually exceed that of the steam used in the generation of electricity.

In order to more fully explore the potential of geothermal energy in Hawaii, the Noi'i O Puna Geothermal Research Center (PGRC) was constructed in 1985 to support innovative approaches toward direct heat use. A small grants program was also established in 1985 to encourage local entrepeneurs to experiment with nonelectric uses of the discarded hot fluids and other by-products from the HGP-A power plant. The Community Geothermal Technology Program (CGTP) was created for this purpose and is managed jointly by DPED's Energy Extension Service in Hilo and UHM's Hawaii Natural Energy Institute. Funding for the program has been provided by the U.S. Department of Energy, the County of Hawaii, and a number of private donors.

The CGTP requested proposals for research and development projects requiring up to $10,000. In January of 1986, five projects were selected for funding from twelve submitted proposals. The projects all make use of the Puna Geothermal Research Center (PGRC) and represent a wide variety of uses of geothermal heat and silica, a by-product of the well fluids. The five projects funded under the CGTP are currently in various stages of development and operation.

Various seedlings sprouting in the Bottom Heating Project's greenhouse.

Bottom Heating — This project is being conducted by James Downing, owner of Leilani Foliage, who has demonstrated that heating the growing medium enhances seed germination, increases the percentage of seeds which sprout, and results in plants maturing more rapidly. Palm seeds are harder to sprout than other plants and consequently, nursery operators are more reluctant to culture certain species. By running plastic tubing beneath germination trays containing waste hot water from the HGP-A well, the soil temperature can be regulated and elevated. This process of "bottom heating" has been successfully conducted on several plant species by Leilani Foliage.

In a small greenhouse constructed by Mr. Downing at the PGRC, several species of ornamental palms will be tried and the results compared with unheated controls. If this project proves successful, Leilani Foliage would like to expand their operation to a full-scale business using geothermal heat.

Green Papaya Powder — Peter Allen, President of Papaya Products of Hawaii, has constructed an experimental fruit dryer and installed it at the PGRC. Papayas, especially green papayas, are an excellent source of papain, a proteinase (enzyme) commonly used as a meat tenderizer, digestive aid and, in some countries, as a medicine. Papaya Products of Hawaii specializes in the dehydration of green papayas, exporting the resulting powder to health food distributors on the U.S. mainland.

The company's current operation utilizes steam, generated by purchased electricity, for dehydration. It is expected that geothermal heat will significantly reduce the organization's operating costs and, if all goes well, Mr. Allen envisions an expanded operation adjacent to the PGRC once commercial lands become available.

Lumber Drying — Bill Irwin and Denver Leaman, partners in King Koa, a woodworking firm located in the Puna district, have recognized the potential of geothermal heat in their business. There are currently no local lumber drying kilns which can reliably dry wood on the Big Island of Hawaii. Local woodworkers are forced either to ship wood to kilns on the U.S. mainland or to use less satisfactory methods, such as dehumidified chambers or air drying.

King Koa plans to develop drying schedules for koa and other local hardwoods and has constructed a small experimental lumber kiln at the Noi'i O Puna (PGRC). By using geothermally heated water through a heat exchanger, hot air will be produced and forced through their kiln. A sophisticated computer monitoring system will record and regulate the time, temperature, humidity and other variables needed to develop reliable lumber drying schedules.

Cloth Dyeing — Mrs. Yukie Kimura and Dr. Motoyuki Kawagoe have created a process of dyeing silks using steam in the geothermally active Matsukawa Prefecture in Japan. They have transplanted their idea to Hawaii and have begun experiments at the PGRC in a specially constructed pinewood vat. Preliminary tests are encouraging and promise exciting results. The steam produced by flashing super-heated brine from the HGP-A well not only sets the dye in the cloth, but the chemistry of the steam also improves the color brilliance. Results to date indicate that the steam from the Puna well results in vibrant colors.

