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ANNUAL REPORT

JULY 1981-JUNE 1982

HAWAII NATURAL ENERGY INSTITUTE

HNEI

MASTER

UNIVERSITY OF HAWAII AT MANOA
HONOLULU, HAWAII

DISCLAIMER

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DIRECTOR'S REPORT

The bulk of this annual report consists of brief progress reports on the thirty-five research and development projects administered by the Hawaii Natural Energy Institute during FY 1981-82, HNEI's eighth year of operation. A breakdown by technology and levels of support is summarized as follows:

	No. of Projects	State Funding	Federal & Other	Total Funding
Geothermal	7	$168,340	$ 254,070	$ 422,410
Ocean	3	75,298	14,975	90,273
Biomass	9	180,578	434,390	614,968
Wind	6	118,200	87,080	205,280
Solar	4	27,494	248,992	276,486
Other	6	33,085	82,975	116,060
Total	35	$602,995	$1,122,482	$ 1,725,477

In addition to the five primary energy resources listed in the left hand column, "Other" projects include research in areas which are common to more than one renewable resource, such as (a) storage of energy from an intermittent resource; (b) corrosion prevention in Hawaii's moist, salt-laden air; and (c) economic and planning studies.

Twenty-five of these projects were supported by two major programs for assisting renewable energy research by university faculty and staff. A sum of $300,000 was provided by the state research and development project fund and $200,000 from U.S. Department of Energy for project support. The University of Hawaii is one of only nine major energy research institutions from throughout the nation to receive a three-year DOE institutional grant. Projects for both state and DOE funding were selected upon the recommendation of the university Energy Advisory Committee, with guidelines and general areas of support established with input from the State Energy Coordinator and the energy officers from each of the four counties.

This report differs from previous annual reports of HNEI in that rather than describing the total renewable energy research and development effort across the state—or even for the entire university—what is described is only those 1981-82 energy projects in which HNEI had a direct role. For a more comprehensive coverage of statewide energy activity, reference may be made to the annual report of the State Energy Resources Coordinator, published by the Department of Planning and Economic Development.

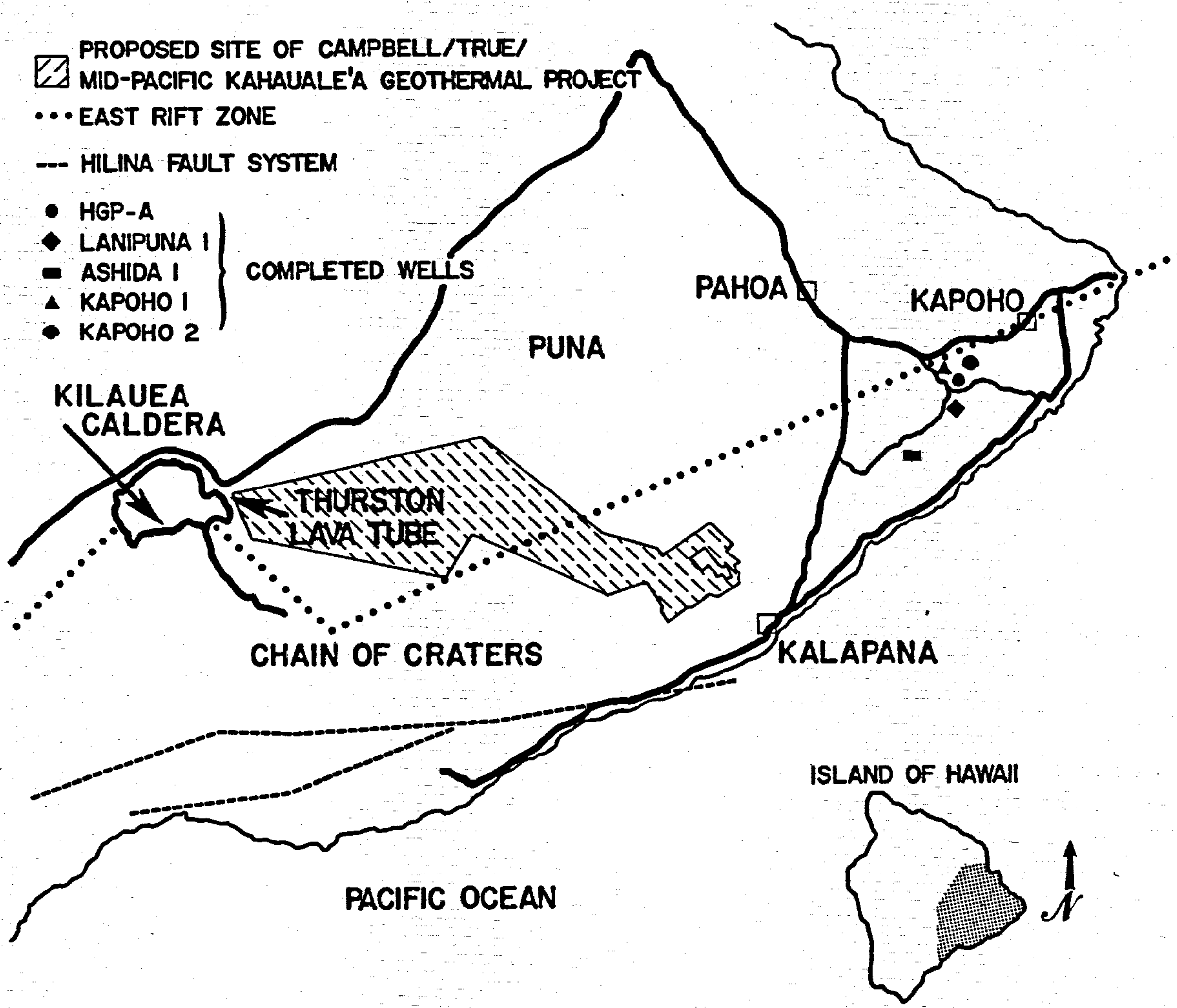
Six events combined to make 1981-82 a period of transition for HNEI:

- Dr. Paul C. Yuen, HNEI's able director for the previous four years, moved on to the position of Dean of Engineering for the University of Hawaii.
- A Division of Energy was established in the Hawaii State Department of Planning and Economic Development in January 1982, with responsibility for supporting commercialization of the state's renewable energy resources.
- The goals and objectives of HNEI became more clearly defined in April 1982, with the authorization by executive order of the Governor of the State Energy Plan and the State Higher Education Plan.
- The severe cutbacks in support by the U.S. Department of Energy for renewable energy resources have resulted in drastic reductions in development and demonstration projects, which for the past decade, have represented the backbone of Hawaii's renewable energy programs.
- In spite of the sharp cutbacks in federal funding for renewable energy, HNEI was successful in obtaining a three-year institutional grant totaling $500,000 for unspecified research on energy alternatives. This was the eighth and final institutional grant to be given by U.S. DOE to outstanding energy research universities from throughout the United States, and the only grant for which the emphasis is on renewable energy. During 1981-82 $150,000 from this institutional support was allocated for research projects, $200,000 will be allocated in 1982-83, and $150,000 in 1983-84.
- The initial recipient of the Coral Industries endowed chair in renewable energy resources, Dr. Michael J. Antal, Jr. of Princeton University, joined the faculty in January 1982 with a joint appointment in HNEI and the Department of Mechanical Engineering.

These final five events are interrelated in that they reinforce an increased emphasis by HNEI for conducting both basic and applied research on renewable energy resources. While HNEI will continue to fulfill its "development" role with the state, the counties, and local business firms in such areas as resource assessment and the monitoring of renewable energy demonstration projects, it will also endeavor to establish greater research breadth and expertise, consistent with its energy research institute mandate. This should increase the opportunity for HNEI to make a greater contribution to the joint effort by the public and private sectors in achieving energy self-sufficiency for Hawaii.

John W. Shupe

John W. Shupe
Director


PROPOSED SITE OF CAMPBELL/TRUE/
MID-PACIFIC KAHAUALE'A GEOTHERMAL PROJECT
EAST RIFT ZONE
HILINA FAULT SYSTEM
HGP-A
LANIPUNA I
ASHIDA I
KAPOHO I
KAPOHO 2
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PUNA
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ISLAND OF HAWAII
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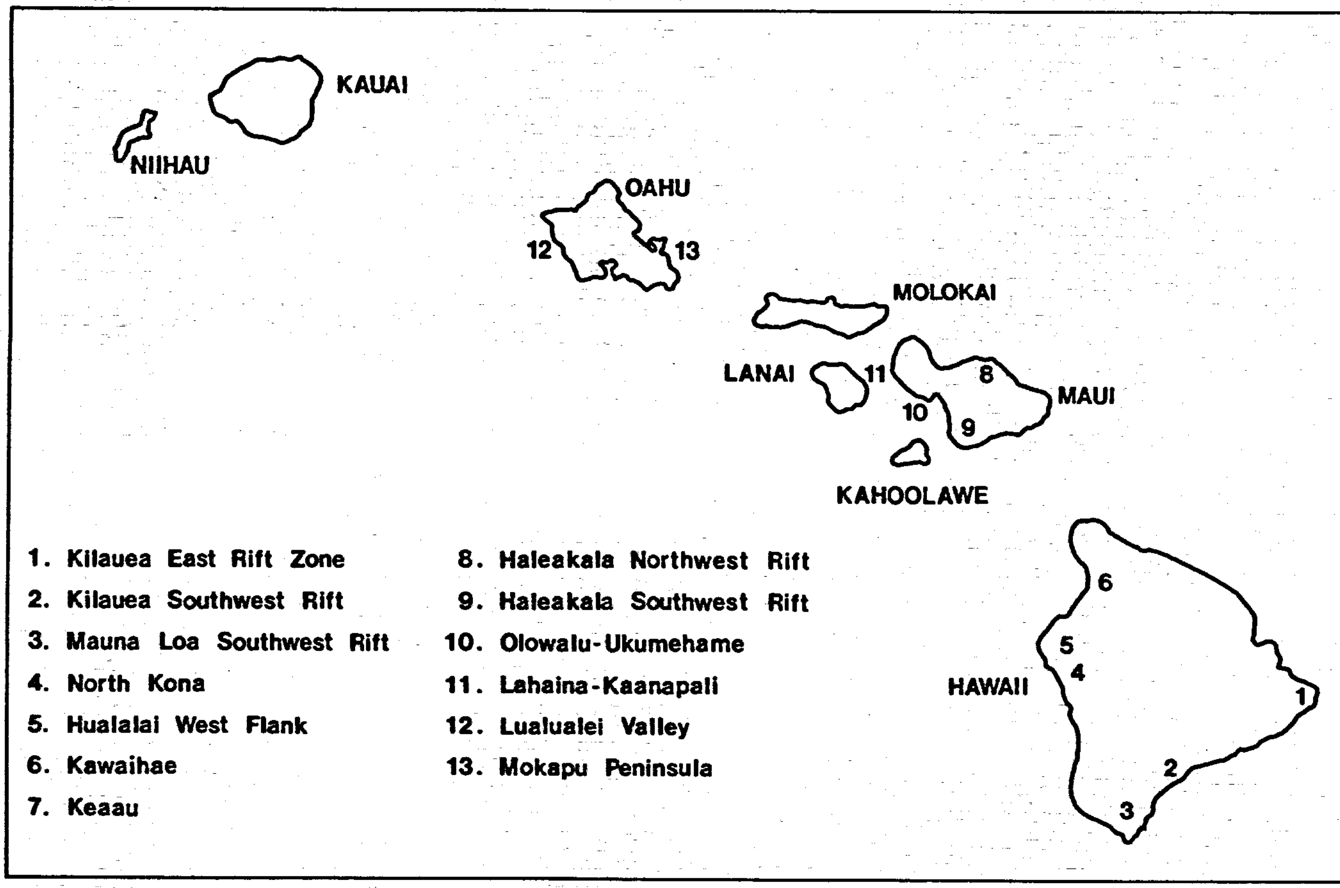
N

GEOTHERMAL ENERGY RESEARCH PROJECTS

Each of the Hawaiian Islands is the top of a volcanic mountain rising from the ocean floor. Those islands at the northwest end of the chain that make up the Hawaiian Archipelago are several millions of years old while those at the southern end are relatively young geologically. In fact, volcanic activity periodically adds land to the Big Island of Hawaii and is forming another island, now several thousand feet below sea level, about 20 miles south of Hawaii. Heat from molten rock or magma in active volcanoes and residual heat from slowly cooling magma bodies from recently inactive volcanoes on the younger islands provide a geothermal energy resource for the state. Thermal energy from these magmas is transferred to water-saturated rock nearby, forming hydrothermal reservoirs which can be tapped by drilling wells from the surface. This releases steam and hot water for generating electricity and providing process heat for industry and agriculture.

The University of Hawaii took the initiative in 1972 to begin exploration of this geothermal resource, and, in 1976, drilled the first geothermal well in the state to a depth of 6,450 feet in the Puna District on the Island of Hawaii. A bottomhole temperature of approximately 676°F makes HGP-A one of the hottest geothermal wells in the world. In order to obtain information on the characteristics and extent of the geothermal resource as well as to demonstrate the feasibility of geothermal energy utilization, the HGP-A Wellhead Generator Feasibility Project was then proposed. This project, funded in June 1978 by the U.S. DOE and supported by the state, the university, the County of Hawaii, and Hawaii Electric Light Co. (HELCO), was for the design, construction, operation, and maintenance of a geothermal electrical power plant at HGP-A. Construction of a steam supply system with hydrogen sulfide abatement equipment, a turbine/generator, and a condenser and cooling water system was completed in June 1981, and the first electrical power from Hawaii's geothermal resource was produced in July 1981.

The success of HGP-A, the availability of preliminary information from a statewide geothermal resource assessment, and two requests for proposal for geothermally-produced electricity from HELCO and Maui Electric have encouraged private interests to drill four additional test wells in Puna and to plan others. Much remains to be learned, however, about Hawaii's geothermal resource. The HGP-A demonstration well is scheduled to operate for at least two years to test geothermal technology, procedures, and possible environmental impacts. Other research is underway to determine the locations, extent, chemistry, heating mechanisms, and environmental impacts of geothermal reservoirs. Many of these projects are supported by HNEI and are described in the following section.



FIELD STUDY SITES FOR HAWAII GEOTHERMAL RESOURCE ASSESSMENT

HAWAII GEOTHERMAL RESOURCE ASSESSMENT

PRINCIPAL INVESTIGATOR: Donald M. Thomas, Ph.D.
Hawaii Institute of Geophysics

PROJECT STAFF: Barry R. Lienert, Ph.D.
Malcolm E. Cox, M.S.
Mark Mattice, M.S.
Hawaii Institute of Geophysics
James P. Kauahikaua, Ph.D.
U.S. Geological Survey

PROJECT PERIOD AND FUNDING SOURCES: This four-year, two-phase assessment project began in 1978 under the sponsorship of the U.S. DOE Western States Cooperative Direct Heat Resource Assessment and has since been funded by Hawaii CIP (Capital Improvement Project) monies administered by the Hawaii Department of Planning and Economic Development (FY 1980-81) and HNEI (FY 1981-82).
Total funding for FY 1981-82: $289,678.

PROJECT DESCRIPTION AND OBJECTIVES

Phase I of this project to determine areas in the state with geothermal energy potential began by compiling and evaluating existing data for the major Hawaiian Islands. Twenty separate areas with potentially high or intermediate temperature resources were identified by considering

- Geological structures and age of volcanoes;
- Geochemical anomalies such as elevated silica concentrations and chloride/magnesium ion ratios which indicate thermally-altered groundwater;
- Geophysical data such as magnetic, gravitational, and temperature anomalies normally associated with geothermal reservoirs.

Phase II has consisted of three years of field explorations at promising sites identified during the initial regional surveys. Thirteen of the twenty were chosen on the basis of probability for finding a usable resource in an area with energy needs. Water wells and springs have been tested; measuring equipment has been installed at various sites; soil samples have been collected and analyzed; geologic field maps have been prepared. Techniques used extensively include geochemical analysis of groundwater; soil mercury and radon surveys; isotopic analysis of rainfall and groundwater; resistivity, gravity, and electromagnetic surveys; seismic and groundwater temperature measurements.

RESEARCH PROGRESS AND PROJECT STATUS

Field surveys have been completed during this last year of the assessment project, and all data are now being compiled for final evaluation and publication. Results indicate that several of the thirteen sites studied may be potential geothermal resource areas in Hawaii.

KILAUEA EAST RIFT ZONE has been the site of frequent eruptive activity during historic times, and a substantial number of geophysical and geochemical studies conducted in the area indicate that it has the greatest geothermal potential of any locale in the state. Estimates of its potential range from 100 to 3,000 megawatt centuries of electrical power.

KILAUEA SOUTHWEST RIFT has experienced intrusive activity as recently as August 1981, and although relatively little geophysical or geochemical work has been done here, aeromagnetic and resistivity anomalies have been studied. In addition, steaming ground and a warm coastal spring have been mapped along the rift. The area is considered to have a very high potential for a high temperature resource within 2 miles of the surface; however, no estimate of its capacity can be made with the data presently available.

The SOUTHWEST RIFT ZONE OF MAUNA LOA has experienced eruptive activity during recent geologic history. However, a limited resistivity survey across the lower southwest rift did not detect evidence of anomalies within .6 mile of the surface.

In NORTH KONA, mercury and radon surveys have identified anomalies that may be associated with a thermal source on the Hualalai southwest flank, infrared anomalies have been reported in the coastal waters, and groundwater chemistry data suggest that some thermal alteration has occurred. Limited geophysical surveys, however, did not detect significant resistivity anomalies. If a geothermal resource is present in this location, it is highly likely to be of low to intermediate temperature.

HUALALAI WEST FLANK has been active during recent times as results of geologic mapping suggest. Mercury and radon surveys here have identified weak anomalies associated with the very diffuse rift zone, and resistivity soundings near the summit have detected lower than expected resistivities at 500- to 1,000-yard depths. The probability that a moderate temperature resource is present within 2 miles of the surface in this general area is considered to be about 20 to 30 percent.

In KAWAIHAE, mercury and radon surveys, groundwater wells with elevated water temperatures, and a modified chloride/magnesium ratio suggest that a thermal source is located in the vicinity east of Kawaihae Bay. Higher than expected resistivities have been found to the northeast of Kawaihae which may be associated with an eruptive vent 80,000 years old. A thermal resource is probably present near Kawaihae, but it is unlikely that temperatures are more than 175°F to 212°F.

At KEAAU, preliminary groundwater chemistry initially suggested that thermal fluids might be present, but no resistivity anomalies were detected to depths of 3 miles. The existence of a geothermal resource in this area is unlikely.

Along the HALEAKALA NORTHWEST RIFT, results of mercury and radon surveys and groundwater geochemical data initially suggested that a number of areas were anomalous. Resistivity studies, however, were unable to detect any significant indications of a thermal source. The probability of a resource being present within 1.25 miles of the surface on the Haleakala northwest rift is low.

HALEAKALA SOUTHWEST RIFT was the site of the only historical eruption on Haleakala Volcano. Limited mercury and radon field surveys across the upper and lower southwest rift and data from passive seismic and electromagnetic studies suggest a thermal resource along this rift.

In the OLOWALU-UKUMEHAME area, a warm water well shows evidence of moderate thermal alteration. In addition, resistivity soundings have mapped a warm water lens within a few hundred yards of the surface, and electromagnetic sounding data suggest that the source of the thermal fluids may be located near the caldera boundary of West Maui Volcano. The probability of a low or moderate temperature resource is considered to be very high.

In the LAHAINA-KAANAPALI area, groundwater geochemical data and limited mercury and radon surveys have identified moderate to low level anomalies, but resistivities are not consistent with a thermal resource. The probability of a viable low temperature resource is remote.

LUALUALEI VALLEY's groundwater chemistry data as well as mercury and radon survey results indicate that thermally altered groundwaters are near the surface of this area which was the original Waianae caldera. Resistivity soundings, too, have identified lower than expected resistivities at depths less than .6 mile that may be due to the presence of thermal fluids. The probability that a geothermal resource is present is considered to be high, although the resource will probably be of low to moderate temperature.

On MOKAPU PENINSULA, a few weak radon and mercury anomalies were identified, but resistivity soundings were unable to detect resistivity structures consistent with the existence of a geothermal resource. A geothermal resource is unlikely in this part of Koolau Volcano.

INTERFERENCE TEST AND RESERVOIR ANALYSIS OF KAPOHO RESERVOIR

PRINCIPAL INVESTIGATOR:	Bill Chen, Ph.D. College of Engineering, UH/Hilo
PROJECT STAFF:	Arthur Seki, M.S. Hawaii Natural Energy Institute Deane Kihara, Ph.D. UHM Department of Mechanical Engineering
PROJECT PERIOD AND FUNDING SOURCE:	State R & D funds administered by HNEI supported this nine-month project in FY 1981-82. HNEI has allocated additional R & D funds for FY 1982-83 to complete interference tests. Total funding for FY 1981-82: $45,079.

PROJECT DESCRIPTION AND OBJECTIVES

HGP-A and two privately drilled geothermal wells are located within several thousand feet of each other, but they may or may not be tapping the same hydrothermal reservoir of steam and hot fluid under Kilauea Volcano's east rift zone. Precisely measuring water level and pressure changes in one of these nonproducing wells when one or both of the other wells are flowing should yield clues to the nature of this reservoir (or reservoirs). Project tasks include

- Evaluating data collected during past flow tests at HGP-A;
- Measuring earthtides before tests in order to account for their effects during the tests; and
- Conducting interference tests to monitor pressure responses among the three wells

in order to identify characteristics of the reservoir(s), estimate its size and storage capacity, and predict its energy potential for electrical generation.

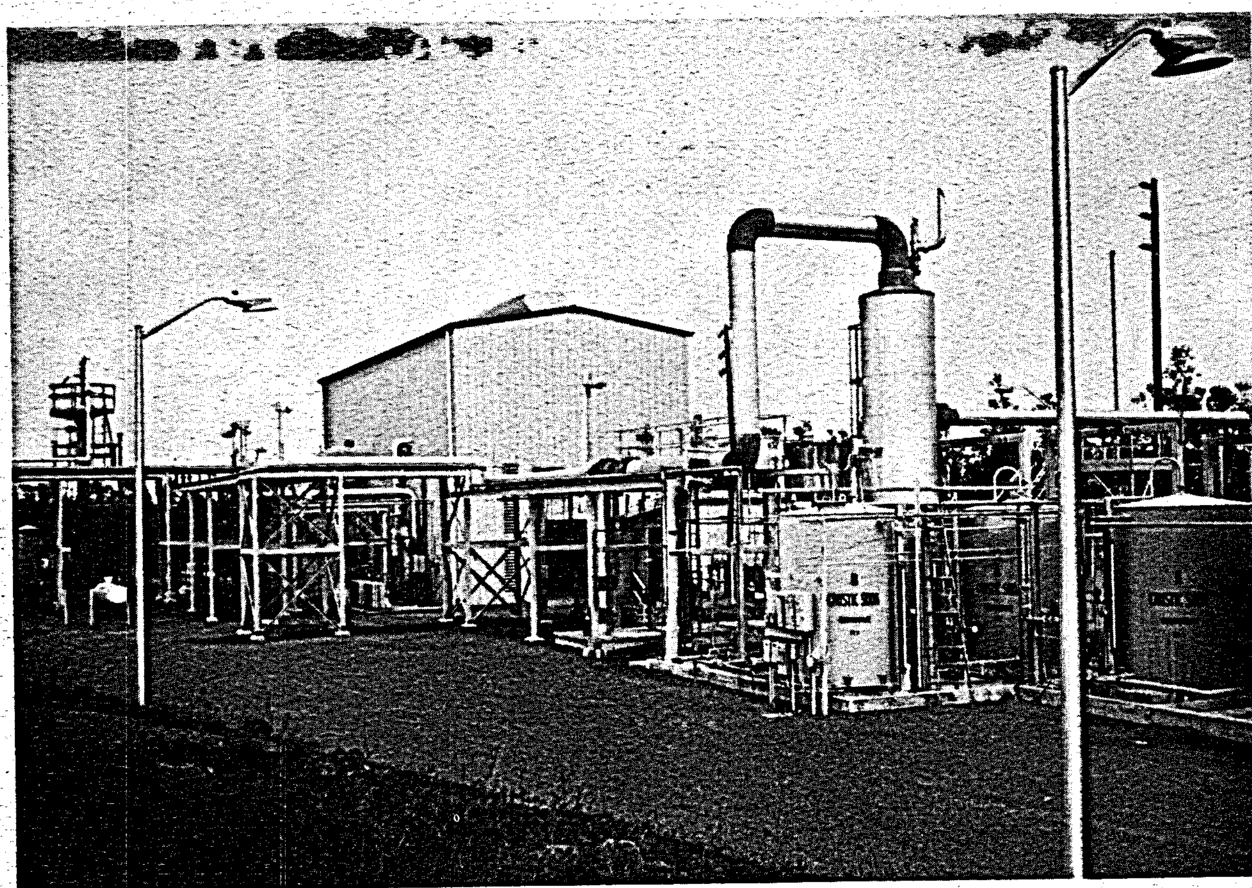
RESEARCH PROGRESS AND PROJECT STATUS

During the nine-month project period, data from production at HGP-A were examined to characterize well recharge and production behavior; equipment was installed at Barnwell/GEDCO's Lanipuna-1 well to measure earthtides; and precision pressure sensing equipment was purchased and field tested to prepare for future interference tests.

An opportunity to study well recovery at HGP-A occurred soon after the well was brought into production on June 2, 1981. Turbine rotor vibration forced shutdown on September 4, and production did not resume until December 11. At this time steam flow rate was comparable to previous well flows, but the percent of steam to hot fluid dropped from a normal 50 percent to 33 percent for two or three weeks before gradually returning to 50 percent. Understanding why this happens is important for future wellhead generator designs, for HGP-A operation, and for reservoir modeling. Thus, project personnel examined earlier production tests at HGP-A which suggest that water moving through the permeable rock formations around the well flashes to steam before it actually enters the wellbore. As HGP-A produces, this "flash front" moves farther out from the wellbore until equilibrium is reached between steam flowing to the turbogenerator at the wellhead and fresh groundwater replacing what has been drawn off and being heated from the geothermal source. As long as the well produces, this recharge zone is relatively stable as are temperatures and pressures. Interrupting production results initially in increased pressures and, thus, in less steam formation. Heat loss during production also reduces fluid temperatures, further limiting steam formation. HGP-A appears to require a thermal recovery time longer than the September to December shut-in period.