As part of their project, Kimura and Kawagoe will investigate the potential of using native Hawaiian plants as sources for dyes. The resulting cloth will be made into boutique garments or smaller items, such as scarves or handkerchiefs, and displayed to local drygoods companies to assess the marketability of the finished products.

Glass Making — Puna artists Norman Miller and Bill Irwin have proposed to develop a formula for a unique "Hawaiian glass" by using dried silica from the HGP-A well together with crushed coral and other local ingredients. A small propane-fired furnace has been constructed at Irwin and Miller's studio and will be used to test their glass making formula.

Preliminary firings indicate that the glass has a slight greenish tinge which may produce desirable effects as objects of art. Small quantities of the HGP-A volcanic glass will be distributed to other artists on the Big Island so that their ideas and products can be incorporated into the program. An exhibition will be held on the Island of Hawaii and possibly in Honolulu on Oahu to display the finished products.

The Community Geothermal Technology Program (CGTP) expects a second round of grand solicitations and funding sometime in 1987.

Furnaces for making Hawaiian glass.

Using geothermal steam to fix dyes in Japanese silks.

Other Geothermal Research

Silica Recovery — Dr. Donald Thomas of the UHM's Hawaii Institute of Geophysics (HIG) has been investigating the possibility of constructing a prototype silica handling/recovery system. In order to utilize the commercial value of the silica-laden geofluids, an economically viable recovery process will have to be developed. Dr. Thomas is currently monitoring the performance of a small heat exchanger in order to develop baseline information on silica scaling.

Fiber Optics — Shiv Sharma of the UHM's Mechanical Engineering Department and Art Seki of HNEI are developing an insulated fiber optic cable which can be lowered down a flowing geothermal well to monitor pressure, temperature, flow, chemistry and possibly other parameters. Preliminary experiments have been conducted with a fiber optic cable using a ruby crystal, and temperatures were measured to ± 0.001 deg. C. Plans are underway to collaborate with researchers from Lawrence Livermore Laboratories on instrumentation to measure other parameters. This project has been approved by the NELH Board for implementation at the PGRC when funds become available.

Atmospheric Surface Corrosion — Dr. Bruce Liebert and associate Salim Qazi of the UHM Department of Mechanical Engineering have set up a test rack of seven different sample materials at the PGRC to investigate the effect of the geothermal environment on metals and plastics. From past experience of geothermal systems, it is known that the environment around the sites causes complex corrosion and scaling problems. The factors involved in the corrosivity of the geothermal environment will be determined so that a reasonable and dependable basis can be developed for materials selection.

Silica Utilization — Samples of the HGP-A silica have been distributed to the Minerals, Pigments and Metals Division of the Pfizer Corporation for testing to investigate possible commercial uses of this by product. We are currently working with Pfizer to proceed further with this project.

Balneology — Jim Woodruff of HNEI has been researching the properties of the geothermal brines for balneological or recreational health spa uses. If they prove suitable for this use, a test program will be implemented to explore such applications.

Future Plans

Kona

Cold Seawater Supply System

The existing 12-inch seawater supply system will be reinforced and realigned from the shoreline out to the depth of the pump station. A new electrical conduit and protection for the onshore portion of the pipelines is also planned. This project is scheduled for construction in early 1987.

NELH will also deploy an 18-inch pipeline in 1987 as an emergency backup to the present 12-inch system. The site, located about 2000 ft south of the existing pipe, will see somewhat different wave conditions and will thus provide secure redundancy. This system is being built with a special CIP appropriation from the 1986 State Legislature.

Hawaiian Abalone Farms is preparing to install its own seawater system to meet its needs. Two pipelines are planned for installation in 1987.

As previously noted, the HOST Park and DOE have reached tentative agreement for a cooperative deployment of a 40-inch coldwater pipe late in 1987. The pipeline will run directly off Keahole Point, parallel to NELH's present 12-inch pipe. This system will include pumps and supply lines for coldwater supplies to NELH and to HOST Park, and an additional warm water supply for NELH.

NELH has responsibility for coordinating these various pipeline plans. Required cross-connection of new and existing systems will provide mutual backup capabilities.

Open-cycle OTEC

SERI is now preparing to expand their open-cycle tests at NELH. These tests will involve expansion of research into heat and mass transfer, gas sorption kinetics, and surface condensers for fresh water production. A heat and mass transfer scoping test apparatus is to be assembled at NELH in late 1986, with experimentation beginning in early 1987. This system will incorporate several surplus heat exchangers from previous ANL projects. Meanwhile, a larger scale systems test apparatus will be designed, with installation scheduled to begin late in 1987. This system will be designed to utilize fully DOE's portion of the HOST/DOE pipeline output.

SERI and ANL researchers are also designing a mist generator test apparatus for installation at NELH in place of one of the heat transfer monitor racks. This sytem will measure and test corrosion and biofouling of candidate mist generator screen materials and configurations.

The Pacific International Center for High Technology Research (PICHTR) is planning to build an operating open-cycle net power producing demonstration plant at NELH. Designs utilize the planned output from the HOST/DOE pipeline to provide a gross output around 165 kw.

West Coast Lobster Company

This company proposes to initiate a lobster hatchery and growout operation on five acres of land subleased from NELH. Plans call for establishing their facility along the ocean side of the access road outside the NELH compound. Initial construction is planned for the spring of 1987.

DUMAND

The DUMAND (Deep Underwater Muon and Neutrino Detection) project plans to deploy the initial instruments in a large proposed array of sensors in the deep ocean off Keahole Point in late 1987. The power and data cables for the project will terminate at NELH, and plans are developing for a data collection and analysis facility at the laboratory. This system will be one of the largest ocean engineering projects ever undertaken.

Coastal Water Quality Monitoring Program

NELH is working with Federal, State and County agencies and with developers of nearby resorts to organize a monitoring program to track changes in the coastal water quality along the West Hawaii coast. It is hoped that this joint venture will provide baseline data for the establishment of realistic standards for control of pollution and protection of the pristine quality of these Kona waters. Periodic measurements will be made of standard oceanographic water chemistry parameters at several sites in addition to the current sampling at NELH. Current measurements along the coast will also aid in prediction of current patterns for future pipeline deployments at NELH and for predictions of effluent trajectories in the ocean. The data base proposed will thus simplify and expedite the preparation of future EIS's and the implementation of future projects in the area.

Seawater Return Systems

NELH is working with HOST Park to develop and implement a trench system which has been proposed for return to the ocean of seawater used for energy and/or aquaculture. A trench dug in the lava would provide a common site for discharge of seawater from many different projects, thus greatly simplifying and making more valid the required monitoring of the water quality. This proposed system appears to have several advantages over alternatives such as an offshore outfall or a series of separate injection wells for each project. The research work on algal stripping of nutrients in an environment such as a trench points toward a possible by-product industry which might develop from the seawater return system.

Jan War and Ajay Bhargava discussing pump characteristics.

Other Projects

Other companies continue to approach NELH about the possibility of growing algae, clams, scallops and other aquadic products using the deep cold water at the laboratory. Inquiries have also been received about desalination, photovoltaics, and solar ponds. Negotiations have begun with several projects. NELH foresees expansion which could rapidly utilize available seawater and infrastructure at Keahole Point.

Facility Improvements

Electrical Distribution System Upgrade—A separate project will provide increased electrical capacity for Cyanotech and the West Coast Lobster Co. New 15-kilovolt underground lines will be run from the laboratory to a transformer adjacent to the leased sites along the NELH access road. These transmission lines are designed for eventual incorportation into the new expanded electrical system being planned for NELH and the HOST Park.

Cold Seawater for Laboratory Air Conditioning—The DPED Energy Division has initiated a project to modify the air conditioning system in the NELH laboratory building so that it will use cold deep seawater to cool the building. Installation, planned for early 1987, will significantly reduce the laboratory electricity bill without additional operating cost, since the water will be effectively unchanged and can still be used for other projects.