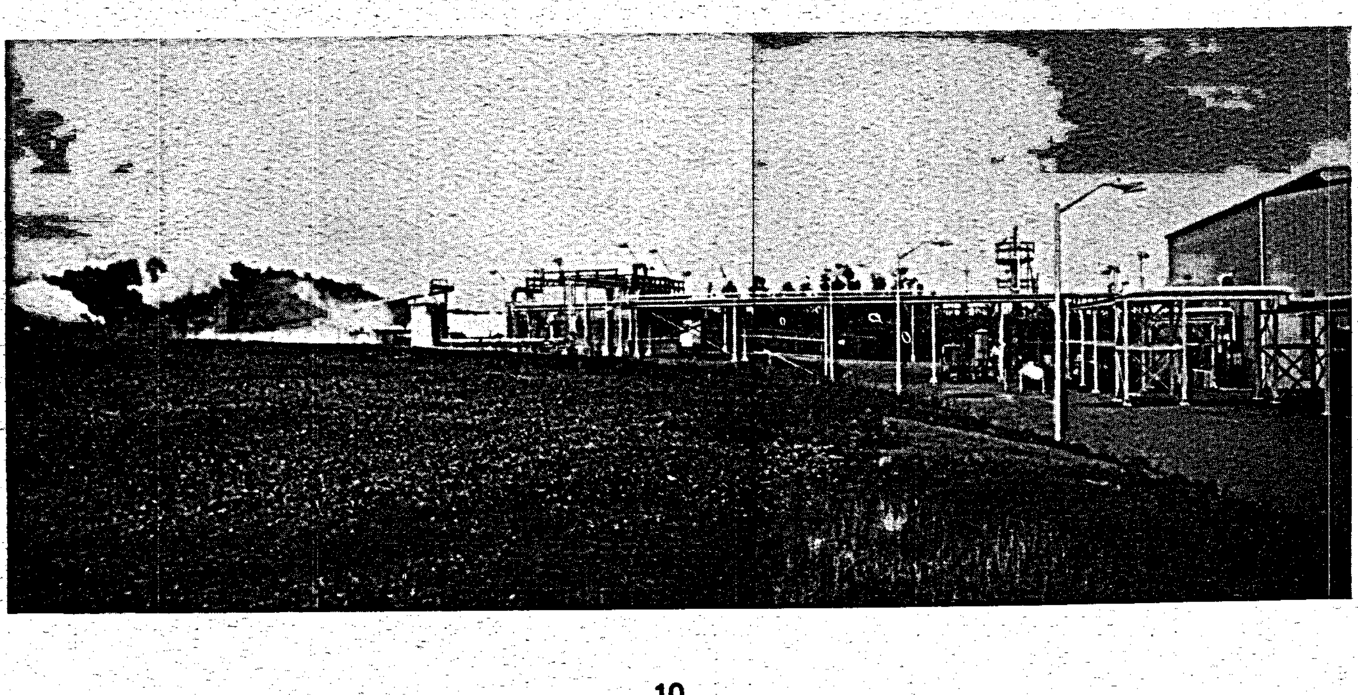
A second task for this project was completed during November and December 1981. A water level indicator was lowered into Lanipuna-1, located approximately 1,500 feet southwest of HGP-A, to measure earthtide and to monitor any possible changes in Lanipuna-1 when HGP-A started on December 11. Results show fairly constant daily earthtide variations of approximately 4 inches until December 4 when well water levels increase by 4 feet. Heavy rainfall from November 30 to December 2 seems to explain this change and strongly suggests some communication between surface water and the well's production layer. No interference was observed between HGP-A and Lanipuna-1 after HGP-A start-up.

To conduct pressure interference tests, a Sperry-Sun pressure sensing recorder capable of measuring 5,000 pounds per square inch (to 1/10 psi) was ordered in December. In June 1982, the equipment was field-tested for one week by lowering it 1,000 feet into Lanipuna-1. Minor repairs are being completed now so that actual deep-hole tests can be conducted during the second phase of the project.



Above, storage tanks of caustic soda for the hydrogen sulfide abatement system sit next to the separator which directs geothermal steam to the HGP-A power plant behind. Below, spent steam and hot fluid lines lead to the cooling tower, center, and to the silica settling pond, left.

Photos by Donald Thomas



HYDROLOGY, TEMPERATURE, AND CHEMISTRY OF WATER IN THE EAST RIFT ZONE OF KILAUEA

PRINCIPAL INVESTIGATOR: David Epp, Ph.D.
Hawaii Institute of Geophysics

PROJECT STAFF: Gary McMurtry, Ph.D.
Frank Peterson, Ph.D.
Jewelle Imada, B.S.
Charles Fraley, M.S.
Douglas Myhre, B.S.
Hawaii Institute of Geophysics
James Kauahikaua, Ph.D.
U.S. Geological Survey

PROJECT PERIOD AND FUNDING SOURCE: State R & D funds administered through HNEI are supporting this one-year project which continues through December 1982.
Total funding for FY 1981-82: $15,560.

PROJECT DESCRIPTION AND OBJECTIVES

The goal of this project is to measure temperatures, water levels, and chemistry in water wells and coastal springs located around the geothermal wells on the east rift zone of Kilauea Volcano. These data and existing data from federal and state sources will be analyzed in order to construct and test thermal and hydrological models which will

- Provide data on the near-surface temperature regime of the east rift zone;
- Provide baseline data on the normal recharge and flow patterns of the groundwater system on the lower east rift zone;
- Identify the natural background temperature, water level, and chemistry to assess any effects of testing and production at HGP-A and other geothermal wells; and
- Chart the distribution in time and space of geothermal well discharge.

RESEARCH PROGRESS AND PROJECT STATUS

Weekly water samples are collected from seven wells and coastal springs and supplied by the County of Hawaii Water Supply Department and the Miller-Leib Water Company from three pumped wells in the Puna District of the Big Island. These samples are filtered for particulate matter and analyzed for silica, chloride, copper, zinc, arsenic, fluoride, lithium, sulfate, cadmium, manganese, magnesium, iron, mercury, and selemium. While results have not yet been synthesized, there are significant variations in the water chemistry of some wells (lithium, copper, and zinc in one well; magnesium, zinc, and arsenic in another; all fourteen elements in a third well) and noticeable changes in the amount of particulate matter from some wells which appear to be related to rainfall. Temperature versus depth profiles, too, are being obtained in three wells, and single temperatures are being measured at the other sites not being supplied by the county and Miller-Leib. Finally, data related to thermal and hydrological models are being collected from the state, county, and U.S. Geological Survey.

All of these data will be combined, refined, and analyzed at a later date in conjunction with records of magmatic movement under Kilauea's summit and rift zones, with testing and production schedules from the several geothermal wells in Puna, and with data on HGP-A effluents.

BOILING HEAT TRANSFER IN GEOTHERMAL SYSTEMS

PRINCIPAL INVESTIGATOR: Ping Cheng, Ph.D.
UHM Department of Mechanical Engineering

PROJECT STAFF: David Chui, B.S.
Francisco Siu, B.S.
UHM Department of Mechanical Engineering

PROJECT PERIOD AND FUNDING SOURCE: State R & D funds administered by HNEI supported this nine-month project during FY 1981-82. Additional funds from a U.S. DOE institutional grant also administered by HNEI have been allocated for FY 1982-83 to complete this project.
Total funding for FY 1981-82: $18,023.

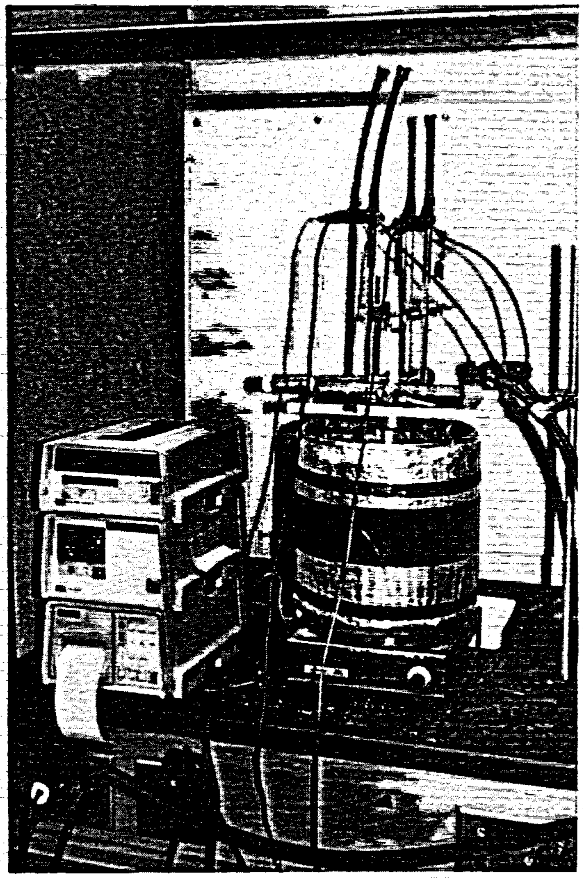
PROJECT DESCRIPTION AND OBJECTIVES

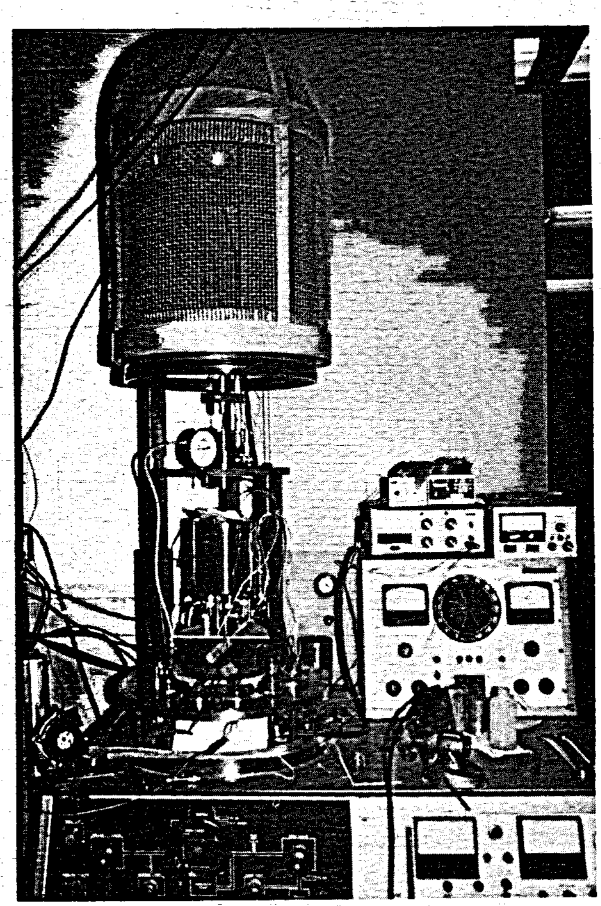
Geothermal systems in Hawaii are water-dominated hydrothermal types which, when producing, emit both steam and fluid. While much is known about single-phase heat transfer, less information is available on two-phase heat transfer mechanisms in a geothermal environment. Thus, the purpose of this project is to study boiling heat transfer in geothermal systems and to develop methodology for the prediction of heat transfer rates and the size of the vapor zone around hot intrusives in a geothermal reservoir. Results of this investigation will have important implications for locating geothermal resources, estimating maximum possible energy extraction rates, and predicting the longevity of a two-phase geothermal reservoir such as the one HGP-A is tapping on the Island of Hawaii. The project consists of two tasks, formulation of a theory for boiling heat transfer about hot intrusives in an underground formation and verification of the theory by experiments.

RESEARCH PROGRESS AND PROJECT STATUS

Analytical methods have been developed to determine heat transfer rates and the size of vapor zones around geothermal intrusives of various shapes. These methods are based on the assumption that a thin film forms at the interface between a high temperature body of molten magma which has intruded into overlying, water-saturated rock and the groundwater it comes into contact with. The heat transfer rate from the hot intrusive to the water is related to rock permeability and to the thickness of this film. Its thickness at any point is, in turn, a complicated function of the

- Temperature of the superheated intrusive;
- Temperature of the surrounding groundwater; and
- Property ratio of saturated steam to saturated liquid.





The laboratory model above allows measurement of heat transfer rates between hot intrusives and surrounding water-saturated rock. At right, a high temperature molybdenum furnace melts Hawaiian basalts for velocity and attenuation studies.

This third element involves parameters related to viscosity and specific heat of groundwater; changes in groundwater density as it becomes steam; thermal expansion coefficient of the saturated water; latent heat of vaporization; and thermal diffusivity of the porous rock medium.

After these analytical solutions were obtained, a physical model was designed and fabricated in the laboratory in order to verify them. The initial model consists of a horizontal cylinder embedded in an insulated tank of glass beads and water. The cylinder, which is heated by an electrical current, idealizes a superheated intrusive, and the glass beads model the water-saturated porous rock medium. Thermocouples and wattmeters, which precisely measure temperatures and heat transfer rates, have just been installed. During FY 1982-83, observations will be made to determine whether a vapor film will indeed form adjacent to the heated surface and at what temperature; temperature and heat flux measurements will be made; and correlations for heat transfer and size of vapor zone will be developed from project data. A second model with a vertical copper plate to simulate a volcanic dike may also be considered if time permits.

SEISMIC AND THERMAL PROPERTIES OF HAWAIIAN BASALTS

PRINCIPAL INVESTIGATOR:	Murli H. Manghnani, Ph.D. Hawaii Institute of Geophysics
PROJECT STAFF:	Chandra S. Rai, Ph.D. Keith W. Katahara, Ph.D. Cheney Milholland, B.S.A., B.S. Hawaii Institute of Geophysics
PROJECT PERIOD AND FUNDING SOURCES:	Funds for this project during FY 1981-82 came from the National Science Foundation and HNEI's U.S. DOE institutional grant. HNEI has provided additional support for FY 1982-83. Total funding for FY 1981-82: $18,443.

PROJECT DESCRIPTION AND OBJECTIVES

A knowledge of *in situ* physical and thermal properties—seismic velocity and attenuation, thermal conductivity or diffusivity, specific heat, and latent heat of fusion—of rocks is important for deriving thermal models of a potential geothermal system, for evaluating the seismic and heat transfer mechanisms in such a system, and for assessing the feasibility of extracting useful energy from it. Probably because laboratory studies of the properties of molten rock are technically difficult due to high temperatures and corrosivity of the melts, almost no data are available on acoustic wave velocity and attenuation in rock melts. Similarly, while data are available on the thermal conductivity of dry basalt samples, almost no data are available on the combined effects of temperature and pressure in actual geothermal environments, on the thermal conductivity of fluid-saturated volcanic basalts, or on the changes in thermal conductivity after the rocks are hydrothermally altered. The research plan for this project, which builds on the principal investigator's previous work, includes preparing and characterizing basalt samples; acquiring and assembling apparatus necessary for measuring seismic velocity and attenuation and thermal conductivity; and collecting and evaluating data for possible thermal modeling as well as interpretation of seismic data.

RESEARCH PROGRESS AND PROJECT STATUS

The project began by characterizing a variety of Hawaiian basalt samples in terms of mineralogic composition, pore volume, and structure. Identifying these parameters helps explain thermal and seismic properties determined during other project work and provides data for identification of basalts in the field.

While these studies were being done, a continuous wave interferometer and related data collection equipment were acquired and installed to test an experimental technique for measuring ultrasonic velocity and attenuation in basalt melts. Knowing their variation with temperature and frequency can yield important information on the structure of the melt and on related properties such as density, compressibility, and velocity. These, in turn, may be useful for differentiating magma bodies from surrounding rock and, thus, identifying their size, shape, migration, and energy potential.

Essentially, the technique involves placing a thin layer of melt between two buffer rods through which pressure waves are transmitted. Multiple reflections of these waves in the melt layer interfere with each other and create resonances. Velocity and attenuation values can be obtained by measuring the amplitude of the transmitted wave as a function of either the melt layer thickness or the frequency. Measurements taken in the field can then be compared to these data. To date, compressional velocity and attenuation have been successfully obtained on three Hawaiian basaltic rock types: alkalic olivine basalt, olivine nephelinite, and tholeiite. Progess is also being made on measuring shear velocity and attenuation on these three types of basalts.

Finally, steps have been taken to set up experiments for measuring thermal conductivity of selected saturated Hawaiian basaltic rocks.

STABLE ISOTOPIC COMPOSITIONS IN ROCKS AND MINERALS FROM HGP-A

PRINCIPAL INVESTIGATOR: Hsueh-Wen Yeh, Ph.D.
Hawaii Institute of Geophysics

PROJECT PERIOD AND FUNDING SOURCE: Funds from HNEI's U.S. DOE institutional grant made this one-year project possible.
Total funding for FY 1981-82: $16,000.

PROJECT DESCRIPTION AND OBJECTIVES

Stable isotopic compositions of hydrogen, oxygen, carbon, and sulfur in hydrothermally-altered rocks can provide information on the sources of geothermal fluids and the nature of subsurface processes and temperatures in geothermal systems. This study, which continues earlier work by the principal investigator, measures isotopes in HGP-A core samples to help explain the thermal history of the Kapoho reservoir and the sources and subsurface circulation patterns of its geothermal fluids.

RESEARCH PROGRESS

Thirteen samples from HGP-A cores taken at various depths have been analyzed for $\delta^{18}O$, an oxygen isotopic ratio which reflects the temperature at which hydrothermal alteration occurs. That is, alteration of basalts at low temperatures results in high $\delta^{18}O$ ratios while high temperature alteration yields lower $\delta^{18}O$ values in basalts: values of +5.7 parts per thousand (ppt) are associated with unaltered fresh basalt; values of +6.9 ppt, with low temperature (390°F-480°F) alteration; and values of +3.1 ppt, with high temperature (750°F) alteration. HGP-A's downhole profile of $\delta^{18}O$ is, in general, consistent with this interpretation. Values near surface are 5.2 to 5.3 ppt; those between 2,235 and 4,447 feet range from 6.6 to 8.4 ppt; and those at bottomhole (6,446-6,451 feet) range from 2.2 to 3.7 ppt. Although an exact figure is difficult to determine, a lower limit on the alteration temperature for the deepest core is estimated to be about 750°F.

Nine HGP-A core samples have also been analyzed for their deuterium contents. The origin of hydrothermal water can be inferred on the basis of this hydrogen isotope since seawater and meteoric water have different ratios of deuterium and regular hydrogen. Calculating this deuterium/hydrogen ratio in hydroxyl (OH) minerals of altered basalts can indicate the source of the water responsible for the alteration because the hydrogen isotopes in H_2O equilibrate with hydrogen isotopes in OH minerals. Such calculations with HGP-A core samples suggest that seawater was the source of the hydrogen which exchanged with the OH in the rocks.

Finally, attempts were unsuccessful to extract carbonate (CO_3) from the core samples for determining $\delta^{13}C$ and confirming $\delta^{18}O$ ratios, apparently because the concentrations of calcite are too low. This modifies earlier evidence that calcite is not uncommon in HGP-A cores.

PHYTOTOXICITY OF GEOTHERMAL SEPARATOR BRINE

PRINCIPAL INVESTIGATORS: Sanford M. Siegel, Ph.D.
UHM Department of Botany
Barbara Z. Siegel, Ph.D.
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PROJECT STAFF: Cheran Wilson, M.S.
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PROJECT PERIOD AND FUNDING SOURCES: Aside from a stipend from the National Institute of Health for a student assistant, HNEI has supported this project in FY 1981-82 with funds from a U.S. DOE institutional grant and has made state R & D funds available for FY 1982-83. Total funding for FY 1981-82: $19,627.

PROJECT DESCRIPTION AND OBJECTIVES

The escalation of geothermal exploration and its subsequent development as an electrical energy resource may be accompanied by disposal of large volumes of hydrogeothermal fluid. Even though the quantities of boron, flouride, cadmium, thallium, lead, mercury, zinc, and copper in HGP-A discharge waters are low and "safe" by usual water quality standards, their impact on the vegetation of the Kapoho area of Puna has never been assessed. Thus, in an effort to continue surveillance of geothermal resource development in Hawaii, this study seeks preliminary answers to two questions. First, are the concentrations of trace ions in aqueous geothermal effluents toxic per se; toxic in the presence of accompanying trace ions; toxic with saline ingredients (Na^+, K^+, Cl^-, $SO_4^=$, etc.); or toxic in concert with both trace and saline adjustments? Second, are there readily visible signs and symptoms of toxication caused by geothermal discharge liquid? Exposing seedlings of several ecologically and economically important plants from the Puna area to tap water, to a saline solution, and to HGP-A fluid should provide answers to these questions.

RESEARCH PROGRESS AND PROJECT STATUS

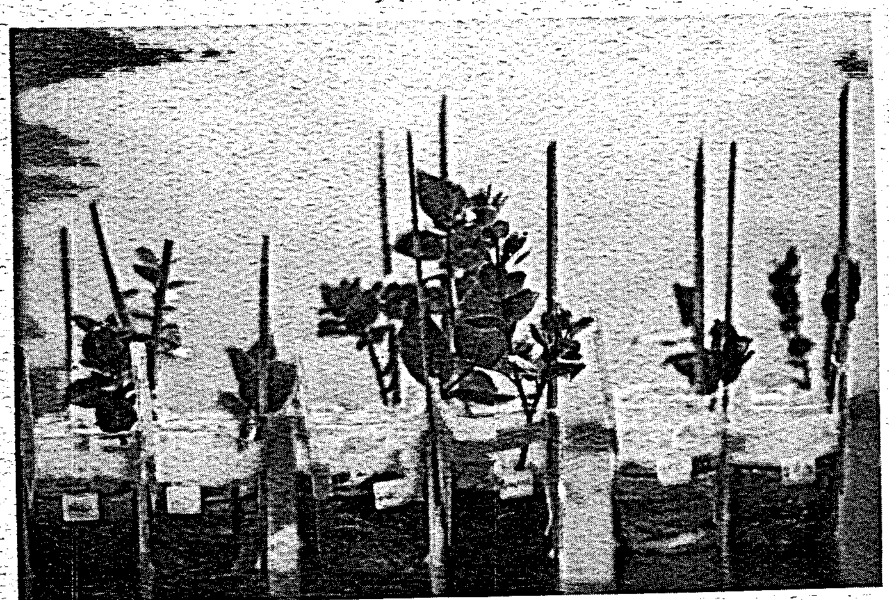
Species tested during this project period include seedlings of *Carica papaya* ("solo") and *Anthurium andraeanum;* rooted cuttings of *Metrosideros collina* var. *polymorpha* (ohia-lehua); seeds of *Phaseolus vulgaris* (kidney bean), *Glycine max* (soybean), *Cucumis sativus* (marketer cucumber), *Brassica pekinensis* (Chinese cabbage), and *Zea mays* (Hawaii sugar corn); and fronds of *Lemna* (duckweed). Most important are papaya, a major economic plant, and ohia, the major native forest tree in Hawaii.

Papaya seeds were cultivated, thinned to uniform seedlings, and treated. Ohia cuttings were rooted and used eight to ten weeks after application of a commercial rooting hormone. Anthurium seedlings were six weeks old when tested. Seeds were germinated in petri dishes routinely, each treatment entailing the use of sixty or more. Duckweed plants were collected from local artificial pond sources and used in lots of fifty or more.

Tests varied from five days to four weeks, depending on the species being tested; and some involved germination while others monitored seedling growth. Samples of separator discharge brine were obtained at HGP-A and adjusted to eliminate the effects of hydrogen sulfide abatement treatment. A sodium chloride solution of 3,500 parts per million (ppm) was used to monitor the effects of simple salinity. Results show that cucumber and maize were unaffected by HGP brine, whereas kidney bean and soybean seedlings were inhibited. Among the remaining tests, three species—anthurium, duckweed, and ohia—displayed discoloration and wilting and in the latter, defoliation. Papaya showed a moderate degree of growth inhibition and mild chlorosis or yellowing. Anthurium, duckweed, and especially ohia also showed salt toxicity. The growth of papaya, however, was actually promoted by salinities of up to about 6,000 ppm.

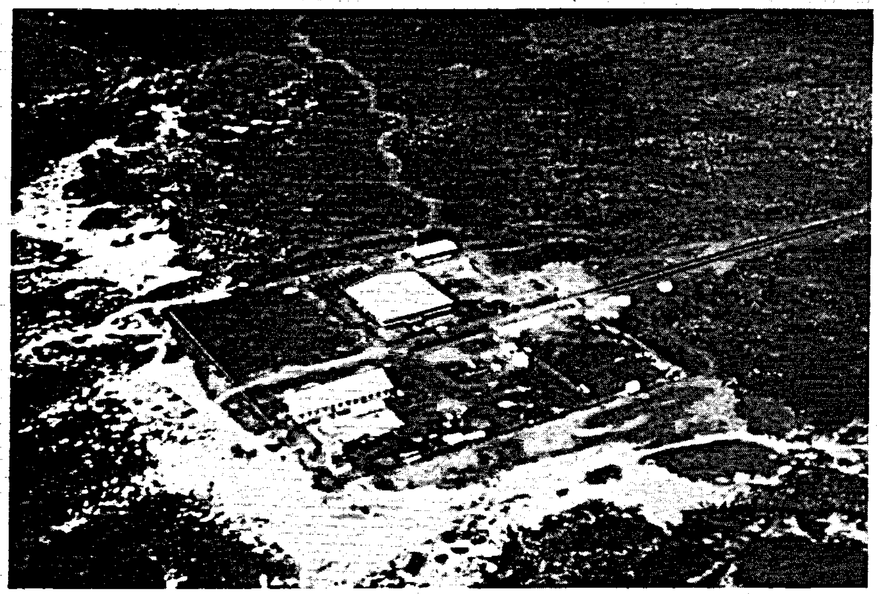
Single salt toxicity trials with papaya, too, have shown growth to be stimulated or unaffected by zinc, copper, or lead at 1 to 10 ppm whereas cadium, thallium, and mercury were all at or near toxic thresholds between 1 and 3 ppm. Both borate and iron were quite inhibitory in test solutions at 5 and 2 ppm respectively. Ohia seems to be appreciably more sensitive than papaya. Thus, brines vary in their suitability for use in irrigation, and their salt content can place limits on safe disposal. The contribution that salinity per se makes is evident in the effects of sodium chloride at 3,500 ppm on anthurium, duckweed, and ohia: its use on sensitive species can result in slowed growth, lowered disease resistance, or other competitive disadvantages. On the other hand, growth of different species such as papaya, cucumber, and maize is not adversely affected and may even be stimulated.

Against this pattern, HGP brine would be expected to stimulate papaya growth if its behavior were based solely on NaCl content. Instead fresh weight of papaya watered with geothermal brine showed a 21 percent reduction and mild chlorosis was evident. The specific ionic basis for any toxic reaction above that related to salinity has not yet been determined, but single ion toxicity can generally be ruled out by comparing threshold concentration tests with HGP-A analyses. Thus, testing for additional interactions remains to be done.

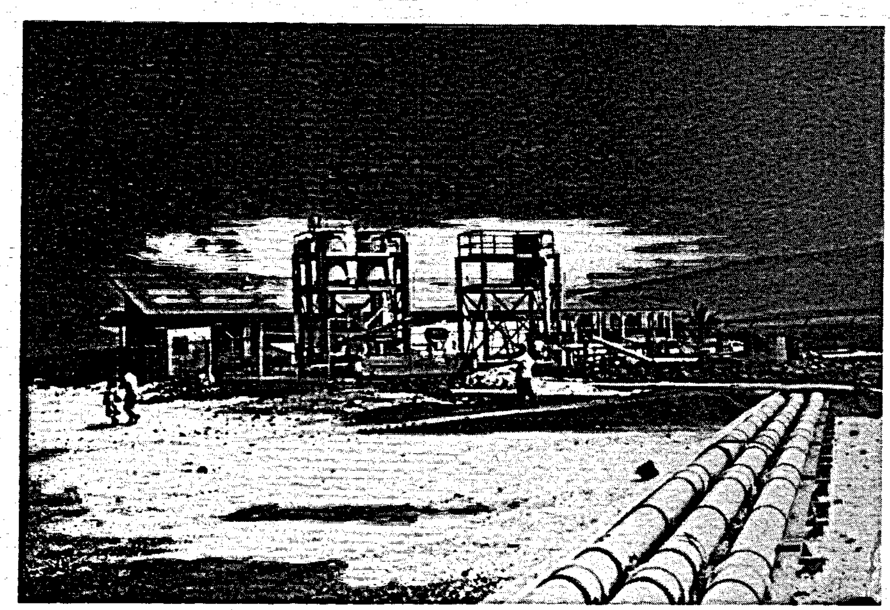


Ohia responses after two months to saline solution, tap water, and HGP-A brine.

Photo courtesy of Sanford Siegel



Polyethylene pipes bring warm and cold ocean water to research facilities at the Natural Energy Laboratory of Hawaii at Ke-ahole Point on the Big Island.