Compound Expansion—Increasing demand for compound space for research and development projects has led NELH to initiate preparation of three additional acres of leveled and fenced land adjacent to the existing compound. State CIP funds have been allocated and a preliminary design completed for this project which is scheduled for completion in 1987.

Infrastructure Expansion

To meet increasing present and expected infrastructure demands, NELH has begun work to increase supplies of freshwater, electricity, and telephone lines.

Barbara Lee and Cathy Yamashita at work on the computer.

Puna

Permanent Staff

In order to provide better support for the Puna Geothermal Facility, NELH will be hiring a part-time Mechanical Technician in early 1987. The main responsibility of this position will be to render assistance to the Noi'i O Puna research projects. We expect to increase our support staff in the future depending on availability of operational funds.

Community Geothermal Technology Program

In the early Fall of 1987, this program is expected to advertise for a second round of grant solicitations. An additional five projects will be funded to further investigations of direct heat utilization from waste geothermal fluids. We anticipate that some of the first round projects will develop into viable commercial businesses and will contract with NELH for long-term leases and useage of resources from the PGRC.

Additional Land Acquisition

NELH has been approached by several of the CGTP researchers for additional space for commercial expansion of their projects. We are currently limited to accepting projects which have minimal space requirements. The need for additional land adjacent to the Puna Geothermal Facility is imperative if we are to continue to provide support for the commercial evolution of programs at the PGRC. NELH is exploring the possibility of either leasing or purchasing additional land in the area. Private development of a commercial geothermal park adjacent to the facility is also being explored.

Pre-transfer Overhauls

Prior to TPC taking over the operation and maintenance of the power plant, a number of improvements to the facility will have to be accomplished. The rock muffler, the hydrogen sulfide abatement system and the main steam turbine seals all require attention.

HGP-A Well Shut-in

Simultaneous with Thermal Power Corporation's taking over the electric power plant, the HGP-A well will be closed, or "shut-in." Once this has been accomplished, and depending on funding, a number of maintenance requirements and upgrades to the surface plumbing will be undertaken.

Facility Improvements

The engineering firm of Okahara and Associates has been contracted to design a Capital Improvement Project to expand the present capabilities of the PGRC. The state has allocated $600,000 to complete the improvements. The project will more than double the enclosed research area; create a concrete test pad; provide rest room facilities; develop additional brine, steam and hot water resources; construct a new brine handling system for the total facility; and also provide other support improvements. The design is expected to be completed in Februrary 1987 and bids to be advertised in March. Once completed, the improvements will allow us to attract a much broader base of research programs.

Surplus Equipment

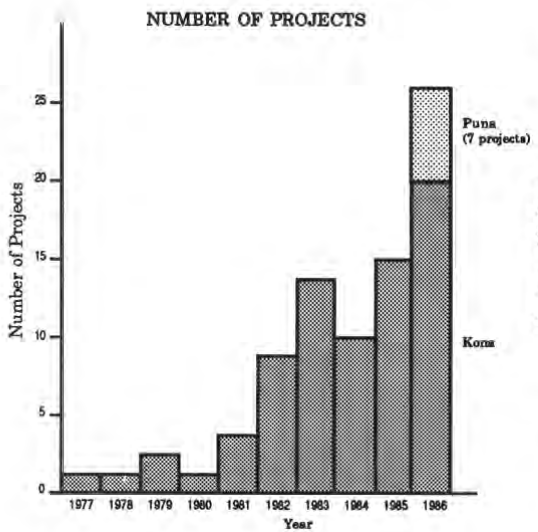
In September 1986, NELH transferred approximately $250,000 worth of surplus equipment and supplies to Hawaii from the DOE East Mesa Geothermal Test Facility in El Centro, California. We were required to pay for only the direct handling and freight costs. The valuable surplus items will be used for capital improvements to the PGRC and in support of research projects at the facility.