OCEAN ENERGY RESEARCH PROJECTS

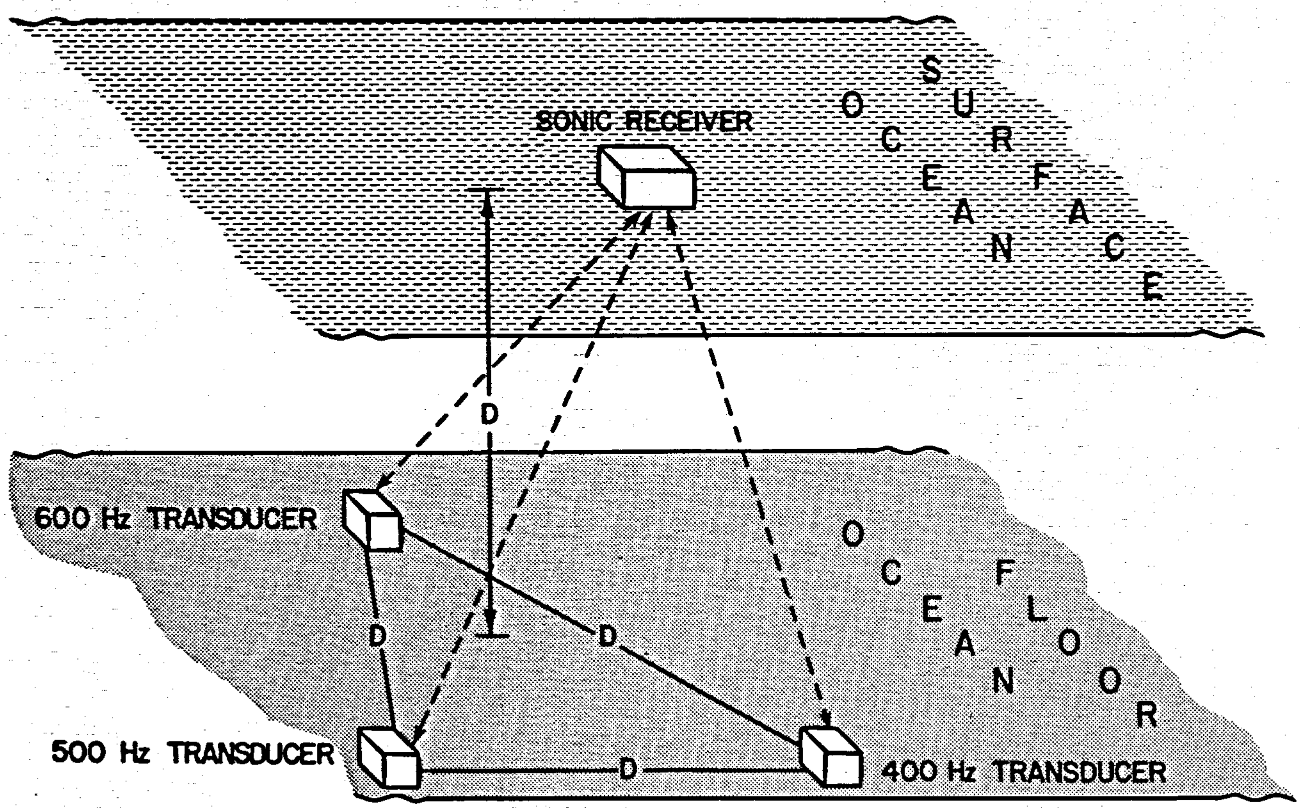
The tropical ocean surrounding Hawaii provides a promising renewable energy option—ocean thermal energy conversion—and puts the state in a favorable position to support and influence needed OTEC development. Because OTEC uses the relatively small temperature differences between deep cold ocean water (40°F) and sun-warmed surface water (80°F) to produce electricity, enormous volumes of seawater need to be processed to extract this heat energy. Thus, commercially-sized OTEC plants will be very large. A 400 MW OTEC platform, for example, will cover an area equal to the deck of an aircraft carrier, its cold water pipe will be 100 feet in diameter and 3,000 feet long, and the amount of water flowing through the cold and warm water pipes will equal the average discharge of the Nile River: 45 million gallons per day.

Two main types of OTEC heat engines have been studied to date, a closed-cycle system which heats and cools a working fluid with warm and cold ocean water and an open-cycle system which uses seawater as the working fluid. Several OTEC system types are also being studied for different sites and circumstances. OTEC facilities could be shore-based, tower-mounted offshore, moored offshore, or designed to graze in open ocean. A variety of products and applications are possible, too, with OTEC: electricity, fresh water, cold nutrient-rich seawater for aquaculture, hydrogen and oxygen from electrolyzed water, ammonia from this hydrogen and nitrogen in air, methane or methanol from a carbon source and OTEC energy, refined metals from raw ores brought to the OTEC plant. OTEC promises to be a truly versatile energy resource.

Several small-scale laboratory and at-sea tests have been completed to initiate development of this new technology. For several years at Ke-ahole Point, studies have been underway to solve biofouling and corrosion problems critical to the efficiency of OTEC heat exchangers. In 1979, Hawaii's Mini-OTEC produced 50 kW of gross power—10 kW net—to prove that OTEC at sea works. Then, the U.S. Department of Energy's OTEC-1 operated in waters off Ke-ahole Point for several months in 1981 to conduct tests on various OTEC components.

Contracts, too, have been awarded for pilot plants and intermediate-scale tests. In February 1982, U.S. DOE announced support of two proposals for the design of OTEC pilot plants in Hawaii, one shore-based facility and one mounted offshore at Kahe Point, Oahu. In addition, Hawaiian Dredging and Construction Company has recently begun Phase II of a three-phase project to design, construct, and install and operate an 8-foot diameter, 400-foot long, fiberglass-reinforced plastic cold water pipe. Phase II of this project will take place at sea, 3.25 miles south of Honolulu, and will use the Mini-OTEC barge. The pipe will then be recovered, modified, and barged to Ke-ahole Point to test installation techniques for shore-based or shelf-mounted OTEC facilities.

Other OTEC-related tests at the Natural Energy Laboratory of Hawaii at Ke-ahole Point and at the university will help answer many remaining questions about OTEC's technology, ocean engineering requirements, and environmental effects. HNEI is supporting several of these.



D=DISTANCE RANGES FROM 500 FEET TO 1000 FEET.

PROTOTYPE OCEAN WAVE MEASURING SYSTEM

DEVELOPMENT OF A DIRECTIONAL WAVE SPECTRUM MEASUREMENT SYSTEM FOR OTEC APPLICATIONS

PRINCIPAL INVESTIGATOR: Theodore T. Lee, Ph.D.
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PROJECT PERIOD AND FUNDING SOURCE: State R & D funds administered by HNEI support this project which runs from January through December 1982. Total funding for FY 1981-82: $21,391.

PROJECT DESCRIPTION AND OBJECTIVES

The goal of this project is to develop a reliable wave measurement system capable of determining directional wave spectra in deep water with good resolution. Such a system is currently not available but is desirable for validation of analytical models which predict the dynamic responses of the platform/cold water pipe/mooring system and for design of offshore OTEC structures. Directional wave data of good quality will be useful for Hawaiian Dredging and Construction Company's at-sea cold water pipe test and for the design of two OTEC pilot plants near Kahe Point, Oahu.

RESEARCH PROGRESS AND PROJECT STATUS

To explore existing technology developments, the principal investigator attended the International Symposium on Directional Wave Spectrum Applications and the Atlantic Remote Sensing Land-Ocean Experiment Workshop. No proven system is suitable for measuring directional wave spectra in deep water, but several shallow water buoy systems under development now have advantages and disadvantages for deep water use: a cloverleaf buoy, a directional waverider buoy, a NOAA research buoy, an ENDECO buoy, and several subsurface buoys. Work continues to examine the relative performances of these.

In May, design of a new directional wave spectra measurement system was completed. All hardware components were ordered by June, and fabrication of the electronic system is scheduled to begin in August pending delivery of key parts. The system itself consists of three low-frequency sonic transducers mounted in a triangle at the ocean bottom and a sonic receiver installed in a buoy floating freely at the ocean surface. The transducers, each of which is assigned a unique audio frequency (400, 500, and 600 Hz) for identification, transmit a continuous audio signal which the sonic receiver detects and amplifies. This receiver also measures, as a function of time, phase differences between incoming audio signals from each transducer and an on-board reference signal and records these data for later processing and analysis. Analyzing phase differences to ascertain absolute position of the buoy as a function of time yields wave height records as well as two-dimensional velocity records; from these, directional spectra can be determined.

Steps to prepare for system validation have also been taken. Arrangements were made with Lawrence Berkeley Laboratory to use a waverider buoy previously used for the OTEC-1 project. The buoy has been checked, repaired, shipped to the NOAA Engineering Support Office for calibration, and returned to Look Laboratory for future use in validation of the new wave spectra measurement system.

BREAKING WAVE FORCES ON OTEC PIPES

PRINCIPAL INVESTIGATOR: Robert A. Grace, Ph.D.
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PROJECT STAFF: Frederick M. Casciano, M.S.
UHM Department of Ocean Engineering
Ian L. Sandison
Matthew W. Bonini
UHM Department of Civil Engineering

PROJECT PERIOD AND FUNDING SOURCE: State R & D funds administered by HNEI supported this two-year project in FY 1981-82 and will continue to do so during FY 1982-83.
Total funding for FY 1981-82: $33,521.

PROJECT DESCRIPTION AND OBJECTIVES

A 12-inch diameter, high-density polyethylene pipe at Ke-ahole Point supplies cold water from a depth of 2,000 feet to laboratories at the Natural Energy Laboratory of Hawaii. The pipe runs along the seafloor to the nearshore zone where it is supported by saddles as it slants up and over a low cliff fronting the facility. Even under moderate wave conditions the area where the pipe comes over the cliff is a churning ball mill. The pipe is subjected to large forces whenever wave conditions are appreciable, and, already in the several months since their emplacement, some pipe saddles have had to be repaired. The purpose of this project is to determine exactly the forces exerted by breaking seas on a pipeline such as the one at NELH or those used by nearshore and shore-based OTEC plants.

For both logistical and financial reasons, the project site is the nearshore area between Kewalo Basin and Honolulu Harbor, directly offshore from the J. K. K. Look Laboratory of Oceanographic Engineering where extensive ocean engineering field research has been done in the past. Two-year project tasks include determining the preparing the locations at sea for experimental components; ordering, constructing, and testing data measuring and recording equipment; designing, fabricating, and installing a wave-measuring mast; assembling the test pipe and installing it at the test site; and collecting and analyzing data.

RESEARCH PROGRESS AND PROJECT STATUS

Investigating breaking wave forces on a test pipe requires a shallow test site in 12- to 14-foot depths. During February and March, after project personnel determined lines of swell propagation and swell movement on the bottom and identified areas of fairly level bottom topography, a site was chosen almost directly downswell of an already established offshore test site at the 37-foot depth, thus allowing measurement of incoming wave conditions. A mooring system was established at the site and two pipe positions were determined for the tests, one oriented to the wave fronts with a 52° angle and the other, with a 90° angle. Holes were drilled in the seabed at appropriate locations; threaded rods were secured in these holes with epoxy; and pipe supports were installed in preparation for the pipe.

Meanwhile, 12-inch diameter standard steel pipe was purchased to fabricate a central test pipe section and two flanking pipe lengths to be fixed to the ocean floor. The 4-foot long test section was constructed to connect to the 12-foot long side pipes through strain gage beams within the pipe to make the overall test pipe length 28 feet. Both ends of the test section were closed off with recessed plates; the ends of the side pipes away from the test section were bulkheaded; and pipe saddles were fabricated and positioned at sea. The three sections of pipe were then barged or towed to the test site where divers, with the help of lift bags, positioned them, bolted them into place, and eventually secured them at each saddle. Because the test pipe had satisfactorily withstood the attack of sizable swells occurring over several stormy periods, it appears that a stable test set up has been established to permit the satisfactory recovery of good test data on wind conditions and concurrent wave forces. Data measuring and recording systems have been ordered and will be assembled, tested, and installed during the next six months to prepare for the data collection.

Photo courtesy of Robert Grace

Waves break over cold and warm water pipes at NELH, left. Above, temporary weights and ropes hold main test pipe while project divers install force-measuring section.

ENVIRONMENTAL EFFECTS OF OTEC CHLORINATION

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Aquaculture Associates
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Natural Energy Laboratory of Hawaii

PROJECT PERIOD AND FUNDING SOURCE: HNEI has allocated sums from both state R & D and U.S. DOE institutional grant funds for this two-year project. Total funding for FY 1981-82: $35,361.

PROJECT DESCRIPTION AND OBJECTIVES

A major problem facing designers of OTEC plants is keeping heat exchanger surfaces free of fast-growing biofouling films in order to optimize temperature differences and, thus, plant operation. Chlorination appears to be a promising means for controlling such biofouling, but chlorination of marine waters can result in the production of halogenated organics, many of which have been shown to exihibit mutagenic, carcinogenic, and/or cytotoxic properties. Little is known about these organics, about their accumulation by aquatic organisms, or about the many halogenated inorganic species that are also major products of seawater chlorination. OTEC development—heat exchanger designs and amount and frequency of chlorination needed to check biofouling—may depend on understanding these processes in tropical waters.

This study aims first at answering the following questions about the chemical dynamics of halogen transformations:

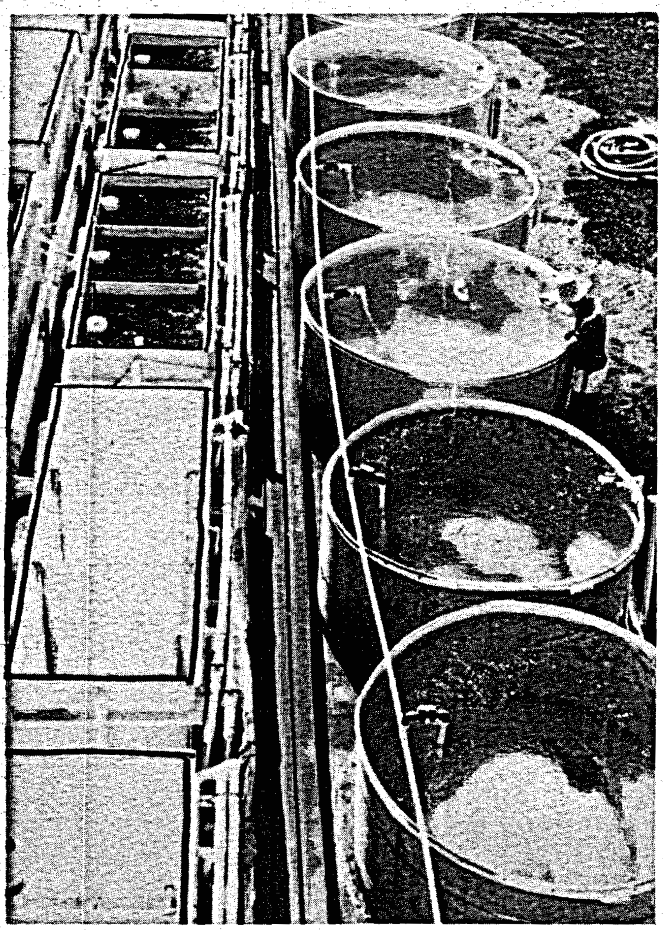
- What are the major organic and inorganic products of seawater chlorination?
- Are these products different qualitatively and/or quantitatively in warm shallow and deep cold waters?
- How do changes in the chlorine concentration affect these reactions and their kinetics?

Tasks include measuring major organic and inorganic products of seawater chlorination, determining their production rates as a function of chlorine added, and conducting bioaccumulation experiments.

RESEARCH PROGRESS AND PROJECT STATUS

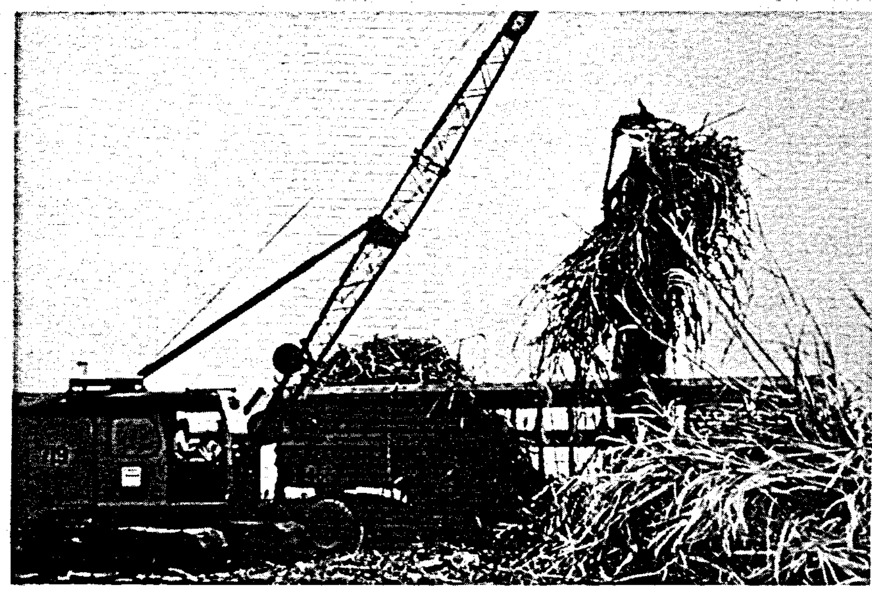
Equipment has been received and methods are being developed to measure the concentration of inorganic halogen species and halogenated organics produced as a function of time after chlorination. Both surface and deep tropical seawater as well as seawater treated with ultraviolet light to eliminate dissolved organic constituents are being used in these tests. Measurement techniques for inorganic halogens include phenylarsine oxide amperometric titration, ultraviolet absorption spectroscopy, and differential pulse polarography. Halogenated organics are detected and measured with high resolution gas chromatography and a halogen-selective Hall electrolytic conductivity detector. Initial results indicate that seawater chlorination at the level of 1 part per million produces approximately 30 parts per million of volatile halogenated organics. Experiments have also begun to determine whether these production rates are well defined functions of the amount of chlorine added to seawater. All of these tests will run for one calendar year.

Construction of tanks at the NELH aquaculture test pad is complete for the bioaccumulation experiments. The cold water pipe and related pumping system are in place and functioning; two tanks, one for chlorination and one for control, are operational. Culturing of organisms to construct a food chain—phytoplankton, brine shrimp, artemia (tilapia), and oysters—have been successful in small tanks. Organisms will be transferred to test tanks soon and retained there for four months. Cells or tissues will then be homogenized and analyzed using methods similar to those used for measuring the halogenated organics.

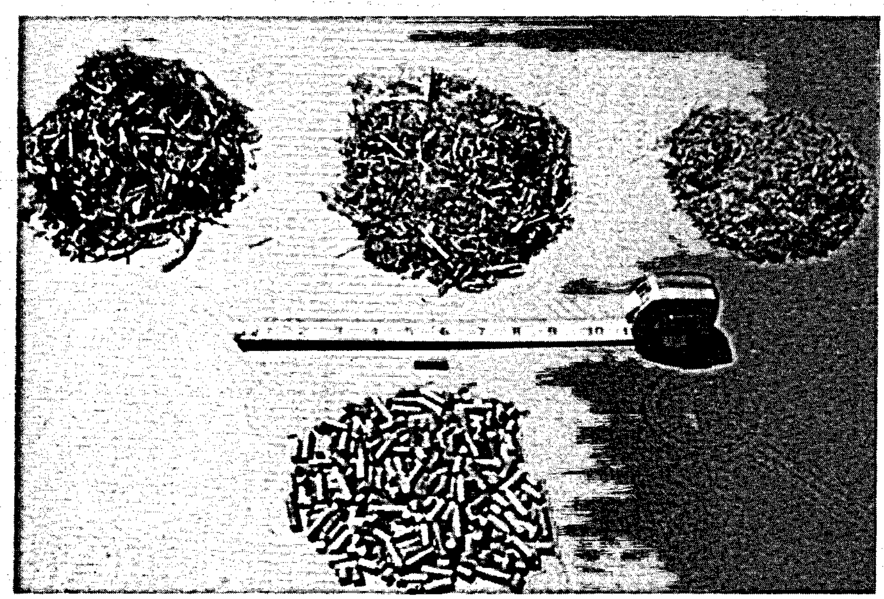


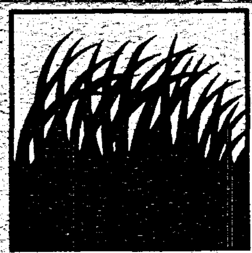
These tanks at NELH hold phytoplankton and brine shrimp for bioaccumulation experiments.

Photo by Frank Sansone



The Hawaiian sugar industry produces over 7 percent of the state's electricity by burning bagasse and pelletized bagasse, below.





BIOMASS ENERGY RESEARCH PROJECTS

Biomass, which includes organic matter such as agricultural crops, grasses, trees, algae, and animal wastes, is a versatile energy resource that can yield solid, liquid, and gaseous fuels for a variety of end uses. The source of this energy is sunlight, which plants and algae use with water and carbon dioxide to produce oxygen, lignin, and carbohydrates. The lignin and these stored carbohydrates—sugars, starches, celluloses—can be converted to usable energy products in several ways.

Currently, the Hawaiian sugar industry is meeting over 7 percent of the state's annual electrical needs by direct combustion of cane waste and bagasse. The plantations' boilers and Molokai Electric's new biomass boiler can also burn hay, pineapple waste, wood chips, municipal waste, macadamia nut shells, and various other feedstocks, including pelletized bagasse. Under consideration, too, are plans for H-POWER, the Honolulu Program of Waste Energy Recovery, which would burn tons of urban waste instead of 500,000 barrels of oil. Maui, Hawaii, and Kauai are discussing urban waste projects as well.

Other thermochemical processes more complicated than direct combustion are also possible for biomass conversion. Gasification or hydrogasification requires high temperatures, and sometimes high pressures with an enriched hydrogen atmosphere, to convert organic matter to gaseous products. Hydrogasification, for example, can turn manure and plant wastes into methane and ethane. Pyrolysis requires high temperatures, and sometimes high pressures and the absence of air, to break apart complex organic molecules to yield a variety of hydrocarbon products. Since August 1980, Pacific Resources, Inc., HNEI, and the Institute of Gas Technology (IGT) have been evaluating a hydropyrolysis method to convert Hawaiian biomass to LPG, oil, and char. The UHM/HNEI Coral Industries Professor of Renewable Energy Resources is also conducting basic research on flash pyrolysis and gasification of biomass.

Biochemical processes are a third way to convert biomass to gas and liquid fuels. In anaerobic digestion, bacteria or other microorganisms break down organic substances in the absence of oxygen to produce methane gas. Yeasts convert sugars to alcohol in the fermentation process. Efficient systems for anaerobic digestion are presently operating on several swine and poultry farms in the state, and a small part of Hawaii's 320,000 tons of sugar cane molasses is now being converted by fermentation into alcohol for fuel use. Ethanol, from this feedstock or from pineapple juice, could be used in gasohol—a 10 percent alcohol, 90 percent gasoline mixture—for internal combustion engines or in vehicles modified to operate on alcohol fuel.

Presently Hawaii's major renewable energy resources, biomass should become increasingly important in contributing to the state's energy future, both as boiler fuel and as feedstock for liquid fuels. To that end, HNEI is supporting several projects for biomass production, biomass conversion, and biomass fuel use.

CHARACTERIZATION OF LIPIDS FROM AN ALGAL PRODUCTION RACEWAY

PRINCIPAL INVESTIGATOR: Edward Laws, Ph.D.
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PROJECT STAFF: Kenneth Terry, Ph.D.
Michael Chalup, B.S.
Janice Hirata, B.S.
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Giacomo DiTullio, B.S.
UHM Department of Oceanography

PROJECT PERIOD AND FUNDING SOURCES: Funds from several sources have supported this multi-phase project since 1979: U.S. DOE Solar Energy Research Institute, Hawaii Department of Planning and Economic Development, and HNEI. For FY 1982-82, HNEI funds came from a U.S. DOE institutional grant.
Total funding for FY 1981-82: $281,601.

PROJECT DESCRIPTION AND OBJECTIVES

Objectives of the algal raceway project are to grow the diatom *Phaeodactylum tricornutum* in a high density mass culture system, to harvest the cells, to determine their lipid content and character, and to evaluate these lipids for use as an energy resource. Overall tasks for this long-term project, lasting perhaps eight years or more with four phases, are to

- Design and construct an algal production raceway system having an area of approximately 540 square feet, and verify that estimated production rates of about 60 tons of oil per hectare-year can be achieved;
- Develop a satisfactory harvesting method for the algal cells;
- Characterize the physiochemical properties of *P. tricornutum,* particularly its lipids.

Construction of the raceway has been completed for many months, and a harvesting device is efficiently removing cells with a minimum of energy expenditure. Efforts during FY 1981-82 have focused primarily on characterizing *P. tricornutum* since using this alga as an energy or protein source requires detailed knowledge of its lipids:

- Determine lipid weight;
- Separate polar and neutral lipids;
- Further characterize these lipid fractions.

RESEARCH PROGRESS AND PROJECT STATUS

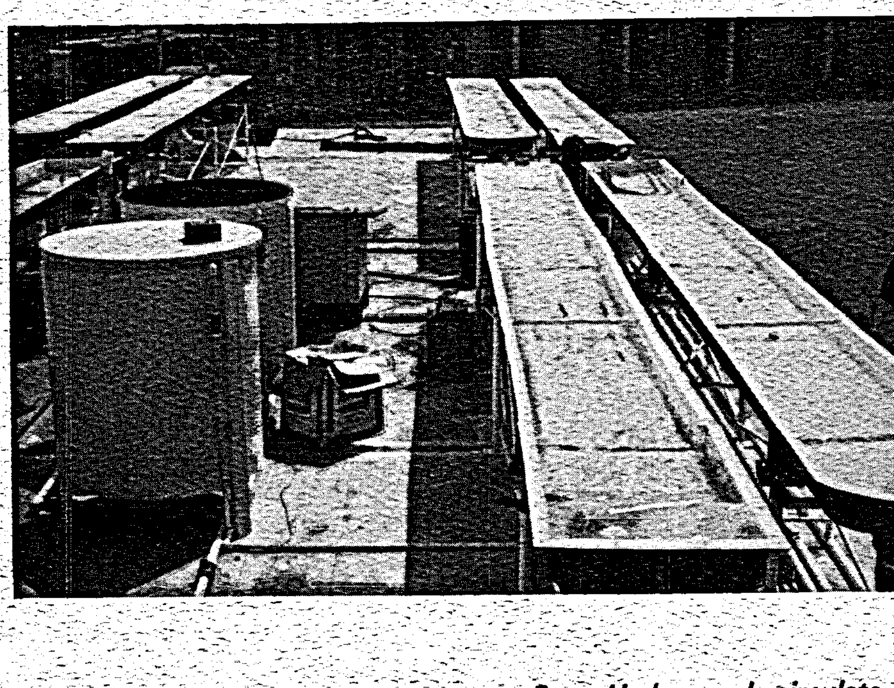
Lipid extraction is accomplished using a modified Bligh-Dyer procedure. The total lipids, extracted in benzene, are dried in a nitrogen atmosphere to remove trace amounts of water and are then suspended in hexane or chloroform and stored in nitrogen at −4°F to prevent oxidation.

Polar and neutral lipids are separated by column chromatography using florisil or silicic acid. Florisil is easier to handle and produces faster flow rates, but it must be pretreated by baking at 1,200°F and by acid washing to develop proper adsorptive characteristics.

Analyses of preliminary samples show that lipids comprise 10 to 20 percent of the dry weight of harvested algae. Between 25 and 30 percent of the lipid material is neutral lipid; the remainder is polar. These polar lipids can be resolved further into a glycolipid fraction (55 to 60 percent) and a phospholipid fraction (20 to 25 percent), using acetone and methanol respectively. The neutral lipids are even further resolved by thin-layer chromatography (TLC). Qualitatively, most of these neutral lipids are tri-, di-, and mono-acylglyerides.

Although reports in the literature cite up to 80 percent lipids in *P. tricornutum* cultured under very low growth rate conditions, results from this project indicate a lipid content of 15 to 20 percent (dry weight) from *P. tricornutum* in mass culture. Since neutral lipids, those of most importance for fuels, constitute about 25 to 30 percent of *P. tricornutum's* total lipids, hydrocarbons account for only 4 percent of the product dry weight. However, fatty acids, which are in both the neutral and polar lipid fractions of *P. tricornutum*, can easily be decarboxylated to yield hydrocarbons. Gas chromatography will be necessary to perform the fatty acid analyses.

Because an intelligent evaluation of the merits of growing *P. tricornutum* in mass culture requires a detailed product analysis, these analyses will be done and will include a study of carbon chain length and degree of saturation of the various classes of lipids. Total fatty acids will be separated, polyunsaturated fatty acids will be measured quantitatively, and batch cultures will be sampled to determine which parameters produce the optimum yield of total fatty acids.



The four fiberglass algal raceways at Snug Harbor each circulate 210 gallons of water.

PILOT-SCALE ENERGY TREE FARM RESEARCH

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PROJECT STAFF: Kenneth MacDicken, B.S.
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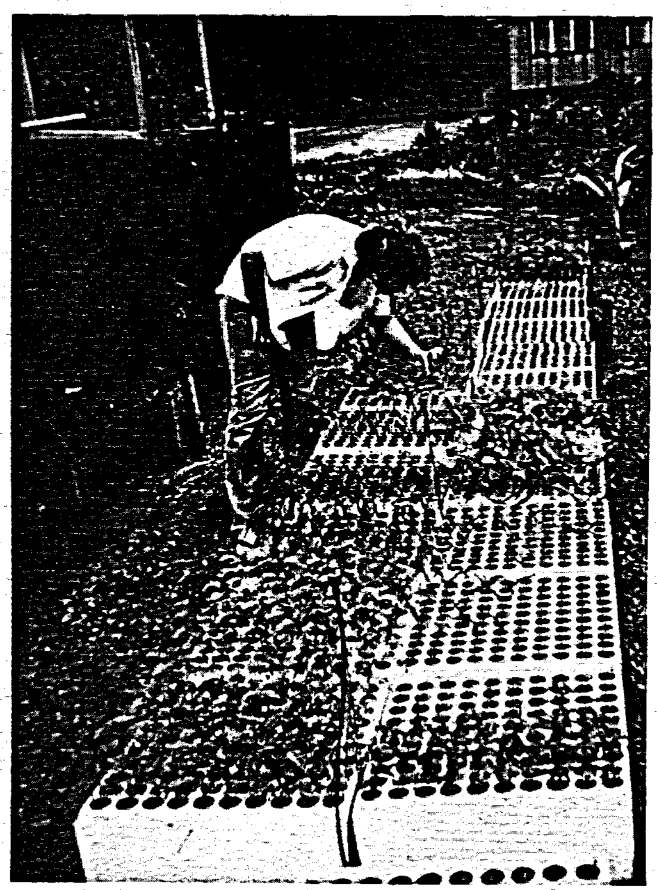
UHM Department of Agronomy and Soil Sciences
Charles Sorensson
Colorado State University Department of Agronomy and Soil Sciences

PROJECT PERIOD AND FUNDING SOURCES: HNEI has provided funds for FY 1981-82 and for FY 1982-83 for this project, which also has limited support from the U.S. Department of Agriculture, the U.S. Agency for International Development, and U.S. DOE.
Total funding for FY 1981-82: $55,461.



Leucaena seedlings are grown at UH's Waimanalo nursery for energy tree farm planting.
Photo courtesey of Kenneth MacDicken

PROJECT DESCRIPTION AND OBJECTIVES

The purpose of this project is to establish small (2- to 20-acre) pilot tree farms on Hawaii, Maui, Molokai, Oahu, and Kauai to determine agronomic feasibility, relative production levels, and costs for biomass fuel species in Hawaii. Each site will be chosen in collaboration with an agency agreeing to make a land commitment to the study, providing the requisite land preparation, and accepting responsibility for the trees at the end of the experiment (three to eight years). The sites will represent the major available zones for fuelwood plantations, agricultural lowlands, midland marginal lands, and highland grass and forested lands; and crops will include nitrogen-fixing trees alone and in combination with nonnitrogen-fixing trees. Research will

- Develop performance data and cost estimates for establishment and management;
- Demonstrate site limitations and potentials in diverse ecological zones to support fuelwood tree species;
- Provide energy trees from dense plantations for critical evaluation of density, moisture content, and calorific value of fuelwood to assess the productivity and value of by-products; and
- Develop comparative data between tree farm biomass and herbaceous plants, notably sugarcane grown for bagasse, other grasses, and pineapple and agricultural waste products.

Planning and preparation, Phase I, will include surveying sites, developing cooperative agreements, planting seedlings, and preparing a data collection system. During Phase II, plantations will be established and a biomass research document will be prepared.

RESEARCH PROGRESS AND PROJECT STATUS

A total of fifteen potential planting sites have been identified during Phase I through discussions with possible cooperators and by site inspections. Of these potential sites, five are currently programmed for site preparation and planting early in Phase II, with three additional sites tentatively scheduled for establishment later. Detailed discussions were held with potential cooperators to determine interests and to define responsibilities for the cooperative demonstration trials. From these discussions informal draft memoranda of agreement were drawn-up for signature prior to actual field plantings.

Details of field trials have also been developed to ensure the generation of data adequate to meet research objectives. Designs are sufficiently flexible to allow for special research needs of individual cooperators and site specific problems, but similar enough to allow comparative analyses of data for statewide recommendations. Estimates of seed, seedling requirements, and nursery production capacity have been made for each of the proposed sites. Some 6,000 seedlings were sown for planting early in Phase II, and additional seed has been procurred for use in direct seeding trials also to be initiated early in Phase II. Equipment and supplies ranging from potting media and hand-held herbicide applicators to measurement instruments and chain saws are ready as well. With these Phase I activities completed, preparation and actual planting of a minimum of three to five sites will begin early in Phase II.

ON-FARM METHANE GENERATION WITH SLUDGE RECYCLING

PRINCIPAL INVESTIGATOR: Ping-Yi Yang, Ph.D.
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PROJECT STAFF: Steven Nagano, B.S.
Brian Koba
UHM Department of Agricultural Engineering

PROJECT PERIOD AND FUNDING SOURCES: HNEI funds supported laboratory studies on methane fermentation in FY 1976-77 which led to installation and operation of an anaerobic digester in 1978. Research on necessary improvements has been funded by the U.S. Environmental Protection Agency (FY 1980-81) and by HNEI (FY 1981-82) from state R & D monies.
Total funding for FY 1981-82: $58,450.

PROJECT DESCRIPTION AND OBJECTIVES

Anaerobic lagoons have been used for many years as the main animal waste disposal system in the U.S. The biodegradable portion of the wastes undergoes anaerobic decomposition to produce carbon dioxide, methane, ammonia, and water, and the undigested wastes are routinely removed from the lagoon for field spreading as soil conditioners. The pond or lagoon is covered if the methane is to be collected or used. Another system, however, a stable anaerobic digester with sludge recycling, offers more efficient biogas production, reduced land costs, and an integrated animal waste management system for energy production and utilization and pollution control. The rubberized digester itself is inexpensive and easy to install and operate as previous tests by the principal investigator show. With sludge recycling, the system promises increased gas production rates per digester volume. This project's purpose is

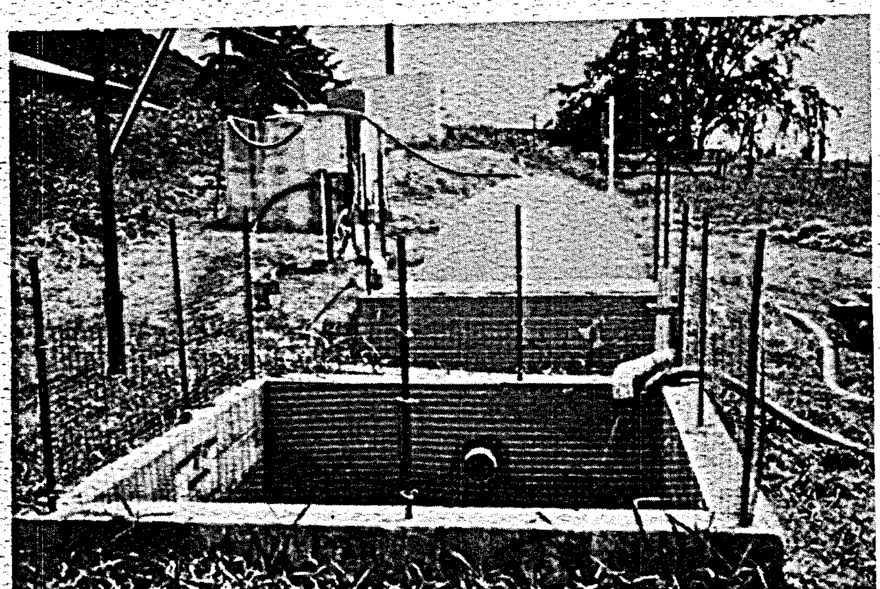
- To investigate the operational performance of anaerobic digestion of swine waste with sludge recycling by varying hydraulic retention time and/or loading rates of total volatile solids; and
- To develop necessary design and operational criteria for an on-farm methane generation process with sludge recycling.

RESEARCH PROGRESS AND PROJECT STATUS

The project began by installing a 706 cubic feet anaerobic digester with feeding tank, settling tank, and sludge recycling tank at the Waialee Livestock Research Farm operated by the UHM College of Tropical Agriculture and Human Resources. Operational performance of the methane fermentation process was monitored by measuring biogas production and total volatile solid (TVS) concentrations in the influent, effluent, and recycled sludge. Biogas was measured by a gas meter; other parameters (pH, TVS, etc.) were determined by following standard methods; and the gas component was analyzed indirectly using reactions of potassium hydroxide and carbon dioxide.

Four hydraulic retention times of nine, six, four, and two days were investigated at various loading rates for total volatile solids. After a number of trials, maximum gas production rate and gas yield obtained were 1.73 cubic feet per cubic foot of liquid volume per day and 8 cubic feet of gas produced per pound of total volatile solids at loading rates of 0.23 (± 0.06) pounds per cubic foot of liquid volume per day. Methane constituted between 66.7 percent to 75 percent of the biogas. Recommendations for design and operational criteria are summarized as follows:

- Temperature: 77°F to 95°F;
- Loading rate: 0.19 to 0.25 pounds TVS per cubic foot of liquid volume per day;
- Ratio of flow rate of recycled sludge to influent flow rate: 0.25;
- Ratio of TVS of recycled sludge to TVS of digested effluent: 2.0;
- Feeding frequency: three times a week when influent TVS concentration is 1.25 to 1.87 pounds per cubic foot or once a day when influent TVS concentration is 0.62 pounds per cubic foot;
- Expected gas production rate: 1.5 cubic feet per cubic foot of liquid volume per day with a methane component in the gas equal to 65 to 75 percent.



Methane gas is produced in this anaerobic digester, installed with feeding, settling, and sludge recycling tanks.

Photo courtesy of P. Y. Yang

HYDROPYROLYSIS OF BIOMASS TO PRODUCE LIQUID HYDROCARBON FUELS

PRINCIPAL INVESTIGATOR FOR HNEI SUBCONTRACT: Paul C. Yuen, Ph.D.
UHM College of Engineering

PROJECT STAFF: Arthur Seki, M.S.
Hawaii Natural Energy Institute

PROJECT PERIOD AND FUNDING SOURCE: In September 1980, Pacific Resources, Inc. was awarded a U.S. DOE grant to examine the feasibility of commercially producing hydrocarbon fuels from biomass feedstocks available in Hawaii. The Institute of Gas Technology has been responsible for testing a conversion process, and HNEI received a subcontract for resource assessment and technical assistance. Project period is from August 1980 through March 1983.
Total funding for FY 1981-82: $33,738.

PROJECT DESCRIPTION AND OBJECTIVES

This project is to evaluate the use of IGT's HYFLEX™ hydropyrolysis process for converting Hawaiian biomass feedstocks to liquid and other fuels such as oil, LPG, and char. HNEI's tasks include

- Characterizing the biomass resources in Hawaii, including amounts presently available and chemical compositions;
- Determining present land use and land ownership to identify potential plant sites;
- Collecting technical, economic, and financial data pertaining to cultivation, harvesting, replanting, and preparation of feedstocks;
- Helping assess environmental and socioeconomic issues related to biomass production;
- Participating in integration and evaluation of overall study results.

RESEARCH PROGRESS AND PROJECT STATUS

HNEI began by gathering information on available and potentially available biomass resources in Hawaii: sugar cane (bagasse, leafy trash, and sugar cane stalks); dried pineapple plants; ocean crops (kelp and seaweed); trees (eucalyptus, giant koa haole, ohia, and albizia); and grasses (napier and guinea). More intensive studies to match cultivation and harvesting requirements with available and accessible land areas were then begun. The State Forestry Division of the Department of Land and Natural Resources and the University of Hawaii provided information on specific environmental requirements for each crop. Additional data came from examining the available literature from the United States Department of Agriculture, the University of Hawaii, the U.S. Forest Service, the Commonwealth Scientific and Industrial Research Organization of Australia, and others.

Next, data maps showing topography, rainfall, land use zones, present land use, soil conditions, and land ownership were made for Hawaii, Maui, Kauai, and Molokai. By combining information on these data maps with environmental requirements for specific crops, new maps were formulated showing the areas available for each crop on each island. PRI and IGT, in the meantime, had determined a base case minimum plant size of 1,000 barrels per day which would require 1,000 bone dry tons of biomass per day plus 500 additional bone dry tons to meet in-plant energy needs. Given a standard biomass production rate of 10 bone dry tons per acre per year, the biomass farm to supply feedstock for this plant must be 45,000 acres. The maps indicated that eucalyptus—*E. Grandis, E. Saligna,* and *E. Globulus*—and the Big Island were the most promising combination of feedstock and area.

The first potential site selected, Waiakea, was rejected because the project could threaten endangered plants and bird species at lower elevations in this area. A second plan called for using noncontiguous sugar lands in Kohala and grazing land above Honokaa and Hilo. A biomass workshop, with participants from the state, the university, and private concerns, met in Hilo October 7, 8, and 9 to examine tree species, site conditions, soil characteristics, nursery requirements, plantation establishment, social and environmental issues, and financial aspects. The market value of producing 467,500 bone dry tons of woodchips per year was calculated to be about $58 per bone dry ton.

Because Puna Sugar Company lands may be idle soon and because eucalyptus tree farms appear feasible for this area, a second tree farm workshop was held June 8, 9, and 10 in Hilo. Results are now being evaluated.

UHM RENEWABLE RESOURCES RESEARCH LABORATORY

PRINCIPAL INVESTIGATOR:	Michael J. Antal, Jr., Ph.D. UHM/HNEI Coral Industries Professor of Renewable Energy Resources
PROJECT STAFF:	Andrew Cutler, M.S. Mark Hopkins, B.S. William Mok, B.A. UHM Renewable Resources Research Laboratory
PROJECT PERIOD AND FUNDING SOURCE:	CIP funds administered by HNEI have been used during FY 1981-82 to support construction of this laboratory. Total funding for FY 1981-82: $121,633.

PROJECT DESCRIPTION AND OBJECTIVES

This project provides a major laboratory capability to support the newly established Coral Industries Chair for Renewable Energy Resources. Establishment of this facility also contributes to both undergraduate and graduate programs in mechanical engineering as well as to the University of Hawaii's research effort in renewable energy resources, especially biomass pyrolysis and solar fired chemical reactor design. Tasks include renovating 1,100 square feet of existing laboratory space in Holmes Hall; providing necessary utilities (electrical, water, air, gas, vacuum), a toxic fume hood, benches, cabinets, safety and security enclosures; and purchasing needed equipment and testing devices. These will supplement the $300,000 worth of equipment the first Coral Industries Professor brings from his federally funded research activities at Princeton University.

RESEARCH PROGRESS AND PROJECT STATUS

Initial work consisted of carpentry work in Holmes 140 to accommodate the laboratory equipment. Major items from Princeton were then unpacked, reassembled, and installed: a 5 kW xenon-powered downward-facing beam arc-image furnace with 5-foot diameter paraboloidal mirrors; five additional 5-foot diameter paraboloidal searchlight mirrors; an optical system with deep ellipsoidal mirrors and a 5 kW Tungsten halogen lamp; a Setarem differential scanning calorimeter with associated pressure vessels and reactor system; an HP5840 gas chromatograph; an F&M model 500 gas chromatograph; an HP3388 GC integrator; a Valco gas sampling valve system; and a gas-phase pyrolysis reactor system using an infrared furnace.

Furnishings and additional laboratory equipment were also purchased and installed:

Erlab CAPTAIR portable fume hoods;
HP5790 gas chromatograph;
Waters ALC 200 liquid chromatograph;
30 kW xenon light system for the arc-image furnace;
Mettler H51AR balance;
Computerized (IBM PC) data acquisition system; and
Two-stage mechanical vacuum pump.

The laboratory has been operational since April 1982, and three research projects are presently in progress.

REACTOR/RECEIVER DEVELOPMENT FOR FLASH PYROLYSIS OF BIOMASS USING CONCENTRATED SOLAR RADIATION

PRINCIPAL INVESTIGATOR: Michael J. Antal, Jr., Ph.D.
UHM/HNEI Coral Industries Professor of Renewable Energy Resources

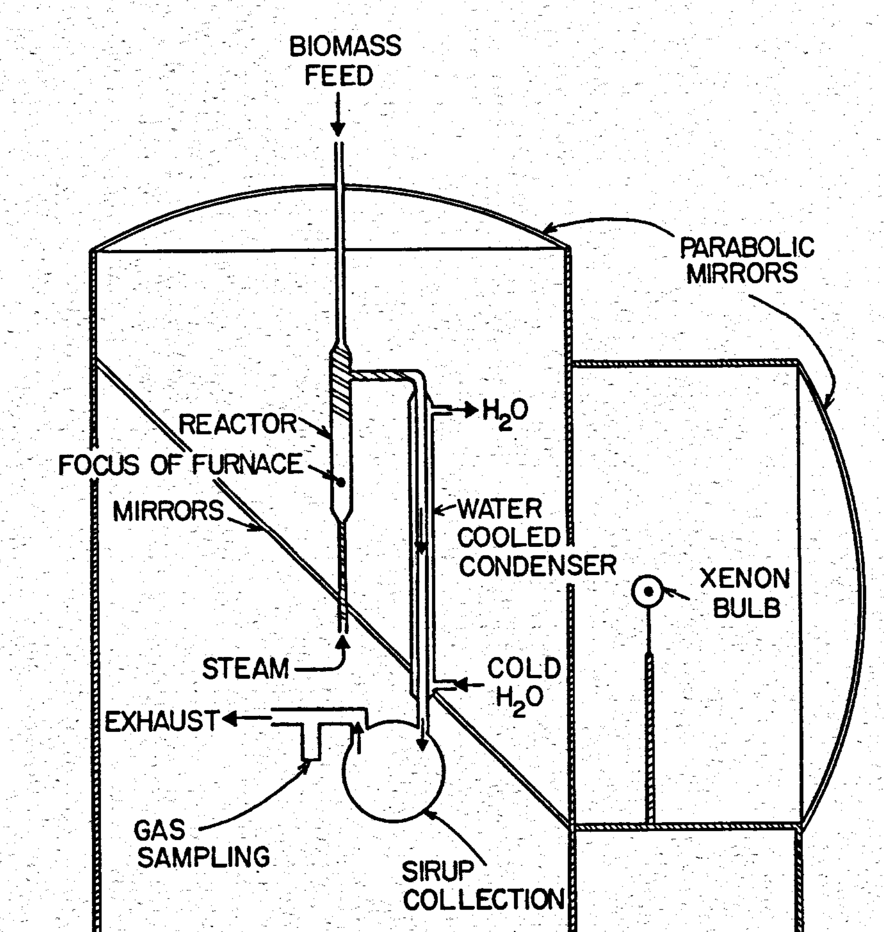
PROJECT STAFF: Mark W. Hopkins, B.S.
UHM Renewable Resources Research Laboratory

PROJECT PERIOD AND FUNDING SOURCES: This project, which runs from April 1981 to September 1983, is funded by the U.S. DOE; additional support has come from the National Science Foundation and the Solar Thermal Test Facilities Users' Association.
Total funding for FY 1981-82: $11,533.

PROJECT DESCRIPTION AND OBJECTIVES

While low temperature wood pyrolysis has been understood and was used in the U.S. as a source of methanol for many years, research in the 1960s suggested that flash pyrolysis—the rapid heating of biomass in a nonoxidative environment—could convert organic materials into more valuable fuels and chemicals. Flash pyrolysis, however, requires a high-temperature heat source and developmental research on equipment design and operating parameters to achieve desired product yields. The objective of this project, then, is to complete bench-scale research activities to develop a solar-fired biomass flash pyrolysis reactor. Tasks include

- Arc-image furnace construction;
- Cold flow tests of spouted-bed reactors;
- Design, fabrication, and testing of a prototype flash pyrolysis reactor;
- Final design and fabrication of the flash pyrolysis reactor, including provisions for continuous removal of char;
- Upgrading of the arc-image furnace to 30 kW and characterization of its performance;
- Installation of the reactor and a reflective cavity within the arc-image furnace;
- Measurements of the system's magnification factor, throughput, product yield, and composition.



SOLAR FURNACE AND PYROLYSIS REACTOR

RESEARCH PROGRESS AND PROJECT STATUS

The first three project tasks have been completed during FY 1981-82. The arc-image furnace used to test reactors being developed is fully constructed and operational. This furnace simulates solar radiation with a 5 kW xenon short-arc bulb and uses a series of parabolic and flat mirrors to reimage the arc of the bulb to intensities of over 200 watts per square centimeter at the focus of the furnace.

Cold flow tests have also been conducted with Pyrex reactor chambers which have various inlet diameters at their tapered lower ends. Particulate biomass and char are placed in the reactor chamber, and carbon dioxide introduced at the bottom inlet passes through this feedstock bed, entrains some of the particles (depending on their particular sizes and densities), and suspends them in the chamber. Varying the gas flow rate allows various components of the biomass material to be "spouted" to different heights and, thus, drawn off or left in the reactor to be pyrolyzed.

After completing cold flow tests to determine optimum operating parameters, a spouted-bed reactor was designed and built from clear quartz tubing 1 inch in diameter and 17 inches long. Biomass is fed into the reactor by a small vibrating feeder placed on top of the reactor. Radiant energy concentrated in the arc-image furnace passes through the transparent walls of the reactor. The biomass quickly pyrolyzes and the volatile products become entrained in the gas flow used to spout the bed. They leave the reactor and are condensed and saved in cold traps for analysis.

Initial tests of the reactor have shown that it is capable of producing sirups equal to 60 percent of the original feedstock weight. Kraft paper and dried corn cob have also been pyrolyzed in the reactor and have yielded high proportions of sirups. These sirups can be converted to many other valuable products including polyurethane, ethanol, glucose, olefins, and pharmaceuticals. Pyrolysis also results in a gaseous mixture of products made up of carbon monoxide and dioxide, hydrogen, acetylene, ethylene, and small amounts of various other hydrocarbons.

The logical conclusion of this report is the fabrication and testing of a continuously operating reactor in order to determine experimentally the reactor's magnification factor, throughput, and product yield and composition. The project continues through FY 1982-83.

Varying operating parameters during flash pyrolysis of biomass produces a variety of energy products.

DETAILED STUDIES OF THE EFFECTS OF PRESSURE ON BIOMASS PYROLYSIS AND GASIFICATION

PRINCIPAL INVESTIGATOR: Michael J. Antal, Jr., Ph.D.
UHM/HNEI Coral Industries Professor of Renewable Energy Resources

PROJECT STAFF: William Mok, B.A.
UHM Renewable Resources Research Laboratory

PROJECT PERIOD AND FUNDING SOURCE: Pacific Northwest Laboratories has funded this project from May 1981 to August 1982.
Total funding for FY 1981-82: $20,197.

PROJECT DESCRIPTION AND OBJECTIVES

Various reactors are presently in commercial operation or running in a pilot scale to pyrolyze and gasify biomass and solid wastes. Many design considerations such as improving throughputs, reducing costs of product gas compression, and increasing reaction rates underlie the development of high pressure reactors. Though the effects of pressure on the pyrolysis chemistry, product distribution, and heat demands are essential for reactor design, they have never been systematically studied. This project, therefore, is designed to detail the effects of pressure on the heat of pyrolysis of six selected biomass materials. A second objective is to extract mechanistic information and test the hypothesis that a certain global competitive mechanism controls the way all biomass materials pyrolyze.

RESEARCH PROGRESS AND PROJECT STATUS

The experimental apparatus consists essentially of two microreactors embedded in a tubular differential scanning calorimeter. Using a DSC to study heat of reaction is common, but the present system is unique because it allows operations under high pressure (25 atmospheres) and controlled flow of carrier gas. Cellulose, hemicellulose (xylan), and lignin, the basic components of wood; levoglucosan, a basic unit of cellulose; plus wood and corncob, representatives of abundant natural biomass resources, have all been tested during the project period.

The basic parametric study has involved pyrolysis of each material under five different pressures and two flow rates. By carefully manipulating pressure, flow rate, and temperature history, different segments of the complex scheme of degradation reactions have been examined and these findings have resulted:

- Specific heat of pyrolysis for six biomass materials;
- Details of cellulose pyrolysis mechanisms;
- Influences of pressure in the degradation routes during pyrolysis.

These new data and other information collected during a literature search suggest that a global competitive mechanism operates in all biomass pyrolysis. Under this mechanism, a material can either dehydrate or decompose to form char (plus gases) by one route, or depolymerize or volatilize to form tar and other light hydrocarbons by another. Remaining project efforts will focus on completing data evaluation and publishing results.

VERIFICATION OF REACTOR PERFORMANCE AND EXAMINATION OF THE MECHANISMS AND KINETICS OF CELLULOSE PYROLYSIS

PRINCIPAL INVESTIGATOR: Michael J. Antal, Jr., Ph.D.
UHM/HNEI Coral Industries Professor of Renewable Energy Resources

PROJECT STAFF: Andrew Cutler, M.S.
UHM Renewable Resources Research Laboratory

PROJECT PERIOD AND FUNDING SOURCE: This three-year project has been funded by the Solar Energy Research Institute and will continue through December 1982.
Total funding for FY 1981-82: $25,390.

PROJECT DESCRIPTION AND OBJECTIVES

Cellulose pyrolysis is extremely complex and can best be understood by studying the pyrolysis of simpler model compounds. Rapid pyrolysis of cellulose produces, as an initial degradation product, levoglucosan, a sugar which is a simple structural unit of the more complex cellulose molecule. In turn, several simpler compounds represent various parts of the levoglucosan structure: glycerol, dioxolane, dioxabicyclooctane. Determining the pyrolytic chemistry of these last two and combining this information with the known mechanism of glycerol pyrolysis should clarify the chemistry of levoglucosan pyrolysis, and ultimately, of cellulose pyrolysis.