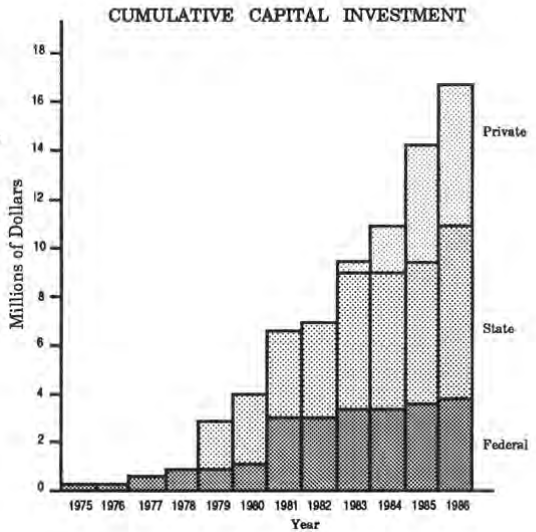
Kelen Dunford explains the OTEC process to a tour group.

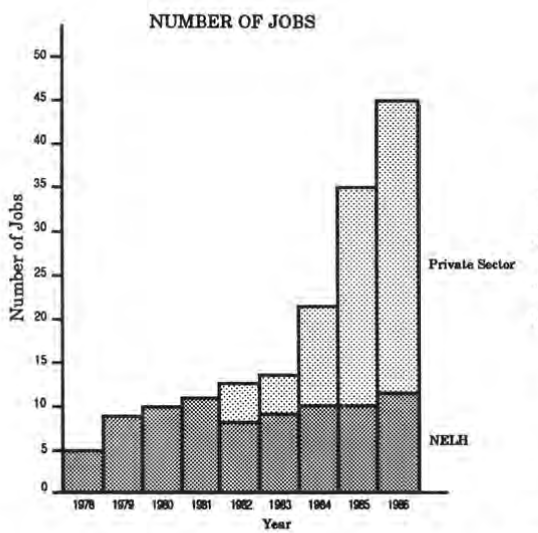
Funding Summary

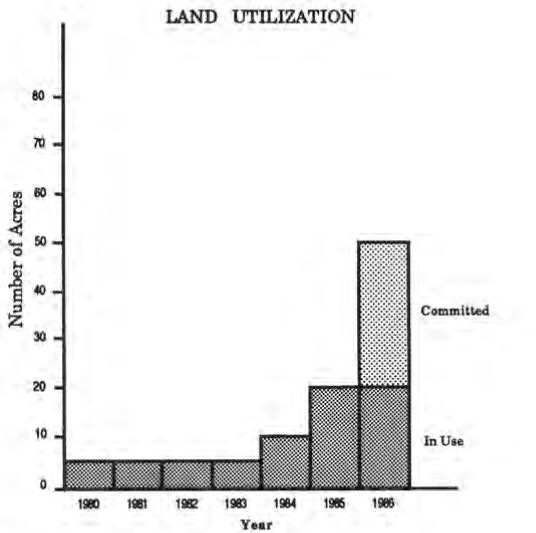
	State	Federal	Other	Total
Operating Funds				
I. Kona Seacoast Test Facility				
A. Operational Support	$ 161,940			
B. Project Funding				
1. OTEC Experiments		$ 384,000	$ 6,362	
2. Aquaculture Projects			$ 72,382	
3. Other Projects			$ 9,814	
C. Transfers	$ -31,838			
Subtotals (Kona):	$ 130,102	$ 384,000	$ 88,558	$ 602,660
II. Puna Geothermal Facility				
A. Operational Support				
B. Project Funding				
1. CGTP Project				
2. Other Projects				
C. Transfer	$ 7,000			
Subtotals (Puna):	$ 7,000			$ 7,000
III. Honolulu				
A. Operational Support				
B. Funded Position	$ 60,940			
C. Transfer	$ 24,838			
Subtotals (Honolulu):	$ 85,778			$ 85,778
Total Operating Budget:	**$ 222,880**	**$ 384,000**	**$ 88,558**	**$ 695,438**