The project has two phases: verifying the performance of a laminar-flow pyrolysis reactor and then examining carefully the pyrolysis of these compounds chemically related to cellulose. Tasks include

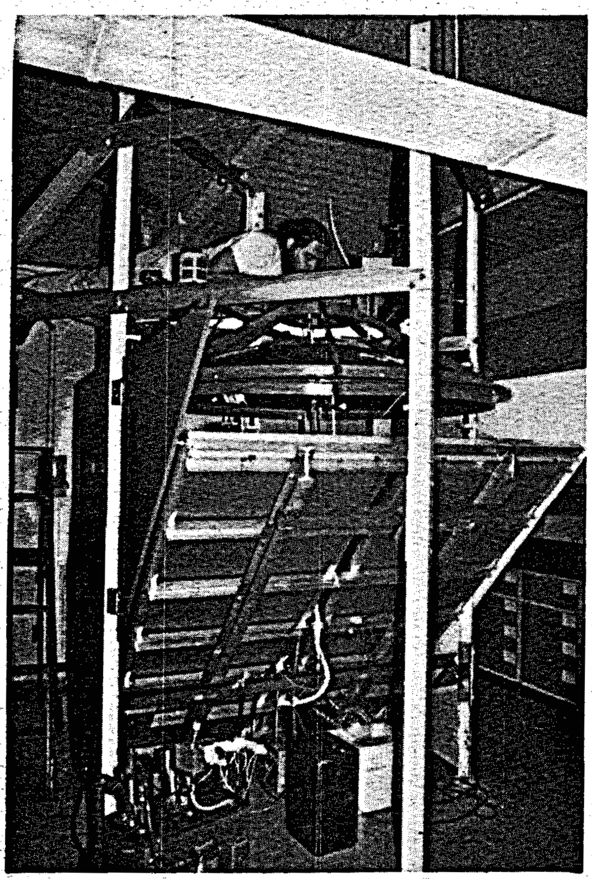
- Design and construction of a laminar-flow reactor;
- Verification of reactor performance and development of a theoretical understanding of reactor behavior;
- Selection and performance of control experiments, including pyrolysis of materials whose pyrolysis mechanism and kinetics are known;
- Synthesis of levoglucosan, α methyl- and α, α dimethylglycerol, and dioxabicyclooctane; and
- Determination of the pyrolytic kinetics and mechanisms of these compounds to clarify cellulose pyrolysis.

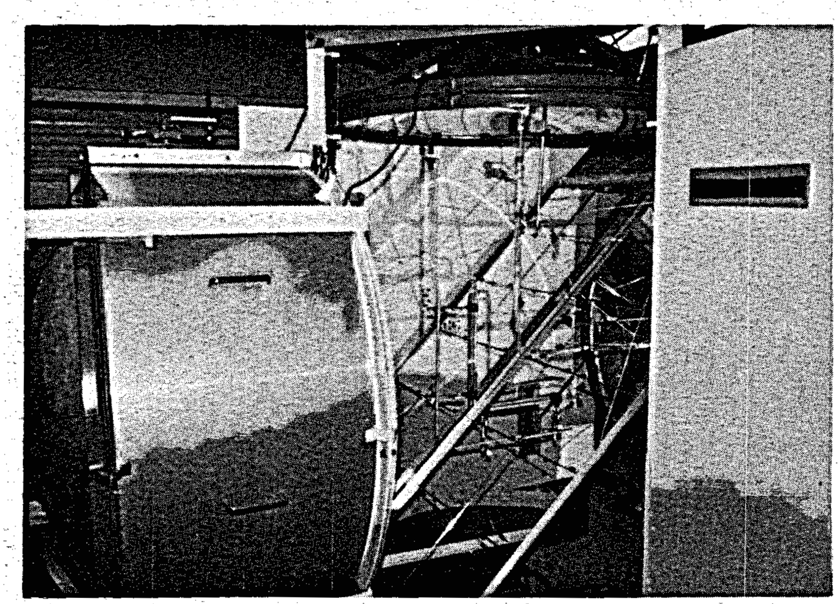
RESEARCH PROGRESS AND PROJECT STATUS

The first three project tasks have been completed during FY 1981-82, and work has started on the fourth. First, design and construction of a laminar-flow (gas flow is slow enough to be laminar instead of turbulent) reactor are complete. The design allows rapid heating of reactants to the desired temperature, holding them at an accurately controlled temperature for a precise time period, and then cooling them rapidly to prevent further reaction. A series of temperature, flow rate, and gas composition measurements were made to verify that the reactor performed as it was designed. These led to a few minor changes in operating procedure. In addition, the literature on laminar-flow reactors (most of which is theoretical in nature) led to some important insights about what to expect from the project reactor.

Since laminar-flow reactors have not been widely used for kinetic investigations, some experiments were conducted to demonstrate the reactor's ability to yield accurate kinetic data. Acetaldehyde and tert-butyl alcohol, which have been widely studied by a variety of techniques, were pyrolyzed; and the values obtained were checked against values in the literature. Results verified reactor performance.

Following this procedure, glycerol, which bears a structural similarity to certain parts of the cellulose and levoglucosan molecules, was pyrolyzed to determine the mechanism of pyrolysis and a first order rate constant describing it. Methyl- and dimethylglycerol have also been synthesized in preparation for pyrolysis. Work continues on synthesis and pyrolysis of these model compounds.





Above, flat and parabolic mirrors concentrate and focus artificial sunlight on a glass reactor at the focal point of the solar furnace. Left, Andrew Cutler controls biomass feed rate into the reactor.

ALCOHOL/WATER MIXTURES AS FUELS

PRINCIPAL INVESTIGATOR: Deane Kihara, Ph.D.
UHM Department of Mechanical Engineering

PROJECT STAFF: Bryan Young, B.S.
Hawaii Natural Energy Institute

PROJECT PERIOD AND FUNDING SOURCE: HNEI supported this nine-month demonstration project from state R & D funds.
Total funding for FY 1981-82: $6,965.

PROJECT DESCRIPTION AND OBJECTIVES

Only initial work has been done to determine the feasibility and advisability of modifying gasoline engines to operate on alcohol fuels, fuels which could be produced from biomass feedstocks. In a preliminary study funded by HNEI, three distinct types of gasoline engines were retrofitted for short-term road tests using 100 percent ethanol. This first effort was impressive but identified several mechanical problems which need to be solved. The purpose of this present project is to begin where the initial work ended by determining procedures for successfully retrofitting internal combustion engines for alcohol fuel under Hawaiian driving conditions; by testing, under controlled laboratory conditions, actual engine performance and fuel combustion efficiencies using ethanol and methanol; and by experimenting with alcohol/water mixes for optimized economics and fuel efficiency. General tasks for this project include

- Retrofitting two automobiles to operate on alcohol fuels;
- Performing laboratory controlled tests with a dynamometer to establish engine performance and emissions rates;
- Testing ethanol and methanol fuels for differences in performance and engine tuning requirements;
- Experimenting with ethanol/water and methanol/water mixtures to identify optimum alcohol fuels; and
- Conducting road tests to verify laboratory results.

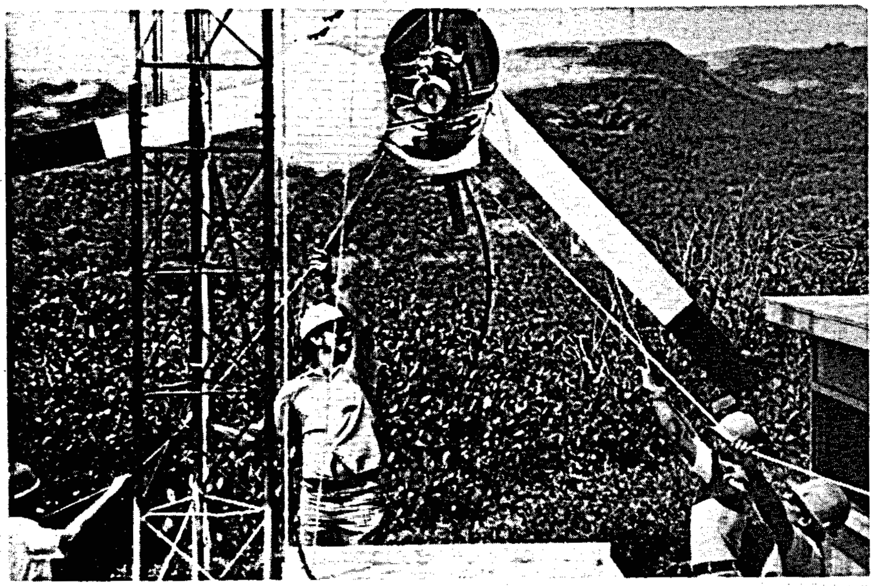
RESEARCH PROGRESS AND PROJECT STATUS

Two automobiles, a 1975 four-cylinder Toyota and a 1963 eight-cylinder Mercury, both with automatic transmissions, were retrofitted by removing and flushing the fuel tanks, replacing fuel outlet hoses, replacing line filters at the carburetors, removing and cleaning the carburetors, enlarging main and idle jets, resetting ignition timing, and reinstalling modified carburetors.

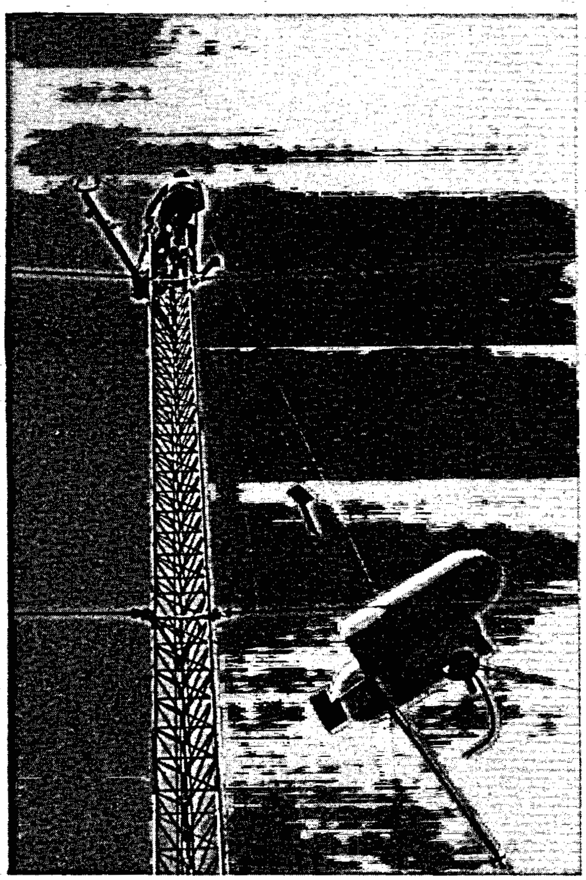
Following conversion, the Toyota logged 768 miles on 100 percent ethanol over a period of two and a half months from November 17, 1981 to February 1, 1982. Mild cold start problems disappeared after normal operating temperatures were reached, and performance was satisfactory. Driving conditions included city as well as freeway driving, and fuel consumption using ethanol was 14.8 miles per gallon as compared to 21.3 miles per gallon with gasoline. After logging 768 miles, however, deposits formed which clogged the carburetor jets. Repeated cleaning of the carburetor, fuel lines, and fuel tank did not rectify the problem. Energy dispersive analysis of x-rays and x-ray power diffraction analysis indicated that the deposits contained a large amount of aluminum, a small amount of iron, and traces of copper and zinc. A search of the literature suggested the possibility that the unknown deposit may be aluminum ethoxide, but due to the absence of published x-ray diffraction data on aluminum ethoxide, the deposit could not be positively identified. Because these deposits made further operation impossible, no tests were run on the engine dynamometer.

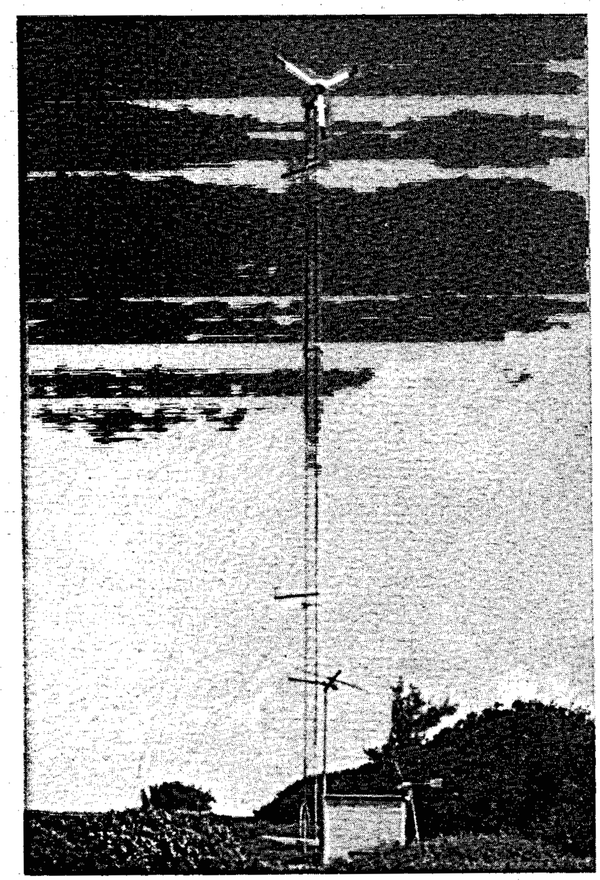
The Mercury station wagon was converted to methanol use in December 1981 and was driven 3,160 miles over a four-month period, primarily on freeways between UHM and the north shore of Oahu. Fuel consumption was 6.8 miles per gallon of methanol compared to 14 miles per gallon of gasoline, and driveability was excellent with no cold start problems or carburetor deposits.

After logging 2,600 miles, the vehicle was tested for performance and power output with alcohol/water mixtures as fuel. The first test used 100 percent methanol, simulated a load, and measured the power output at the rear wheels at speeds of 40 and 50 miles per hour. Then, without changing the carburetor settings or the ignition timing, the fuel was changed to a methanol/water mixture and the engine tested again. Results indicate that with mixtures as dilute as 80 percent methanol/20 percent water, power output on the dynamometer was comparable to that for gasoline use. No long-term road tests were conducted, however. Engine performance with a 70/30 mixture was erratic; at least without further modification of the engine, this mixture is unsuitable as an automotive fuel.



A 1.8 kW Enertech is installed on a 90-foot tower at Kahuku during an HNEI Wind Energy Technical Workshop. Below right, a 200 kW Winco and a 300 kW Dragonfly charge batteries under the Enertech.





WIND ENERGY RESEARCH PROJECTS

Hawaii has some of the most favorable wind regimes in the world. Northeasterly trade winds blowing across the state approximately 70 percent of the time and mean annual wind speeds between 16 to 24 miles per hour (at 30 feet) at numerous sites provide a total wind energy potential equal to many times Hawaii's energy needs. But a number of technical and nontechnical aspects of wind energy need to be addressed to accelerate its use: wind's intermittent nature, proper siting of wind energy conversion systems (WECS), WECS reliability, utility interfacing and grid stability, corrosion, financing, permitting, safety, and aesthetics among others.

Many public and private groups who have recognized the key role that wind can play in Hawaii's energy future have already committed funds and effort to wind energy development. The federal government has provided funds for WECS and meteorological towers; state and county funds have made wind studies and an additional data tower possible; the University of Hawaii's Department of Meteorology (UHM-M) has undertaken a pioneering resource assessment program; utilities, industry, wind resource developers, landowners, and others have already installed over 70 WECS, including a 200 kW MOD-OA at Kahuku, and have plans for additional WECS for diverse applications; and plans are in various states or readiness for an 80 MW wind farm on Oahu and several smaller wind farms on Maui, Molokai, and Hawaii.

In addition, HNEI, in cooperation with many of these same public and private groups, has established a Wind Energy Research, Development, and Demonstration Program to focus efforts on the key issues of resource assessment, WECS reliability verification, wind energy applications research, and nontechnological issues related to wind energy development. Because good wind energy conversion results—that is, those that maximize output at minimum cost—depend on good wind regimes, the most important element of any wind energy development program is comprehensive wind energy resource assessment to compile accurate information for intelligent WECS siting and research. With wind data and equipment to collect data readily available for research and siting decisions, WECS hardware development and optimization can occur. Siting prototype WECS in Hawaii's 16 to 24 mile per hour wind regimes makes possible long-term reliability verification and helps to resolve questions such as economic viability, corrosion protection, optimization of output, and grid interfacing. Then, although generation of electricity is likely to be the primary application of wind energy, many other applications are possible, especially given wind's intermittent nature. Pursuing areas of research which will lead to a variety of viable wind energy applications serves to increase wind's total contribution to Hawaii's various energy needs. But hardware development, optimization, and diversification are only part of any thorough wind energy development program. While these are being carried on, many other issues need to be addressed, possible barriers removed, and support programs developed. Environmental and social issues related to wind energy development need to be examined; legal questions of infringement and wind rights need to be settled; zoning and permitting requirements need to be clarified; and economic details and financing alternatives need to be developed. Projects supported by HNEI during FY 1981-82 have focused on these four elements of the Wind Energy RD & D Program.

WIND ENERGY RESOURCE ASSESSMENT

PRINCIPAL INVESTIGATOR: John W. Shupe, Ph.D.
Hawaii Natural Energy Institute

PROJECT STAFF: D. Richard Neill, B.S., M.Div.
Bernard Holst, A.A.
Raymond Rapalee, A.A.
Robert Connelly, M.S.
Michael Burger, B.A.
Hawaii Natural Energy Institute

PROJECT PERIOD AND FUNDING SOURCE: This ongoing project has been supported by HNEI's state R & D and CIP funds during FY 1981-82.
Total funding for FY 1981-82: $53,596.

PROJECT DESCRIPTION AND OBJECTIVES

Three kinds of data are important for those who wish to consider investing in and installing wind machines or for those interested in wind research: information identifying overall areas where wind speeds are high; long-term measurements in those areas identified as good wind regimes; very specific wind data to help determine precise WECS locations. The UHM Department of Meteorology completed several years ago a statewide assessment which established wind power classes and classified sites on each island according to them. Several long-term data stations were then installed by UHM-M, the U.S. DOE's Pacific Northwest Laboratory, and HNEI, among others, to add to those already operated by the National Weather Service. UHM-M and HNEI also acquired mobile meteorological vans with sensing and recording equipment, hand-held TALA (tethered aerodynamically lifting anemometer) kites, and portable wind data accumulators for short-term, site-specific data collection.

During FY 1981-82, tasks related to wind energy resource assessment include

- Maintaining three HNEI and three U.S. DOE/PNL meteorological towers;
- Identifying the site for a fourth HNEI tower;
- Improving an anemometer loan program;
- Establishing an Hawaii Wind Energy Data Bank; and
- Publishing wind energy data.

RESEARCH PROGRESS AND PROJECT STATUS

HNEI has three meteorological towers, two 150-foot towers at Kahua Ranch, Hawaii, and Moomomi Beach, Molokai, and a 60-foot tower at Kalaupapa, Molokai. The 150-foot towers have been instrumented with wind speed and direction sensors at approximately 30-, 90-, and 150-foot levels, and at the base of the towers automatic recording systems collect data on magnetic tape at 6-minute intervals. The 60-foot tower at Kalaupapa, part of HNEI's Wind Energy Battery Storage Research Program, measures wind speed, wind direction, global insolation, and time of wetness at 30 and 60 feet, and a Campbell Scientific CR-21 micrologger records the data at 6-minute intervals. Under a contract with Pacific Northwest Laboratory of the U.S. DOE Wind Systems Program, HNEI is also maintaining three 164-foot towers located at Kahuku, Oahu; Ilio Point, Molokai; and Kahua, Hawaii.

Keeping these wind data acquisition systems on line, operational, and providing reliable data is difficult because Hawaii's very corrosive environment and a strong steady wind regime take their toll on the sensitive electronic equipment. HNEI has made regular bimonthly inspections to lubricate moving parts, make wiring checks, clean tapeheads, and replace malfunctioning parts, including wind speed and direction sensors and datalogging equipment.

A fourth, 90-foot tower is to be installed on Kauai when the appropriate site is selected. HNEI, in consultation with Kauai County and Kauai Community College, has installed a portable anemometer at two promising sites, one near Koloa and the other on a ridge near Kawelioka Point. Data, which were collected at 6-minute intervals for two months, indicate that neither site is optimal for siting of the long-term meteorological station. The first site has good aggregate wind energy but varies significantly from gusty to calm periods; wind speeds at the second site are so similar to Lihue Airport data that erecting the tower here is not justifiable. Two additional sites suggested by the county and the community college will be measured before the tower site is determined.

During FY 1980-81, HNEI purchased nineteen portable wind data accumulators and twenty Dwyer hand-held wind speed indicators for an anemometer loan program which has been firmly established during FY 1981-82. Coordinators on Oahu, Molokai, Kauai, Hawaii, and Maui provide a 36-foot telescoping mast with guy wires; an anemometer, connecting cable, and wind data accumulator assembly; written instructions for siting the measuring equipment; and assistance with data interpretation. Several dozen individuals and groups interested in making site-specific wind energy measurements have borrowed this equipment this year in exchange for making their collected data available to HNEI for the Wind Energy Data Bank.

This data bank, too, has been established this year. Equipment purchased includes an Apple Computer, storage diskettes, software programs, and an upgraded printer. The system can retrieve data from the UHM Department of Meteorology's data system as well as store information in the University's HP3000 computer. Seventeen long-term meteorological towers throughout the state, including UHM-M's and HNEI's towers and several operated by the National Weather Service, U.S. DOE, Maui County, and Kahua Ranch, are now collecting wind data and relaying them to HNEI's central wind data bank. Short-term data taken by those who use HNEI's anemometer loan program are also recorded. Average daily wind speeds from the long-term stations and wind energy maps of each island are made available to Hawaii's wind energy community through the quarterly "HNEI Wind Energy Technical Bulletin," the first issue of which was mailed in March 1982.

WECS RELIABILITY VERIFICATION AND WIND ENERGY APPLICATIONS RD & D

PRINCIPAL INVESTIGATOR: John W. Shupe, Ph.D.
Hawaii Natural Energy Institute

PROJECT STAFF: D. Richard Neill, B.S., M. Div.
Byron Auker, S.M.
Bernard Holst, A.A.
Raymond Rapalee, A.A.
James Bac, B.B.A.
Hawaii Natural Energy Institute

PROJECT PERIOD AND FUNDING SOURCE: This continuing project was supported during FY 1981-82 by state R & D and CIP funds administered by HNEI. Total funding for FY 1981-82: $59,858.

PROJECT DESCRIPTION AND OBJECTIVES

Long-term operating experience with adequate instrumentation and performance data gathering and monitoring are needed to identify and correct WECS developmental problems and to prove WECS reliability so that economics can be accurately calculated and investor risk can be reduced. HNEI's Reliability Verification Program has been established to provide and/or encourage such testing. And the Wind Energy Applications RD & D Program aims at putting wind machines to work in diverse applications, electrical and nonelectrical, to solve complex utility-related problems as well as to address issues such as installation procedures, storage, corrosion, and output optimization. Tasks for FY 1981-82 include developing and testing a WECS monitoring system, procuring wind energy conversion systems, and planning specific applications for these WECS.

RESEARCH PROGRESS AND PROJECT STATUS

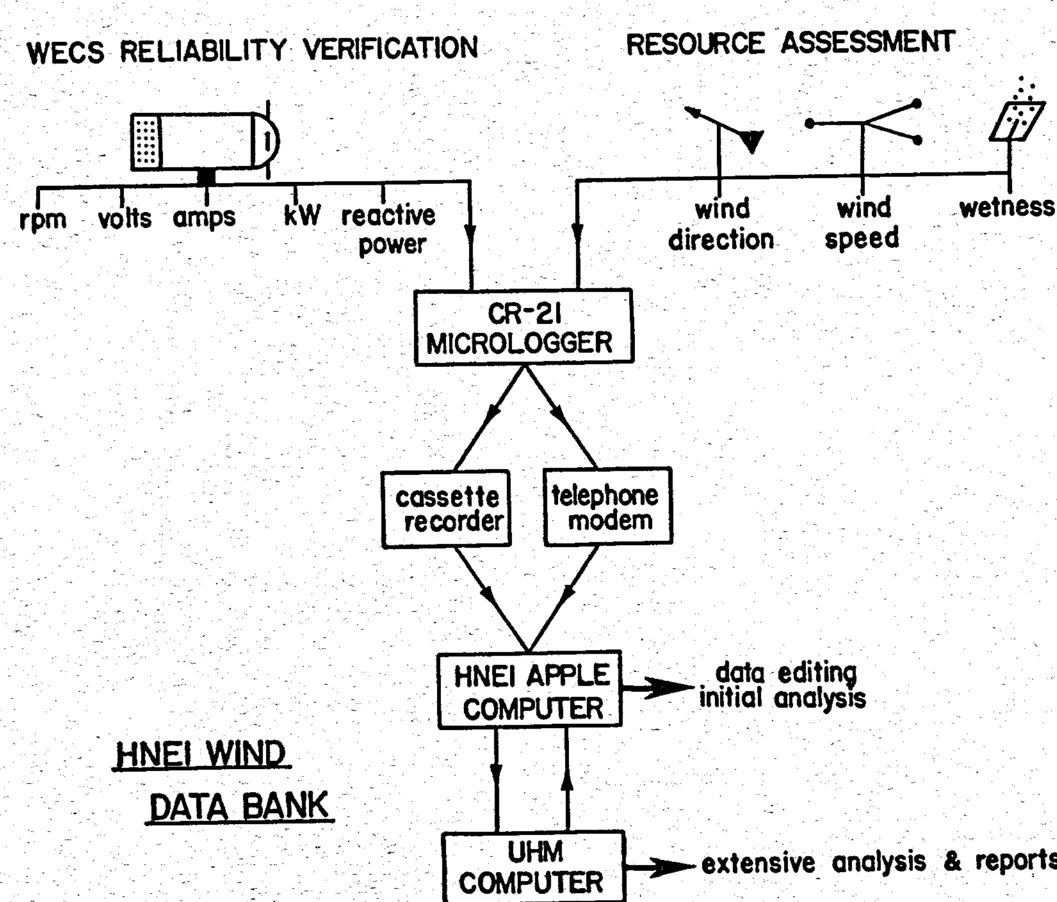
HNEI has purchased ten CR-21 microloggers from Campbell Scientific which will be used to secure data on installed WECS in Hawaii. This equipment measures wind speed, wind direction, and time of wetness as well as kilowatt output, amps, volts, reactive power, and blade revolutions per minute. The system has been designed to document long-term performance by collecting data at 6-minute intervals with cassette tape changes every month.

The first effort to put this monitoring system into use was successful, even if the WECS being monitored was poorly sited and installed. HNEI instrumented a 5 kW WECS located in Honokaa by another state agency. The Campbell Scientific equipment monitored wind speed and WECS performance but collected only limited data before the machine failed. HNEI's monitoring system is, however, ready to be used.

HNEI has acquired several machines for various applications which will be equipped with this monitoring equipment:

15 kW Windtech
15 kW Millville-Hawaii
9.2 kW TUMAC
1.8 kW Enertech
1.5 kW Aeropower
300 W Dragonfly
200 W Winco

Plans are in various stages for their installation and testing. The 15 kW Windtech is scheduled to be erected in September 1982 at Kahuku as part of a wind/nitrogen fertilizer project (see project description this section). The 1.8 kW Enertech was installed in July 1982 on a 90-foot tower at Kahuku during an HNEI Wind Energy Technical Workshop. Two small 200 W direct current WECS, the Dragonfly and the Winco, will also be instrumented and monitored along with the Windtech and Enertech at Kahuku. The 12 volt DC Aeropower battery charger will either be mounted on a 40-foot tower on the roof of a building, possibly Holmes Hall at UHM, as an experiment for rooftop WECS or be used for classroom training.



HNEI WIND DATA BANK

The City and County of Honolulu and HNEI have also made arrangements for cooperative research and development on wind energy conversion systems at the Kahuku Wastewater Plant. HNEI will install and maintain a 15 kW Millville-Hawaii horizontal axis wind turbine and/or a 9.2 kW TUMAC vertical axis wind turbine at the plant to help produce energy needed to operate sludge and influent pumps and other equipment. The machines will, at the same time, provide an opportunity for research on corrosion protection and system performance. The City and County will cost share up to 80 percent of the value of the electricity the WECS produce. Eventually, Honolulu will have the option to acquire the machines.

WIND ENERGY BATTERY STORAGE PROJECT

PRINCIPAL INVESTIGATOR: John W. Shupe, Ph.D.
Hawaii Natural Energy Institute

PROJECT STAFF: D. Richard Neill, B.S., M. Div.
George Curtis. B.S.
Byron Auker, S.M.
Robert Connelly, M.S.
James Bac, B.B.A.
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Hawaii Natural Energy Institute

PROJECT PERIOD AND FUNDING SOURCE: This three-phase research and development effort is supported by U.S. DOE through Sandia National Laboratories and the Rocky Flats Wind Systems Program. Phase I was completed July 31, 1982. Phase II contracts are now being discussed.
Total funding for FY 1981-82: $74,280.

PROJECT DESCRIPTION AND OBJECTIVES

Since utilities need to control precisely their generating capability and loads and since wind is intermittent and unpredictable, storage can increase wind energy's contribution to utilities' fuel requirements. Thus, the purpose of this Wind Energy Battery Storage (WEBS) Project is to analyze, design, construct, and test a battery storage system attached to a WECS and Molokai Electric's (MOECO's) utility grid. Phase I of the project is a preliminary design analysis; Phase II consists of evaluating Molokai Electric's newly installed generating system and completing a final system design; Phase III will include construction, operation, and monitoring of the system.

Specific tasks for Phase I include

- Collecting meteorological, utility loading, and component cost data;
- Developing various system configurations and performance measures;
- Evaluating system configurations by computer simulation; and
- Refining system design parameters.

RESEARCH PROGRESS AND PROJECT STATUS

Data necessary for a WECS/battery/utility system analysis have been collected during this year. First, meteorological data were collected at two sampling sites, HNEI's Moomomi Beach tower and the Kalaupapa Settlement, to determine WECS siting and performance projections. Data were collected as usual from the 150-foot Moomomi tower, and a new 60-foot meteorological tower was installed near Kalaupapa Airport and instrumented at 30- and 50-foot levels to measure wind speed and global insolation, rainfall, temperature, and time of wetness. A Campbell Scientific CR-21 micrologger recorded these data from November 1981 through June 1982. Then a procedure was developed to project long-term data from Kalaupapa by correlating long-term hourly wind data from Kahuku, Oahu, a similar wind site, with the short-term Kalaupapa data. Next, a set of voltage, current, and power transducers and a CR-21 micrologger were connected to Molokai Electric's Kalaupapa substation to collect data on typical daily loads and power variations. MOECO supplied this information for the entire island, and both sets of data were stored in HNEI/UHM computers. Finally, equipment, shipping, installation, operation, and maintenance costs were collected by questionnaires for all primary system components—WECS, batteries, power conditioning units, and related equipment.

While these data were gathered, two available computer programs were evaluated for use in the WEBS simulation, but neither was appropriate. A new program was then developed to project system performance, rough sizing, and costs. Variables include WECS size, battery size, transmission losses, wind energy at WECS site, percentages of time battery system and utility provide power, and amounts of battery discharge. Two measures of performance were also determined, the primary one being percent of annual demand supplied by WEBS.

A number of reviews verified the basic program, provided important additions, and identified the need for certain modifications. Trial runs and sensitivity tests were completed to refine the program even further. One important test, for example, consisted of running the program with a year of constant wind and then comparing results with those from manual calculations. Inputs were refined; nomenclature was clarified; data were rounded off to significant figures; limiting condition tests were done.

Finally, various simulations, primarily for Kalaupapa, were run and analyzed. Although batteries and WECS located at Kalaupapa could increase the level of wind energy used by MOECO, costs were too high for a storage system in such a limited application. Storage located at MOECO's power plant and used as an integral part of the total generating system, however, appears promising. Phase II will examine MOECO's new generating system and estimates of output from the wind farm being developed by Molokai Energy, Inc. in northwest Molokai.

WIND ENERGY NITROGEN FERTILIZER PRODUCTION

PRINCIPAL INVESTIGATOR FOR HNEI TASKS: John W. Shupe, Ph.D.
Hawaii Natural Energy Institute

PROJECT STAFF FOR HNEI TASKS:

D. Richard Neill, B.S., M.Div.
Bernard Holst, A.A.
Raymond Rapalee, A.A.
Hawaii Natural Energy Institute

PROJECT PERIOD AND FUNDING SOURCES:

This three-year research program is cooperatively funded by the UHM College of Tropical Agriculture and Human Resources, the East-West Center, and the Kettering Institute, which are responsible for the fertilizer production process, and by HNEI, which is responsible for the WECS to power the process.
Total funding for FY 1981-82: $5,000.

PROJECT DESCRIPTION AND OBJECTIVES

Nitrogen fertilizer, which is currently being produced primarily from natural gas, requires the second highest energy use in Hawaiian agriculture and aquaculture after water pumping. In an effort to cut costs and ensure supply, this project proposes to generate fertilizer in the field using nitrogen from air and electricity from a wind turbine generator. The process simply sends an electric arc through air in a hollow tube to combine free nitrogen and oxygen. Water is then added to produce nitric acid which, when combined with either limestone or phosphate rock, produces a nitrogen fertilizer.

The Kahuku Seafood Plantation of Systemsculture, Inc. on Oahu is the research site where HNEI is installing the small wind energy conversion system which will supply electricity for the process. HNEI tasks for FY 1981-82 include

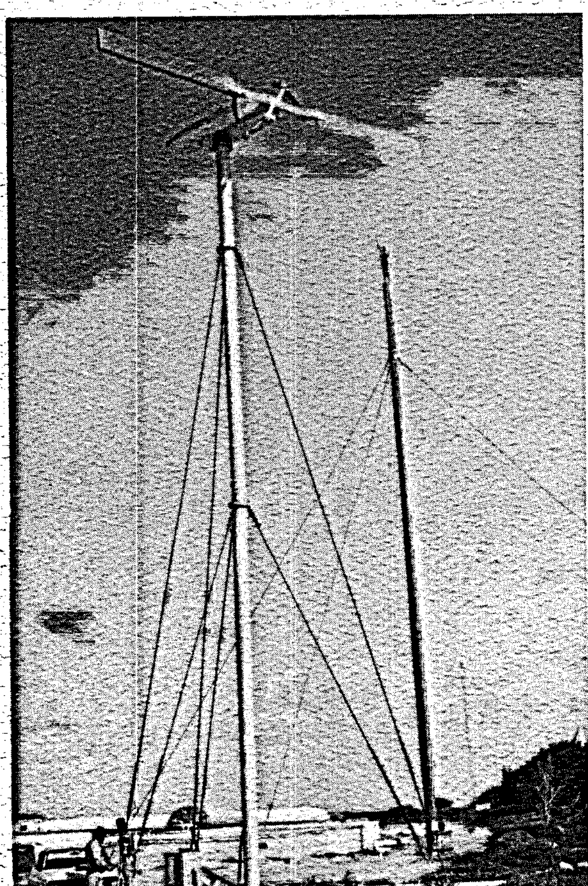
- Purchasing WECS;
- Preparing site and foundation;
- Installing tower and electrical hookups;
- Installing and testing WECS.

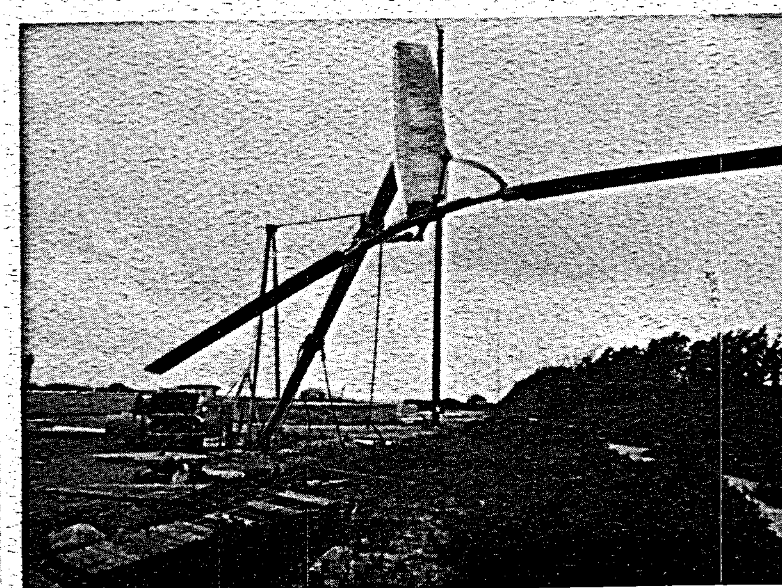
RESEARCH PROGRESS AND PROJECT STATUS

A United Technologies Research Corporation 15 kW prototype WECS was delivered at Kahuku in early 1981. Several months later UTRC decided not to produce their machine commercially and offered to repurchase the machine. Windtech, Inc., however, who acquired the UTRC designs, agreed to make major modifications in the WECS system with the repurchase money provided by UTRC. The generator assembly, rotor, and tower remained essentially the same while major changes were made in the support column and turbine frame. The 15 kW Windtech is a three-phase, 480 volt system with a 32-foot blade diameter, and its 50-foot tilt-up tower can be raised and lowered by one man, using a battery operated winch. It cuts in at 9 miles per hour, and produces 2 kW at 12 miles per hour and up to 15 kW at 25 miles per hour or above. An estimated 50,000 to 60,000 kWh of electricity will be generated each year at this location.

During November 1981, efforts began to install the WECS foundation. A soil survey indicated that the high water table and coral bed on the site would necessitate modifications of normal foundation specifications. The site was excavated, reinforcing rods were installed, and a total of 27 cubic yards of concrete were poured in five pads, one for the tower, three for guy wires, and one for the winch.

In June, an 8-inch diameter tubular steel tower was delivered to the site in two 26-foot pieces which were bolted together. Because of the severely corrosive atmosphere at Kahuku, the tower was reprimed with zinc chromate and repainted with exterior marine paint. The 50-foot tower was then erected and guyed at two heights with 1-inch wire. Plans were also drawn for electrical wiring, and this was done before the modified WECS was installed on the tower .





HNEI's 15 kW Windtech is installed at Kahuku with the 1.8 kW Enertech, in the distance. The Windtech's 50-foot tilt-up tower can be raised and lowered by one man, using a battery operated winch.

SAIL-ASSISTED TECHNOLOGY FOR PACIFIC MARINE TRANSPORTATION

PRINCIPAL INVESTIGATOR: Theodore T. Lee, Ph.D.
UHM Department of Ocean Engineering

PROJECT STAFF: Karl Samples, Ph.D.
UHM Department of Agricultural Economics
Wayne Thiessen, B.S.
Leo A. Daly, Inc., Alfred Yee Division
Angela Topliss, B.S.
UHM College of Business Administration
Mauro Vidal, B.S.
UHM Department of Ocean Engineering

PROJECT PERIOD AND FUNDING SOURCE: This project runs from March 1982 through June 1983 and is supported by HNEI's state R & D funds in FY 1981-82 and U.S. DOE institutional grant funds in FY 1982-83.
Total funding for FY 1981-82: $7,746.

PROJECT DESCRIPTION AND OBJECTIVES

The goal of this project is to evaluate the economic and technical feasibility of sail-assisted ocean transportation in the Pacific Basin. Objectives of the project are several:

- Complete a market opportunity analysis for sail-assisted technology in the Pacific;
- Establish appropriate routes for sail-assisted technology by evaluating the ocean environment (wind, wave, and current conditions);
- Complete an economic analysis of sail-assisted ocean transportation for specified routes;
- Evaluate the most appropriate technology and ship configurations for sail-assisted ships intended for different purposes;
- Compare the costs of retrofitting existing ships with sails versus newly designed and constructed sail-assisted ships.

Preparing vessel performance comparisons, vessel routes, and economic feasibility analyses could result in important and advantageous modifications to dozens of shipping routes under the responsibility of the United States, the Federated States of Micronesia, the Marshall Islands Government, the Commonwealth of the Northern Marianas, and the Republic of Palau.

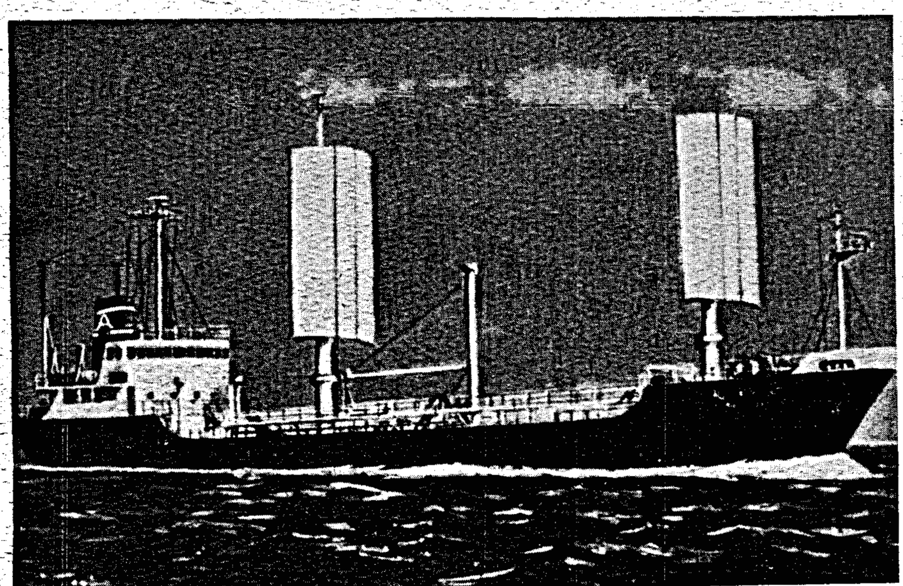
RESEARCH PROGRESS AND PROJECT STATUS

During the last several months much effort has gone into developing an economic computer model. Input parameters include vessel design and materials, capital and operating costs, vessel speed and performance, sailing routes, environmental and meteorological factors, markets, and operating requirements. Some of these input data have also been collected. A literature search provided details on vessel types; propeller, hull, sail, and rigging designs; engine size; hold and deck capacities; and vessel lifetime. Technical information on sail configurations and vessel performance is being secured from the developer of the world's first computer-operated sail-assisted ship, *Shin Aitoku Maru.* In April, data on wind and climate were collected from the UHM Department of Meteorology which will also provide more detailed information as specific sail-ship routes are selected. And during June and July data related to economics, markets, and sailing routes were collected in Ponape and Yap.

Various sailing routes have also been studied, especially in the Federated States of Micronesia where some of the routes are lifelines for food, supplies, and export cargo. In order of study priority they include

- Yap District Circuitous Route
  (Yap-Faraulep-Lamotrek-Satawal-Eauripik-Yap);
- Ponape Route
  (Ponape-Nukuoro-Kapengamangi-Ponape);
- Ponape to New Ireland;
- Honolulu to Pago Pago;
- Saipan to Rota;
- Interisland route among Hawaiian Islands.

Because a significant amount of information about the Yap and Ponape routes is currently available, data are being collected on these for initial iterations of the economic model.



The Shin Aitoku Maru *is the world's first computer-operated sail-assisted ship.*

Photo courtesy of Inamura Ship Building Company

A VERTICAL CORROSION PROFILE STUDY AT KAHUKU, OAHU

PRINCIPAL INVESTIGATOR: Anders Daniels, Ph.D.
UHM Department of Meteorology

PROJECT STAFF: Kirk Lauritsen, B.S.
UHM Department of Meteorology

PROJECT PERIOD AND FUNDING SOURCE: HNEI supported this one-year project with funds from a U.S. DOE institutional grant.
Total funding for FY 1981-82: $4,800.

PROJECT DESCRIPTION AND OBJECTIVES

Many of Hawaii's excellent wind regimes are located in coastal areas with salt-laden atmospheres. Thus, data on salt concentrations at various elevations above ground level will be necessary for designing wind energy conversion systems which can withstand these corrosive environments. The purpose of this project is to measure sea salt concentrations in a vertical profile at Kahuku, Oahu, site of the U.S. DOE/HECO 200 kW MOD-OA wind turbine and planned site of an 80 MW wind farm. Tasks include

- Developing an inexpensive measuring method using kites;
- Verifying the accuracy of this method in trials at Bellows Field; and
- Profiling the Kahuku area during trade winds at different distances from the beach.

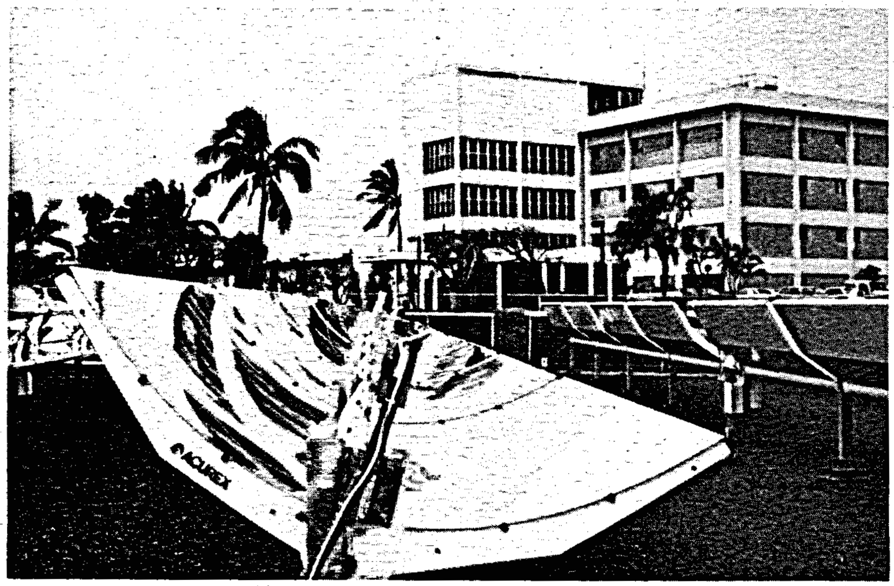
RESEARCH PROGRESS AND PROJECT STATUS

Because meteorological towers and airplanes are expensive, initial project efforts focused on developing an inexpensive, practical, and reliable system for measuring corrosion profiles: modified hand-held TALA kites. These tethered aerodynamically lifting anemometer kites are normally used to measure wind speeds and turbulence at 50- to 500-foot altitudes where a large wind turbine operates. The 2- by 3-foot waterproof paper sled kite is connected by a nonstretching Kevlar line to a spring inside a plastic tube, and the position of the top of the spring indicates speed on a miles per hour scale on the tube. A fishing reel with a string length meter and a handle completes the system. During operation, height and azimuth of the kite are measured optically with a clinometer and a compass. In order to adapt the kites for measuring atmospheric salt concentrations, the kite string was cut at ten places at 72-foot intervals; snap swivels were inserted; and 4-inch long, 0.14-inch diameter stainless steel fishing line leader wires were inserted at the breaks. Before each test, the wires were cleaned in a nitric acid solution and rinsed with deionized water. Each wire was stored in an Erlemeyer flask to avoid contamination during storage and transport, and wire ends touched before and after flights were excluded from the subsequent analysis. In the lab, the wires were rinsed by a known volume of distilled and deionized water which was then run through an atomic absorption spectrophotometer to obtain the sodium concentration.

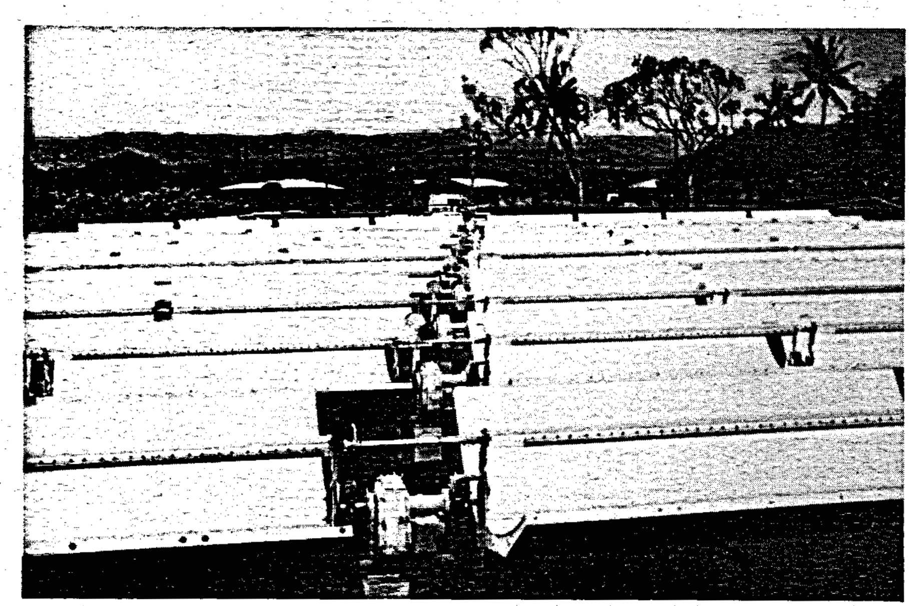
Kites were flown for 1-hour periods during six trials in November 1981 at Bellows Field near Kahuku. Fortunately, a team of scientists from New York State University were measuring salt concentrations on the windward side of Oahu using a specially equipped airplane. This provided an opportunity to sample simultaneously with the NYSU group in order to evaluate the kite method for obtaining corrosion profiles. Results showed good correlation, and, thus, tests were run at Kahuku during January, February, and March 1982.

During each test, two kites were flown, one along the shoreline and one inland. Inland locations included Kahuku Field, the MOD-OA site, Opana, and Site 14 on the upper Kahuku hill area. Results indicate a large concentration gradient between 50 and 500 feet during moderate to strong trade winds. At the beach, a very high concentration at 50 feet is probably caused by spray from breaking waves. The much larger values in Kahuku compared with Bellows probably reflect a more active wave breaking zone at Kahuku. Concentrations in the middle half of the 500-foot layer are about equal at the beach and at the inland sites. Since it is from this layer that large wind turbines will extract their energy, it would seem that locating turbines away from the beach plain would not result in a lower corrosion potential. But a tower on the beach would experience twice as much salt concentration as one at a site farther inland. Concentrations at 500 feet are higher at the beach than inland, even though increased mixing at inland sites might reasonably produce a more uniform distribution there. Concentrations do not seem to be proportional to the local wind speed or wind direction. Surface concentrations generally decrease with distance from the beach.

James Bac assembles one of the TALA kites used in corrosion studies at Kahuku.



The concentrating photovoltaic energy system at Lihue's Wilcox Hospital consists of ten rows of eight parabolic collectors.



SOLAR ENERGY RESEARCH PROJECTS

Hawaii's most obvious renewable energy resource is the sun. In fact, as the only tropical state in the union, Hawaii has global isolation rates—amounts of direct and diffuse incoming solar radiation—among the best in the nation.

Techniques to use this free, renewable, abundant, and clean fuel are numerous, of varying complexity, and in various developmental stages. Passive solar systems, for example, essentially make a building a collector by designing it to absorb or reflect sunlight to reduce energy costs for seasonal heating and cooling. Flat-plate collectors, too, are fuel savers which use both diffuse and direct sunlight. These systems absorb heat which can then be transferred to household water supplies or used for space heating.

Other, more technically sophisticated systems are also being developed which, rather than simply absorbing sunlight, actually concentrate it with mirrors or parabolic metal troughs or dishes. These systems increase intensities from ten to as much as several hundred times and, thus, produce much higher temperatures than flat-plate collectors. In addition, concentrating systems normally use only direct sunlight, and many track the sun as it moves from east to west. The solar power tower is one particular concentrating system which produces temperatures of about 900°F to generate electricity. Dozens of mirrors or heliostats collect sunlight and focus it on a boiler at the top of a central tower, at the base of which is a conventional turbogenerator.

Electricity is also the product of photovoltaic (PV) cells, perhaps the most miraculous of the new solar technologies. A simple solar cell is a 4-inch diameter silicon wafer crisscrossed by a grid of metal contacts. When photons of sunlight strike the cell, they free electrons which migrate to the contacts and produce a direct current of electricity. PV cells can be used in flat arrays, or their efficiencies can be increased by placing them at the focal points of concentrating systems.

Prototypes, developmental models, and commercial systems of all of these technologies are operating in the U.S. and most are in Hawaii. The Hawaii State Legislature and several county councils have developed building codes which support energy efficient designs; nearly 20,000 solar water heating units in the state give Hawaii the highest per capita rate in the U.S.; and several photovoltaic systems on Kauai, Oahu, and Molokai are producing electricity and hot water for homes and hospitals. Research continues, however, to solve technical problems, increase conversion efficiencies, and reduce costs. HNEI is contributing to that research as the following projects indicate.

WILCOX HOSPITAL SOLAR PHOTOVOLTAIC DEMONSTRATION

PRINCIPAL INVESTIGATOR FOR HNEI SUBCONTRACT: Paul C. Yuen, Ph.D.
UHM College of Engineering

PROJECT STAFF: Arthur Seki, M.S.
George Curtis, B.S.
Hawaii Natural Energy Institute

PROJECT PERIOD AND FUNDING SOURCES: U.S. DOE awarded this project contract to Acurex Corporation in September 1979 with additional funds coming from the Hawaii Department of Planning and Economic Development and the Department of Health. HNEI initially provided logistic support, and in May 1982 Acurex subcontracted with HNEI for project operation and maintenance for an eighteen-month period.
Total funding for FY 1981-82:$6,000.

PROJECT DESCRIPTION AND OBJECTIVES

The overall goal of the Wilcox Hospital PV concentrator applications experiment is to obtain operating experience with a concentrating photovoltaic energy system. The system at Wilcox consists of a field of ten rows of eight parabolic collectors, each 6 feet by 10 feet in aperture. These collectors concentrate incident sunlight on photovoltaic cells on both faces of receivers mounted at the collectors' focal points. With this concentrating system, the cells receive about twenty-eight times the normal solar intensity and convert that into direct current electrical energy. Each receiver (eighteen PV modules or nine on each side) has the capability of producing 450 watts—30 amps at 15 volts DC. An electrical power conditioning unit converts DC to usable AC power. For optimal system operation, the PV cells are cooled by water passing in series through the hollow centers of all eighty receivers. This water, part of a closed, continually recirculating system with a 3,000 gallon storage tank, takes excess thermal energy away from the PV cells and transfers it through a heat exchanger to the hospital's hot water supply. The entire 35 kW system is capable of producing 22,000 kW net and 620,000 gallons of 180°F water annually. Electrical storage is not required because variations in the output from the solar system are offset by utility power from Kauai Electric. A central automated system controls the tracking mechanism, cell cooling, power conditioning, and data acquisition.

HNEI's responsibilities for FY 1981-82 include completing an Acurex training session, assisting Acurex with logistics and fine tuning of the system, and accepting responsibility in May for operation and maintenance activities which include conducting routine tests and operating the visitor center.

RESEARCH PROGRESS AND PROJECT STATUS

The Wilcox PV facility was completed in November 1981 and dedicated in January 1982. Acurex held training sessions for personnel from the hospital, Kauai Electric, and HNEI in March and April to detail operation, maintenance, and testing procedures. On May 1, 1982, HNEI assumed responsibility for operation and maintenance of the solar photovoltaic system and designated

Wilcox hospital personnel as daily operators of the system and Kauai Electric personnel as technicians for troubleshooting.

Early system operation resulted in bubbling and browning of the polyvinyl buteral bonding material and cracking of the photovoltaic cells. Acurex and HNEI determined that inadequate PVB bonding and curing cycles during fabrication probably explain the bubbling. Browning and cracking are attributed to insufficient application of thermal grease during installation which also seems to explain the presence of a microbial or fungal growth that has caused the circuitry, wires, diodes, and silver backing of the PV cells to deteriorate. Laboratory tests HNEI had done indicate that moisture is the likely source of nutrients for the organism. Acurex, with HNEI's help, has reworked most of the damaged PV receivers; however, because of the extent of damage from the fungal growth and the limited supply of PV cells, the work is slow and several remain to be repaired or replaced.

Even though those technical problems and generally bad weather have hampered system operations, the hospital is now using what electricity and hot water the photovoltaic system produces. Data are also being collected to monitor system performance: meteorological information, temperature data at various points in the system, and measurements of currents and voltages of the power conditioning unit and subarrays in the field. The sensors are read every minute, averaged for a 10-minute period, and then stored on computer tapes. Data reduction is done by Boeing Computer Service in Washington which receives data via telephone modem, analyzes them, and forwards results to U.S. DOE.