	State	Federal	Other	Total
Capital Improvment Funds				
I. Kona Seacoast Facility				
A. Site Studies				
B. Site Development	$ 160,000			
Subtotals (Kona):	$ 160,000			
II. Puna Geothermal Facility				
A. Site Studies				
B. Site Development	$ 575,000			
Subtotal (Puna):	$ 575,000			
Total Capital Improvements:	**$ 735,000**			









Appendix A

NELH Policy on Project Acceptance

The criteria for acceptance of projects at NELH shall be based upon the projects' relation to the development of natural energy resources and upon their utilization of those resources that are available at the NELH sites in Kona and Puna. Projects that are only tenuously related to alternate energy development and/or do not require the resources that are available shall be referred to the appropriate governmental agency for action and recommendations.

The 1984 Hawaii State Legislature enacted changes to the NELH legislation which allow commercialization of projects at NELH facilities. Leasing of NELH land for commercial purposes can now be approved by the Board of Directors, provided that some initial phases of the research are accomplished at the laboratory.

Appendix B

Publications Resulting from Research at NELH—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, pp. 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, pp. 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," *Proceedings of the Pacific Conference on Marine Technology—PACON 84*, Marine Technology Soc., April 1984, pp. MRM2/47-52.

Daniel, T.H., "Aquaculture Using Cold OTEC Water," *Oceans '85 Conference Record*, Marine Technology Soc., San Diego, Ca., November 12-14, 1985, pp. 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., September 23-25, 1986, pp. 185-90.

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 International 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.

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, pp. 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, vol. 2, pp. 285-89.

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., September 1986, pp. 191-95.

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 no. 346, NACE, San Francisco, Ca., March 1987.

Larsen-Basse, J., N. Sonwalkar and A. Seki, "Preliminary Seawater Experiments with Open Cycle O.T.E.C. Spout Evaporation," *Ocean '86 Conference Record*, Marine Technology Soc., Washington, D.C., September 1986, pp. 202-6.

Lee, C.K.B. and S.L. Ridgway, "Vapor/Droplet Coupling and the Mist Flow (OTEC) Cycle," *J. Solar Energy Engrng.*, vol. 105, May 1983, pp. 181-86.

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.*, 14:458-70, 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.

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

Sansone, F.J. and T.J. Kearney, "Unusual Chlorine Kinetics of Tropical Seawater, and the Potential Environmental Effects," *Proc. of the Pacific Conf. on Marine Technology—PACON 84*, Marine Technology Soc., Honolulu, April 1984, pp. 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.

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., September 1986, pp. 232-37.

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

Appendix C

Publications Resulting from Research at NELH—Puna

Baughman, E.C., "HGP-A Single Stage Direct Flash Geothermal Power Plant First 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 Spent Geothermal Fluids by Adsorptive Bubble Technique," submitted to *Separation Science*, 1986.

Hawaii 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.

Kroopnick, 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.

Mottle, M.J. and H.D. Holland, "Chemical Exchange During Hydrothermal Alteration of Basalt by Seawater—I. Experimental Results for Major and Minor Components of Seawater," 1978.

Mottle, M.J., H.D. Hollad and R.F. Corr, "Chemical Exchange During Hydrothermal Alteration of Basalt by Seawater—II. Experimental Results for Fe, Mn, and Sulfur Species," 1979.

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

Thomas, D.M., "Status Summary of the HGP-A Generator Facility," 1983.

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

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

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

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

Staff

June 30, 1986

Honolulu

Jack P. Huizingh
Executive Director

Barbara Hill
Secretary

Site Addresses

Kona:	Keahole Point P.O. Box 1749 Kailua-Kona, HI 96745 (808)329-7341
Tours	(808)329-0648
Puna:	Puna Geothermal Facility P.O. Box 2172 Pahoa, HI 96778 (808)965-9699
Honolulu:	Central Pacific Plaza 220 S. King St., Suite 1280 Honolulu, HI 96813 (808)548-7017