A RESEARCH EXPERIMENT IN ROOFTOP MOUNTING OF PHOTOVOLTAIC SYSTEMS ON LIVED-IN UNITS IN HAWAII

PRINCIPAL INVESTIGATOR:	Paul C. Yuen, Ph.D. UHM College of Engineering
PROJECT STAFF:	D. Richard Neill, B.S., M. Div. George Curtis, B.S. Raymond Rapalee, A.A. Hawaii Natural Energy Institute
PROJECT PERIOD AND FUNDING SOURCES:	U.S. DOE, through MIT-Lincoln Laboratory and Jet Propulsion Laboratory, funded this HNEI project in May 1980 for two years. First-year cost sharing came from HNEI and the Hawaii Housing Authority. Support from DOE may be available for a third year. Total funding for FY 1981-82: $248,760.

PROJECT DESCRIPTION AND OBJECTIVES

The goal of this project is to help identify and resolve problems related to designing, installing, and operating residential rooftop PV systems which are connected to a utility for backup power and energy credits. The three homes selected for this demonstration are different residential building types broadly representative of Hawaiian housing. One is a two-story duplex near downtown

Honolulu which was part of a redevelopment program several years ago; the second is a quadraplex in a new public housing area in Pearl City; and the third is a forty-year-old ranch home in an Hawaiian homestead area on Molokai. Arco Solar, Inc., contractor for the project, designed the three systems to provide the approximate annual energy requirements of the households. The smallest system is a nominal 2 kW assembly in the urban home in Kalihi which has gas water heating and cooking. The other two, in larger households in Pearl City and Molokai, are 3.5 kW. ASI 16-2300 solar modules have been used at all sites. Fourteen modules were wired in series to form a subarray, and these were then paralleled to form the final array. The Kalihi array is composed of four subarrays while the Pearl City and Molokai sites have eight subarrays each. The direct current which these systems produce is fed to Gemini synchronous inverters and passed through an isolation transformer before being fed to the residence. Meters record system output (to home and utility) and utility input, and Hawaiian Electric and Molokai Electric provide credit for net energy generated by the PV systems.

HNEI's role during design and installation included critically reviewing designs, acquiring building permits, completing agreements with residents and utilities, and planning data monitoring systems. Tasks for FY 1981-82 include

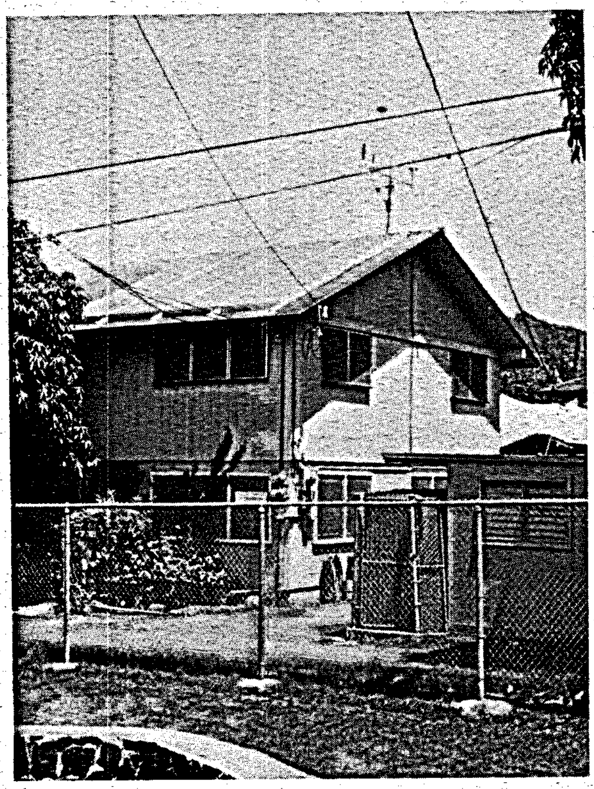
- Installing monitoring equipment;
- Conducting safety inspections;
- Operating the three systems; and
- Collecting data for system evaluation and reports.

RESEARCH PROGRESS AND PROJECT STATUS

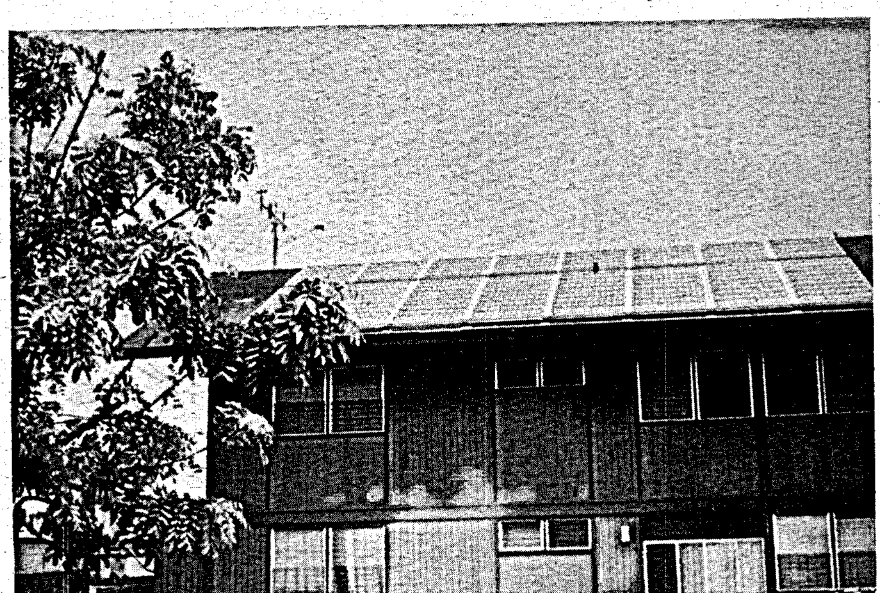
HNEI's monitoring equipment was installed shortly after the three PV systems were completed in June 1981. Data collection systems at each site use two Campbell Scientific CR-21 microloggers to record data from a variety of sensors and meters for these outputs: insolation; DC voltage; total array current; AC power, volt-amps, and AC voltage from the inverters; array temperature; AC power from the utility; subarray currents; wind speed and direction; ambient temperature and time of wetness. Data, initially collected at 6-minute intervals, are now collected hourly with daily midnight summaries. Semiprocessed data are fed to cassette tapes or, via modem, to an Apple computer for compression and storage on floppy disk. An HP3000 computer, interfaced with the Apple, is used for final processing and reports.

Safety concerns have been an important part of this project since early in the project when building department officials, Hawaii Housing Authority officials, utility personnel, and homeowners were briefed on the intent of the project and the basic operation of the system with stress on safety aspects of the design. The design was thoroughly reviewed for safety of operation and maintenance. After installation, each site received a structural inspection, a safety inspection performed by MIT, two safety inspections by HNEI, and at least one fire inspection. Safety briefings were also held with all concerned individuals, including residents and neighbors of residents, and fact sheets stressing safety were distributed to all. Residents' operation and maintenance manuals clearly and completely explain all pertinent safety procedures.

Insights into the systems' performance in real-world situations are expanding as data collection and analysis programs continue and develop. After one year of operation, the systems appear to be highly reliable with no rooftop panel failures or signs of degradation. Several electrical



Sensors on T-bars collect meteorological data at the 2 kW photovoltaic array in Kalihi, left, and the 3.5 kW system in Pearl City, below.



malfunctions have occurred and been corrected. The inverter at the Molokai site, for example, behaved sporadically with resulting blown fuses and a popping circuit breaker. After interruptions became almost daily occurrences, the entire inverter was replaced and the system has performed satisfactorily since. A shunt problem, consisting of corrosion product build-up at the terminals with resulting changes of resistance, was also noted and corrected at this site. Night switch malfunctions at all three sites led to modifications in the switch mechanisms. Finally, a malfunctioning circuit board and silicon controlled rectifiers were replaced at the Kalihi unit.

Minor problems with monitoring equipment also developed and have been corrected. Human error during cassette tape changes, micrologger failures requiring rework and/or replacement, and incorrect operating procedures during initial data collection resulted in data losses. With experience, these problems disappeared. Data continue to be routinely collected from all three sites for evaluation of long-term operating performance.

USE OF SOLAR ENERGY FOR INTENSIVE AQUACULTURE SYSTEMS IN HAWAII

PRINCIPAL INVESTIGATOR: Kakkala Gopalakrishnan, Ph.D.
Honolulu Community College, Department of Oceanography

PROJECT PERIOD AND FUNDING SOURCE: This seven-month project is being supported by HNEI with state R & D funds.
Total funding for FY 1981-82: $5,226.

PROJECT DESCRIPTION AND OBJECTIVES

Although various methods of aquaculture cultivation are used in Hawaii—ponds and raceways—the high cost of land and finite water supplies favor intensive culture methods using semi-closed or closed systems. But, such systems will require more energy for recirculation, aeration, and water-quality control. Use of energy may be the only solution to meet such large energy needs since the rising cost of fossil fuel will make such attempts nonprofitable and unattractive. This project is designed to examine the feasibility of utilizing solar energy to provide warm water in intensive culture systems to stimulate production of a fresh water prawn, *Macrobrachium rosenbergii,* and tilapia. Because these and many other organisms grow faster at slightly elevated temperatures, the project system is designed to provide heated water with a steady temperature of about 4°F above ambient readings. Tasks include installing a solar heating system at the Aquaculture Demonstration Facility of Honolulu Community College and documenting the potential of such devices in stimulating increased aquaculture production in Hawaii.

RESEARCH PROGRESS AND PROJECT STATUS

Initial efforts for this project focused on designing a closed aquaculture system which uses solar photovoltaic panels to operate system pumps and solar collectors to heat circulating water. Then, the following items were purchased to complete the installation: eight plastic solar collectors (sealed Air FW 40); one sealed Air K-1 system kit; two temperature sensors and automatic control systems; two Sta-Rite pumps (1/6 HP - 1½ HP); one pool cover; one poly-cal hot water storage tank (1,000 gallon capacity); and one "March" DC pump (12 volt) with photovoltaic panels.

Preliminary tests will begin in August to examine the degree of temperature elevations, heat storage capacity, heat output (Btu) to the culture tank, and effectiveness of the DC pump in recirculation. After completion of these tests, experiments will be conducted to analyze the effectiveness of the system for increasing the efficiency of intensive culture systems.

DEVELOPMENT OF A NOVEL CONCENTRATOR PHOTOVOLTAIC CELL

PRINCIPAL INVESTIGATOR: James Holm-Kennedy, Ph.D.
UHM Department of Electrical Engineering

PROJECT STAFF: Norman Hall, Ph.D.
Mark Lancaster, B.S.
UHM Department of Electrical Engineering

PROJECT PERIOD AND FUNDING SOURCE: HNEI has supported this project for two years, and several industries and laboratories (3M, Motorola, Hewlett-Packard, Sandia) have assisted with materials. Funds for FY 1982-83 will come from HNEI's institutional grant from U.S. DOE. Total funding for FY 1981-82: $16,500.

PROJECT DESCRIPTION AND OBJECTIVES

One way to improve the efficiency and costs of state-of-the-art solar cells is to concentrate sunlight before it strikes the cell. But concentrating sunlight also creates problems which can reduce cell performance: increased resistance and increased heat. Resistance can be reduced by adding more metal grids to the cell surface to carry the electron currents the cell produces, but these metal strips also reflect sunlight rather than absorb it and so create a different kind of efficiency loss. Cooling systems can be used with PV systems to keep temperatures moderate and recapture waste heat for other applications, but they can also have an adverse effect on system efficiency and costs. The purpose of this project is to design, fabricate, test, and analyze a solar cell which minimizes these two problems.

Efforts during FY 1981-82 are theoretical and experimental and address the problem of series resistance and the related problem of increasing grid densities without increasing reflection. Tasks include

- Analytical formulation of the problem;
- Development of a ridged technology;
- Design and acquisition of masks for cell etching;
- Development of required special photolithographic techniques; and
- Analysis and testing of the cell at concentrations greater than 1,000 suns.

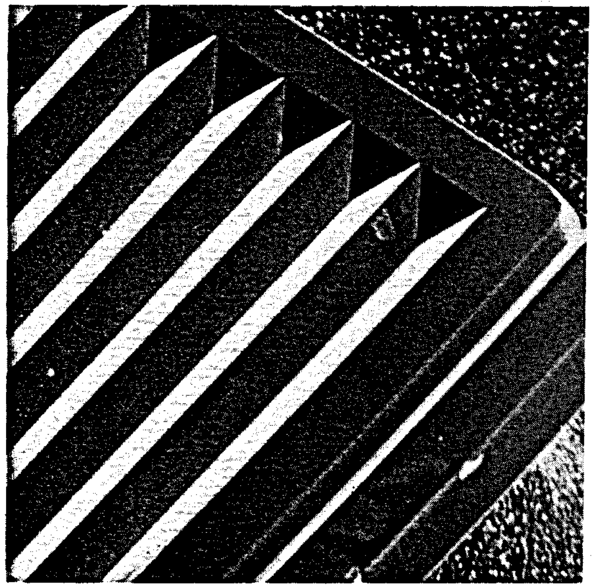
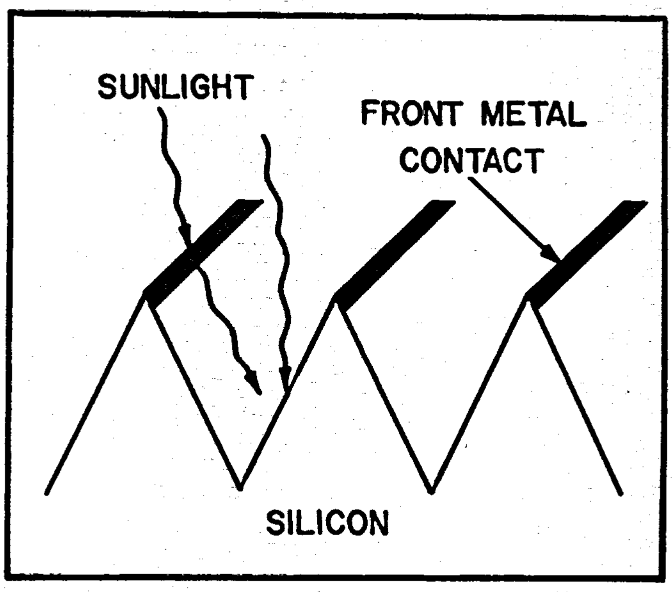


Photo by Mark Lancaster

A scanning electron microscope magnifies (210 times) the right corner of a novel solar cell to reveal its V-grooved structure. Metal contacts will be applied as shown in the schematic below.



NOVEL SOLAR CELL SURFACE

RESEARCH PROGRESS AND PROJECT STATUS

A number of sophisticated transport phenomena were incorporated into a theoretical examination of this solar cell, and numerical techniques were applied to the specific structure. The cell, instead of having a flat surface as conventional cells do, consists of many parallel ridges. Metal contact strips are placed along the edge of each ridge so that any incoming sunlight is deflected onto the opposite ridge and absorbed. Thus, the number of grid lines is increased to decrease resistance, but the ridge structure prevents reflection.

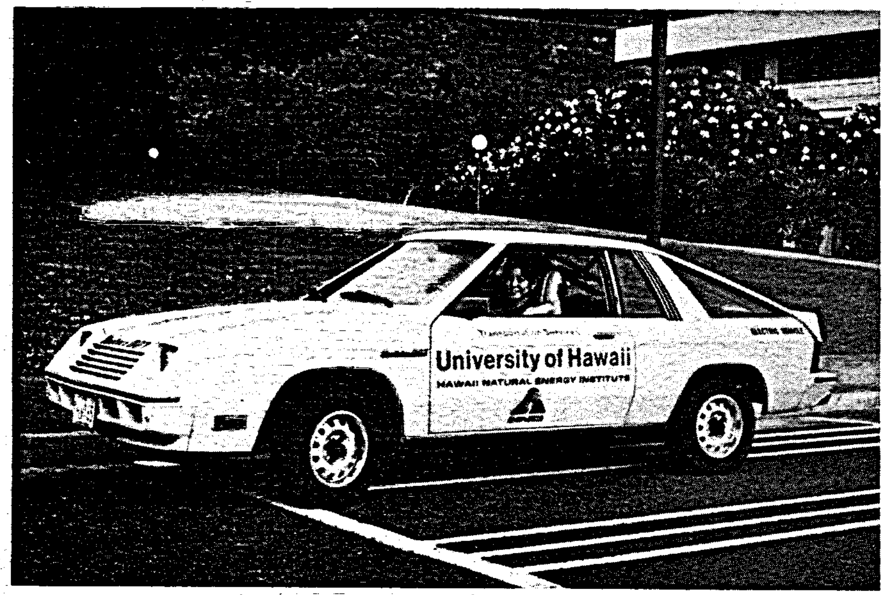
The first step in fabricating this ridged grid solar cell is to etch the front surface of the silicon wafer to produce a very clearly defined V-grooved structure. Before the front surface of the wafer can be etched, however, a protective oxide layer about 1 micron in thickness must be grown on both sides of the cell. The oxide layer on the back surface protects it during the etching process, while the front surface oxide layer is selectively etched by a photolithographic process to expose the silicon surface where the etching is desired. The desired parallel line pattern is transferred to photoresist on the wafer by exposure to ultraviolet light. Once exposed, the photoresist is developed, making visible the lines and spaces. After a postbake step, the oxide is removed from the wafer by using buffered hydrofluoric acid. The remaining photoresist is then removed from the wafer surface and etching can begin.

The etching solution used in this process is a slow working mixture of sodium hydroxide and isopropyl alcohol which is heated to 167°F. The entire wafer is then placed in the heated etching solution for approximately 2.5 hours. After the etching process is completed, the wafer is cleaned in a very dilute hydrochloric acid solution to remove the sodium hydroxide. The remaining oxide layers on both surfaces are then removed using buffered hydrofluoric acid.

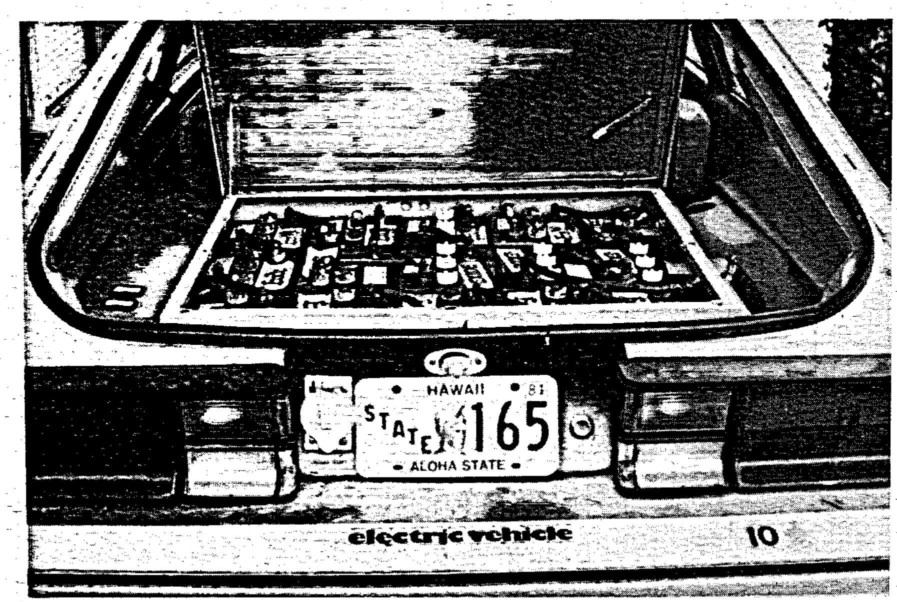
The last major step in the fabrication sequence consists of defining metal grid lines along the front side ridges by a second photoresist process. A primer and photoresist are applied to the new grooved cell surface. A light source etches the area of each peak not shadowed by the preceding peak. Aluminum is then evaporated over the entire front surface of the wafer, and, finally, photoresist removal/aluminum lifting is done for 15 minutes using low level ultrasonic action. Only metal grid lines along the front surface ridges remain.

Testing has been done with a flashlamp system to measure the output characteristics of the ridged grid cell. The flashlamp provides a short, intense pulse of light equivalent to many hundreds of suns at close distances to the cell. A fixed load resistance is placed across the cell and then the flashlamp is fired. The voltage across the cell is measured by a storage oscilloscope and the cell's output current is obtained by dividing the output voltage by the load resistance. This method gives one point per flash. The load resistance is then changed and the process continued until twenty or so data points are collected to yield a current/voltage (I-V) curve.

A circuit is now being developed that will measure the entire I-V curve during one flash, thus increasing the accuracy of the data as well as speeding up testing time. Testing and further cell refinement will occur during FY 1982-83.



Gail Yonamine, above, is one of more than fifty specially trained drivers who operate electric vehicles in the UHM/HNEI fleet. Below, the rear battery pack of an Electrica 007 sedan fits compactly under the rear compartment. Charger socket is to the left of the license plate.



OTHER RENEWABLE ENERGY RESEARCH PROJECTS

Projects discussed in the preceding sections are directly related to development of the five renewable energy resources which hold the most promise for reducing Hawaii's heavy petroleum dependence. HNEI is also supporting research which addresses common problems associated with these developing energy technologies, which studies options for relieving an oil-based transportation sector, and which provides planning tools for those determining Hawaii's energy future.

While Hawaii's renewable energy resources are abundant, some are dispersed and intermittent, and others provide low rather than high temperatures. This diversity results in several technological and social problems. First, wind machines and solar panels or collectors exposed to the elements—Hawaii's strong trade winds, salt-laden marine atmosphere, and tropical sun—tend to corrode, crack, and require replacement quickly unless they are specially treated. Pipes and equipment designed for transmitting water are not necessarily satisfactory for geothermal brine. Thus, corrosion and materials studies are essential for developing some of Hawaii's renewable resources.

In addition, energy storage systems which retain energy generated during off-peak hours and then release it when needed will help to alleviate problems associated with intermittent energy sources: utility grid stability and load leveling, transmission of energy from resource to end use. Batteries charged by renewables can also be used to power electric vehicles which operate without pollution, noise, or gasoline. Then, low temperature energy sources will require generating systems different from those used in conventional coal- and oil-fired power plants.

Finally, the transition from conventional to innovative energy systems will require careful planning to protect Hawaii's people and environment while new energy benefits are gained; to initiate programs according to a considered, coordinated set of priorities; and to implement laws, policies, and regulations which will expedite renewable energy development. Estimates of resource potentials, demand models and energy use projections, and project feasibility studies are necessary planning tools.

CORROSION PROTECTION FOR ALTERNATE ENERGY SYSTEMS

PRINCIPAL INVESTIGATOR: Jorn Larsen-Basse, Ph.D.
UHM Department of Mechanical Engineering

PROJECT STAFF: Raymond Lam, B.S.
Rais Azhar, M.S.
Steven Smuck
UHM Department of Mechanical Engineering

PROJECT PERIOD AND FUNDING SOURCE: Funds from HNEI's U.S. DOE institutional grant are supporting this project during FY 1981-82 and FY 1982-83. Atmospheric corrosion studies continue work initially funded by Argonne National Laboratory in 1979.
Total funding for FY 1981-82: $16,350.

PROJECT DESCRIPTION AND OBJECTIVES

The overall goal of this project is to develop a basic understanding of the mechanisms of corrosion which could hinder development of Hawaii's renewable energy resources. The current project focuses on corrosivity of brine from the university's HGP-A geothermal well and on atmospheric corrosion in Manoa Valley and at Ke-ahole Point, inland and coastal areas representative of many solar and wind resource sites in the state.

The HGP-A geothermal well produces a two-phase fluid consisting of steam and hot water. The steam is used in energy generation, and the hot water, which has considerable potential value as a heat source for industrial drying processes or similar applications, is brought to ambient pressure in a brine flash chamber, enters a silica settling pond, and is eventually discarded. Obtaining engineering data on corrosion rates in the secondary steam and hot water can form a basis for selection of materials for pipes, valves, heat exchangers, and other equipment for uses of the geothermal brine.

Wind energy conversion systems and solar collectors are also exposed to severe corrosion in Hawaii's salt-laden marine atmosphere. Exposure testing of common construction materials, originally done as part of a nationwide testing program for solar collectors by Argonne National Laboratory, helps identify corrosion-resistant materials for these renewable energy systems. Testing various techniques for corrosion measurement also identifies the most efficient ones and suggests modifications to improve them for rapid estimation of the corrosivity of a particular environment.

RESEARCH PROGRESS AND PROJECT STATUS

During FY 1981-82, geothermal corrosion experiments were performed by exposing sets of twenty to twenty-five corrosion coupons to the secondary steam of the HGP-A brine flash chamber and to hot water in the silica settling pond. The samples were removed after two weeks to three months and evaluated by conventional weight loss and metallographic methods. Results to date show that the steam is very corrosive and that its corrosiveness depends considerably on which hydrogen sulfide abatement method is used upstream. Only titanium; highly alloyed stainless steels such as AL-6X, Avesta 254 SMO, and Jessop 700; and some high nickel alloys in the Hastelloy family show complete resistance. All other materials tested so far deteriorate severely in a short period of time. The hot water is less corrosive, and its attack on metals is partly related to the

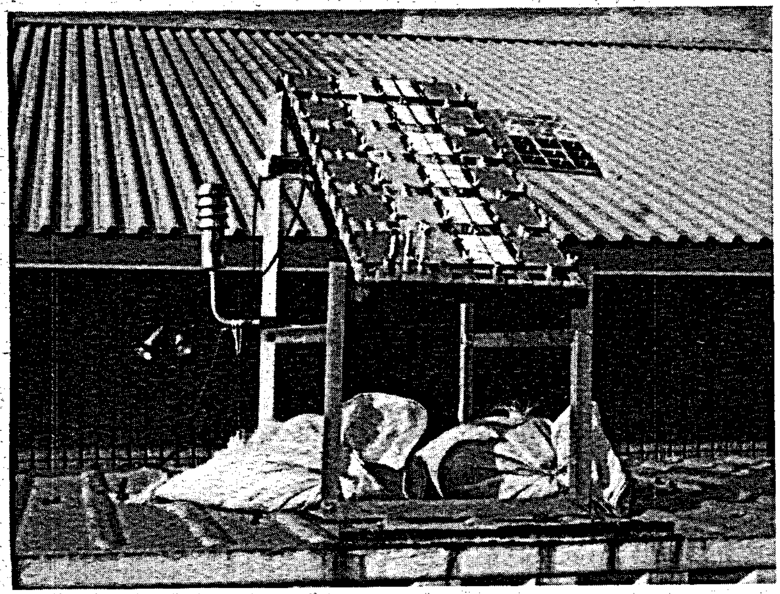


Photo by Frank Sansone

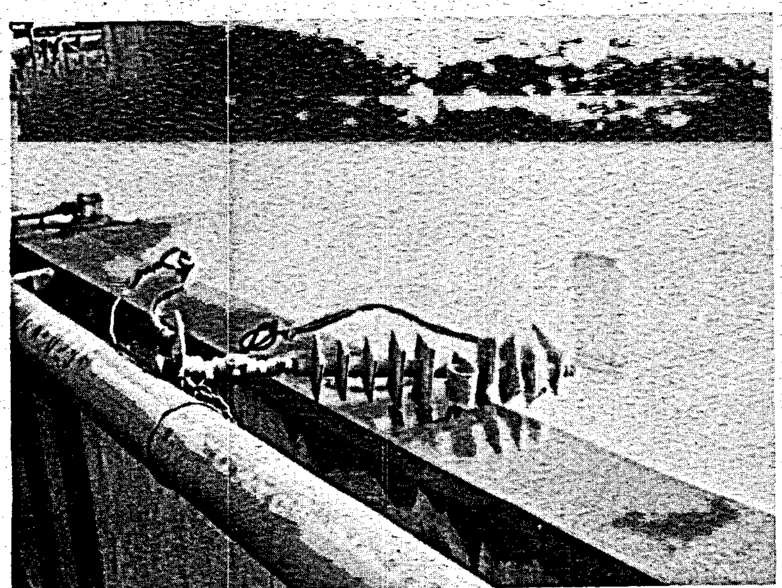


Photo by Donald Thomas

Metal coupons are exposed to atmospheric conditions at Ke-ahole Point, above, and to geothermal steam at HGP-A, left. Magnifying 1,120 times scale on a stainless steel coupon from HGP-A reveals calcium and silica crystals.