Kona

Thomas H. Daniel
Laboratory Director

Jan C. War
Operations Manager

Aarne Haas
Electronics Engineer

Ajay Bhargava
Data Analysis Engineer

James W. Placek
Electronics Technician

Stephen B. Wilson
Facilities Maintenance

Kent Merrill
Mechanical Technician

Barbara J. Lee
Laboratory Technician

Carla Hannaford
Water Chemistry Technician

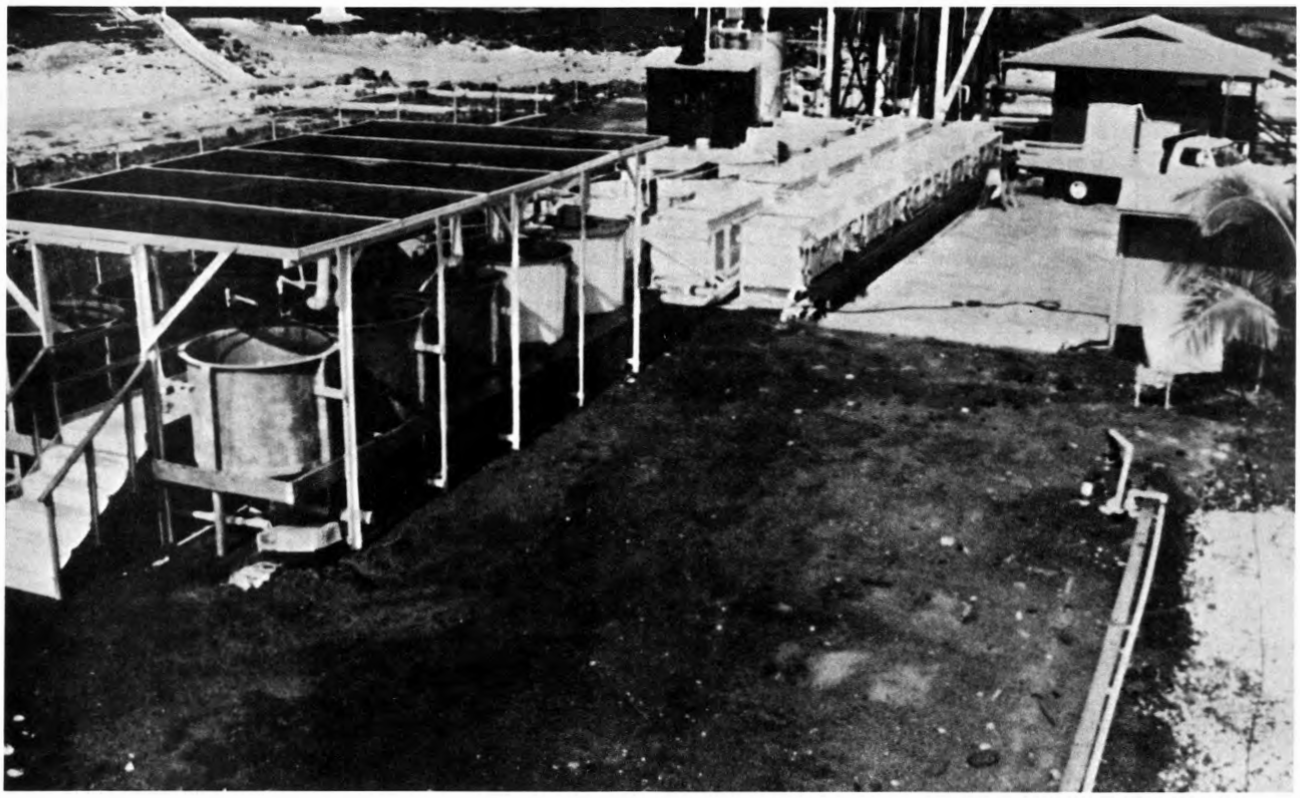
Catherine Yamashita
Secretary/Receptionist

Wendall Shuckert
Groundskeeper

Kelen Dunford
Public Relations Officer
(1/2 Time, E.E.S.)

Puna

Jan C. War
Laboratory Manager



Seawater pipelines (top left) bring warm and coldwater to the aquaculture experiment area.