Photo by Raymond Lam

formation of strongly adherent silica scales. Stainless steel 304, a common stainless alloy, appears to be resistant as are titanium and the higher alloy stainless steels. Copper base alloys suffer severe general corrosion, while ferrous materials and aluminum and zinc alloys show severe pitting and crevice corrosion. No stress corrosion cracking or hydrogen embrittlement has been found so far. These results have been used to select other materials for testing during FY 1982-83.

Atmospheric corrosion tests have also been performed during this period with galvanized, aluminized, and painted steel and aluminum specimens supplied by Argonne National Laboratory. Specimens were exposed for periods of up to one year at two sites: the roof of Holmes Hall and the Natural Energy Laboratory at Ke-ahole. Preliminary results indicate that aluminum coating corrodes much more slowly than the galvanized coat but doesn't protect the underlying steel at cuts and scratches. Zinc corrosion follows a parabolic relation with time, indicating diffusion control. Comparison of results from the two sites will be made when testing at Ke-ahole is complete.

At the same time that these metal coupons were tested, experiments were performed on techniques for measuring atmospheric corrosion. The current flow between copper and zinc plates in small atmospheric corrosion monitors (ACM's) was recorded, integrated, and converted to zinc weight loss, and these results were compared with weight loss of pure zinc coupons. Very close correlations indicate that lengthy weight loss testing can be replaced with short-term ACM tests in order to determine the atmospheric corrosiveness of a site. Considerable effort, too, has gone into determining the accuracy of a second, wet candle method by comparing results with salt nuclei deposition rates on glass slides and metal surfaces. During tests, the candle collected approximately three times as much salt as a plate of glass, plexiglass, or steel; and about eight times more salts at Ke-ahole than at Holmes Hall. A similar ratio exists between the zinc corrosion rates at the two sites. Thus, this inexpensive wet candle method can be used to determine the relative corrosivity of different geographic locations.

HYDROGEN STORAGE IN TRANSITION METAL HYDRIDES: AN ASSESSMENT OF THE THERMODYNAMICS AND KINETICS USING ELECTROCHEMICAL TECHNIQUES

PRINCIPAL INVESTIGATOR: Bruce E. Liebert, Ph.D.
UHM Department of Mechanical Engineering

PROJECT STAFF: Glenn A. Engle, B.S.
UHM Department of Mechanical Engineering

PROJECT PERIOD AND FUNDING SOURCE: HNEI's U.S. DOE institutional grant supported this project in FY 1981-82 and will continue to do so during FY 1982-83. Total funds for FY 1981-82: $25,464.

PROJECT DESCRIPTION AND OBJECTIVES

Discovery of inexpensive hydrides capable of storing hydrogen near ambient temperatures and pressures would provide an economical and safe alternative to present, less-than-satisfactory hydrogen storage procedures and would allow practical off-peak storage of electricity from intermittent renewable energy resources. Thus, the purpose of this project is to study a number of transition metal oxides with structures capable of accommodating large amounts of hydrogen without undergoing a structural transformation in order to minimize energy losses during charging and discharging. Materials with structures containing open tunnels, such as the manganese dioxides, have been shown to be capable of rapidly and reversibly incorporating a number of electroactive species, such as the alkali metals, in advanced batteries. Therefore, these materials offer considerable promise for the inexpensive storage of hydrogen in the form of hydrides. Project tasks include determining electrochemically the kinetics, thermodynamics, and ultimate storage capacity per unit mass of at least eight different manganese dioxide compounds. The kinetics of these materials are evaluated by experimental determination of the diffusion coefficient using the galvanostatic intermittent titration technique. Thermodynamics of hydrogen incorporation in the samples are found by adding hydrogen and determining the titration curve (equilibrium voltage versus hydrogen content).

RESEARCH PROGRESS AND PROJECT STATUS

Diffusion coefficients of hydrogen in a number of metal and metal-oxide systems at low hydrogen concentrations have been measured experimentally. The well known hydride, iron titanium (FeTi), has been compared to other, less familiar materials including manganese oxides (MnO_2), lanthanum-nickel (La-Ni), and lanthanum-nickel-aluminum (La-Ni-Al) alloys. Results indicate that the measured hydrogen diffusion coefficient in these other materials is one million times greater than that of FeTi.

These initial results encouraged continued tests which required solutions to several methodological problems. The first problem, short sample life during titration, limited efforts to determine the ultimate hydrogen capacity of the materials. This problem was minimized by adding powdered teflon to the powdered sample material to serve as an inert binder. Another problem encountered was a slow reaction rate: FeTi required many days to come to equilibrium. The other materials tested did not require this much time, but the delay limited the number of experiments that could be accomplished. Increasing the temperature decreased the equilibration time, but did not allow measurement of hydride kinetics at expected (ambient) operating temperatures. In an effort to minimize the time for equilibration, two parallel paths were tested to determine the more effective one: using multiple samples in the same reaction vessel and using multiple reaction vessels. The latter method proved to have fewer disadvantages.

A third problem appeared during the initial evaluation of calcium nickel ($CaNi_5$) when a sample's short-term response differed significantly from that measured during longer time periods. Measuring the response of the sample after the current is interrupted (no surface reaction can occur during this time) and comparing it to results recorded while the current is flowing indicated that a surface rate-determining reaction affected the short-time response of $CaNi_5$. This technique may also reveal interesting information about surface contamination or surface reactions of other materials in addition to serving as a check on the magnitude of the diffusion coefficient measured during the addition of hydrogen.

With these methodological problems solved, the different MnO_2 compounds can be evaluated for rapid hydrogen diffusion and ranked accordingly by the end of 1982; the kinetics and thermodynamics of the La-Ni-Al and Ca-Ni compounds, as well as the most promising MnO_2 compound, will be evaluated by mid-1983.

UHM/HNEI ELECTRIC VEHICLE DEMONSTRATION PROJECT

PRINCIPAL INVESTIGATOR: H. H. Hwang, Ph.D.
UHM Department of Electrical Engineering

PROJECT STAFF: D. Richard Neill, B.S., M.Div.
Hawaii Natural Energy Institute
Harry Curry
UHM Transportation Services
James Otsuka, B.S.
UHM Department of Electrical Engineering

PROJECT PERIOD AND FUNDING SOURCES: This four-year project has been funded by U.S. DOE with cost sharing from HNEI since FY 1979-80.
Total funds for FY 1981-82: $50,0l9.

PROJECT DESCRIPTION AND OBJECTIVES

During the first year of this four-year program, vehicles were selected and road-readied; drivers and mechanics were trained; and charging stations were installed. The vehicles, purchased from Jet Industries of Austin, Texas, include five converted Dodge Omni sedans, five converted Ford Courier pickup trucks, and five converted Dodge passenger vans and are part of a fleet operated and maintained by UHM Transportation Services. Organizations within the UH system now regularly operate EVs assigned to them and keep records of vehicle performance: acceleration, range, energy consumption, payload capacity, maximum speed, battery life, safety, maintenance requirements, user response, and similar information. The goals of this long-term road testing are to help optimize EV systems and components and expedite EV commercialization by identifying problems experienced by users and by defining equipment limitations under realistic operating conditions. Tasks for FY 1981-82 include

- Restoring to full operation all vehicles requiring service or replacement parts;
- Improving battery box ventilation to minimize the possibility of explosions from accumulated hydrogen gas;
- Training additional drivers in order to keep the EV fleet in use and data collection continuing;
- Expanding the public awareness program by providing information on the advantages, limitations, safety precautions, operational requirements, and other EV data;
- Assisting with a legialative resolution to adopt EVs for state and local government agencies.

RESEARCH PROGRESS AND PROJECT STATUS

Every effort was made to restore to full operation defective vehicles delivered by Jet Industries at the end of 1980. Long delays in receiving replacement parts not available locally and several serious problems found in the vehicles have hampered repair efforts, however. The five 1400 vans, which were defective when they arrived, were thoroughly examined to determine that the main problem involved malfunctioning chargers which overcharged the batteries. External timers were designed and installed on the charging stations at a minimal cost as a temporary solution until

Five converted Dodge passenger vans are part of UHM/HNEI's electric vehicle fleet.

Jet Industries sends a technician to correct the problem permanently. Several battery packs also failed to hold their charge after only about 1,000 miles of use. These battery packs were replaced with new Alco batteries which are available locally. A third problem, melting of battery terminal posts in several vehicles, apparently occurred because the batteries are not designed for the heavy duty use required by EVs. To minimize this problem, batteries are now being regularly scheduled for inspection and maintenance. As of July 1, 1982, eleven vehicles are operable with four requiring parts from the mainland.

Since several explosions occurred during FY 1980-81 in the UHM/HNEI and the Hawaiian Telephone EV fleets, strict precautions have been taken to ventilate battery packs during charging. Steps have also been taken to remedy the problem of deterioration of ventilation fan blades. Alternative blade shapes and materials are now being evaluated.

At the end of this third project year, more than fifty drivers from twelve units in the UH system and other government agencies are now thoroughly trained EV operators. Some of these are qualified undergraduate and graduate students who volunteered to train new drivers, work on the public awareness programs, and collect data: utility rate changes, vehicle inventory data, daily operation logs, charging data, and monthly maintenance data.

The public awareness program has also received attention this year. To inform and educate high school students, university students, and the general public, EVs were displayed at the annual UHM College of Engineering open house, the Hawaii State Capitol, and a number of public schools on Oahu; demonstrations were also given to various groups which included representatives of IBM, Boeing Co., and Westinghouse; and papers on the EV project were presented at several mainland conferences. In addition, on April 8, 1982, the Hawaii State Senate held a hearing regarding Resolution No. 72 which requests the adoption of electric cars for state and county vehicles. This resolution, sponsored by State Senator Charles M. Campbell, was passed on April 21, 1982.

A FREON BOILER FOR ALTERNATE ENERGY POWER CYCLES

PRINCIPAL INVESTIGATOR: Hi Chang Chai, Ph.D.
UHM Department of Mechanical Engineering

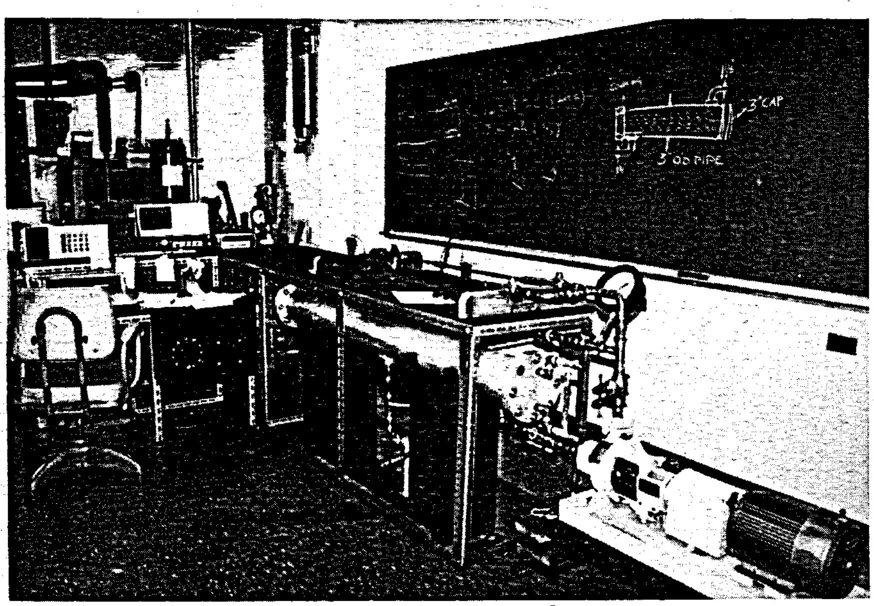
PROJECT STAFF: Deane Kihara, Ph.D.
Daniel Keenan, B.S.
UHM Department of Mechanical Engineering

PROJECT PERIOD AND FUNDING SOURCE: HNEI is supporting this project during FY 1981-82 and FY 1982-83 from its institutional grant from U.S. DOE.
Total funds for FY 1981-82: $13,100.

PROJECT DESCRIPTION AND OBJECTIVES

Relatively low temperature renewable energy resources can be used to generate electricity in Rankine cycles with low boiling point refrigerants. Information needed to design the evaporator or boiler, the most important and expensive component of the cycle, includes a correlation equation for flow boiling heat transfer to the selected working fluid. Thus, the objectives of this study are to collect data needed to formulate the design equation of heat transfer for a Freon-11 boiler; to determine the effect of heat flux, mass velocity, and wall superheat on the average flow boiling heat transfer coefficient of Freon-11; and to formulate a correlation equation with the data obtained in this experimental investigation. First year's work on this project includes

- Calibrating and repairing a heat transfer loop and related equipment in the UHM Mechanical Engineering lab;
- Modifying the piping system, test section, and heating system to obtain more accurate data; and
- Conducting preliminary tests of the loop.



This heat transfer loop is being used to determine the boiling heat transfer coefficient of Freon-11.

RESEARCH PROGRESS AND PROJECT STATUS

Research activities began in September 1981 with a literature search for recent articles on flow boiling heat transfer in refrigerants, and no published data were found. The boiling heat transfer loop was then dismantled, and major components for a data acquisition system were ordered as well as parts needed to repair and modify the loop.

The major components of the heat transfer loop are a 5 horsepower Freon pump, test section, constant voltage transformer which supplies electric power to the test section, condenser, water chiller which supplies cold water to the condenser, and liquid receiver. Modifications made on the existing heat transfer loop include up-grading the data collection and processing system; installing a larger condenser and a 30 gallon water tank between the water chiller and the condenser to obtain uniform coolant temperature for the condenser; and modifying the test section in such a way that boiling phenomena can be observed and photographed. The loop has also been designed so that major components can be isolated and removed for repair without draining Freon from the loop. Pressure gauges and thermocouples are placed at appropriate locations so that heat balance computations can be made and the state of Freon can be checked at various locations. Cooling or heating capacity of the water chiller, the condenser, and the heater have been matched to approximately 35,000 Btu per hour; the water chiller and the Freon pump have been cleaned and tested; and two turbine flow meters have been checked and calibrated. Thus, the heat transfer loop has now been modified sufficiently to begin preliminary tests on Freon-11 during August.

A data acquisition system, which includes an HP85 microcomputer, an HP3497A Data Acquisition/Control Unit, and plug-in units for flow and temperature measurement, has also been assembled. During FY 1982-83, data will be collected and analyzed to formulate a correlation equation for flow boiling heat transfer of Freon-11.

DEMAND ANALYSIS OF GROUND TRANSPORTATION FUELS IN HAWAII

PRINCIPAL INVESTIGATOR: PingSun Leung, Ph.D.
UHM Department of Agricultural and Resource Economics

PROJECT STAFF: Mary Vesenka, B.S.
UHM Department of Agricultural and Resource Economics

PROJECT PERIOD AND FUNDING SOURCE: HNEI has funded this project from state R & D funds for the period January through December 1982.
Total funds for FY 1981-82: $4,842.

PROJECT DESCRIPTION AND OBJECTIVES

This research focuses on the demand for ground transportation fuels in Hawaii. Since more than 25 percent of the state's energy budget is consumed by ground transportation, primarily in the form of gasoline and diesel oil, an econometric model to forecast fuel consumption over the next twenty-five years for the state serves as an important planning tool. Thus, the purpose of this project is to develop such an engineering/econometric demand model.

This model will be a refinement and extension of the ground transportation section of the Hawaii Integrated Energy Assessment (HIEA) demand model which was designed to project energy uses for each county to the year 2005. The refinements proposed in this research will make possible explicit analysis of variables such as higher efficiency standards for automobiles, conservation policies, and responses to price changes in vehicles and fuel. Tasks for the project include

- Searching all literature related to previous transportation studies for Hawaii;
- Collecting and compiling all relevant data;
- Refining the demand model;
- Running demand scenarios and documenting the model.

RESEARCH PROGRESS AND PROJECT STATUS

While previous studies related to this subject have been completed at the regional and national levels, assumptions used in those studies are not realistic for Hawaii where composition and use of the vehicle fleet differ significantly from mainland patterns. Thus, every effort has been made to collect demographic, socioeconomic, and fleet-related data specific to Hawaii. First, information on vehicle miles driven per car per county during 1979-80 was collected from the Hawaii Department of Planning and Economic Development. Data from the U.S. Census for 1970 and 1980 were collected and compiled on numbers of licensed drivers, their ages, their working and driving habits, and related demographic and socioeconomic statistics. Arrangements were also made with Oak Ridge National Laboratory, which has compiled transportation information for all fifty states, for copies of their files on Hawaii's vehicle fleet from 1970 through 1980, on gasoline consumption, on motor vehicle sales, etc. Thus, data are now collected and will be incorporated into the demand model after necessary refinements are completed.

MOLOKAI COMMUNITY ENERGY MANAGEMENT PROGRAM

PRINCIPAL INVESTIGATOR FOR HNEI SUBCONTRACT:	Paul C. Yuen, Ph.D. UHM College of Engineering
PROJECT STAFF:	Arthur Seki, M.S. D. Richard Neill, B.S., M.Div. Hawaii Natural Energy Institute
PROJECT PERIOD AND FUNDING SOURCE:	In March 1981, the National Center for Appropriate Technology awarded a one-year contract to Maui County for this project. HNEI has a subcontract to complete several program tasks as do Maui Economic Opportunity, Inc., Molokai Electric Co., and the State Energy Office. Total funds for FY 1981-82: $6,285.

PROJECT DESCRIPTION AND OBJECTIVES

The goal of this program is to prepare an implementation plan for energy conservation and renewable energy resource development which favorably affects the people of Molokai. The program is to document present and future energy demands, energy conservation and alternate energy program costs, socioeconomic impacts, environmental and legal constraints and benefits, public attitudes on energy issues, and public acceptance of an energy education program.

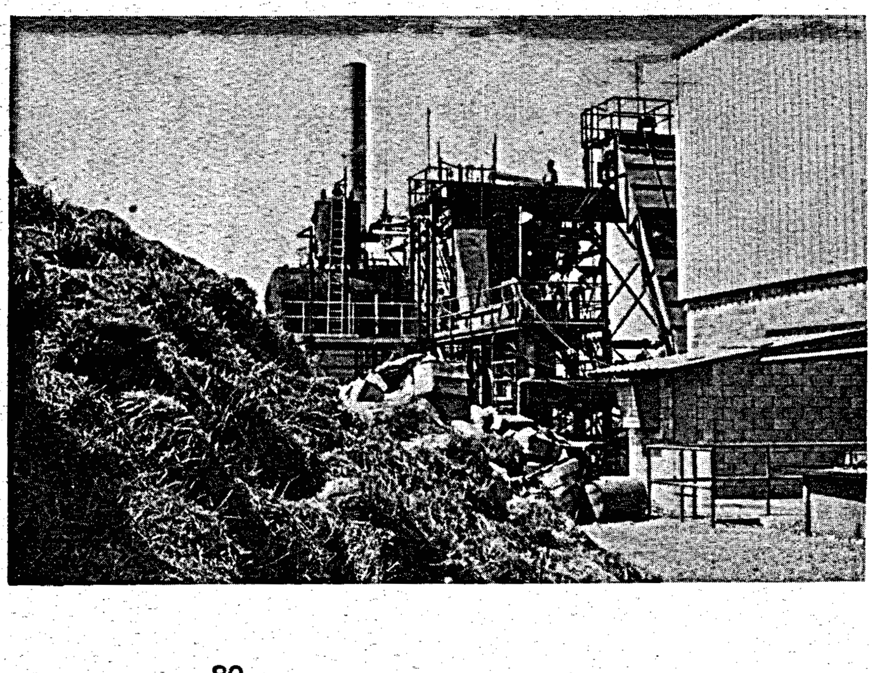
HNEI's tasks include

- Projecting energy use, demand, and cost figures for conventional and renewable energy sources;
- Assisting with the preparation of renewable energy resource development programs for Molokai and with their presentation for funding;
- Presenting energy programs at public meetings, workshops, and training sessions on Molokai.

RESEARCH PROGRESS AND PROJECT STATUS

During the four months that this program has been underway, data have been collected from a number of sources to use in an HNEI-developed energy use model: Molokai Electric, tax offices, locally-based oil companies, *Hawaii Data Book*, Stanford Research Institute, engineering firms involved in renewable energy development. After data compilation, several energy use scenarios were run for growth rates between 2 to 5 percent, representing conservation, moderate growth, and stimulated growth.

Model results show that Molokai's primary renewable energy resource is biomass—hay, grass, trees, pineapple—and that wind power and hydropower are possible secondary sources. The model also projects that, while liquid fuels for transportation will probably need to be imported, electrical energy self-sufficiency is obtainable between 1983-84 and 1988-89, depending on the rate of energy use. Conservation will be important, not only to accomplish early electrical ESS but also to maintain it. After 1990, demand must be curbed or new renewable resources must be developed to avoid oil (or coal) imports for electrical power generation.



Hay and waste paper are two fuel sources for Molokai Electric's new biomass boiler.

HNEI

SYNTHETIC FUELS WORKSHOP, NO. 1, OCTOBER 7, 8, 9, 1981

HNEI and Pacific Resources, Inc., as part of a feasibility study to produce hydrocarbon fuels from Hawaiian biomass, sponsored this three-day workshop on eucalyptus tree farms for the Island of Hawaii. Representatives from the Hawaii Department of Land and Natural Resources, the U.S. Department of Agriculture, the University of Hawaii, the East-West Center, and various private industries studied characteristics of eucalyptus, general site information, soils, rainfall, other environmental concerns, nursery and plantation requirements and specifications, harvesting techniques, and various agricultural options to determine the economic and technical feasibility of a nursery and plantations at specific Big Island sites, Kapaau, Kukaiau, and Pua Akala. Results of this Hilo workshop are reported in *Hydropyrolysis of Biomass to Produce Liquid Hydrocarbon Fuels: Report on Energy Tree Farm Workshop No. 1* (HNEI, 1982).

WIND ENERGY ADVISORY SEMINAR, NOVEMBER 18, 1981

HNEI and the Department of Planning and Economic Development (DPED) sponsored this all-day seminar to identify and clarify obstacles to commercialization of wind power in Hawaii; to recommend appropriate future roles for HNEI and DPED in wind energy research, development, demonstration, and commercialization; and to encourage communication among key participants in Hawaii's wind energy program. After University of Hawaii and HNEI personnel summarized the status of wind data collection, analysis, and distribution efforts in Hawaii, landowners, utility spokesman, wind farm developers, industrial energy users, consultants/dealers, county and state representatives, and the U.S. DOE regional manager made presentations and reports on issues related to wind energy. The afternoon session consisted of discussion which resulted in recommendations that the state should focus on statewide wind energy resource assessment, a legal framework for wind energy development, long-term land use and zoning decisions, accelerated permitting procedures, tax incentives for alternative energy projects, and public education about wind and other renewable energy resources.

WORKSHOP ON THE EFFECTIVE UTILIZATION OF THE NATURAL ENERGY LABORATORY OF HAWAII (NELH), FEBRUARY 17, 1982

Purposes of this workshop, sponsored by HNEI, the Department of Planning and Economic Development, Research Corporation of the University of Hawaii, and the Office of Research Administration at UHM, included evaluating R & D capabilities at NELH, recommending R & D projects suitable for the facility, identifying potential customers, and establishing an inventory of research competence and support services from the state's scientific and industrial communities.

U.S. Senator Spark Matsunaga and Hideto Kono, Director of DPED, discussed federal energy research funds and reiterated the state's commitment to using NELH wisely and efficiently. Bill Richards of U.S. DOE, Rich Norling of NOAA, Norm Sather of Argonne National Laboratory, and Ben Shelpuk from the Solar Energy Research Institute indicated interest in conducting or supporting research at the National Energy Laboratory. Then members of the UHM Scientific Advisory Committee for NELH, who toured the facility the previous day, discussed resources at NELH; issues related to the laboratory's use; and possible marine, energy, industrial, and biological research projects. Following this background session, the fifty-five participants divided into seven groups for a working lunch to consider projects and recommend actions. Areas for project development include OTEC-related research, solar ponds, desalination, aquaculture, agriculture, cable testing, materials testing, physical oceanography, and meteorological processes.

SYNTHETIC FUELS WORKSHOP, NO. 2, JUNE 7, 8, 9, 1982

This second synthetic fuels workshop was held because Puna Sugar Company lands may be idle soon and because preliminary study indicates that eucalyptus tree farms on the Island of Hawaii are promising. Pacific Resources, Inc. sponsored the three-day study effort as part of their U.S. DOE-funded project for production of hydrocarbon fuels from Hawaiian biomass. Representatives from PRI, HNEI, Hawaii County, the University of Hawaii at Manoa, and UH Hilo College evaluated eucalyptus species; Puna sites, soils, and environmental parameters; possible sociological impacts; seedling requirements; plantation specifications and design; harvesting methods; and project economics. Results are reported in *Hydropyrolysis of Biomass to Produce Liquid Hydrocarbon Fuels: Report on Energy Tree Farms Workshop No. 2* (HNEI, in preparation).

HNEI/EAST-WEST CENTER ENERGY LECTURES

"Energy and the Global Predicament: The Role of Renewables," John P. Holdren, Professor in Energy and Resources, University of California, Berkeley, March 22, 1982.

"Solar Towers: U.S. and International Development," Alvin F. Hildebrandt, Professor and Director of the Solar Energy Laboratory, University of Houston, April 26, 1982.

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HAWAII NATURAL ENERGY INSTITUTE

UNIVERSITY OF HAWAII AT MANOA

The Hawaii Natural Energy Institute (HNEI) was established by the 1974 State Legislature as a research institute at the University of Hawaii at Manoa (UHM). The primary purpose of HNEI is to provide leadership, focus, and support for energy related research at the university, which will lead to the development of the state's indigenous natural energy resources—geothermal, direct solar radiation, biomass, wind, and ocean energy systems. These renewable energy alternatives can (a) diminish Hawaii's near-total dependence on imported oil for energy, (b) help meet increasing energy demands with minimum environmental degradation, and (c) have a positive effect on the state's economic future—both through the development of cost competitive alternatives to seaborne petroleum and as a generator of jobs and taxes.

Much of the early thrust for developing Hawaii's renewable energy resources came from the university, with HNEI providing the role of catalyst and entrepreneur in identifying support for energy projects. HNEI works closely with the federal, state, and county governments, the utilities, community organizations, and the private sector to initiate and to complete these activities.

The research, development, and demonstration projects in which HNEI engages cut across the entire range of renewable energy technologies. The storage and transport of these energy alternatives, which are essential to the effective utilization of site-specific intermittent energy resources, have also come under review. There are active projects on undersea electric cables, energy storage systems, and electric vehicles. Nor have the social, economic, environmental, legal, and regulatory aspects of renewable energy development been neglected.

Throughout its brief existence the research staff of HNEI has been small, and the bulk of the research administered by the institute has been conducted by faculty representing the entire university system. The research and development funds allocated to HNEI by the Hawaii State Legislature and those obtained from the U.S. Department of Energy have been used effectively to support energy research projects in most of the major colleges and institutes on Manoa Campus, as well as at Hilo College and in the UH Community College System.

In summary, the university is the lead agency in the state for research and development on Hawaii's renewable energy resources. The responsibilities of the university in general and of HNEI in particular are further delineated in the State Energy Plan and the State Higher Education Plan, authorized by executive order of the Governor in April 1982. HNEI will continue to assist in bringing the full research capability of the university to bear on furthering the state goal of achieving energy self-sufficiency with renewable energy resources.

JWS: 9/82